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Changes in Water Level Regimes in China's Two Largest Freshwater Lakes: Characterization and Implication

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Abstract: The complex water regimes and fragile ecological systems in Dongting Lake and Poyang Lake, located in the middle reach of the Yangtze River, have been significantly affected by regional climate change and anthropogenic activities. The hydrological data from the outlets of Dongting Lake (Chenglingji station) during 1955–2016 and Poyang Lake (Hukou station) during 1953–2014 were divided into two periods: the pre-impact period and the post-impact period. Four statistical tests were used to identify the change years: 1979 at Chenglingji and 2003 at Hukou. The indicators of hydrologic alteration and range of variability approach were used to assess alterations in water level regimes. Results show that the severely altered indicators were January water level at both lake outlets, and 1-, 3-, 7- and 30-day minimum water level at Chenglingji, with the degree of hydrological alteration being larger than 85%. The overall degrees of hydrological alteration at Chenglingji and Hukou were 52.6% and 38.2%, respectively, indicating that water level regimes experienced moderate alteration and low alteration or that ecosystems were at moderate risk and low risk, respectively. Changes in water level regimes were jointly affected by climate change and anthropogenic activities. Water level regimes at Dongting Lake outlet were mainly affected by increased rainfall and dam regulation. Decreased rainfall, dam regulation, and sediment erosion and deposition were the main impact factors of water level regimes at Poyang Lake outlet. These changes in water level regimes have greatly influenced both aquatic and terrestrial ecosystems, especially for fish and vegetation communities. This study is beneficial for water resource management and ecosystems protection under regional changes.

Keywords: water level regimes; hydrological alteration; ecological effects; lake outlet

1. Introduction

Hydrological regimes between rivers and lakes exhibit complicated interactions, supporting critical hydrological and ecological processes in river-lake systems (i.e., chains of lakes connected with rivers that flow into or out of them). These include the physical and chemical properties of the water body [1], sediment and nutrient transportation [2–4], and habitat availability [5,6]. As a typical eco-tone between river and lake, a lake outlet is regarded as a key component of a river-lake system and plays an important role in maintaining the health of both aquatic and adjacent terrestrial ecosystems [7,8]. However, this area has not received enough attention in the literature [7,9], especially for the full ranges of water level in a large lake. Moreover, water level regimes are suffering dramatic changes under the impacts of ongoing climate change and intensive anthropogenic activities [10,11]. Global warming and

related extreme climate events (e.g., extreme precipitation or drought) can modify the water cycle [12,13], causing abnormal fluctuations of water level. In addition, anthropogenic activities, such as dam construction, lake sedimentation, water withdrawal, and land use change may directly or indirectly affect water level regimes [14,15], subsequently degenerating river and lake ecosystems [16–18]. Therefore, it is necessary to evaluate the changes in water level regimes at the outlets in large lakes, especially in consideration of both climate change and anthropogenic activities.

Indicators of hydrologic alteration (IHA) is a useful tool to assess hydrological regimes, such as river streamflow, ground water level, and lake water level [19]. This approach has been widely used in global rivers for evaluating climate- or human-induced water regime changes and potential ecological influences [20–22]. IHA includes 33 indicators within five groups, covering a full range of water regimes in terms of magnitude, duration, timing, frequency, and rate of change. As a complementary method, the range of variability approach (RVA) was proposed by Richter et al. [23] to evaluate the hydrological alteration between two different periods, i.e., the pre-impact period and the post-impact period. Although these methods have been widely used in the related published literature over the past two decades, most of those studies focused on river streamflow [24,25]. The applications of IHA and RVA to water level have been reported by Zhang et al. [26] and Xu et al. [27] in river network regions. Water level is a fundamental feature of hydrological conditions in a lake, and has a close connection with both aquatic and neighboring terrestrial ecosystems [16,28]. Regardless of concerns on river flow, relevant ecologists, hydrologists and other stakeholders should pay more attention to understanding the full range of water level regimes in large lakes.

Dongting Lake and Poyang Lake are the two largest freshwater lakes and the only existing lakes connected to the Yangtze River in China, and thus play an important role in flood prevention, water supply, and biodiversity protection. In recent years, many studies about the two lakes' water level changes have been published. However, to our knowledge, these studies have mainly focused on temporal changes in water level [29,30], hydrological drought or extremely low water level [31,32], and ecological water level [33,34]. Few studies have examined the full range of water level regimes in terms of magnitude, duration, timing, frequency, and rate of change [35]. Moreover, changes in water level regimes have been observed in both Dongting Lake and Poyang Lake due to the impacts of climate change, dam construction (e.g., the Three Gorges Dam) and other human activities [36,37]. Consequently, our objectives in this study were: (1) to characterize variations in the full range of water level regimes; (2) to quantitatively evaluate the hydrological alterations in the post-impact period compared with the pre-impact period; and (3) to discuss the implications of main factors in water level changes and their impacts on ecosystems. The results of this study will be helpful for providing a better understanding of water level conditions and implications for ecosystem protection in Dongting Lake and Poyang Lake, China.

2. Materials and Methods

2.1. Study Area and Data

The Yangtze River is the largest river in China, with more than 600 lakes distributed along the river and its tributaries. Located in the middle reach of the Yangtze River basin, Dongting Lake and Poyang Lake are the two largest freshwater lakes in China, with a total area of 2625 km² and 2933 km², respectively. The two lakes are located in a subtropical monsoon climate zone, with a wet season from April to July and a dry season from September to February. This study area is a typical river-lake system. As shown in Figure 1, Dongting Lake receives water from four main tributaries (i.e., Xiangjiang River, Zishui River, Yuanjiang River, and Lishui River) and the Yangtze River via Three Inlets (i.e., Songzi River, Hudu River, and Ouchi River). At last, the water discharges into the Yangtze River through the lake outlet of Chenglingji. Poyang Lake receives water from five main tributaries, namely Raohe River, Xinjiang River, Fuhe River, Ganjiang River, and Xiushui River. The water in Poyang Lake drains into the Yangtze River through the lake outlet of Hukou. Moreover, Poyang Lake is subjected to

backflow events that occur for several days to several weeks in specific years when the water level and discharge in the Yangtze River were higher than those of Poyang Lake [38]. The Three Gorges Dam, located in the upper reach of the Yangtze River (Figure 1), holds one of the largest reservoirs in the world, with a total capacity of 39.9 km³. Consequently, the Three Gorges Dam has exerted significant impacts on the water regimes of the two downstream lakes [39].

Both Dongting Lake and Poyang Lake were listed as important international wetlands by the Ramsar Convention on Wetlands. They are also recognized as being among the most biodiverse regions in China, serving as natural habitats for water birds (e.g., White-fronted Geese and White Cranes), aquatic mammals (e.g., Baiji Dolphin and Finless Porpoise), and local fish (e.g., four famous major carp: silver carp, grass carp, black carp, and bighead carp). Nevertheless, the hydrological condition changes caused by climate change and anthropogenic activities could lead to degeneration of lake ecosystems.

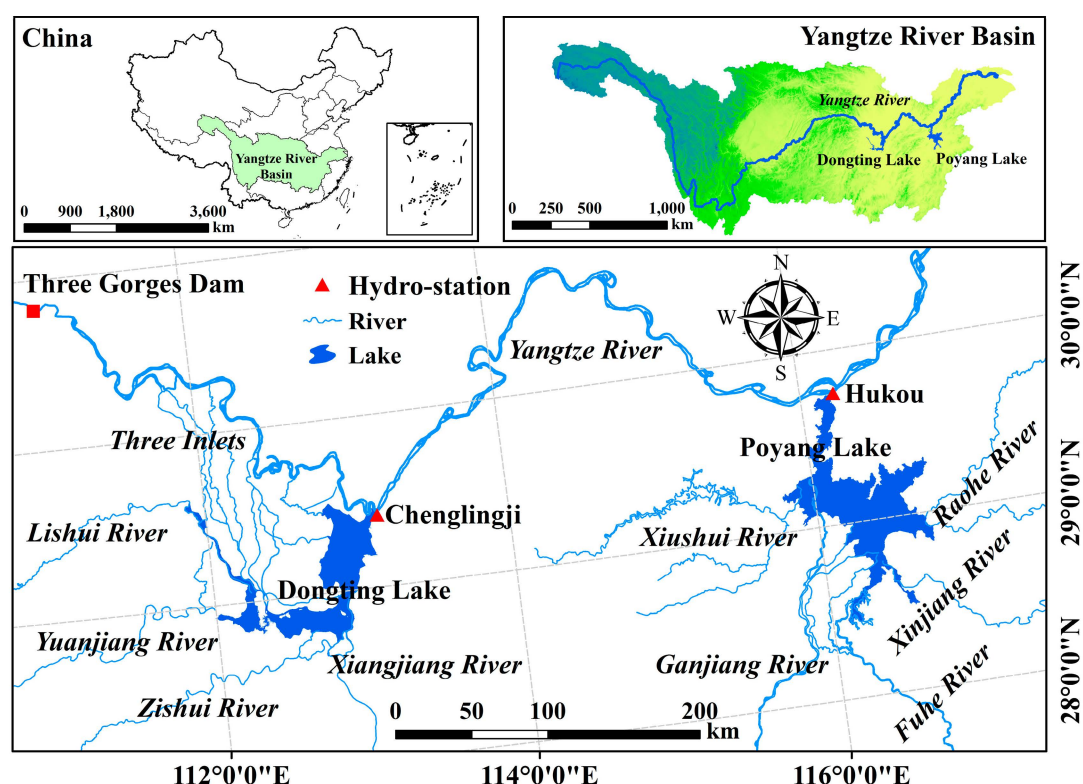


Figure 1. The river-lake system in the middle of Yangtze River basin with the two largest freshwater lakes, Dongting Lake and Poyang Lake, in China.

Table 1 lists basic information of the two gauge stations in Dongting Lake and Poyang Lake. Daily water level data, covering a period of 1955–2016 of Chenglingji and 1953–2014 of Hukou, were collected from the Changjiang Water Resources Commission of the Ministry of Water Resources, China. These data were carefully controlled before analysis and no missing data were found. To evaluate the alteration of hydrological regimes at the outlets of Dongting Lake and Poyang Lake, the hydrological data were divided into two periods, the pre-impact period and the post-impact period, according to the methods introduced in Section 2.2.1.

Table 1. List of gauge stations and their characteristics.

Gauge Station	Location	Catchment Area (10 ⁴ km ²)	Average Elevation (m)	Mean Annual Value	
				Water Level (m)	Discharge (m ³ /s)
Chenglingji	Dongting Lake	26.28	35	24.76	8787.49
Hukou	Poyang Lake	16.22	20	12.76	4726.44

2.2. Methods

2.2.1. Change Point Detection

In order to efficiently and reliably detect the change point of a time series, four tests, i.e., Pettitt's Test [40], Lanzante's Test [41], Standard Normal Homogeneity (SNH) Test [42], and Buishand Range (BR) Test [43], were used in this study. These tests have been examined as useful techniques to determine the change years of hydrological data in previous studies [44–46]. More details of the calculation procedures used in the four tests can be obtained from Verstraeten et al. [47] and Lanzante [41]. In addition, some tests used in this study have been successfully applied to identify the change years of hydrological data series in Dongting Lake [29] and Poyang Lake [48].

2.2.2. Indicators of Hydrologic Alteration (IHA)

IHA includes 33 indicators and is categorized into five groups, referring to the full spectral water regimes of magnitude, duration, timing, frequency, and rate of change (Table 2) [49]. The data were examined carefully before analysis, and no zero-flow events were observed at Chenglingji and Hukou. As a result, two indicators, “number of zero-flow days” and “base flow index”, were eliminated in this study. The thresholds of high and low pulse can be determined by two types of statistics: parametric statistics (mean and standard deviation) and non-parametric statistics (median and percentile). Non-parametric statistics was used in this study due to the non-normal distribution of hydro-data [50]. In this situation, the high and low pulse thresholds were calculated by the median value plus or minus 25%, respectively. In addition, each IHA group corresponds to different ecosystem influences, as listed in Table 2.

Table 2. IHA groups, parameters, and their ecosystem influences [49]. Indicators of “number of zero-flow days” and “base flow index” in Group 2 were eliminated from this study.

IHA Groups	IHA Parameters (No.)	Ecosystem Influences
1. Magnitude of monthly water level conditions	Median monthly water level (12)	Habitat availability for aquatic organisms; soil moisture availability for plants; availability and reliability of water for terrestrial animals; availability of food/cover for furbearing mammals; access by predators to nesting sites; influences water temperature, oxygen levels, photosynthesis in water column
2. Magnitude and duration of annual extreme water level conditions	Annual minimum and maximum 1-, 3-, 7-, 30-, and 90-day means (10)	Balance of competitive, ruderal, and stress-tolerant organisms; creation of sites for plant colonization; structuring of aquatic ecosystems by abiotic vs. biotic factors; structuring of river channel morphology and physical habitat conditions; soil moisture and anaerobic stress in plants; dehydration in animals; volume of nutrient exchanges between rivers and floodplains; duration of stressful conditions such as low oxygen and concentrated chemicals in aquatic environments; distribution of plant communities in lakes, ponds, floodplains; duration of high flows for waste disposal, aeration of spawning beds in channel sediments
3. Timing of annual extreme water level conditions	Julian date of each annual 1-day minimum and maximum (2)	Compatibility with life cycles of organisms; predictability/avoidability of stress for organisms; access to special habitats during reproduction or to avoid predation; spawning cues for migratory fish; evolution of life history strategies, behavioral mechanisms
4. Frequency and duration of high and low pulses	Number of low and high pulses with each year (2) Median duration of low and high pulses (2)	Frequency and magnitude of soil moisture stress for plants; frequency and duration of anaerobic stress for plants; availability of floodplain habitats for aquatic organisms; nutrient and organic matter exchanges between river and floodplain; soil mineral availability; access for water birds to feeding, resting, reproduction sites; influences bedload transport, channel sediment textures, and duration of substrate disturbance (high pulses)
5. Rate and frequency of water level condition changes	Rise and fall rates (2) Number of hydrologic reversals (1)	Drought stress on plants (falling levels); entrapment of organisms on islands, floodplains (rising levels); desiccation stress on low-mobility streamedge (varial zone) organisms

2.2.3. Degree of Hydrological Alteration

Based on IHA, Richter et al. [23] proposed an RVA method to quantitatively assess hydrological alteration. Two different periods, the pre-impact period and the post-impact period, are required to conduct RVA analysis. According to the values in the pre-impact period, the RVA target range can be determined by the percentile values of each IHA parameter. In other words, the upper and lower boundaries of RVA target range are the median value plus or minus 17%, respectively. Then the values in the post-impact period are compared to the RVA target range to calculate the hydrological alterations, expressed as:

$$D_i = \frac{\text{Observed frequency} - \text{Expected frequency}}{\text{Expected frequency}} \times 100\% \quad (1)$$

where, the observed frequency is the post-impact value of the i th indicator actually falling within the RVA target range, and the expected frequency is the post-impact value of the i th indicator should fall within the RVA target range [49]. D_i is the degree of hydrologic alteration of the i th indicator. A positive or negative D_i indicates that the annual values of that parameter fell within the RVA target range more or less often than expected [51].

However, a single D_i cannot reflect the overall alteration. Therefore, Shiau and Wu (2007) [52] proposed an integrative index, the overall degree of hydrological alteration (D_0), expressed as:

$$D_0 = \left(\frac{1}{n} \sum_{i=1}^n D_i^2 \right)^{\frac{1}{2}} \quad (2)$$

In consideration of ecosystem needs [52], D_0 was applied in similar studies [53,54]. In addition, a five-class criterion of hydrological alteration [55] was used for both D_i and D_0 in this study. An absolute value of D_i or D_0 that falls within the range of 0–20%, 20–40%, 40–60%, 60–80%, and 80–100% is defined as no or slight alteration, low alteration, moderate alteration, high alteration, and severe alteration, respectively. Furthermore, the classification of hydrological alteration also means that the ecosystem is at no risk, low risk, moderate risk, high risk, or severe risk, respectively.

3. Results

3.1. Identification of Change Years and Segmentation of Periods

Multiple methods, including Pettitt's Test, Lanzante's Test, SNH Test, and BR Test, were used to identify the change years in time series of Chenglingji and Hukou, respectively. The results of detected change years were shown in Table 3. The time series of Chenglingji were tested and a significant change year in 1979 was identified with any of the four tests, indicating that the change in water level at Chenglingji occurred in 1979. Although Lanzante's Test produced the only significant result for Hukou, the year 2003 was regarded as a probable change year for the water level at Hukou.

Table 3. Detection of change year from four statistical methods.

Methods	Chenglingji			Hukou		
	Statistic	<i>p</i> -Value	Change Year	Statistic	<i>p</i> -Value	Change Year
Pettitt's Test	615	<0.001	1979	259	0.3795	2003
Lanzante's Test	155	<0.001	1979	410	<0.05	2003
SNH Test	20.567	<0.001	1979	6.4647	0.1647	2003
BR Test	2.2247	<0.001	1979	1.3294	0.1994	2003

In addition, there were two peak periods of dam construction in the Yangtze River basin: one was the period from 1970 to 1990; and the other started in 2000 [56]. The change years identified by the four

tests were consistent with the schedule of the mentioned projects. Moreover, a recent abrupt change but not a long-term trend change of hydrological regimes was observed in Poyang Lake since the 2000s in previous studies [57,58]. Thus, the year 2003 was accepted as the abrupt change year of water level regimes at Hukou. According to the change years, the time series in this study were divided into two periods: the years 1955–1978 and 1953–2002 were the pre-impact periods for Chenglingji and Hukou, respectively; the years 1979–2016 and 2003–2014 were the post-impact periods for Chenglingji and Hukou, respectively.

3.2. Characterization of Water Level Regimes

The full range of water level regimes in terms of magnitude, duration, timing, frequency, and rate of change at Chenglingji and Hukou were calculated using IHA software 7.1. Median values in the pre-impact period and the post-impact period, significance, and the D_i of 31 indicators were listed in Table 4. The results were summarized by five IHA groups as follows.

Table 4. Median values of water level in two periods and the degree of hydrologic alteration (D_i).

Indicators	Chenglingji				Hukou			
	Median		Significance	D_i (%)	Median		Significance	D_i (%)
	Pre-Impact	Post-Impact			Pre-Impact	Post-Impact		
Group 1: Magnitude of monthly water level conditions (m)								
January	19.2	20.6	0.000	−92 (SA)	7.8	7.8	0.861	85 (SA)
February	19.2	20.9	0.000	−76 (HA)	8.0	8.3	0.613	39 (LA)
March	19.6	22.3	0.000	−68 (HA)	9.4	10.2	0.284	62 (HA)
April	22.3	24.0	0.001	−21 (LA)	12.3	10.9	0.033	−34 (LA)
May	26.3	26.3	0.997	42 (MA)	14.6	14.2	0.449	16 (NA)
June	27.3	27.7	0.351	74 (HA)	15.9	15.5	0.612	−31 (LA)
July	30.3	30.5	0.518	58 (MA)	18.1	16.3	0.018	−31 (LA)
August	28.8	29.4	0.192	−29 (LA)	16.8	16.2	0.413	16 (NA)
September	28.0	28.7	0.315	−5 (NA)	16.4	16.0	0.495	16 (NA)
October	26.1	26.3	0.664	11 (NA)	14.5	12.8	0.015	−54 (MA)
November	23.7	23.9	0.674	−13 (NA)	12.0	9.8	0.002	−31 (LA)
December	20.6	21.4	0.000	−37 (LA)	9.1	8.5	0.141	39 (LA)
Group 2: Magnitude and duration of annual extreme water level conditions (m)								
1-day minimum	18.3	20.1	0.000	−100 (SA)	7.2	7.3	0.426	39 (LA)
3-day minimum	18.3	20.2	0.000	−100 (SA)	7.2	7.4	0.405	16 (NA)
7-day minimum	18.4	20.2	0.000	−100 (SA)	7.2	7.4	0.429	16 (NA)
30-day minimum	18.7	20.6	0.000	−100 (SA)	7.4	7.8	0.200	16 (NA)
90-day minimum	19.5	21.4	0.000	−76 (HA)	8.5	8.8	0.460	62 (HA)
1-day maximum	31.5	32.4	0.054	3 (NA)	19.5	18.0	0.035	16 (NA)
3-day maximum	31.4	32.4	0.057	3 (NA)	19.5	18.0	0.035	16 (NA)
7-day maximum	31.3	32.1	0.073	18 (NA)	19.5	18.0	0.030	16 (NA)
30-day maximum	30.4	31.1	0.023	34 (LA)	18.6	17.4	0.044	16 (NA)
90-day maximum	29.2	29.8	0.032	−13 (NA)	17.3	16.5	0.182	−7 (NA)
Group 3: Timing of annual extreme water level conditions (Julian date)								
Date of minimum	33.0	18.0	0.088	−2 (NA)	27.0	3.0	0.040	−54 (MA)
Date of maximum	196.5	204.5	0.068	3 (NA)	195.0	209.0	0.039	−60 (HA)
Group 4: Frequency and duration of high and low pulses								
Low pulse count	2.0	0.5	0.001	−28 (LA)	2.0	2.0	0.513	−23 (LA)
Low pulse duration (day)	44.0	26.0	0.259	−19 (NA)	53.5	34.5	0.265	−75 (HA)
High pulse count	2.0	2.0	0.230	1 (NA)	2.0	2.0	0.256	−23 (LA)
High pulse duration (day)	27.3	41.5	0.178	−37 (LA)	48.0	22.3	0.044	−51 (MA)
Group 5: Rate and frequency of water level condition changes								
Rise rates (m/day)	0.2	0.1	0.045	−9 (NA)	0.1	0.1	0.479	19 (NA)
Fall rates (m/day)	−0.1	−0.1	0.112	26 (LA)	−0.1	−0.1	0.616	1 (NA)
Number of reversals	41.5	46.0	0.017	−48 (MA)	45.5	38.0	0.070	4 (NA)

Note: NA denotes no or slight alteration, LA denotes low alteration, MA denotes moderate alteration, HA denotes high alteration, SA denotes severe alteration.

3.2.1. Magnitude of Monthly Water Level Conditions

Nearly all of the median values of monthly water level (except for May) increased from 0.9% to 13.6% in the post-impact period compared with the pre-impact period at Chenglingji. A significant

increase was observed from December to April for the water level at Chenglingji. In contrast, only two monthly water level (February and March) increased and the other monthly water level decreased with a range of -18.4% to -0.8% compared with the two periods at Hukou. April, July, October, and November water level showed a significant decreased trend at Hukou. Slight or low degrees of hydrological alteration was observed in most of months, especially for those months in the second half of the year at the two lake outlets. Water level in May and July at Chenglingji and in October at Hukou were categorized as moderate alteration. The absolute values of D_i in February, March, and June at Chenglingji and March at Hukou exceeded 60%, which fell within the category of high alteration (Table 4). Severely altered indicators were observed in January water level with a maximal D_i (absolute value) among monthly water level of -92% at Chenglingji and 85% at Hukou, respectively.

Figure 2 showed the median variation of the highly and severely altered monthly water level in the two periods. Compared with the pre-impact period, median values of water level in January, February, March, and June at Chenglingji increased by 7.1%, 9.3%, 13.6%, and 1.3%, respectively, in the post-impact period, with the former three indicators falling outside of the RVA target range (Table 4 and Figure 2). The average D_i (absolute value) of monthly water level at Chenglingji was 43.9%, which was higher than the value at Hukou (37.7%). In addition, the percentage of monthly water level that fell within the moderate to severe alteration category at Chenglingji (50%) was also greater than that at Hukou (25%), indicating that the monthly water level conditions at Chenglingji was worse than that at Hukou.

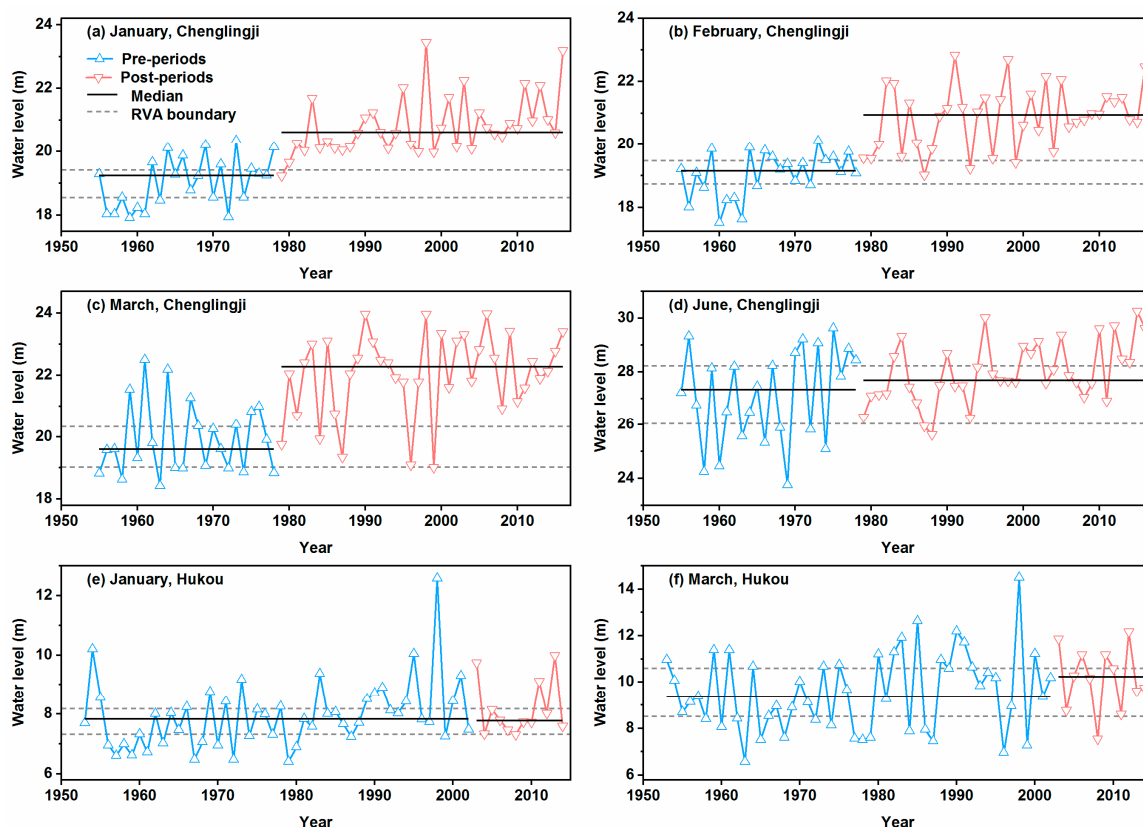


Figure 2. Variations in the highly and severely altered monthly water level at Chenglingji and Hukou. (a) January water level at Chenglingji, (b) February water level at Chenglingji, (c) March water level at Chenglingji, (d) June water level at Chenglingji, (e) January water level at Hukou, (f) March water level at Hukou.

3.2.2. Magnitude and Duration of Annual Extreme Water Level Conditions

The median values of annual 1-, 3-, 7-, 30-, and 90-day minimum water level and annual 30- and 90-day maximum water level in the post-impact period significantly increased at Chenglingji, with

a change rate of 2–10.3% (Table 4). However, the medians of minimum water level increased from 2.1% to 5.6%, while the medians of 1-, 3-, 7-, and 30-day maximum water level decreased significantly by −7.7 to −5.0% at Hukou in the post-impact period compared to the pre-impact period (Table 4). The alterations in annual 1-, 3-, 7-, and 30-day minimum water level at Chenglingji were observed to have an astonishing high level with an absolute value of D_i of 100%, indicating severe alteration. A high alteration of annual 90-day minimum water level was observed at both lake outlets, with a D_i of −76% at Chenglingji and 62% at Hukou, respectively. Consequently, all medians of annual 1-, 3-, 7-, 30-, and 90-day minimum water level in the post-impact period fell outside of the RVA target range at Chenglingji (Figure 3). Except for low alteration in annual 30-day maximum water level at Chenglingji and annual 1-day minimum water level at Hukou, the other indicators not mentioned above were classified as slight alteration. The slightly altered indicators accounted for 80% of all annual extreme water level at Hukou, much higher than the one at Chenglingji. The mean absolute values of D_i were 54.7% and 21.9% at Chenglingji and Hukou, respectively, indicating that the annual extreme water level conditions at Chenglingji suffered a more serious alteration.

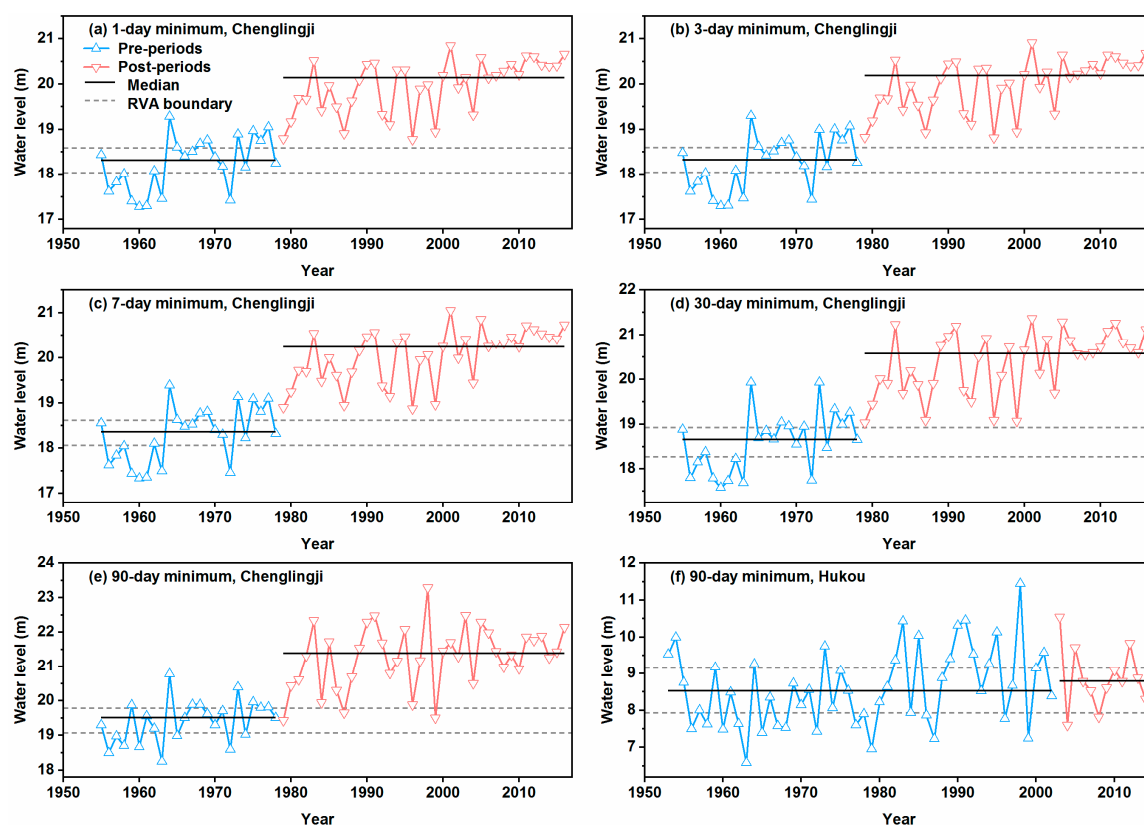


Figure 3. Variations in the highly and severely altered annual minimum water level at Chenglingji and Hukou. (a) Annual 1-day minimum water level at Chenglingji, (b) Annual 3-day minimum water level at Chenglingji, (c) Annual 7-day minimum water level at Chenglingji, (d) Annual 30-day minimum water level at Chenglingji, (e) Annual 90-day minimum water level at Chenglingji, (f) Annual 90-day minimum water level at Hukou.

3.2.3. Timing of Annual Extreme Water Level Conditions

The same change trends were observed in the timing of annual extreme water level conditions at both lake outlets. The median Julian date of minimum water level advanced 15 days and 24 days in the post-impact period compared with the pre-impact period at Chenglingji and Hukou, respectively. However, the median Julian date of the maximum water level was delayed by 8 days and 14 days in the post-impact period compared with the pre-impact period at Chenglingji and Hukou, respectively (Table 4). Moreover, these changes in Julian date of the minimum and maximum water level were

significant at Hukou but not significant at Chenglingji. Slight alterations were observed in the Julian date of both minimum and maximum water level at Chenglingji. The D_i of Julian date of minimum water level was -54% at Hukou, a moderate alteration. The median of the Julian date of the maximum water level in the post-impact period at Hukou was even larger than the upper RVA boundary as shown in Figure 4a, which was classified as high alteration with a D_i of -60% . Due to a much higher average D_i (absolute value) at Hukou (57%) than the one at Chenglingji (2.5%), it was concluded that the degree of hydrological alteration of the timing of annual extreme water level conditions was more serious at Hukou than at Chenglingji.

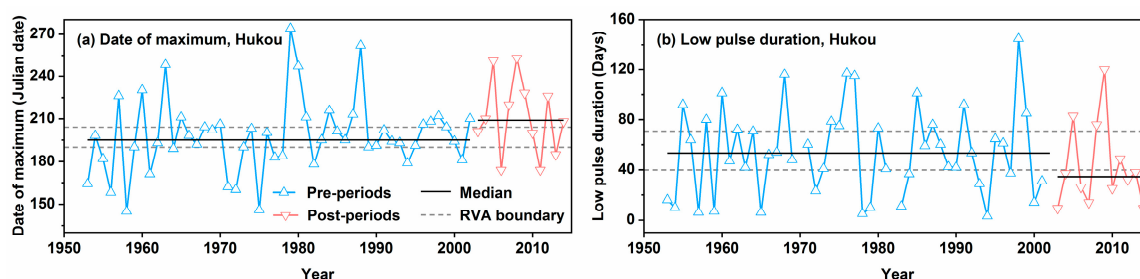


Figure 4. Variation of (a) date of maximum water level and (b) low pulse duration at Hukou.

3.2.4. Frequency and Duration of High and Low Pulses

Compared with the pre-impact period, the medians of low pulse count significantly decreased and the median of high pulse duration increased in the post-impact period at Chenglingji. It can be seen from Table 4 that the absolute values of D_i in low and high pulses count and duration were less than 40% at Chenglingji, indicating that these indicators belonged to the categories of slight alteration and low alteration, respectively. There were no obvious changes in low and high pulse count at Hukou. However, low pulse duration sharply decreased and high pulse duration decreased significantly at Hukou, so they were classified as high and moderate alterations, respectively. The median of low pulse duration in the post-impact period at Hukou was lower than the lower RVA boundary (Figure 4b). The average D_i (absolute value) in Group 4 was 21.1% at Chenglingji and 43.2% at Hukou, respectively, indicating that the frequency and duration of high and low pulses at Hukou were more affected than that at Chenglingji.

3.2.5. Rate and Frequency of Water Level Condition Changes

From Table 4: there were no obvious variations observed in rise rate or fall rate at either lake outlets. The median of number of reversals significantly increased in the post-impact period compared to the pre-impact period at Chenglingji, which fell into the class of moderate alteration with a D_i of -48% . Although the median of number of reversals in the post-impact period decreased by 16.48% compared with the pre-impact period at Hukou, the degree of hydrological alteration was only 4% , a slight alteration. The average absolute value of D_i in Group 5 was 27.67% at Chenglingji and 8% at Hukou, respectively.

3.3. Quantitative Evaluation of Water Level Alteration

The values of D_0 were calculated to evaluate the overall degree of water regimes alteration at the two lake outlets, according to Equation (2). The D_0 was 52.6% at Chenglingji, indicating that the water regimes experienced moderate alteration or the ecosystem was at moderate risk. The value of D_0 was 38.2% at Hukou, suggesting that the water regimes experienced low alteration or the ecosystem was at low risk. Figure 5 showed the distribution of hydrological indicators within the five classes of alteration. Nearly one-third of the total indicators was categorized as high or severe alteration at Chenglingji, while 61% of the 31 indicators belonged to slight and low alteration. The distribution of indicators was quite different between Hukou and Chenglingji. At Hukou, the percentage of highly

and severely altered indicators accounted for only 16%; however, 74% of the total indicators were regarded as slight or low alterations. These results showed a spatial pattern of hydrological alterations: the water regimes at Dongting Lake outlet were more affected than that of Poyang Lake outlet.

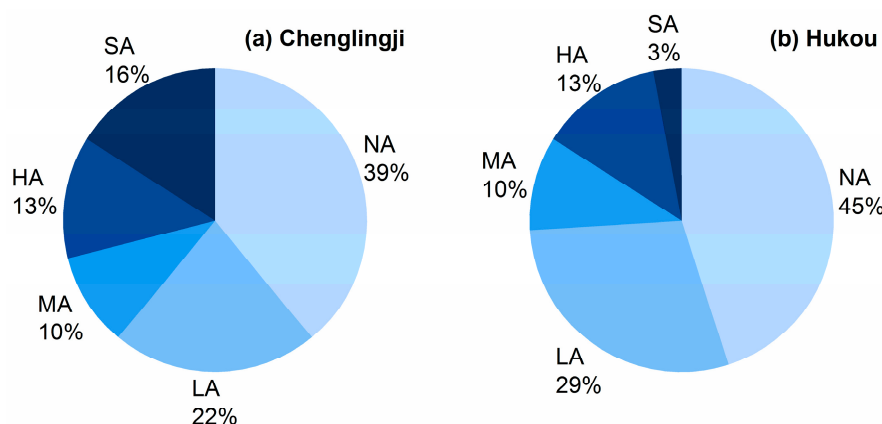


Figure 5. Distribution of hydrological indicators within the five classes of alteration for (a) Chenglingji and (b) Hukou. NA denotes no or slight alteration, LA denotes low alteration, MA denotes moderate alteration, HA denotes high alteration, and SA denotes severe alteration.

4. Discussion

4.1. Impact Factors of Water Level Changes

Climate change and anthropogenic activities were recognized as the two major factors that exerted impacts on water level alteration [59,60]. Climate change could alter the hydrological cycle at a global or regional scale [61,62], resulting in the alteration of water regimes (e.g., water level, runoff). It was demonstrated that precipitation, temperature, and evaporation were the most important climatic factors, and could cause obvious changes in water level conditions [63–66]. Water in both Dongting Lake and Poyang Lake was mainly supplied by precipitation and river runoff, which was also controlled by monsoon rainfall in the catchments. Consequently, variations in water level were closely associated with precipitation, to some extent. Water level in Dongting Lake had increased significantly since 1980 due to the increased annual rainfall in the lake region [30], which explained the water level changes in Group 1 and 2 (Table 4). Some studies have discussed how precipitation and evaporation would affect water level in Poyang Lake; the decreased monthly water level (Table 4) might be attributed to the frequent drought events since the 2000s [67,68]. The average annual rainfall decreased from 1699 mm year^{−1} in 1960–2000 to 1577 mm year^{−1} in 2003–2010 in Poyang Lake basin [69]. This decreasing rainfall trend was also consistent with the decline in monthly water level at Poyang Lake outlet. These results illustrated the impact of precipitation on water level regimes at the two lake outlets.

Meanwhile, anthropogenic activities, such as the construction of dams or reservoirs, land use change, and irrigation, had direct impacts on water level [60,70]. Water regimes in both lakes were affected by the Yangtze River and rivers in the local basin due to the complex river-lake systems (see Figure 1). Nearly 371 large dams, with a total storage capacity of 192.6 km³, have been constructed in the Yangtze River basin [71]. Those dams usually store water from August to October and release water from November to May for water supplementation in the dry season and flood control in the rainy season [53]. The peak flow was reduced and low flow was elevated in rivers as a result of the operational rules of dams; thus, the maximum water level decreased at Hukou and the minimum water level increased at Chenglingji and Hukou. Dam construction was one of the main factors that affect water regimes at the two lake outlets. Due to the imbalanced development in Hunan province (Dongting Lake) and Jiangxi province (Poyang Lake), other anthropogenic activities' impacts on water regimes of the two lake outlets were different in manner and degree. For example, water level regimes

were more affected by lake sedimentation and reclamation in Dongting Lake [29] and by sand mining in Poyang Lake [72]. Sediment exchange between rivers and lakes was important for lake evolution as it would affect water regimes at both inlets and outlets [73–75]. Compared to the pre-impact period, sediment exports significantly decreased at Chenglingji and increased at Hukou in the post-impact period [76]. Although the sediment erosion and deposition had changed at Chenglingji, the water surface slope did not show obvious change [76] and thus had a limited impact on water level regimes at Dongting Lake outlet. The increased sediment exports, mainly affected by serious sand mining, could increase the volume of Poyang Lake and lower lake bed elevation, resulting in a decline in water level at Poyang Lake outlet [69,77].

In general, effects of climate change on water regimes are a long-term and slow process, while anthropogenic activities can have dramatic impacts on water regimes in a short period. Notably, changes in water level regimes at the outlets of Dongting Lake and Poyang Lake were the results of the joint influence of climate change and anthropogenic activities. Therefore, the results of variations in water level regimes derived from the IHA method presented different characteristics in Dongting Lake and Poyang Lake due to the different effects of climate change and anthropogenic activities in individual lake outlets.

4.2. Negative Impacts on Ecosystems

Natural water level fluctuation is an important process for maintaining the ecological biodiversity and ecosystem health of a lake [18]. The inter- and intra-annual water level fluctuations in Dongting Lake and Poyang Lake were huge, and thus affected the environment and ecosystem of the lakes in several ways.

Variations in water regimes are critical for fish. For example, the magnitude, duration, and timing of extreme water conditions are key signals for fish spawning [78]. The hydrothermal conditions downstream of dams have changed, which further affected the growth, reproduction, and survival of native fish [79]. The two lake outlets are important passages for migrating fish (e.g., four famous major carp), which reproduce in rivers and grow in lakes [80]. However, dam construction not only altered the downstream water regimes, but also impaired the original passages for migrating fish [81]. These impacts could lead to changes in the diversity and communities of fish. Although the total fishery production showed small variations across normal years in Dongting Lake and Poyang Lake, the proportion of fish types changed a lot in Dongting Lake, with migratory species decreasing by at least 20% and resident species increasing by more than 20% [82]. The weaker variability of water level might be one possible reason for the changes in fish types. In addition, variations in water level could also affect the trophic environment and wetland ecology in Dongting Lake and Poyang Lake [37,83].

The earlier date of annual minimum water level and the delayed date of annual maximum water level in Dongting Lake and Poyang Lake were observed (Table 4), resulting in the expansion of lake grass to a relatively lower elevation zone [84] and showing a positive succession of wetland vegetation [85]. Due to the significant decline in water level, the wetland vegetation was severely degraded, and the aquatic vegetation area decreased from 1834 km² (62.5%) in 1983 to 1000 km² (34.1%) in 2013 in Poyang Lake [86]. Both Dongting Lake and Poyang Lake are the Ramsar wetlands and important habitats for the wintering of migratory birds. A recent study revealed that variations in water level affected the distribution dynamics of Lesser White-fronted Geese in the past decade at Dongting Lake [87].

As discussed above, changes in water level regimes could affect both aquatic and terrestrial ecosystems in several ways. Moreover, these changes will continue in the foreseeable future. By 2030, the projected reservoir capacity will reach 300 billion m³ and the projected annual water usage will be 260 billion m³ in the Yangtze River basin [56]. The water from South-to-North Water Diversion Project in China will reach 36.8 billion m³ [56]. Undoubtedly, these projects will provide numerous benefits, such as hydropower, flood control, and meeting the social and economic demands for water. Additionally, climate change in the Yangtze River basin still poses great uncertainties [88,89].

Nevertheless, the ongoing impacts of climate change and anthropogenic activities on the hydrological and ecological processes of the two lakes will be inevitable.

5. Conclusions

The water level regimes at the outlets of Dongting Lake and Poyang Lake experienced moderate and low alterations, respectively. The low monthly water level and minimum water level conditions experienced the most serious alterations, especially for those water regimes at Dongting Lake outlet. Changes in water level regimes were jointly affected by climate change (e.g., rainfall) and anthropogenic activities (e.g., dam construction, sediment erosion and deposition). Hydrological alteration could affect both aquatic and terrestrial ecosystems in several ways. Moreover, the uncertainty of climate change and increased anthropogenic activities in the future will have inevitable effects on the hydrological and ecological processes of both outlets in Dongting Lake and Poyang Lake.

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References

1. Råman Vinnå, L.; Wüest, A.; Zappa, M.; Fink, G.; Bouffard, D. Tributaries affect the thermal response of lakes to climate change. *Hydrol. Earth Syst. Sci.* **2018**, *22*, 31–51. [[CrossRef](#)]
2. De Jonge, C.; Stadnitskaia, A.; Fedotov, A.; Sinninghe Damsté, J.S. Impact of riverine suspended particulate matter on the branched glycerol dialkyl glycerol tetraether composition of lakes: The outflow of the Selenga River in Lake Baikal (Russia). *Org. Geochem.* **2015**, *83*, 241–252. [[CrossRef](#)]
3. Loken, L.C.; Small, G.E.; Finlay, J.C.; Sterner, R.W.; Stanley, E.H. Nitrogen cycling in a freshwater estuary. *Biogeochemistry* **2016**, *127*, 199–216. [[CrossRef](#)]
4. Nöges, P.; Nöges, T.; Adrian, R.; Weyhenmeyer, G.A. Silicon load and the development of diatoms in three river-lake systems in countries surrounding the Baltic Sea. *Hydrobiologia* **2008**, *599*, 67–76. [[CrossRef](#)]
5. Lesack, L.F.W.; Marsh, P. River-to-lake connectivities, water renewal, and aquatic habitat diversity in the Mackenzie River Delta. *Water Resour. Res.* **2010**, *46*, 16W12504. [[CrossRef](#)]
6. Zvezdin, A.O.; Pavlov, D.S.; Kostin, V.V. On the mechanism of orientation and navigation of sockeye salmon underyearlings (*Oncorhynchus nerka* Walb.) during feeding migration in the inlet-lake-outlet system. *Inland Water Biol.* **2015**, *8*, 287–295. [[CrossRef](#)]
7. Brunke, M. Stream typology and lake outlets—a perspective towards validation and assessment from northern Germany (Schleswig-Holstein). *Limnologica* **2004**, *34*, 460–478. [[CrossRef](#)]
8. Mitrovic, S.M.; Baldwin, D.S. Allochthonous dissolved organic carbon in river, lake and coastal systems: Transport, function and ecological role. *Mar. Freshw. Res.* **2016**, *67*, i–iv. [[CrossRef](#)]
9. Marcarelli, A.M.; Wurtsbaugh, W.A. Nitrogen fixation varies spatially and seasonally in linked stream-lake ecosystems. *Biogeochemistry* **2009**, *94*, 95–110. [[CrossRef](#)]
10. Robertson, D.M.; Rose, W.J. Response in the trophic state of stratified lakes to changes in hydrology and water level: Potential effects of climate change. *J. Water Clim. Chang.* **2011**, *2*, 1–18. [[CrossRef](#)]
11. Zhang, Q.; Li, L.; Wang, Y.-G.; Werner, A.D.; Xin, P.; Jiang, T.; Barry, D.A. Has the Three-Gorges Dam made the Poyang Lake wetlands wetter and drier? *Geophys. Res. Lett.* **2012**, *39*, L20402. [[CrossRef](#)]

12. Back, L.; Russ, K.; Liu, Z.; Inoue, K.; Zhang, J.; Otto-Bliesner, B. Global hydrological cycle response to rapid and slow global warming. *J. Clim.* **2013**, *26*, 8781–8786. [[CrossRef](#)]
13. Yoon, J.-H.; Wang, S.-Y.S.; Gillies, R.R.; Kravitz, B.; Hippias, L.; Rasch, P.J. Increasing water cycle extremes in California and in relation to ENSO cycle under global warming. *Nat. Commun.* **2015**, *6*, 8657. [[CrossRef](#)]
14. Lai, X.; Jiang, J.; Yang, G.; Lu, X.X. Should the Three Gorges Dam be blamed for the extremely low water levels in the middle-lower Yangtze River? *Hydrol. Process.* **2014**, *28*, 150–160. [[CrossRef](#)]
15. Schafer, M.P.; Dietrich, O.; Mbilinyi, B. Streamflow and lake water level changes and their attributed causes in Eastern and Southern Africa: State of the art review. *Int. J. Water Resour. Dev.* **2016**, *32*, 853–880. [[CrossRef](#)]
16. Evtimova, V.V.; Donohue, I. Water-level fluctuations regulate the structure and functioning of natural lakes. *Freshw. Biol.* **2016**, *61*, 251–264. [[CrossRef](#)]
17. Hofmann, H.; Lorke, A.; Peeters, F. Temporal scales of water-level fluctuations in lakes and their ecological implications. *Hydrobiologia* **2008**, *613*, 85–96. [[CrossRef](#)]
18. Wantzen, K.M.; Rothhaupt, K.-O.; Mörtl, M.; Cantonati, M.; G.-Tóth, L.; Fischer, P. Ecological effects of water-level fluctuations in lakes: An urgent issue. *Hydrobiologia* **2008**, *613*, 1–4. [[CrossRef](#)]
19. Richter, B.D.; Baumgartner, J.V.; Powell, J.; Braun, D.P. A method for assessing hydrologic alteration within ecosystems. *Conserv. Biol.* **1996**, *10*, 1163–1174. [[CrossRef](#)]
20. Gorla, L.; Perona, P. On quantifying ecologically sustainable flow releases in a diverted river reach. *J. Hydrol.* **2013**, *489*, 98–107. [[CrossRef](#)]
21. Papadaki, C.; Soulis, K.; Munoz-Mas, R.; Martinez-Capel, F.; Zogaris, S.; Ntoanidis, L.; Dimitriou, E. Potential impacts of climate change on flow regime and fish habitat in mountain rivers of the south-western Balkans. *Sci. Total Environ.* **2016**, *540*, 418–428. [[CrossRef](#)]
22. Wang, Y.; Rhoads, B.L.; Wang, D. Assessment of the flow regime alterations in the middle reach of the Yangtze River associated with dam construction: Potential ecological implications. *Hydrol. Process.* **2016**, *30*, 3949–3966. [[CrossRef](#)]
23. Richter, B.D.; Baumgartner, J.V.; Wigington, R.; Braun, D.P. How much water does a river need? *Freshw. Biol.* **1997**, *37*, 231–249. [[CrossRef](#)]
24. Fantin-Cruz, I.; Pedrollo, O.; Girard, P.; Zeilhofer, P.; Hamilton, S.K. Effects of a diversion hydropower facility on the hydrological regime of the Correntes River, a tributary to the Pantanal floodplain, Brazil. *J. Hydrol.* **2015**, *531*, 810–820. [[CrossRef](#)]
25. Zhang, Q.; Gu, X.; Singh, V.P.; Chen, X. Evaluation of ecological instream flow using multiple ecological indicators with consideration of hydrological alterations. *J. Hydrol.* **2015**, *529*, 711–722. [[CrossRef](#)]
26. Zhang, Q.; Xu, C.-Y.; Chen, Y.D.; Yang, T. Spatial assessment of hydrologic alteration across the Pearl River Delta, China, and possible underlying causes. *Hydrol. Process.* **2009**, *23*, 1565–1574. [[CrossRef](#)]
27. Xu, G.; Xu, Y.; Luo, X.; Xu, H.; Xu, X.; Hu, C. Temporal and spatial variation of water level in urbanizing plain river network region. *Water Sci. Technol.* **2014**, *69*, 2191–2199. [[CrossRef](#)]
28. Zohary, T.; Ostrovsky, I. Ecological impacts of excessive water level fluctuations in stratified freshwater lakes. *Inland Waters* **2011**, *1*, 47–59. [[CrossRef](#)]
29. Han, Q.; Zhang, S.; Huang, G.; Zhang, R. Analysis of long-term water level variation in Dongting Lake, China. *Water* **2016**, *8*, 306. [[CrossRef](#)]
30. Yuan, Y.; Zeng, G.; Liang, J.; Huang, L.; Hua, S.; Li, F.; Zhu, Y.; Wu, H.; Liu, J.; He, X.; et al. Variation of water level in Dongting Lake over a 50-year period: Implications for the impacts of anthropogenic and climatic factors. *J. Hydrol.* **2015**, *525*, 450–456. [[CrossRef](#)]
31. Huang, Q.; Sun, Z.; Opp, C.; Lotz, T.; Jiang, J.; Lai, X. Hydrological drought at Dongting Lake: Its detection, characterization, and challenges associated with Three Gorges Dam in central Yangtze, China. *Water Resour. Manag.* **2014**, *28*, 5377–5388. [[CrossRef](#)]
32. Zhang, Z.; Chen, X.; Xu, C.-Y.; Hong, Y.; Hardy, J.; Sun, Z. Examining the influence of river-lake interaction on the drought and water resources in the Poyang Lake basin. *J. Hydrol.* **2015**, *522*, 510–521. [[CrossRef](#)]
33. Dai, L.; Mao, J.; Wang, Y.; Dai, H.; Zhang, P.; Guo, J. Optimal operation of the Three Gorges Reservoir subject to the ecological water level of Dongting Lake. *Environ. Earth Sci.* **2016**, *75*, 1111. [[CrossRef](#)]
34. Shang, S. Lake surface area method to define minimum ecological lake level from level-area-storage curves. *J. Arid Land* **2013**, *5*, 133–142. [[CrossRef](#)]
35. Cheng, J.; Xu, L.; Wang, X.; Jiang, J.; You, H. Assessment of hydrologic alteration induced by the Three Gorges Dam in Dongting Lake, China. *River Res. Appl.* **2018**, *34*, 686–696. [[CrossRef](#)]

36. Sun, Z.; Huang, Q.; Opp, C.; Hennig, T.; Marold, U. Impacts and implications of major changes caused by the Three Gorges Dam in the middle reaches of the Yangtze River, China. *Water Resour. Manag.* **2012**, *26*, 3367–3378. [[CrossRef](#)]
37. Yang, G.; Zhang, Q.; Wan, R.; Lai, X.; Jiang, X.; Li, L.; Dai, H.; Lei, G.; Chen, J.; Lu, Y. Lake hydrology, water quality and ecology impacts of altered river-lake interactions: Advances in research on the middle Yangtze River. *Hydrol. Res.* **2016**, *47*, 1–7. [[CrossRef](#)]
38. Li, Y.; Zhang, Q.; Werner, A.D.; Yao, J.; Ye, X. The influence of river-to-lake backflow on the hydrodynamics of a large floodplain lake system (Poyang Lake, China). *Hydrol. Process.* **2017**, *31*, 117–132. [[CrossRef](#)]
39. Lai, X.; Liang, Q.; Jiang, J.; Huang, Q. Impoundment effects of the Three-Gorges-Dam on flow regimes in two China's largest freshwater lakes. *Water Resour. Manag.* **2014**, *28*, 5111–5124. [[CrossRef](#)]
40. Pettitt, A.N. A non-parametric approach to the change-point problem. *J. R. Stat. Soc. Ser. C-Appl. Stat.* **1979**, *28*, 126–135. [[CrossRef](#)]
41. Lanzante, J.R. Resistant, robust and non-parametric techniques for the analysis of climate data: Theory and examples, including applications to historical radiosonde station data. *Int. J. Climatol.* **1996**, *16*, 1197–1226. [[CrossRef](#)]
42. Alexandersson, H. A homogeneity test applied to precipitation data. *J. Climatol.* **1986**, *6*, 661–675. [[CrossRef](#)]
43. Buishand, T.A. Some methods for testing the homogeneity of rainfall records. *J. Hydrol.* **1982**, *58*, 11–27. [[CrossRef](#)]
44. Gebremicael, T.G.; Mohamed, Y.A.; van der Zaag, P.; Hagos, E.Y. Temporal and spatial changes of rainfall and streamflow in the Upper Tekezē-Atbara river basin, Ethiopia. *Hydrol. Earth Syst. Sci.* **2017**, *21*, 2127–2142. [[CrossRef](#)]
45. Kazemzadeh, M.; Malekian, A. Homogeneity analysis of streamflow records in arid and semi-arid regions of northwestern Iran. *J. Arid Land* **2018**, *10*, 493–506. [[CrossRef](#)]
46. Ma, Z.; Kang, S.; Zhang, L.; Tong, L.; Su, X. Analysis of impacts of climate variability and human activity on streamflow for a river basin in arid region of northwest China. *J. Hydrol.* **2008**, *352*, 239–249. [[CrossRef](#)]
47. Verstraeten, G.; Poesen, J.; Demarée, G.; Salles, C. Long-term (105 years) variability in rain erosivity as derived from 10-min rainfall depth data for Ukel (Brussels, Belgium): Implications for assessing soil erosion rates. *J. Geophys. Res.-Atmos.* **2006**, *111*, D22109. [[CrossRef](#)]
48. Gu, C.; Mu, X.; Gao, P.; Zhao, G.; Sun, W.; Li, P. Effects of climate change and human activities on runoff and sediment inputs of the largest freshwater lake in China, Poyang Lake. *Hydrol. Sci. J.* **2017**, *62*, 2313–2330. [[CrossRef](#)]
49. The Nature Conservancy. *Indicators of Hydrologic Alteration Version 7.1 User's Manual*; The Nature Conservancy: Arlington, VA, USA, 2009.
50. Sarlak, N. Annual streamflow modelling with asymmetric distribution function. *Hydrol. Process.* **2008**, *22*, 3403–3409. [[CrossRef](#)]
51. Chen, Y.D.; Yang, T.; Xu, C.-Y.; Zhang, Q.; Chen, X.; Hao, Z.-C. Hydrologic alteration along the Middle and Upper East River (Dongjiang) basin, South China: A visually enhanced mining on the results of RVA method. *Stoch. Environ. Res. Risk Assess.* **2010**, *24*, 9–18. [[CrossRef](#)]
52. Shiau, J.-T.; Wu, F.-C. Pareto-optimal solutions for environmental flow schemes incorporating the intra-annual and interannual variability of the natural flow regime. *Water Resour. Res.* **2007**, *43*, W06433. [[CrossRef](#)]
53. Duan, W.; Guo, S.; Wang, J.; Liu, D. Impact of cascaded reservoirs group on flow regime in the middle and lower reaches of the Yangtze River. *Water* **2016**, *8*, 218. [[CrossRef](#)]
54. Zhang, Q.; Zhang, Z.; Shi, P.; Singh, V.P.; Gu, X. Evaluation of ecological instream flow considering hydrological alterations in the Yellow River basin, China. *Glob. Planet. Chang.* **2018**, *160*, 61–74. [[CrossRef](#)]
55. Xue, L.; Zhang, H.; Yang, C.; Zhang, L.; Sun, C. Quantitative assessment of hydrological alteration caused by irrigation projects in the Tarim River basin, China. *Sci. Rep.* **2017**, *7*, 4291. [[CrossRef](#)]
56. Dai, Z.; Liu, J.T.; Xiang, Y. Human interference in the water discharge of the Changjiang (Yangtze River), China. *Hydrol. Sci. J.-J. Sci. Hydrol.* **2015**, *60*, 1770–1782. [[CrossRef](#)]
57. Liu, Y.B.; Wu, G.P.; Zhao, X.S. Recent declines in China's largest freshwater lake: Trend or regime shift? *Environ. Res. Lett.* **2013**, *8*, 9014010. [[CrossRef](#)]
58. Guo, H.; Hu, Q.; Zhang, Q.; Feng, S. Effects of the Three Gorges Dam on Yangtze River flow and river interaction with Poyang Lake, China: 2003–2008. *J. Hydrol.* **2012**, *416*, 19–27. [[CrossRef](#)]

59. Du, J.; He, F.; Zhang, Z.; Shi, P. Precipitation change and human impacts on hydrologic variables in Zhengshui River Basin, China. *Stoch. Environ. Res. Risk Assess.* **2011**, *25*, 1013–1025. [\[CrossRef\]](#)
60. Jeppesen, E.; Brucet, S.; Naselli-Flores, L.; Papastergiadou, E.; Stefanidis, K.; Nöges, T.; Nöges, P.; Attayde, J.L.; Zohary, T.; Coppens, J.; et al. Ecological impacts of global warming and water abstraction on lakes and reservoirs due to changes in water level and related changes in salinity. *Hydrobiologia* **2015**, *750*, 201–227. [\[CrossRef\]](#)
61. Huntington, T.G. Evidence for intensification of the global water cycle: Review and synthesis. *J. Hydrol.* **2006**, *319*, 83–95. [\[CrossRef\]](#)
62. Jackson, R.B.; Carpenter, S.R.; Dahm, C.N.; McKnight, D.M.; Naiman, R.J.; Postel, S.L.; Running, S.W. Water in a changing world. *Ecol. Appl.* **2001**, *11*, 1027–1045. [\[CrossRef\]](#)
63. Kebede, S.; Travi, Y.; Alemayehu, T.; Marc, V. Water balance of Lake Tana and its sensitivity to fluctuations in rainfall, Blue Nile basin, Ethiopia. *J. Hydrol.* **2006**, *316*, 233–247. [\[CrossRef\]](#)
64. Li, X.-Y.; Xu, H.-Y.; Sun, Y.-L.; Zhang, D.-S.; Yang, Z.-P. Lake-level change and water balance analysis at Lake Qinghai, west China during recent decades. *Water Resour. Manag.* **2007**, *21*, 1505–1516. [\[CrossRef\]](#)
65. Mooij, W.M.; Hulsmann, S.; Domis, L.N.D.; Nolet, B.A.; Bodelier, P.L.E.; Boers, P.C.M.; Pires, L.M.D.; Gons, H.J.; Ibelings, B.W.; Noordhuis, R.; et al. The impact of climate change on lakes in the Netherlands: A review. *Aquat. Ecol.* **2005**, *39*, 381–400. [\[CrossRef\]](#)
66. Motiee, H.; McBean, E. An assessment of long-term trends in hydrologic components and implications for water levels in Lake Superior. *Hydrol. Res.* **2009**, *40*, 564–579. [\[CrossRef\]](#)
67. Wang, X.; Gong, P.; Zhao, Y.; Xu, Y.; Cheng, X.; Niu, Z.; Luo, Z.; Huang, H.; Sun, F.; Li, X. Water-level changes in China's large lakes determined from ICESat/GLAS data. *Remote Sens. Environ.* **2013**, *132*, 131–144. [\[CrossRef\]](#)
68. Zhang, G.; Xie, H.; Yao, T.; Kang, S. Water balance estimates of ten greatest lakes in China using ICESat and Landsat data. *Chin. Sci. Bull.* **2013**, *58*, 3815–3829. [\[CrossRef\]](#)
69. Gao, J.H.; Jia, J.J.; Kettner, A.J.; Xing, F.; Wang, Y.P.; Xu, X.N.; Yang, Y.; Zou, X.Q.; Gao, S.; Qi, S.H.; et al. Changes in water and sediment exchange between the Changjiang River and Poyang Lake under natural and anthropogenic conditions, China. *Sci. Total Environ.* **2014**, *481*, 542–553. [\[CrossRef\]](#)
70. Swenson, S.; Wahr, J. Monitoring the water balance of Lake Victoria, East Africa, from space. *J. Hydrol.* **2009**, *370*, 163–176. [\[CrossRef\]](#)
71. Lehner, B.; Liermann, C.R.; Revenga, C.; Vörösmarty, C.; Fekete, B.; Crouzet, P.; Döll, P.; Endejan, M.; Frenken, K.; Magome, J.; et al. High-resolution mapping of the world's reservoirs and dams for sustainable river-flow management. *Front. Ecol. Environ.* **2011**, *9*, 494–502. [\[CrossRef\]](#)
72. De Leeuw, J.; Shankman, D.; Wu, G.; de Boer, W.F.; Burnham, J.; He, Q.; Yesou, H.; Xiao, J. Strategic assessment of the magnitude and impacts of sand mining in Poyang Lake, China. *Reg. Environ. Chang.* **2010**, *10*, 95–102. [\[CrossRef\]](#)
73. De Vincenzo, A.; Covelli, C.; Molino, A.J.; Pannone, M.; Ciccaglione, M.; Molino, B. Long-Term Management Policies of Reservoirs: Possible Re-Use of Dredged Sediments for Coastal Nourishment. *Water* **2019**, *11*, 1915. [\[CrossRef\]](#)
74. De Vincenzo, A.; Molino, A.J.; Molino, B.; Scorpio, V. Reservoir rehabilitation: The new methodological approach of Economic Environmental Defence. *Int. J. Sediment Res.* **2017**, *32*, 288–294. [\[CrossRef\]](#)
75. Molino, B.; Viparelli, R.; De Vincenzo, A. Effects of river network works and soil conservation measures on reservoir siltation. *Int. J. Sediment Res.* **2007**, *22*, 273–281.
76. Zhu, L.; Chen, J.; Yuan, J.; Dong, B. Sediment erosion and deposition in two lakes connected with the middle Yangtze River and the impact of Three Gorges Reservoir. *Adv. Water Sci.* **2014**, *25*, 348–357. (In Chinese) [\[CrossRef\]](#)
77. Ye, X.; Li, X.; Zhang, Q. Temporal variation of backflow frequency from the Yangtze River to Poyang Lake and its influencing factors. *J. Southwest Univ. (Nat. Sci. Ed.)* **2012**, *34*, 69–75. (In Chinese) [\[CrossRef\]](#)
78. Yang, Y.-C.E.; Cai, X.; Herricks, E.E. Identification of hydrologic indicators related to fish diversity and abundance: A data mining approach for fish community analysis. *Water Resour. Res.* **2008**, *44*, W04412. [\[CrossRef\]](#)
79. Bunn, S.E.; Arthington, A.H. Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. *Environ. Manag.* **2002**, *30*, 492–507. [\[CrossRef\]](#)

80. Yi, Y.J.; Yang, Z.F.; Zhang, S.H. Ecological influence of dam construction and river-lake connectivity on migration fish habitat in the Yangtze River basin, China. In *International Conference on Ecological Informatics and Ecosystem Conservation*; Yang, Z., Chen, B., Eds.; Elsevier Science Bv: Amsterdam, The Netherlands, 2010; Volume 2, pp. 1942–1954.
81. Zhang, H.; Li, J.Y.; Wu, J.M.; Wang, C.Y.; Du, H.; Wei, Q.W.; Kang, M. Ecological effects of the first dam on Yangtze main stream and future conservation recommendations: A review of the past 60 years. *Appl. Ecol. Environ. Res.* **2017**, *15*, 2081–2097. [[CrossRef](#)]
82. Xie, P. Ecological impacts of Three Gorges Dam on Lakes Dongting and Poyang. *Res. Environ. Yangtze Basin* **2017**, *26*, 1607–1618. (In Chinese) [[CrossRef](#)]
83. Cai, Y.J.; Lu, Y.J.; Wu, Z.S.; Chen, Y.W.; Zhang, L.; Lu, Y. Community structure and decadal changes in macrozoobenthic assemblages in Lake Poyang, the largest freshwater lake in China. *Knowl. Manag. Aquat. Ecosyst.* **2014**. [[CrossRef](#)]
84. Wu, H.; Zeng, G.; Liang, J.; Chen, J.; Xu, J.; Dai, J.; Sang, L.; Li, X.; Ye, S. Responses of landscape pattern of China's two largest freshwater lakes to early dry season after the impoundment of Three-Gorges Dam. *Int. J. Appl. Earth Obs. Geoinf.* **2017**, *56*, 36–43. [[CrossRef](#)]
85. Xie, Y.; Tang, Y.; Chen, X.; Li, F.; Deng, Z. The impact of Three Gorges Dam on the downstream eco-hydrological environment and vegetation distribution of East Dongting Lake. *Ecolhydrology* **2015**, *8*, 738–746. [[CrossRef](#)]
86. Zhang, Y.; Jeppesen, E.; Liu, X.; Qin, B.; Shi, K.; Zhou, Y.; Thomaz, S.M.; Deng, J. Global loss of aquatic vegetation in lakes. *Earth-Sci. Rev.* **2017**, *173*, 259–265. [[CrossRef](#)]
87. Zhang, P.; Zou, Y.; Xie, Y.; Zhang, H.; Liu, X.; Gao, D.; Yi, F. Shifts in distribution of herbivorous geese relative to hydrological variation in East Dongting Lake wetland, China. *Sci. Total Environ.* **2018**, *636*, 30–38. [[CrossRef](#)] [[PubMed](#)]
88. Guo, J.; Chen, H.; Xu, C.-Y.; Guo, S.; Guo, J. Prediction of variability of precipitation in the Yangtze River Basin under the climate change conditions based on automated statistical downscaling. *Stoch. Environ. Res. Risk Assess.* **2012**, *26*, 157–176. [[CrossRef](#)]
89. Su, B.; Huang, J.; Zeng, X.; Gao, C.; Jiang, T. Impacts of climate change on streamflow in the upper Yangtze River basin. *Clim. Chang.* **2017**, *141*, 533–546. [[CrossRef](#)]



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