

Refined Identification and Spatiotemporal Characteristics of Drought and Flood Abrupt Alternation Events in the Poyang Lake Basin from 1965 to 2023

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Abstract. This paper utilizes actual observation data from 75 precipitation stations in the Poyang Lake Basin (PLB), combined with the daily scale drought and flood abrupt alternation (DFAA) index, to analyze the occurrences of DFAA in the basin from 1965 to 2023. This includes the frequency and spatiotemporal variation of events, as well as the spatial variation in the intensity of DFAA events. The results indicate that there is no apparent temporal pattern in the frequency and intensity of events in the PLB, with spatial concentration mainly in the Fuhe, Xinjiang, and Raohe river basins. The analysis of a typical drought-to-flood event (DTF) in 1994 and a typical flood-to-drought event (FTD) in 2022 shows that the 1994 event progressed from the northeast to the south, and the prolonged drought following the 2022 event exacerbated the losses caused by the DFAA.

Keywords: Poyang Lake; Drought and Flood Abrupt Alternation; DWAAI; spatiotemporal variation.

1. Introduction

Due to the impact of global climate change and human activities, the frequency and intensity of flash drought and flood events in summer have been continuously increasing, causing severe effects on China and resulting in significant losses. Since the 1950s, the interannual and [1] interdecadal changes in drought and flood climate disasters in China have become more pronounced. Since the 1960s, the area affected by abrupt drought and flood events in the Yangtze River Basin has been expanding, and both the frequency and intensity of these events have shown a yearly increasing trend. Poyang Lake, located in the middle and lower reaches of the Yangtze River Basin, has also experienced some changes in its drought and flood characteristics under this backdrop [2].

DFAA are typically defined as the rapid transition between dry and wet conditions over a short period, encompassing both sudden changes from DTF and vice versa. Unlike the identification of individual droughts and floods, these rapid transition events are characterized by their suddenness, unpredictability, and potential for severe damage. Currently, various indicators such as consecutive dry days and the Standardized Precipitation Index (SPI) have been employed by numerous researchers to study these transitions, effectively identifying them using conventional metrics [3, 4]. Shan propose using runoff data for a more direct analysis of rapid drought and flood transitions [5], which is crucial for water resource management and strategy development. The Daily-scale Drought and Wetness Abrupt Alternation Index (DWAAI) introduced by Shan and others focuses on the abruptness and alternation of conditions, offering a more detailed approach to analysis [2].

Poyang Lake, as the largest freshwater lake in China and a crucial strategic water source, plays a significant role in maintaining ecological balance and ensuring water security. However, in recent years, the PLB has been facing dual pressures from climate change and human activities, leading to frequent occurrences of composite disasters characterized by abrupt transitions between drought and flood [6]. This article mainly conducts a detailed analysis of the drought-flood abrupt alternation events (DFAA) in the Poyang Lake Basin (PLB) from 1965 to 2023, through the daily scale Drought and Wetness Abrupt Alternation Index (DWAAI), providing references for flood control and drought relief efforts in the PLB.

2. Data and Methodology

2.1 Study area

PLB is located on the southern bank of the middle and lower reaches of the Yangtze River, in the northern part of Jiangxi Province, spanning from 113°35'E to 118°29'E and from 24°29'N to 30°05'N. It is currently the largest freshwater lake in China. The region has a well-developed water system, with the main rivers including the Xiushui, Ganjiang, Fuhe, Xinjiang, and Raohe rivers as the five major tributaries. The climate is characterized by a subtropical monsoon, warm and humid, with an average annual temperature of about 18°C and an average annual precipitation of 1676mm. Precipitation in the Poyang Lake Basin shows significant seasonal variation, generally entering the rainy season from April, with a sharp decrease in precipitation starting from July, and entering the dry season after September, making it a typical seasonal lake (Figure 1).

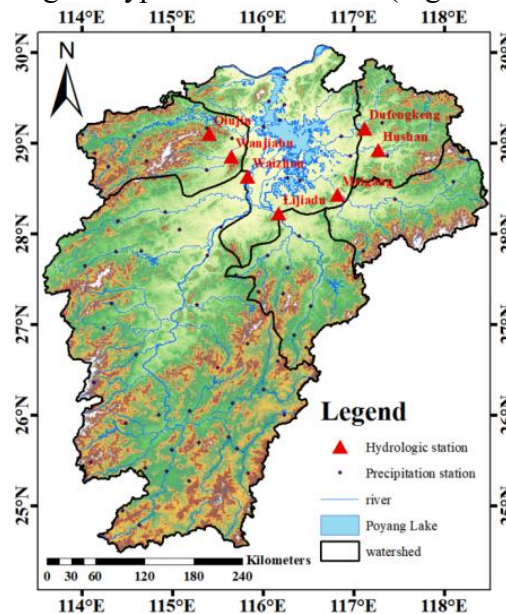


Fig. 1 Study area

The data on daily precipitation in the PLB from 1960 to 2023 were derived from actual precipitation monitoring data from 75 meteorological stations provided by the Jiangxi Province Poyang Lake Hydrological Monitoring Center, along with data from five rivers and seven major inflow control stations into the lake.

2.2 Methodology

This paper primarily adopts the daily scale Drought and Wetness Abrupt Alternation Index (DWAAl) proposed by Shan et al[2], with the formula as follows:

$$DWAAl = \left[K + (SPA_l - SPA_e) \times (|SPA_e| + |SPA_l|) \right] \times a^{-|SPA_e + SPA_l|}$$

$$K = \sum_{i=1}^n \left(\frac{SPA_{l_i} - SPA_{l_0}}{i} \right)$$

Where SPA_e and SPA_l represent the standardized precipitation anomaly values for the early and late periods, respectively; SPA_{l_i} and SPA_{l₀} represent the standardized early precipitation index anomaly values for the i-th day of the late period and the last day of the early period[7], respectively, meaning the early precipitation index (API) for the i-th day of the late period and the last day of the early period are standardized[8]; n is the number of days in the late period. Due to the different responses of drought and flood events to time, the duration of drought and flood periods need to be considered separately. Since the impact of early precipitation on the current day's drought or flood level exhibits exponential decay, and due to the short-term and sudden nature of flood disasters,

combined with the meteorological characteristics of Jiangxi Province, this paper selects a duration of 40 days for drought periods and 10 days for flood periods[9].

In the definition of the DWAAI index, its calculation formula can be further decomposed:

$(SPA_l - SPA_e) \times (|SPA_e| + |SPA_l|) \times a^{-|SPA_e+SPA_l|}$ representing the degree of "turn," where $a^{-|SPA_e+SPA_l|}$ in the expression is the weight coefficient[10]. The range of values for parameter a is generally between 1 and 1.4. After combining the hydrogeological conditions of Jiangxi Province and a rationality analysis, this article decides to select a value of 1.2 for a ; representing the degree of "urgency," where $K \times a^{-|SPA_e+SPA_l|}$ denotes the sum of slopes of the SPA_i relative to SPA_0 for each subsequent day[11]. This can be interpreted as the larger the K value, the earlier the occurrence of heavy rain in the later period, indicating a more urgent transition in drought and flood events.

The classification of the intensity of sudden drought-flood shifts is shown in Table 1. If the absolute value on a certain day exceeds 10, it is considered that a sudden drought-flood shift event has occurred, and the date with the maximum value exceeding 10 is considered the start date of this event.

Table 1. DWAAI Level Classification

Degree	DWAAI
Normal	$0 < DWAAI < 10$
Mild	$10 \leq DWAAI < 15$
Moderate	$15 \leq DWAAI < 18$
Serious	$ DWAAI \geq 18$

3. results

3.1 Spatiotemporal variations in the frequency of DFSA.

3.1.1 Temporal Variation Characteristics of Sudden DTF

Based on the daily precipitation series in the PLB, the DWAAI of 75 rain gauge stations within the basin from 1965 to 2023 was calculated, and the occurrence of DFSA at each station was tallied (Figure 2). Between 1965 and 2023, stations experienced DFSA events every year, but the annual fluctuation in the cumulative number of events is significant, without a clear pattern.

The multi-year average cumulative frequency of three types of DTF is 54.34 (Fig 2A), and that of mild events is 30.54. The occurrence of mild DTF reached a peak in 1999 with 49 instances, accounting for 65.3% of the total station counts, followed by 46 occurrences in 2000, the second highest year. Moderate DTF occurred less frequently, accounting for 10.26% of the total occurrences. Compared to moderate events, severe DTF were more frequent, with particularly high occurrences in 1973 (38 times), 1998 (35 times). Since the turn of the 21st century, the basin has experienced an average of 13.86 severe DTF per year, a 1.98% decrease from the 14.14 average of the previous century. Overall, the trend over the past eight years indicates a slight increase in DTF events across the basin.

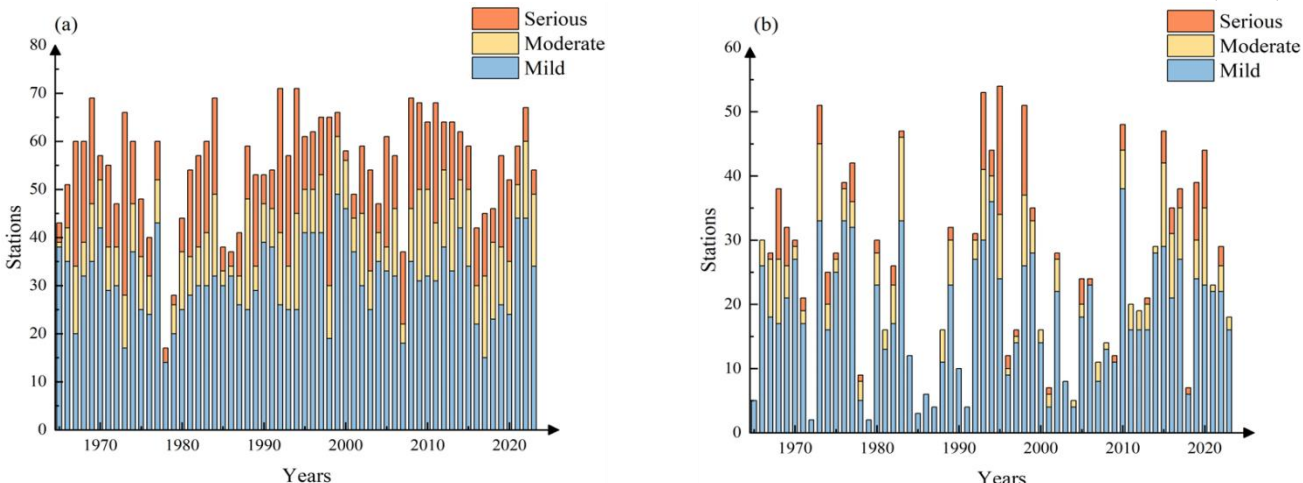


Fig. 2 Annual frequency of (a) DTF, (b) FTD Statistics

Compared to the frequency of DTF, the frequency of FTD at various stations (Figure 2b) is relatively low, with an average annual cumulative number of 24.27, which is only 44.7% of the frequency of DTF. The annual average station occurrences of mild, moderate, and severe sudden FTD are 17.71, 3.98, and 2.58 times, respectively. The occurrences of mild sudden FTD reached a maximum of 38 times in 2010, with a station ratio of 50.67%. Moderate sudden FTD reached a peak in 2015 and 1983, both at 13 times; in 1973 and 2020, they reached 12 times, just below the peak value.

Table 2. Sub-basin Frequency Statistics

Basin	Level	frequency (Flood turns to drought\Drought turn to flood)						
		1960s	1970s	1980s	1990s	2000s	2010s	2020s
Gan River	Mild	44\80	93\172	85\154	105\170	78\179	116\165	30\56
	Moderate	10\20	14\63	17\59	15\56	10\57	18\69	6\15
	Heavy	9\34	8\48	5\63	12\80	9\65	13\64	3\13
Fu River	Mild	9\21	19\41	24\37	27\42	11\40	33\33	8\19
	Moderate	3\5	5\6	6\6	4\13	0\10	7\8	3\2
	Heavy	3\12	6\8	2\23	10\24	2\15	5\18	1\1
Rao River	Mild	6\10	20\23	8\22	16\21	8\21	16\17	7\7
	Moderate	1\2	4\5	3\4	5\12	0\9	5\11	4\2
	Heavy	2\11	2\14	0\4	14\20	0\6	2\18	3\8
Xiushui River	Mild	8\8	11\19	5\17	16\21	5\22	13\14	8\8
	Moderate	2\9	1\3	3\6	6\5	1\7	7\14	1\3
	Heavy	1\4	0\6	1\8	2\19	0\4	0\8	1\2
Xin River	Mild	10\20	29\34	12\28	27\49	18\38	29\42	10\13
	Moderate	12\3	5\14	7\8	14\17	1\11	14\21	2\5
	Heavy	0\11	2\25	0\24	5\21	0\23	1\17	1\5
Lake District	Mild	10\13	20\15	10\29	17\41	5\24	14\25	5\9
	Moderate	0\2	5\8	3\12	2\10	1\5	4\17	1\7
	Heavy	3\10	5\19	0\8	13\14	0\23	6\10	3\4

For the sub-basin of PLB (table 2), statistical results reveal that within the Gan River basin, a total of 105 and 116 instances of mild DTF occurred in the 1990s and 2010s, respectively, accounting for 34.53% of all such events in this sub-basin. Medium to high intensity DTF were relatively common in the 1960s. The frequency of sudden FTD peaked in the 2000s, representing 17.34% of all events, with mild sudden FTD accounting for 59.47% of all events during the 2000s. Furthermore, the occurrence of severe FTD reached a peak in the 1990s, with an average annual station count of 2.16. In the 2010s, the Fu River basin experienced its highest frequency of mild FTD (3.3 times/10a). In comparison, the frequency of DTF was relatively higher, with severe DTF

accounting for 26.3%. The frequency of FTD events in the Raohe River Basin was highest in the 1990s, with severe FTD incidents reaching a peak, accounting for 60.87% of all severe events in the basin. Additionally, the basin experienced a high frequency of moderate and severe DTF, constituting 51.0% of all incidents, also predominantly occurring in the 1990s. The severity of sudden FTD in the Xin River basin account for only 5.4% of all events in the basin. DTF in the Xin River basin are quite prominent, with the average annual station count for mild DTF reaching 9.8 and 8.4 in the 1990s and 2010s, respectively, The Poyang Lake area often experiences severe sudden changes from drought to flood, with an average frequency of 1.49 station counts per decade, but the phenomenon of sudden changes from flood to drought is relatively mild.

3.1.2 Spatial Variation Characteristics of DTF

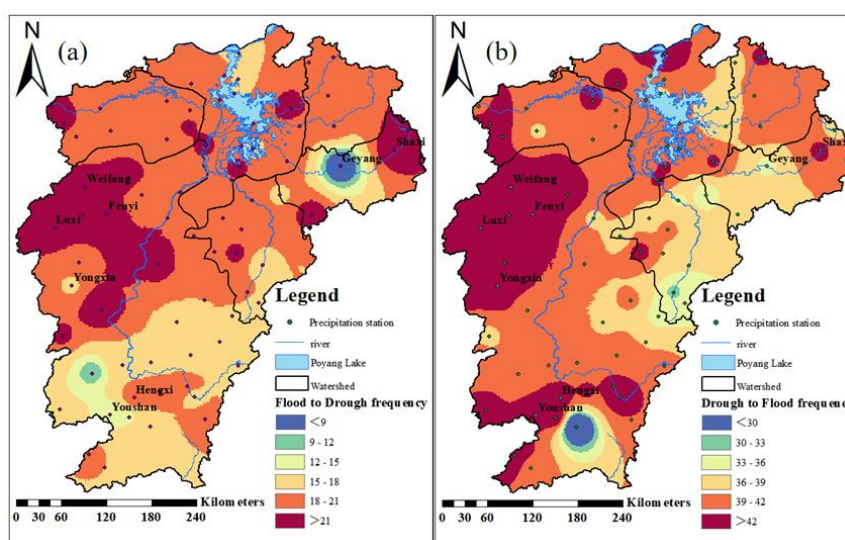


Fig. 3 Spatial Distribution of DFAA Frequency

The spatial distribution pattern of the frequency of DTF was obtained (Fig 3). Overall, the DTF (Figure 3a) occurred more frequently in the northern, western, and some southwestern regions (such as Youshan, Hengxi, etc.). Between 1965 and 2023, the frequency of FTD (Figure 3b) fluctuated between 16 and 21 times. The western part of Jiangxi Province along the Gan River basin experienced a higher frequency of FTD. On the whole, the northern, western, and northeastern regions of the PLB were more prone to FTD, but the northeastern region centered around Geyang experienced a minimal frequency of occurrence.

3.2 Spatial and Temporal Variations in the Intensity of DFAA

3.2.1 Temporal Changes in the Intensity of DFAA

According to the annual average DWAAI for the watershed from 1965 to 2023, the higher the average intensity, the more severe the DFAA within that year. As shown in Figure 4, the intensity of DFAA fluctuates greatly from year to year, with no significant linear trend. The multi-year average intensity of DTF in the PLB is 11, and the maximum value of the watershed's DTF reached 20.26 in 1969, indicating the severity of that period. Additionally, the river basin had relatively high levels of DWAAI in 1994, 2003, and 2008, with values of 18.86, 18.43, and 18.23 respectively. The average DWAAI of FTD in the basin still shows significant interannual variability without distinct characteristics. Moreover, the intensity was higher in 1995 and 1993, reaching -21.15 and -18.06 respectively. Other years with high intensity include 1998, 2017, and 2020, with the basin's multi-year average intensity reaching -15.80, -14.64, and -12.99 respectively.

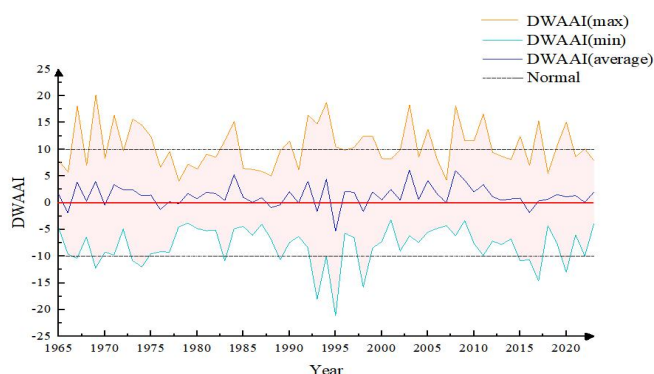


Fig. 4 DWAAI Annual Extreme Value Statistics

3.2.2 Spatial Variation of the Intensity of Abrupt Changes from DTF

The average intensity of DFAA is unevenly distributed across various observation stations. Overall, the intensity distribution of both DTF (Figure 5A) and FTD (Figure 5B) is essentially consistent. The highest intensities of DFAA are mainly concentrated in the eastern Xinjiang River Basin and the northeastern Rao River Basin. Areas with relatively lower intensities are primarily located in the southern part of the Ganjiang River Basin and the northwestern part of the lake region, centered around the Zifang station.

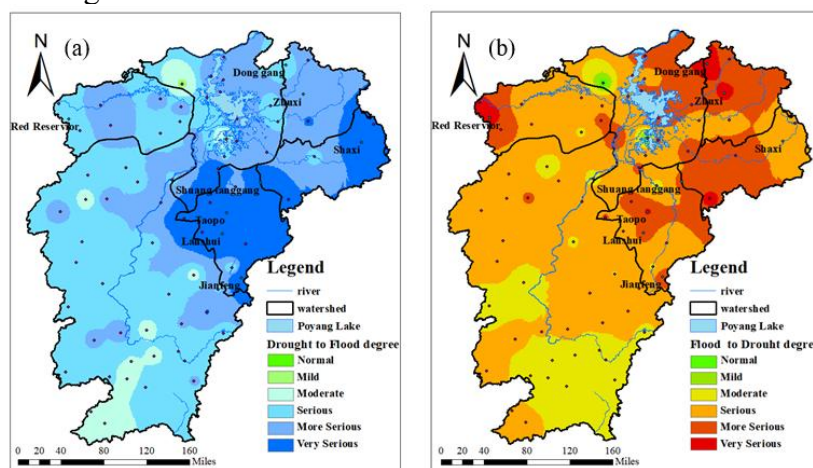


Fig. 5 Spatial Distribution of (a) DTF, (b) FTD Change Intensity

3.3 Development Process of Typical Sudden Drought and Flood Events

Due to the high frequency and intensity of the sudden shift from drought to flood in the Poyang Lake basin in 1994, this year was selected as a typical year for the sudden drought-to-flood transition, and the spatiotemporal distribution of the drought-to-flood events during this year was analyzed. Based on the daily process line of the basin average, it can be seen that the extreme point of the drought-to-flood event in 1994 occurred on June 6, reaching 18.86, with a duration of about a week (Figure 6a), which is considered a severe event. The initial stage of this event occurred in the northeastern region (Fig 7a), and as the drought-to-flood process continued, it shifted towards the southern region, while the daily average intensity decreased.

2022 was a year that typified the rapid transition from flood to drought in the Poyang Lake basin in recent years. According to the daily rainfall data and the DWAAI index chart (Figure 6b) for 2022, it is observed that the drought period lasted for about 45 days within the year.

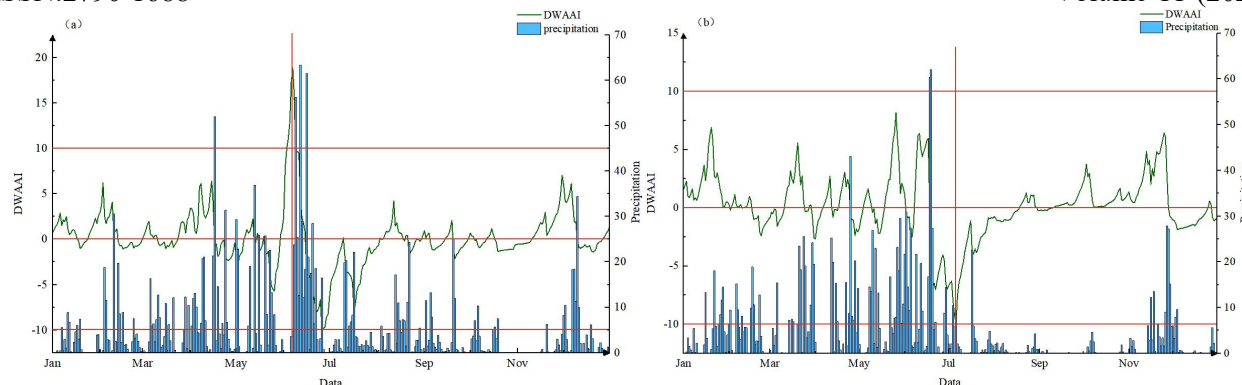


Fig. 6 DWAAI Index and Daily Precipitation Series

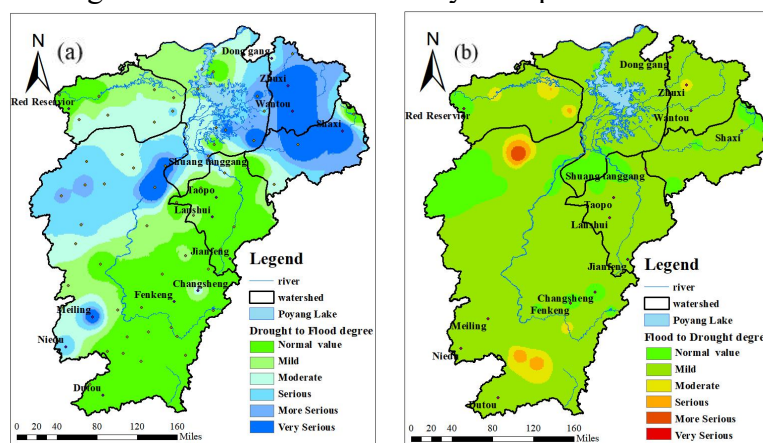


Fig. 7 The spatial distribution of the DWAAI in (a) 1994.6, (b) 2022.7

The initial date of the event on July 6th and the end date on August 20th (Fig 7b), it was noted that the most severe areas of rapid transition from flood to drought in the Poyang Lake basin were located in the northeastern part, including the Rao River basin and the Xinjiang and Ganjiang River Basins.

Observing the precipitation data, it was found that after the end of this flood-to-drought event, the Poyang Lake basin remained in a state of drought, continuing for about a month. This indicates that although the rapid transition from flood to drought was not extremely severe, the prolonged drought following the rapid transition had a significant impact on the basin.

4. Conclusion

(1) The occurrence of sudden drought-to-flood events in the Poyang Lake Basin fluctuates greatly from year to year, without a clear pattern. The frequency of drought-to-flood events is higher than that of flood-to-drought events, with the 1990s being a period of high incidence for such abrupt changes in the basin. Spatially, the northern and western parts of the basin are more prone to these sudden drought-to-flood events.

(2) The intensity of sudden drought and flood shifts in the Poyang Lake basin does not show a clear linear pattern over time, with the extreme value for sudden drought-to-flood events occurring in the 1860s, and the extreme value for sudden flood-to-drought events in the 1890s. Spatially, the intensity distribution is uneven, but the intensity distribution of both drought-to-flood and flood-to-drought events is basically consistent, with a concentration in the Fu River, Xin River, and Rao River basins in the eastern and northeastern parts.

(3) In 1994, the drought-to-flood event in the Poyang Lake basin lasted for about 7 days, progressing from the northeast to the south. The intensity gradually decreased from the northeast to the south, with the intensity in the south being slightly higher than in the north when the event ended. In 2022, the flood-to-drought event in the Poyang Lake basin lasted for about 45 days. At the onset, the average intensity of the event in the basin was -10.98, indicating a mild drought-flood

sudden change event. However, after the event ended, a dry condition persisted for about a month. This prolonged period of drought had a significant impact on the flood control and drought relief efforts in the Poyang Lake basin.

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