Rainfall Variety and its Effect to Runoff Reduction of Status Year in the Region from Hekouzhen to Longmen

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Abstract. The natural runoff of the Yellow River has been reduced sharply since 2000. Based on rainfall network of 1966 and 1977 are built on GIS platform, the trend of rainfall variety in 1956~2013 is analyzed. The turning point of runoff of natural period and human activities impact period in the eighteen tributaries was analyzed with the method of orderly clustering and MWP test and so on. The model was established with the data from 1956 to the turning point year, and the runoff during this period was regarded as benchmark value. The runoff variety and the impacts brought by rainfall in the status series from 2007 to 2013 were analyzed by equation of runoff division. It is showed that natural runoff reduced 5.411 billion cubic meters, among which brought by rainfall not negative value but increased 0.424 billion cubic meter.

1. Introduction

According to the results of Yellow River water resources utilization[1], the average natural runoff of Huayuankou Hydrology station from 1919 to 1975 was 56 billion m$^3$. According to the results of investigation and evaluation of water resources in the Yellow River basin[2] and comprehensive planning of the Yellow River basin[3], the average natural runoff of Huayuankou hydrology station from 1956 to 2000 was 53.3 billion m$^3$ and it was only 45.4 billion m$^3$ from 2000 to 2013 (Fig.1).

![Fig.1 Natural annual runoff of Huayuankou hydrology station from 1919 to 2013](image-url)
Facing the severe situation of natural runoff falls sharply in the Yellow River, Liu Xiaoyan and Jiao Juying et al. analyzed the influence of underlying surface variation such as forest-grass vegetation and level terraces on the river runoff [4-7]. The region from Hekouzhen to Longmen (hereinafter referred to as He-Long region) in the middle reaches of the Yellow River with the most severe runoff reduction is taken as the research object to analyze the variation trend of rainfall and runoff in He-Long region and each research unit from 1956 to 2013, the research units are divided based on the existing network of hydrology stations. The model between rainfall and runoff was established with the data from 1956 to the turning point year, and the runoff during this period was regarded as the base year. Taking the years from 2007 to 2013 as the current year, the runoff variety and the impacts brought by rainfall variation in current year were analyzed.

2. Study area and basic data

2.1 General situation of study area

The area of He-Long Region is 129654km², which is the difference of catchment area between the Longmen hydrology station and Hekouzhen hydrology station. Eighteen first-level tributaries of the Yellow River are selected, the Huangfuchuan, Gushanchuan, Kuye river, Tuwei river, Jialu river, Wuding river, Qingjian river, Yan river, Fenchuan river and Shiwangchuan on the right side of the Yellow River, and Hong river, Pianguan river, Xianchuan river, Zhujiachuan, Qingliangsigou, Qiushui river, Sanchuan river, Chuan river and Xinshui river on the left side of the Yellow River. The area above the control stations of the eighteen tributaries is controlled area, and the area without hydrology stations of the Yellow River mainstream is ungauged area.

2.2 Rainfall network

According to the Yellow River historical records in the volume 3 of Yellow River records [8], the first hydrology station network planning of Yellow River basin was carried out uniformly in 1956. From 1963 to 1965, 1977 to 1979 and in 1983, the station network planning was adjusted and supplemented. The rainfall stations network change process is shown in Fig.2. The station network of He-Long region in 1966 and 1977 is shown in Fig.3.

![Fig.2 The rain stations network change process in He-Long region(overall,18 tributaries, ungauged area)](image-url)
2.3 Research unit division

There are 41 research units in the He-Long region. The controlled tributaries on the left bank are divided into 8 research units. 54 rainfall stations were selected according to the network in 1966, and the control area of single station was 397.9km². 105 rainfall stations were selected on the basis of the network in 1977, and the control area of single station was 204.6km² (Tab.1). The number of rainfall stations of He-Long region on the left bank of the Yellow River was 107 in 2013, which exceeded 50% of 1966 and was only two more than that in 1977.

| NO. | Basin         | Control station | Basin area (km²) | Network of 1966 | Network of 1977 | Station control area |
|-----|---------------|-----------------|------------------|-----------------|-----------------|----------------------|
| 1   | Hong river    | Fangniugou      | 5461             | 8               | 25              | 682.6                |
| 2   | Pianguan river| Pianguan        | 1896             | 7               | 10              | 270.9                |
| 3   | Zhuijiachuan  | Qiaotou         | 2854             | 7               | 11              | 407.7                |
| 4   | Qingliangsigo | Yangtiao        | 283              | 3               | 5               | 94.3                 |
| 5   | Qushui river  | Linjiaping      | 1873             | 5               | 7               | 374.6                |
| 6   | Sanchuan      | Houdacheng      | 4102             | 11              | 24              | 372.9                |
| 7   | Quchan river  | Peigou          | 1023             | 4               | 6               | 255.8                |
| 8   | Xinshui river | Daning          | 3992             | 9               | 17              | 443.6                |
|     | Total         |                 | 21484            | 54              | 105             | 397.9                |

The controlled tributaries on the right bank are divided into 33 research units. 101 rainfall stations were selected according to the network in 1966, and the control area of single station was 596.8km². 217 rainfall stations were selected on the basis of the network in 1977, and the control area of single station was 277.8km² (Tab.2). The number of rainfall stations of He-Long region on the right bank of the yellow river was 237 in 2013, which exceeded 57% of 1966 and exceeded 8.4% of 1977.
### Tab.2 Ten tributaries rain stations network statistics of the right bank of the Yellow River

| NO. | Basin       | Region                           | Basin area | Network of | Network of | Station control |
|-----|-------------|----------------------------------|------------|------------|------------|----------------|
| 1   | Huangfuchua | Above Huangfu                    | 3175       | 6          | 12         | 1966           |
| 2   | Gushanchuan | Above Heishiya                   | 1263       | 4          | 4          | 1977           |
| 3   | Kuye river  | Above Wangdaohengda              | 3839       | 2          | 9          | 1919.5         |
| 4   |             | Above Ximinjiao                  | 1527       | 2          | 8          | 763.5          |
| 5   |             | Region of Ximinjiao,             | 1932       | 6          | 6          | 322.0          |
| 6   |             | Above Shenmu                     | 7298       | 10         | 23         | 729.8          |
| 7   |             | Region of Shenmu and Wenjiachan  | 1347       | 6          | 6          | 224.5          |
| 8   |             | Above Wenjiachuan                | 8645       | 16         | 29         | 540.3          |
| 9   | Tuwei river | Gaojiabao                       | 2095       | 6          | 7          | 349.2          |
| 10  |             | Region of Gaojiabao and Gaojiajchuan | 1158   | 3          | 3          | 386.0          |
| 11  | Jialu river | Above Shenshiwai                 | 3253       | 9          | 10         | 361.5          |
| 12  |             | Above Hengshan                   | 2415       | 6          | 9          | 402.5          |
| 13  |             | Above Diansi                     | 327        | 2          | 3          | 163.5          |
| 14  |             | Region of Hengshan, Diashi and   | 12493      | 4          | 19         | 3123.3         |
| 15  | Wuding river| Above Zhaoshiyao                 | 15235      | 12         | 31         | 1269.6         |
| 16  |             | Yuxi river                       | 4938       | 4          | 7          | 1234.5         |
| 17  |             | Above Mahuyu                     | 371        | 2          | 7          | 185.5          |
| 18  |             | Region of Zhaoshiyao and Dingjiagou | 2878   | 6          | 9          | 479.7          |
| 19  |             | Above Dingjiagou                 | 23422      | 24         | 54         | 975.9          |
| 20  |             | Above Suide                      | 3893       | 14         | 26         | 278.1          |
| 21  |             | Region of Dingjiagou and         | 2347       | 6          | 10         | 391.2          |
| 22  |             | Above Baijiachuan                | 29662      | 44         | 90         | 674.1          |
| 23  | Qingjian river | Above Zichang               | 913        | 3          | 8          | 304.3          |
| 24  |             | Region of Zichang to Yanchuan    | 2555       | 4          | 9          | 638.8          |
| 25  | Yan river   | Above Yanchuan                   | 3468       | 7          | 17         | 495.4          |
| 26  |             | Above Yan             | 3208       | 4          | 17         | 802.0          |
| 27  |             | Region of Yanci and Ganguyi      | 2683       | 2          | 15         | 1341.5         |
| 28  |             | Above Ganguyi                   | 5891       | 6          | 32         | 981.8          |
| 29  |             | Region of Linzhen and Xinshi river | 1121   | 2          | 7          | 560.5          |
| 30  | Fenchuan river | Linzhen                    | 1121       | 2          | 7          | 541.0          |
| 31  |             | Region of Linzhen and Xinshi river | 1662   | 3          | 10         | 554.0          |
| 32  |             | Xinshi river                    | 2141       | 2          | 7          | 1070.5         |
| 33  | Shiwangchua | Dachun                          | 1121       | 2          | 7          | 560.5          |
|     | Total       |                                 | 60281      | 101        | 217        | 596.8          |

### 2.4 Hydrological Data

(1) Flow data. The runoff variation analysis of 33 hydrology stations in eighteen tributaries adopted the measured monthly and annual discharge data of each station from 1956 to 2013, all derived from the hydrology yearbook of the Yellow River basin [8].

In addition, in Yellow River basin water resources investigation [2], the monthly runoff reduction calculation of five hydrology station (Wenjiachuan of Kuye River, Linjiaping of Quishui River, Houdacheng of Sanhuan River, Baijiachuan of Wuding River and Yanchuan of Qingjian River) in He-Long region from 1956 to 2000 was carried out. Natural runoff of the five tributaries was adopted as the base year series in the model establishment of rainfall and runoff. The other tributaries still use the measured data, only the year before the turning year as the natural series.

(2) Rainfall data. In 1966, there were 194 rainfall stations in He-Long region, including 155 in the controlled tributaries and 39 in ungauged areas. In 1977, there were 417 rainfall stations, including 322 in the controlled tributaries and 95 the ungauged areas. The control area of each rainfall station...
was calculated by Thiessen Polygon Method, monthly and annual rainfall data of each rainfall station from 1956 to 2013 were statistically collated, to analyze the rainfall variation of annual, flood season and main flood season of each research unit, tributary and ungauged area.

3. Analysis method

3.1 The natural period of each tributary

In order to analyze the current annual runoff changes and influencing factors of each tributary in He-Long region, it is necessary to clarify the natural hydrology sequence. The method of orderly clustering [9], MWP test [10], Mann-kendall [11] and double cumulative curve were used to analyze the stage change of runoff, and the turning point of significant disturbance of human activities on hydrology sequence was determined. The year before the turning point was the natural period.

3.2 The calculation method of natural annual runoff of status year

(1) The calculation of annual runoff variety of 18 tributaries in status year

The four methods are adopted to analyze the annual runoff variation of controlled tributaries in status year. Respectively, the relationship between annual rainfall and runoff, the relationship of rainfall and runoff in flood season (June to September), the relationship of rainfall and runoff in main flood season (July to August) and the method of runoff coefficient.

The calculation step of method 1: establish the relationship model of rainfall and runoff in the base year of each tributary, calculate the current natural annual runoff, the runoff variety and impacts brought by rainfall in the status year were analyzed by equation of runoff division. The calculation steps of the other two methods are similar to method 1.

The steps of runoff coefficient method are as follows: calculate the average annual runoff coefficient in the base year period; the current annual rainfall is used to calculate the natural runoff of the current year; the runoff variety in the status year were analyzed by equation of runoff division and the impacts brought by rainfall were calculated.

(2) The method of runoff variety of ungauged areas of status year

The method of relationship of annual rainfall -runoff and runoff coefficient were used to calculate annual runoff variety in each uncontrolled area. The procedure is the same as the controlled tributaries.

3.3 The runoff separation evaluation calculation

The difference between measured runoff in the present year and natural runoff in the base year includes the influence of climate change and human activities. The runoff separation evaluation formula is as follows:

\[\Delta W_T = W_2 - W_1\]  
\[\Delta W_H = W_2 - W_3\]  
\[\Delta W_C = W_3 - W_1\]

Where: \(\Delta W_T\), total amount of runoff variation; \(\Delta W_H\), influence amount of human activities; \(\Delta W_C\), influence of climate change on runoff; \(W_1\), natural runoff in base year; \(W_2\), measured runoff in current year; \(W_3\) is the natural runoff in current year.

4. Results

4.1 Analysis of rainfall variation characteristics

(1) Variation of total rainfall in the He-Long region

The rainfall in each decade in He-Long region showed decreasing trend before 2000 and began to rise and exceeded the average after 2000. Compared with that from 1956 to 2000, the rainfall of annual in the year from 2007 to 2013, flood season and main flood season in He-Long region increased by 17.7%, 19.5% and 9.6% respectively.

(2) The controlled tributaries variation in He-Long region

Compared with the period in 1956-2000, the annual and flood season rainfall from 2007 to 2013 of the eighteen tributaries increased except Hong river (Fig. 4). Flood season increases of more than 10% are Wudinghe river, Qingjian river, Qingliangsigou, Jialu river, Shiwangchuan, Zhujiachuan, Qiushui river, Pianguan river, Yan river and so on (Fig. 5).
(3) The rainfall variation of ungauged region in He-Long region

The area of ungauged area in He-Long region is 46457 km². Compared with 1956-2000, the rainfall of annual, flood season and main flood season in ungauged area from 2007 to 2013 increased by 11.5%, 12.4% and 4.2% respectively.

4.2 Analysis of runoff variation characteristics

Since the 1960s, the runoff in the He-Long region has been decreasing year by year. After 2000, it has remained low and increased slightly in 2012 and 2013 (Fig. 6).

Fig. 4 The rainfall variation of the controlled tributaries in He-Long region 2007-2013 compared with 1956-2000

Fig. 5 The rainfall variation range of controlled tributaries in He-Long region 2007-2013 compared with 1956-2000

Fig. 6 The annual runoff variation of He-Long region from 1956 to 2013

4.3 The turning year of runoff and the rainfall-runoff model

The method of orderly clustering, MWP test, Mann-kendall and double cumulative curve were used to analyze turning year of runoff series, the results are shown in Tab.3.

The rainfall-runoff simulation model of each tributary in the base year period are established by the methods of rainfall-runoff relationship during annual, flood season and main flood season. The annual rainfall-runoff relationship of some tributaries is given in Fig. 7. The rainfall-runoff relationship in flood season and main flood season is usually better than that in year.
tributaries in current year was -2.569 billion m$^3$, and the mean variety of runoff caused by rainfall change in current year was 351.2 million m$^3$ (Tab.4).

Compared with the base year period of each tributary, the natural runoff variety of controlled tributaries are negative. Among them, the largest amount of water reduction is 696.7 million m$^3$ in Wuding River, followed by 543.7 million m$^3$ in Kuye River. Six tributaries, including Hong River, Huangfuchuan, Gushanchuan, Tuwei River, Xinshui River and Shiwangchuan have negative runoff variety caused by rainfall changes, while the other 12 tributaries are positive.

Tab.4 Runoff variety by rainfall change in four methods of He-Long Region in current year

(Unit:10$^8$m$^3$)

| Name         | Station | Turning year | Name         | Station | Turning year |
|--------------|---------|--------------|--------------|---------|--------------|
| Hong river   | Fangniugou | 1979        | Huangfuchuan | Huangfu  | 1978         |
| Pianguan river| Pianguan | 1979        | Gushanchuan | Gaoshiya | 1979         |
| Zhuajiachuan | Qiaotou  | 1982        | Kuye river   | Wenjiachua | 1979       |
| Qingliangsigou | Yangjiapo | 1979      | Tuwei river  | Gaojiachuan | 1977      |
| Qushui river | Linjiaping | 1978     | Jialu river  | Shenjiawan | 1980        |
| Sanchuan river | Houdacheng | 1979    | Wuding river | Baijiachuan | 1972      |
| Quchan river | Peigou  | 1981        | Qingjiang river | Yanchuan | 1974        |
| Xinshui river | Daning  | 1979        | Yan river    | Ganguyi  | 1974         |
| Ungauged area of Toudaoguai and Fugu | 1974 | Fenchuan river | Xinshihe | 1995 |
| Ungauged area of Wubao and Gaojiachua | 1972 | Shiwangchuan | Dacun | 1984 |

Fig.7 The annual rainfall-runoff relationship of some tributaries in He-Long region

4.4 Runoff variation caused by rainfall change in current year

4.4.1 The results of controlled tributaries

Compared with the base year, the runoff variety of eighteen tributaries are negative. Among them, the largest amount of water reduction is 696.7 million m$^3$ in Wuding River, followed by 543.7 million m$^3$ in Kuye River. Six tributaries, including Hong River, Huangfuchuan, Gushanchuan, Tuwei River, Xinshui River and Shiwangchuan have negative runoff variety caused by rainfall changes, while the other 12 tributaries are positive.

Tab.4 Runoff variety by rainfall change in four methods of He-Long Region in current year

(Unit:10$^8$m$^3$)

| Number | Region         | The runoff variety | The runoff variety brought by rainfall |
|--------|----------------|---------------------|---------------------------------------|
|        |                | Method 1            | Method 2            | Method 3            | Method 4            | Average          |
| 1      | Hong river     | -2.192              | -0.384               | -1.189               | -1.174              | -0.376            | -0.781          |
| 2      | Pianguan       | -0.489              | 0.099                | 0.002                | 0.040               | 0.053             | 0.049           |
| 3      | Huangfuchuan   | -1.479              | 0.085                | -0.089               | -0.350              | -0.035            | -0.097          |
| 4      | Gushanchuan    | -0.865              | 0.061                | -0.031               | -0.075              | -0.010            | -0.014          |
| 5      | Zhuajiachuan   | -0.249              | 0.049                | 0.043                | 0.151               | 0.003             | 0.061           |
| 6      | Kuye river     | -5.437              | 0.398                | 0.930                | -1.644              | 0.726             | 0.102           |
| 7      | Tuwei river    | -2.189              | 0.028                | -1.957               | -2.451              | 0.755             | -0.906          |
| 8      | Jialu river    | -0.553              | 0.195                | 0.142                | -0.056              | 0.239             | 0.130           |
| 9      | Qingshanxigou  | -0.058              | 0.032                | 0.050                | 0.014               | 0.037             | 0.033           |
| 10     | Qiushui river  | -0.719              | 0.217                | 0.281                | -0.162              | 0.106             | 0.111           |
| 11     | Sanchuan       | -1.376              | 0.547                | 0.737                | 0.176               | 0.520             | 0.495           |
| 12     | Quchan river   | -0.208              | 0.103                | 0.185                | 0.177               | 0.052             | 0.129           |
| 13     | Wuding river   | -6.967              | 1.842                | 4.331                | 3.323               | 4.447             | 4.386           |
| 14     | Qingjiang     | -0.606              | 0.280                | 0.103                | 0.519               | 0.233             | 0.284           |
| 15     | Xinshui river  | -1.197              | -0.078               | -0.201               | 0.257               | -0.067            | -0.022          |
| 16     | Yan river      | -0.805              | 0.173                | 0.642                | 1.279               | 0.239             | 0.583           |
| 17     | Fenchuan       | -0.031              | 0.026                | -0.027               | 0.014               | 0.048             | 0.015           |
| 18     | Shiwangchuan   | -0.270              | 0.049                | -0.416               | -0.239              | 0.024             | -0.145         |
| Total  |                | -25.69              | 3.722                | 3.535                | -0.202              | 6.993             | 3.512           |
4.4.2 The results of ungauged tributaries

The ungauged area occupies 31.2% of the total area of He-Long region, which can be divided into three sections: Hekouzhen to Fugu, Fugu to Wubao and Wubao to Longmen.

Compared with the base year, the runoff variety of ungauged region in current year was -2.842 billion m$^3$, and the mean variety of runoff caused by rainfall change in the method of annual rainfall-runoff relationship and runoff coefficient was 72.48 million m$^3$ (shown in Tab.5).

| Name of ungauged areas                  | The runoff variety brought by rainfall (Unit: 10$^8$m$^3$) |
|----------------------------------------|-----------------------------------------------------------|
|                                        | Method 1 | Method 2 | Average |
| Region from Hekouzhen to Fugu          | -15.81   | 0.2377   | 0.4183   | 0.3280   |
| Region from Fugu to Wubao              | 3.294    | 1.3821   | 1.3838   | 1.3830   |
| Region from Wubao to Longmen           | -15.91   | -0.8100  | -1.1624  | -0.9862  |
| Region from Hekouzhen to Longmen       | -28.42   | 0.8098   | 0.6397   | 0.7248   |

4.4.3 The results of He-Long region

The total water reduction in He-Long region in current year is 5411 million m$^3$, i.e. 2569 million m$^3$ of controlled tributaries and 2842 million m$^3$ of uncontrolled areas.

The mean value of runoff variety caused by rainfall change is 423.7 million m$^3$, which is calculated by method of rainfall-runoff relationship during annual, flood season and main flood season, and method of runoff coefficient. That is, the runoff increased by 423.7 million m$^3$ due to rainfall change in He-Long region. Among them, the runoff increased amount of controlled tributaries and ungauged region are 351.2 million m$^3$ and 72.48 million m$^3$ respectively.

5. Conclusions

(1) The rainfall of He-Long region showed a decreasing trend before 2000, and began to rise and exceeded the average after 2000. From 1960s, the runoff in He-Long region showed a decreasing trend year by year, continued to be low after 2000 and increased slightly in 2012 and 2013.

(2) The methods of orderly clustering, MWP test, Mann-Kendall and double cumulative curve were used to analyze the turning year of natural period and of human activities influence period of eighteen tributaries and ungauged region, the base year of them was determined.

(3) Compared with the base year, natural runoff of He-Long region from 2007 to 2013 reduced 5.411 billion cubic meters, among which brought by rainfall not negative value but increased 0.424 billion cubic meter.

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