Analysis of River System Structure and Runoff Evolution of Typical Section in Ziya River Plain

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Abstract: In this study, by interpretation method, the density, quantity, length and variation of rivers in Ziya River Plain increased in the 1960s and 1980s, mainly related to the excavation of small tributaries and canals. By comparing the series of years before and after 1980, the amount of surface water resources in the study area has decreased in the past 30 years. By using cumulative anomaly method and Kendall trend test method, it is found that the annual average runoff of typical cross-section decreases obviously, and the time series sudden change occurs in the late 1970s. The situation of the trunk runoff cut-off and drying-up caused by the river system structure and runoff evolution is evaluated, and the interannual evolution of the eco-hydrological system in Ziya River Plain is obtained. These can provide scientific support for water environment research and water ecological restoration in plain areas.

1. Introduction

The Ziya River is located in the south-central part of the Haihe River Basin. Its west comes from the Taihang Mountain, east end in the Bohai Sea, south border is the Zhangwei River, and north border is the Daqing River, which distribution across Shanxi, Hebei and Tianjin three provinces. The area of the river is 46,868 km², of which the plain area is 15620 km², accounting for 33.3%. Aiming at the problem of structural and functional degradation of river ecosystems in the plain section [1], it is necessary to systematically study the river network structure and runoff evolution trend of the basin. This study uses the arcgispro software digital interpretation [2] [3] to analyze the river density, quantity, length and its changes, and obtain the structure and evolution of the water system of the Ziya River Plain [4]. Comparing the two series of years from 1980 to 2015 and from 1956 to 1979, the changes in water resources in the study area were analyzed. The main sections of Dongwushi Reservoir, Zhuzhuang Reservoir, Xian county, Lianhuakou and Aixinzhuang Station were selected, and the cumulative anomaly method and Mann-Kendall trend test method [5]-[7] were used to explore the long-term trend of the typical section of Ziya River Plain [8], and evaluation of the main stream cutoff and dryness in the study area. Through the analysis of the water system structure and runoff evolution in the study area, it provides scientific support for water environment research and water ecological restoration in the plain area.

2. River Structure and Evolution

2.1 Change in river network density

According to the results of the interpretation, the density of the river network in the Ziya River Plain has increased, and it has not changed much since the 1980s. Comparing the water system landscape index in different periods: 1960 to the current year (2013), the river network density in the plain area...
increased from 0.17km per square kilometer to 0.25km, and the river network density increased to a certain extent, which mainly related with small tributaries and the excavation of the canal.

![Fig. 1 Evolution of the Plain Pattern of Ziya River](image)

Refer to "Fractal Dimension Calculation Method of River Morphological Characteristics"[9] (Feng Ping, Tianjin University); computational grid method and river network law is used to study the fractal dimension of river morphology[10][11]. The water system fractal dimension D is calculated by the following formula, where $R_b$ and $R_d$ are the water branch ratio and length ratio, and the values are 5 and 2.52, respectively.

$$D = \frac{\log R_b}{\log R_d}$$

The fractal dimension of the river network of the Ziya River is calculated to be 1.74, which is higher than the average of the Haihe River system, indicating that there are many tributaries of the Ziya River plain and well developed.

### 2.2 The number, length and changes of plain rivers

The number of rivers in the Ziya River Plain increased from the 1960s to the 1980s. The total number of tributaries at all levels increased from 42 in the 1960s to 117 in the 1980s. The tributaries of the 2nd to 4th grades did not change much, of which 3, 4 and tributaries were slightly decrease, and the increase of the 5th and 6th grades, especially the 6th grade tributary are more obvious. In addition to the increase of the main canal of the Middle Route of the South-to-North Water Transfer Project in 2013, there is basically no change compared with the 1980s. The total length of rivers increased from 2593km to 3828km, of which the increase of 5th and 6th tributaries accounted for more than 75%, mainly due to small tributary excavation and dredging. The increase of tributaries of Grades 2~4 was mainly due to the excavation of the main canal of the Middle Route of the South-to-North Water Transfer Project.

| Tributaries grade | Number of rivers (strips) | 2013 | 2013 |
|-------------------|---------------------------|------|------|
|                   | 60s | 80s | 60s | 80s |
| 2                 | 4   | 4   | 5   | 901 | 901  | 1152 |
| 3                 | 9   | 8   | 8   | 595 | 650  | 650  |
| 4                 | 10  | 9   | 9   | 644 | 615  | 615  |
| 5                 | 7   | 11  | 11  | 179 | 239  | 239  |
| 6                 | 12  | 85  | 85  | 274 | 1172 | 1172 |
| Total             | 42  | 117 | 118 | 2593| 3577 | 3828 |

### 2.3 Adjustable storage capacity in per unit area

The adjustable storage capacity of the river[12] refers to the increase in the volume of the river from the lowest water level to the highest water level. ASR is an adjustable storage capacity per unit area, and the adjustable storage capacity per unit area reflects the water storage and flood control capacity of the
river network. For the plain river network water system, the water system has a considerable storage capacity. ASR is related to river branching ratio and river network density. According to the Ziya River Flood Control Plan [13], the designed embankment height of the Ziya River Plain is between 5.5 and 6 m, which is a safety meter. The highest water level is 4 to 4.5 m, taking an average of 4.25 m, taking into account the water environment, irrigation, etc. In terms of requirements, the minimum water level is generally not less than 2m, so the adjustable storage capacity here refers to the channel volume with a water level from 2 to 4.25m. According to the interpretation results, the ASR value of the Ziya River Plain was calculated to be $1.74 \times 10^4$ m$^3$/km$^2$.

3. Change in water resources
With the change of rainfall and underlying surface [14], the surface water resources of the cities around the Ziya River Plain have decreased in the past 30 years. The annual average surface water resources from 1980 to 2015 are higher than the annual average of from 1956 to 1979. Compared with the decrease of 65.5%, the groundwater resources decreased from 1980 to 2015 compared with from 1956 to 1979, and the total area decreased by 17.4%. The characteristic values of water resources in the Ziya River Basin are shown in Table 2.

Historically, the 1950s was a period of abundant water in the Ziya River Plain, and the main river water in the plains were abundant. From 1960 to 1969, this “water boom” changed due to reduced precipitation and increased water use, especially after the 1965 drought. From 1970 to 1979, it was the basin's flat-water period. From 1980 to 1989, the basin entered the dry season, and the precipitation decreased continuously, then the five years of consecutively dry period from 1980 to 1984 occurred. From 1990 to 1999, the basin was in the flat-water period, and there were two wet years in 1995 and 1996 and two serious dry years in 1997 and 1999. Since 2000, except for the abundance in 2000, most of them are flat water years or dry years.

| Statistical parameter | Statistical items | Surface water resources | Unduplicated Quantity of Groundwater Resources and Surface Water Resources | Total water resources |
|-----------------------|-------------------|------------------------|-------------------------------------------------|-----------------------|
|                       |                   | Han dan | Xing tai | Shijiazhuang | Hengshui | Canzhoushui |                             |                        |
| average value         | 1956-2015         | 8841    | 2105     | 2060        | 2034     | 2450        | 192                         | 127130                 | 135972                 |
|                       | 1956-1979         | 14567   | 2773     | 4394        | 4320     | 2838        | 242                         | 141961                 | 156528                 |
|                       | 1980-2015         | 5025    | 1660     | 504         | 511      | 2192        | 158                         | 117243                 | 122267                 |
| Water resources at different frequency | 75%    | 1100    | 208      | 0          | 0        | 200         | 0                           | 84755                  | 88515                  |
|                       | 50%               | 6070    | 936      | 617         | 329      | 1432        | 96                          | 123759                 | 128579                 |
|                       | 25%               | 10604   | 2818     | 2148        | 2117     | 3810        | 322                         | 155018                 | 162244                 |

4. Main section runoff evolution trends
The annual runoff of Zhuzhuang Reservoir Station changed significantly in 1977, and the runoff after the change was significantly reduced. After the transition, the annual average runoff before the change was reduced by 71%. Except for the flood occurred in 1996, the annual runoff was smaller than the average runoff before the change.

The annual runoff of Dongwushi Reservoir Station continued to decrease. It changed significantly in 1978, mainly in two aspects. First, the runoff after the change was significantly reduced. After the transition, the average annual runoff before the change was reduced by 46%. Except for the floods in 1996, the annual runoff is less than the average runoff before the change. The second is the significant decline in the trend of annual runoff reduction after the change.
The annual runoff of Lianhuakou Station changed significantly in 1977, which mainly shows in two aspects. First, the runoff after the change was significantly reduced, and the annual average runoff before the change was reduced by 58%. Second, the annual runoff before the change didn’t show a significant increase or decrease trend, the trend of annual runoff reduction trend increased significantly after the change.

The annual runoff of Aisinzhuang Station changed significantly in 1979, mainly due to the significant decrease in runoff after the change, and the annual average runoff before the change was reduced by 71%. In addition, as can be seen from the figure, from 2002 to the current year, the annual runoff trend fluctuated.
The annual runoff of Xian county Station changed significantly in 1968, mainly due to the significant decrease in runoff after the change, and the annual average runoff before the change was reduced by 95%. In addition, as can be seen from the figure, from 2002 to the current year, the annual runoff trend fluctuated.

5. River cutoff and dryness
Quantitative representations were made by using two indicators: river cutoff and river dryness \[15\]. Drying means that there is no water body cover in the riverbed, that is, the river is dry; the flow interruption means that there is no water flowing in or out of the river section, and the water body is in a static state, that is, the flow rate is zero. The water level and flow data of the hydrological stations in Zhangzhuang Bridge Gate, Lianhuakou, Xingjiawan, Aixinzhuang, Hengshui Gate and Xian county of the River Section from Beijing-Guangzhou railway Railway Bridge to the Xian county, and the water level and flow data of the hydrological stations such as Xian county, Nanzhaofu and Sixth Fort in the Baohe section were selected. The dryness and disconnection of the Fuyang River and Ziya River were analyzed, see in Table 3 to 5.

### Table 3 Statistics of Drying Days of Rivers in Ziya River Plain

| River name     | reach                      | Average number of dry days per year (days) |
|----------------|----------------------------|--------------------------------------------|
|                |                            | 60s | 70s | 80s | 90s | 2000-2015 |
| Fuyang River   | Beijing-Guangzhou          | 16  | 82  | 90  | 85  | 365        |
|                | Railway Bridge ~ Xian county |     |     |     |     |            |
| Ziya River     | Xian county ~ Fort six     | 84  | 280 | 349 | 328 | 365        |

### Table 4 Statistics of River Drying-up Length in Ziya River Plain

| River name     | reach                      | Reach length (km) | Average annual River dry-up total length (km) |
|----------------|----------------------------|-------------------|-----------------------------------------------|
|                |                            | 60 s | 70 s | 80 s | 90 s | 2000-2015 |
| Fuyang River   | Beijing-Guangzhou          | 343  | 52   | 162  | 182  | 170        |
|                | Railway Bridge ~ Xian county |     |     |     |     |            |
| Ziya River     | Xian county ~ Fort six     | 147  | 79   | 136  | 143  | 147        |

The number of dry days in the Fuyang River and the Ziya River was 16 days and 84 days in the
1960s. After 2000, the two rivers existed in the Cognac section almost all year round. From the data of the hydrological station, in the past 10 years, the rivers in the upper part of the Xingjiawan Gate and the Hengshui Gate have been dried up. The dry time is almost covered throughout the year. In addition, the river channel at the Lotus Station is also easy to dry up. The average number of dry days is 120 days.

| River name       | Average Days of Channel Discontinuation (days) |
|------------------|-----------------------------------------------|
|                  | 60s  | 70s  | 80s  | 90s  | 2000-2015 |
| Fuyang River     |      |      |      |      |          |
| Beijing-Guangzhou| 92   | 90   | 117  | 110  | 364       |
| Railway Bridge   |      |      |      |      |          |
| Xian county      |      |      |      |      |          |
| Ziya River       |      |      |      |      |          |
| Xian county ~ Fort six | 124  | 295  | 354  | 328  | 343       |

The number of days of disconnection in the Fuyang River and the Ziya River was 92 days and 124 days in the 1960s. After 2000, the two rivers had a discontinuous river section almost all year round. From the data of the hydrological station, in the past 10 years, the river channel at the Xian county Station was interrupted, and the average number of dry days was 312 days.

It can be seen that the rivers in the Ziya River Plain have experienced severe interruptions and dryness since the 1970s, which is more obvious than in the 1960s. The flow cuts from 1980 to 1989 were significantly worse than in the 1970s, and the rivers were cut off in the 1990s and 2000s. The situation was roughly the same as in the 1980s.

6. Conclusion
1. The density, quantity and length of rivers in the Ziya River Plain have been increased in the 60s and 80s, mainly related to the excavation of small tributaries and canals. The small ditches are mostly used for drainage, water diversion and water abstraction. Compared with the main canal of the Middle Route of the South-to-North Water Transfer Project, there is basically no change compared with the 1980s. The ASR value of the adjustable storage capacity per unit area of the Ziya River Plain is calculated to be $1.74 \times 10^4$ m$^3$/km$^2$.

2. According to the analysis, the amount of surface water resources in the cities around the Ziya River Plain has decreased in the past 30 years, the annual average runoff of the main sections has decreased significantly, and the time series of the runoff time series has occurred in the late 1970s. It is related to the completion of the construction of large reservoirs.

3. The rivers in the Ziya River Plain have experienced severe interruptions and dryness since the 1970s. They continued to deteriorate after the 1980s. After 2000, the two rivers had dry and interrupted river sections almost all year round.

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