Analysis of the Change Features and Trend in Runoff Volume of the East River

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ABSTRACT: Based on the hydrologic data collected in Boluo Hydrologic Station of the East River in Guangdong Province for 57 years, this thesis applied three methods—moving average method, Spearman rank correlation analysis, and Mann-Kendall testing method—to analyze the change features and trend in runoff volume of the East River. All these three methods reflected that the runoff volume of the East River was in non-significant progressive increase during 57 years. The results of moving average analysis and Spearman rank correlation analysis were basically the same. Moving average analysis showed the average runoff volume in May, June, September and October was in significant decrease (P=0.05) while that in July, August, December and from January to April was in significant progressive increase (P=0.05). Spearman rank correlation analysis showed that the average runoff volume in December and from January to April was in significant progressive increase (P=0.05) while that in May and June was in significant decrease. Mann-Kendall test showed that the average runoff volume in the first quarter and the fourth quarter was in continuous progressive increase after 1959 and the increase trend reached a significant level after 1975 (P=0.05) while the average runoff volume was in alternative change law of non-significant progressive increase and non-significant decrease in the second quarter and the third quarter.

Keywords: Boluo Hydrologic Station; moving average; rank correlation analysis; Mann-Kendall test

1 BACKGROUND

With a total drainage basin area of almost 36,000 km², the East River is one of the three river systems in the Pearl River. The multi-year average precipitation is 1500–2400mm with uneven spatial and temporal precipitation distribution. Social economy in the East River basin is developed with great demand in water resources. The East River is also responsible for water supply to Hong Kong and Renping Peninsula. Thus, the pressure of water resources there is high. In recent years, human activities and climate change have left significant influence on the runoff features of the East River basin, leading to gradually complicated evolution rule of basin water resources. According to research, Yanhu He et al. [1] found the runoff coefficients from 1964 to 2012 increased with the progressive increase of spatial scale. Evaporative capacity of river basin is an important influence factor of runoff. Ping Xie et al. [2] pointed out that both the actual evaporation of the East River basin and the evaporation of evaporating pan were in decrease from 1956 to 2003. In their research, Leting Lv et al. [3] pointed out that spatial and temporal disparity of rainfall is a key factor that influences the runoff depth of the East River basin; and it can especially influence the change law of annual scale runoff. Moreover, human activities constitute a main factor of influencing change in monthly scale of the East River basin runoff. Based on the
hydrologic and meteorological data of the East River in almost 50 years, Kairoing Lin et al. [4] and Jie Liu et al. [5] obtained similar results and pointed out that precipitation was in non-significant progressive increase and temperature was in significant progressive increase in the East River basin. Thus, rainfall is the main driving force that causes runoff changes in the East River basin.

At present, the unit of time used in most research results related to changes in runoff volume of the East River basin is year. However, there’s little research result related to change laws of monthly or quarterly runoff volume which contain important guiding significance in reasonable allocation and use of surface water resources. Based on the moving average analysis, Spearman rank correlation analysis, and Mann-Kendall testing method applied in this thesis, analysis of the change features and trend in runoff volume of the East River basin has been conducted in different time scales, providing scientific proof for reasonable development and utilization of water resources in the East River basin.

2  DATA SOURCE AND ANALYTICAL METHODS

2.1 Data source

The hydrologic data used in this thesis is the monthly and annual observed runoff volume of Boluo Hydrologic Station of the East River basin from 1954 to 2010. Boluo Hydrologic Station is a Class I national precision hydrologic station founded in August, 1953. Located in the East Village of Luoyang Town in Boluo County of Guangdong Province, Boluo Hydrologic Station is the downstream control station for the main stream of the East River.

2.2 Analytical methods

There are certain tendency, phasic pattern, and mutability in river runoff volume. Moving average analysis [7], Spearman rank correlation analysis [8, 9], and Mann-Kendall test [10, 11] are respectively applied in this thesis to conduct tendency analysis and mutability test on the sixty-year runoff observation data of Boluo Hydrologic Station in different time scales, aiming to figure out the change features and trend in runoff volume of the East River in 60 years.

2.2.1 Spearman rank correlation method

For time series \( Y_i \)\( \cdots \)\( Y_n \), the ascending sort numbers are \( N_1 \)\( \cdots \)\( N_n \). Calculate rank difference of two sequences \( m \) and calculate coefficient of rank correlation \( r \) according to Formula (1):

\[
r = 1 - \frac{6 \sum m_i^2}{n(n^3 - n)}
\]

Calculate statistical test amount \( M_a \) according to \( r \). See the formula as follows:

\[
M_a = r(1 - r^2)^{0.5} \tag{2}
\]

Among which, \( M_a \) complies with the t-distribution of DOF (degree of freedom) of \( n-2 \). If \( M_a > t_{\alpha/2} \), the change trend is significant, and vice versa.

2.2.2 Mann-Kendall test

For time series \( Y_1, Y_2, \ldots, Y_n \), \( m_i \) refers to the accumulative number by which the No.\( i \) sample \( Y_i \) is larger than \( Y_j \) (\( i \in [1,i] \)). Define the statistical amount as follows:

\[
d_k = m_1 + m_2 + \cdots + m_k \tag{3}
\]

Among which, \( k \in [2,n] \).

Each element based on \( Y_i \) is mutually independent and in the same continuous distribution. The mean value \( d_k \) and variance can be expressed as:

\[
E(d_k) = k(k-1)/4 \tag{4}
\]

\[
\text{var}(d_k) = k(k-1)(2k+5)/72 \tag{5}
\]

The following equation can be obtained by standardizing the above formula \( d_k \):

\[
U_{F_k} = \frac{d_k - E(d_k)}{\sqrt{\text{var}(d_k)^{0.5}}} \tag{6}
\]

If \( U_{F_k} > 0 \), it means the series is in ascending trend; otherwise, it is in descending trend. For a given significant level \( \alpha \), if \( |U_{F_k}| > U_{\alpha/2} \), there’s significant change trend in the series.

While conducting Mann-Kendall mutation test, repeat the above steps in the reversed order of time series \( Y_i \) and calculate \( U_{B_k} \). The intersection point of \( U_{F_k} \) and \( U_{B_k} \) within a given significant level range is the series abrupt change point.

3 RESULTS AND ANALYSIS

3.1 Annual distribution analysis

See Figure 1 for the distribution characteristics of Boluo Hydrologic Station within monthly average flow rate years from 1954 to 2010. It can be seen that the runoff volume distribution of the East River concentrated from May to September. The average flow rate of each month accounted for about 10% of the annual flow rate. The accumulated flow rates of all months accounted for 58.92% of the annual flow rate. The flow rate of each other month accounted less than 7.5% of the annual flow rate, among which the average runoff volumes of January, February, March, November and December were all lower than 5% of the annual runoff volumes. The runoff volumes of June were the largest with an average value of 1595.47 m\(^3\)
s$^{-1}$ in several years. The maximum monthly runoff volume in history (4910 m$^3$ s$^{-1}$) also appeared in June (1959). In general, the annual runoff volume distribution of the East River was relatively uneven, going against deployment and usage of water resources within the drainage basin. However, according to Xinjun Tu et al.'s\textsuperscript{12} and Zhaoli Wang et al.'s\textsuperscript{13} research, with influence of climate change and human being’s activities, such as precipitation change, engineering construction of water conservancy project, and deployment of water resources in different drainage basins, both the annual runoff concentration degree of the East River and the annual changing process of its unevenness were in significant progressive decrease trend.

After several times of trials, it has been found that ideal analysis results can be obtained through 10-year moving period processing. Figure 2 shows the moving average processing results of the monthly average flow rate of Boluo Hydrologic Station in 27 years, taking 10 as the period. It can be seen that the average flow rates of May, June, September and October were all in significant progressive decrease in 57 years (P $< 0.05$). However, the flow rates of the months mentioned above were in continuous fluctuant increase before 1985, and started to be in progressive decrease since 1985. In 57 years of research, the average annual flow rates were in non-significant fluctuant increase trend which can accord with the result obtained in Yanhu He et al.’s\textsuperscript{1} research.

### 3.2 Analysis of change trend

#### 3.2.1 Moving average analysis

![Figure 2: Moving average curves of monthly and annual mean stream flow](image)

Figure 2. Moving average curves of monthly and annual mean stream flow (Note: the second, third and fourth columns in the chart refer to the slope, determination coefficient, and significance level of the linear fitting equation of moving average processing curve respectively.)

#### 3.2.2 Spearman rank correlation analysis

Figure 3 shows the Spearman rank correlation analysis results of monthly and annual average flow rates in 57 years. It can be seen that the Spearman correlation coefficients of average flow rates in May and June were negative in 57 years, failing to reach the significance level. It means the average flow rates of May and June were in non-significant progressive decrease trend, slightly different from the moving average analysis. However, the Spearman correlation coefficients of the average flow rates in January, February, March, April, and December were higher than 0 and reached the significance level, meaning the average flow rates in the months mentioned above were in significant progressive increase (P=0.05). The average flow rates of September and October were in non-significant progressive increase which was contrary to the results obtained in the moving average analysis. The annual average flow rates were in non-significant progressive increase.

![Figure 3: Spearman rank correlation analysis results of monthly and annual mean stream flow](image)

#### 3.2.3 Mann-Kendall Test

Mann-Kendall trend analysis and abrupt change test were used to analyze Boluo Hydrologic Station of the East River for its runoff flow change law in 57 years, taking quarter as the unit. See Figure 4 for the results.

![Figure 4: Mann-Kendall trend analysis and abrupt change test](image)
Since 1956, the average flow rates of the first quarters were in progressive increase (Figure 4A), among which the increase trend had reached the significance level since 1975 ($P=0.05$). From 1966 to 1969, the average flow rates of the first quarters had three abrupt changes. Before 1994, the average flow rates of the second quarters were in alternative decrease and increase, and had been in continuous decrease after 1994 till 2010 (Figure 4B), all failing to reach the significance level. From 1962 to 1986, the average flow rates of the second quarters had 17 abrupt changes intensively. The average flow rates of the third quarters were also in alternative increase and decrease (Figure 4C), all failing to reach the significance level. From 1958 to 1964 and from 1976 to 1988, the flow rates of the third quarters were in continuous non-significant decrease. From 1989 to 1996, the flow rates of the third quarters were in continuous non-significant decrease. In 57 years, the average flow rates of the third quarters had 15 abrupt changes. After 1959, the average flow rates of the fourth quarters were in progressive increase (Figure 4D), and reached the significance level after 1975 ($P=0.05$). The average flow rates of the fourth quarters only had 1 abrupt change from 1959 to 1960.

Except some specific years, the annual average flow rates were in progress increase, especially that they had been in continuous progress increase after 1973 (Figure 4E); however, all the average flow rates failed to reach the significance level. From 1954 to 1968, the annual average flow rates had 11 abrupt changes intensively, and still had 6 abrupt changes after 2002. Since 1950s, the evaporative power of the East River basin had been in downtrend, and reached its minimum value in 1990s [13] which is the basic reason to explain the progress increase change law of the runoff volume of the East River. Zhaoli Wang et al. [14] also obtained similar conclusions. They pointed out that the precipitation in the East River basin was in non-significant decrease and the surface runoff was in non-significant increase mainly because of the decrease in basin evaporative capacity.

4 CONCLUSIONS

Based on the actual measurement data of the runoff volume of the East River basin collected by Boluo Hydrologic Station in 57 years, moving average method, Spearman rank correlation analysis, and Mann-Kendall test were applied to analyze the monthly, quarterly and annual average flow rate change trends of the East River. Related conclusions are shown below:

1) The average flow rates of the East River were higher from May to September, accounting for 59% of the annual runoff volume.

2) The moving average analysis shows that the runoff volume of the East River was in non-significant progressive increase in 57 years, among which the runoff volumes in May, June, September and October were in significant decrease ($P=0.05$) and those in January, February, March, April, July, August, and December were in significant increase ($P=0.05$).

3) Spearman rank correlation analysis shows that the average flow rates in January, February, March, April, and December were in significant progressive increase ($P=0.05$) while those in May and June were in non-significant progressive decrease. The average flow rates of the other months and the annual average flow rate were all in non-significant progressive increase.

4) Mann-Kendall test shows that there were few abrupt change points in the average flow rates of the first quarters and the fourth quarters in 57 years, each had 3 times and 1 time of abrupt change respectively. After 1959, these two quarters were in continuous progress increase and reached the significance level after 1975 ($P=0.05$). There were more abrupt change points in the average flow rates of the second quarters and the third quarters, each had 21 times and 15 times of abrupt change in 57 years respectively. The average flow rates were in alternative non-significant progressive increase and progressive decrease. Before 1973, the average annual flow rates were in alternative progressive increase and progressive decrease; and had been in continuous progress increase since 1973. However, all the average annual flow rates failed to reach the significance level.

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6 REFERENCES


