Analysis of Runoff Characteristics in Dry Season at Datong Station on the Mainstream of the Yangtze River

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Abstract. As an important control station for the mainstream of the lower reaches of the Yangtze River, studying the runoff change characteristics in dry season at Datong Hydrological Stations can provide a comprehensive grasp of the hydrological conditions in the lower reaches of the Yangtze River. This study uses linear trend method, Mann-Kendall method and wavelet analysis method to analyze the dry season runoff change characteristics at Datong Station, and the following conclusions are obtained: the average flow in the dry season at Datong Station has shown a significant increasing trend and a significant change period, while the first main period is 35-year; for the typical dry months, there is no significant increasing trend in December, but the increasing trend is significant in January and February; The dry season runoff at Datong Station accounted for a significant increase in the proportion of the entire year since 2003.

1. Introduction
The Yangtze River is the mother river of the Chinese nation and an important support for the development of the Chinese nation. With its huge river and lake system, unique and complete natural ecosystem, and powerful functions of water conservation, biological breeding, oxygen release and carbon fixation, and environmental purification, the Yangtze River maintains China’s important biological gene treasure house and ecological safety barrier [1]; with its rich water and soil, forests, minerals, hydropower, and shipping resources, it guarantees China’s water supply security, food security and energy security; through the management and development of the river basin, it has nurtured 459 million people, nurtured the splendid Yangtze River civilization, and played an important role in economic and social development.

Datong hydrological station, located at downstream of the Yangtze River, is an important station controlling the Yangtze River basin and is the uppermost boundary of ocean tide rising of East China Sea [2]. Studying the characteristics of its dry season runoff changes can guide the production and domestic use of water in the lower reaches of the Yangtze River, and can also provide a certain reference for the study of changes in the Yangtze River's water flow into the sea.
2. Study Area
Datong Station is an important hydrological station in the middle and lower reaches of the Yangtze River. It is located in Meilong Town, Chizhou City, Anhui Province [3]. It has a history of more than 90 years. The station is located in the mainstream water system of the lower reaches of the Yangtze River, with a catchment area of about 1.7×10^6 km^2 and a distance of 624 km from the estuary.

Datong Station is the upper boundary of the river that can be reached by ocean tides in the East China Sea. It is also a national first-class hydrological station. It is an important station for monitoring the water regime in the lower reaches of the Yangtze River. It is responsible for flood control forecasting and water quality monitoring tasks in the lower reaches of the Yangtze River, Jiangxi, Anhui, Jiangsu, and Shanghai. Studying the law of flow changes at Datong Station on the Yangtze River and the impact of climate change on the changes in flow at Datong Station on the Yangtze River in recent years plays an important role in hydrological forecasting and studying the evolution of the Yangtze River Estuary.

3. Data and Methodology

3.1. Data
This study collected daily runoff data from Datong Station from 1950 to 2018. The data comes from the Hydrological Yearbook of the Yangtze River Basin and has been checked for data consistency, reliability, and representativeness.

3.2. Methodology
In this study, in-suit observation data was used to analyze the runoff changes in dry season and in typical dry months. The liner trend method [4], Mann-kendall (M-K) method [5] and wavelet analysis [6] were employed to analyze the characteristics of runoff changes.

4. Results and Discussion

4.1. Analysis on runoff change in the dry season

4.1.1. Trend analysis
Figure 1 shows that the average flow changes in the dry season at Datong Station from 1950 to 2018. based on linear trend method, the average flow in the dry season at Datong Station shows an increasing trend, and the amplitude increases by 439m^3/s every 10 years. The M-K statistic value is 2.24, which has passed the significance test at the 95% confidence level, showing a significant increasing trend. It can be seen from the inter-decadal average that the average flow in the dry season at Datong Station changes slightly from 1950 to 2009, and the average flow in the dry season increased significantly after 2010, with an average of 17,700 m^3/s.

Figure 2 shows that the wavelet analysis of the average flow in the dry season at Datong Station, the average flow in the dry season has periodic variation on three levels, concluding the large scale of 20-50a, the mesoscale of 8-19a, and the small scale of 4-7a (Fig.2a). On the large scale, there is a strong signal, showing the three fluctuations of alternating abundance and dryness, and the periodic variation was stable and global. On the mesoscale, there were 9 dry-abundant oscillations. The periodic change was stable from 1978 to 1994, and the period stability began to weaken in 1995. On the small scale, the average flow fluctuation in the dry season was not obvious and has slightly strengthened since 1992, but still at a weak level.

The wavelet variance figure (Figure 2b) shows that there are 4 obvious peaks in the figure, which correspond to the time scales of 35-year, 44-year, 10-year, and 5-year, respectively. Among them, the largest peak correspond to the 35-year time scale, showing that the 35-year periodic fluctuation is the strongest, which is the first main period of the average flow change in the dry season, and the 44-year...
time scale corresponds to the second peak, which is the second main period. The 10-year and 5-year time scales are the third and forth main period in sequence.

Figure 2c and 2d show the wavelet analysis of the first and second main periods. It can be seen from the figure that on the 35-year time scale, the average change period of the average flow in the dry season is about 23 years, experiencing 3 times periodic variation of abundance-dryness, and on 44-year time scale, the average change period of the average flow in the dry season is about 33 years, experiencing twice periodic variation of abundance-dryness.

Figure 1 Average flow change in the dry season at Datong Station from 1950 to 2018

Figure 2 Wavelet analysis of the average flow in the dry season at Datong Station
4.1.2 Intra-annual distribution change of runoff in the dry season
The previous analysis shows that the flow in the dry season has a significant increasing trend. To clarify the intra-annual distribution change of runoff in the dry season at Datong Station, calculate the distribution proportion of the dry season runoff in the total annual runoff from 1950 to 2018, as shown in Figure 3. Figure 3 shows that the intra-annual distribution proportion of the dry season is basically between 22% and 36%, and the proportion of the dry season runoff varies greatly from year to year, but the overall change trend is not obvious. Table 1 shows the inter-decadal proportion of the runoff in the dry season. The annual runoff at Datong Station in each era is between $8427.1 \times 10^{10}$ m$^3$ and $959.51 \times 10^{10}$ m$^3$, and the runoff fluctuates without obvious trend of increase or decrease. The runoff in the dry season is between $2383.6 \times 10^{10}$ m$^3$ and $2959.0 \times 10^{10}$ m$^3$, of which the average ($2959.0 \times 10^{10}$ m$^3$) from 2010 to 2018 is the largest, and the total runoff is only $8973.0 \times 10^{10}$ m$^3$. The inter-decadal proportion of the runoff in the dry season does not change significantly, the proportion is 28% from the 1950s to the 1970s. As the years increased, the proportion increased slightly. In the 2000s, the proportion increased to 31%, and the proportion reached 33% from 2010 to 2018.

4.2. Analysis of the runoff change in typical dry months

4.2.1. Trend change
The dry months when salt tide intrusion occurs frequently in the Yangtze River estuary, namely December, January, and February, were selected as typical dry months. The trend of monthly average flow change was analyzed using data from 1950 to 2018.

   (1) December
It can be seen from figure 4 that the average flow in the dry season at Datong Station shows an increasing trend in December, with the linear trend amplitude increasing by 303 m$^3$/s every 10 years. The M-K statistic is 1.25, which fails the significance test at 95% confidence level, indicating that the increasing trend is not significant.
(2) January

It can be seen from figure 5 that the average flow in the dry season at Datong Station shows an increasing trend in January, with the linear trend amplitude increasing by 674 m$^3$/s every 10 years. The M-K statistic is 4.27, which passes the significance test at 95% confidence level, showing a significant increasing trend.

(3) February

It can be seen from Figure 6 that the average flow in the dry season at Datong Station shows an increasing trend in February, with the linear trend amplitude increasing by 599 m$^3$/s every 10 years. The M-K statistic is 3.18, which passes the significance test at 95% confidence level, showing a significant increasing trend.

4.2.2. Analysis of distribution change

To clarify the annual distribution change of the flow in typical dry months at Datong Station, the runoff distribution proportion of the dry season in the total annual runoff was calculated from 1950 to 2018. It can be seen from figure 7 that the distribution proportions of the runoff are basically between 2.4% and 7.6% in December, and the proportions in each year fluctuate significantly, and the annual distribution proportion has been greater than 3.3% since 2003. The distribution proportions are basically between 2.2% and 6.1% in January, the proportion in each year fluctuate significantly, which is similar to the change in December, and the annual distribution proportion has been greater than 3.2% since 2003. The distribution proportions are basically between 2.1% and 5.1% in February, and the proportions fluctuate greatly. Since 2003, the annual distribution proportion has increased in February, which is greater than 2.9%.

Table 2 shows the inter-decadal proportion in typical dry months. It can be seen that the inter-decadal proportion change pattern in the typical months is basically similar to that in each year.
From the 1950s to the 1990s, the distribution proportion in each month has shown a periodic fluctuation. Among them, the proportion was 4.09–4.41% in December, 3.03–3.69% in January and 2.69–3.59% in February, respectively. The distribution proportions in December, January and February have increased since 2000s. From 2010 to 2018, the proportion in December, January and February has reached 5.09%, 4.50% and 4.06%, respectively.

5. Conclusions

(1) The average flow in the dry season at Datong Station has shown a significant increasing trend. The inter-decadal average has increased significantly since the 2010s. Based on wavelet analysis, the average flow in the dry season has a significant change period. The first main period is 35 years, and the runoff in the dry season accounts for 22–36% in the entire year. The proportion has increased slightly with the increase of years, and the proportion was 33% from 2010 to 2018.

(2) Based on the analysis of the average flow in typical dry months (December, January and February), there is no significant increasing trend in December, but the increasing trend is significant in January and February. The linear trend change amplitude is the largest in January, which increased 674 m$^3$/s every 10 years.

(3) The dry season runoff at Datong Station accounted for a significant increase in the proportion of the entire year since 2003. The preliminary consideration is that it will be affected by the construction and operation of the Three Gorges Reservoir. The specific analysis will be discussed in the next study.

Figure 7 Annual proportion changes in December, January and February from 1950 to 2018

Table 2 Inter-decadal distribution proportion in typical dry months from 1950 to 2018

| Years   | Annual average runoff($10^8$m$^3$) | December | January | February |
|---------|----------------------------------|----------|---------|----------|
|         | Runoff ($10^8$m$^3$) | Percentage (%) | Runoff ($10^8$m$^3$) | Percentage (%) | Runoff ($10^8$m$^3$) | Percentage (%) |
| 1950-1959 | 9365.1 | 374.7 | 4.00 | 294.4 | 3.14 | 307.3 | 3.28 |
| 1960-1969 | 8768.2 | 386.5 | 4.41 | 268.1 | 3.06 | 236.0 | 2.69 |
| 1970-1979 | 8509.5 | 353.4 | 4.15 | 267.9 | 3.15 | 259.8 | 3.05 |
| 1980-1989 | 8985.7 | 385.7 | 4.29 | 272.0 | 3.03 | 267.6 | 2.98 |
| 1990-1999 | 9595.1 | 392.0 | 4.09 | 353.2 | 3.68 | 344.4 | 3.59 |
| 2000-2009 | 8427.1 | 385.4 | 4.57 | 327.6 | 3.89 | 325.6 | 3.86 |
| 2010-2018 | 8973.0 | 456.5 | 5.09 | 403.5 | 4.50 | 364.2 | 4.06 |

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