Analysis of flow process variation degree and influencing factors in inner Mongolia reach of the Yellow River

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Abstract: The provincial hydrological sections of Shizuishan and Toudaoguai are selected as the object of study to analyze flow process variation degree and influencing factor in Inner Mongolia reach of the Yellow River, according to observe and natural monthly runoff from 1956 to 2013. The result shows that there are three phases of the flow process variation degree of the two sections, namely the year 1956 to 1968, 1969 to 1986 and 1987 to 2013, and which increase by phases. The markings appear to decrease by phases and the marking in Toudaoguai section is lower than that in Shizuishan section. The key reasons of the above features are water consumption of industry and agriculture along the river and reservoir operation of Longyangxia and Liujiaxia.

1. Introduction

The Inner Mongolia reach located in the northern end of the Yellow River, the flow process variation degree(FD) is considered and the provincial hydrological sections of Shizuishan and Toudaoguai are selected to analyze the influence of water resources development and utilization on the river hydrological regime variation. The paper aims at offer hydrological technical support for comprehending the health conditions and the cause problems of the Inner Mongolia reach.

2. General situation of study area

The Inner Mongolia reach of the Yellow River from Mahuanggou of Shizuishan to Mashan village of Zhungeerqi, the river length is 830km and there are 5 hydrology stations of the trunk stream, namely Suizuishan, Bayangaole, Sanhuhekou, Baotou and Toudaoguai. There are 10 intake projects with water use license which is distributed by the Yellow River Conservancy Commission between Shizuishan to Toudaoguai (shown in Fig.1).

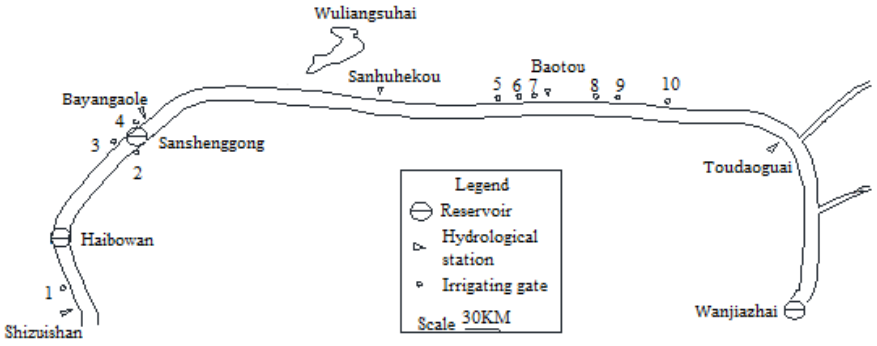

Figure 1. The main water intake layout of the Inner Mongolia reach

3. Data source and research method

3.1 Data source

3.1.1 Assessed sections. The water diversion of the Inner Mongolia reach is mainly takes place in the reach from Shizuishan to Bayangaole, and the recession flow is mainly takes place in the reach from Bayangaole to Toudaoguai. If the observe flow of Sanhuhekou section is reduced, then the mount of observe flow will greater than the natural flow, the runoff reaeration has never been carried out in the hydrological stations of Bayangaole and Sanhuhekou, therefore, the provincial hydrological sections of Shizuishan and Toudaoguai are selected to analyze the flow process variation degree of the Inner Mongolia reach.

3.1.2 Hydrological data. The observed and natural monthly runoff data of the sections of Shizuishan and Toudaoguai from 1956 to 2013 was adopted as the hydrological data in the study. All the observe runoff data comes from No.2 book of Yellow River basin hydrological yearbook which is included by the No.4 volume of the people's Republic of China hydrological yearbook. The variation of reservoir storage above the section of Shizuishan and the data of draught and recession of main intakes were reduced, the natural monthly runoff of the two sections were calculated.

3.2 Calculation formula

The flow process variation degree refers to in the current development status, the difference of between the observe and the natural monthly runoff of the studied reaches in the past years, which can reveal the influence of water resources development and utilization on river hydrological regime variation. The flow process variation degree is expressed by the average deviation between the observed and the natural monthly runoff, the equation is as follows:

$$\begin{cases} FD = \left\{ \sum_{m=1}^{12} \left(\dfrac{q_m - Q_m}{\bar{Q}_m} \right)^2 \right\}^{1/2} \\ \bar{Q}_m = \dfrac{1}{12} \sum_{m=1}^{12} Q_m \end{cases} \tag{1}$$

Where:q_m, the observe monthly runoff, m^3/s;Qm, the natural monthly runoff, m^3/s;$\bar{Q}m$,the mean value of yearly natural runoff in the past years.

3.3 Scoring Criteria

The scoring criteria of the flow process variation degree is shown in Table 1. The flow process variation degree (FD) of the hydrological sections of Shizuishan and Toudaoguai from 1956 to 2013 are respectively scored by the linear interpolation method. The greater the value of FD is, the greater variation of the hydrological regime is, and the effect on river ecology is greater.

Table 1. The scoring criteria of the flow process variation degree

FD	Scoring
0.05	100
0.1	75
0.3	50
1.5	25
3.5	10
5.0	0

The results of the flow process variation degree are divided into 5 levels according to the 5 grades evaluating method of river health, namely ideal state (80~100 points), health (60~80 points), sub-health (40~60 points), unhealthy (20~40 points) and morbid state (0~20 points).

4. Calculation result

4.1 The flow process variation degree

(1) The flow process variation degree can be divided into 3 phases which is shown from fig.2 and fig.3.The first phase is the year 1956 to 1968, before the operation the Liujiaixa Reservoir; the second phase is the year 1969 to 1986, during the sole operation the Liujiaxia Reservoir; the third phase is the year 1987 to 2013, during the joint operation of the Liujiaxia and Longyangxia.

(2) The flow process variation degree presents a rising tendency stage by stage. The FD of Shizushan section from 1956 to 1968 is fluxing between 0.4 and 0.8, from 1969 to 1986 totally maintains 0.8~1.5 and from 1987 to 2013 basically remains 1.5~2.8 (shown in Figure 2). The FD of Toudaoguai section from 1956 to 1968 is fluxing between 0.8 and 1.6, from 1969 to 1986 totally maintains 1.4~2.3 and from 1987 to 2013 basically remains 2.0~3.5 (shown in Figure 3).

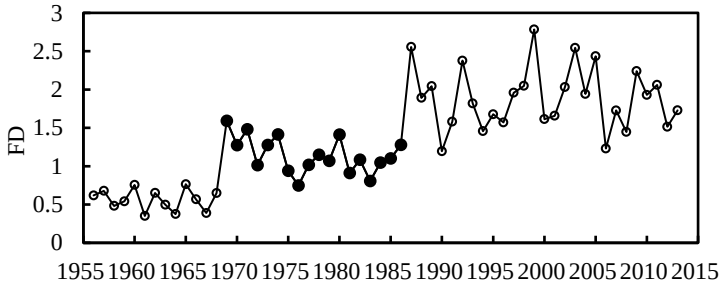

Figure 2. The FD value of Shizuishan section from 1956 to 2013

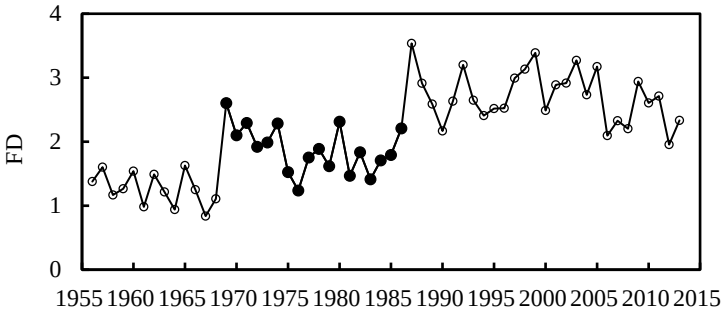

Figure 3. The FD value of Toudaoguai section from 1956 to 2013

4.2 Scoring

(1) the scoring is obviously divided into 3 phases which is shown from the Figure 4 and Figure 5. The first phase is the year 1956 to 1968, before the operation the Liujiaixa Reservoir; the second phase is the year 1969 to 1986, during the sole operation the Liujiaxia Reservoir; the third phase is the year 1987 to 2013, during the joint operation of the Liujiaxia and Longyangxia.

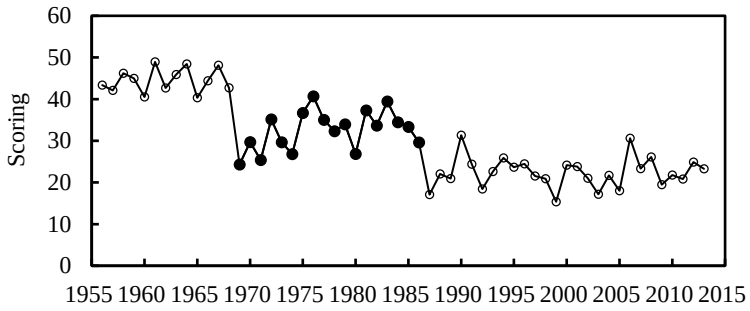

Figure 4. The FD scoring of Shisuishan section from 1956 to 2013

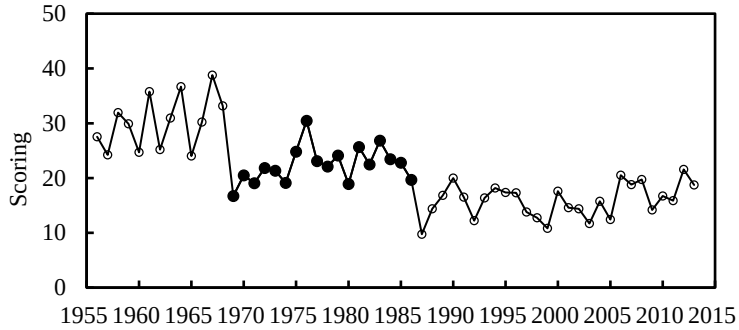

Figure 5. The FD scoring of Toudaoguai section from 1956 to 2013

(2) The scoring presents a declining tendency stage by stage. The scoring of Shizuishan section from 1956 to 1968 is 40~50 points, which is in sub-health status; the year 1969 to 1986 is 25~40 points, which is in unhealthy status; and the year 1987 to 2013 is 15~25 points, most of the year is in a state of unhealthy, few years is in morbid state. The scoring of Toudaoguai section from 1956 to 1968 is 24~40 points, which is in unhealthy status; the year 1969 to 1986 is 19~26 points, which is unhealthy and more deteriorated than the first phase; and the year 1987 to 2013 is 10~20 points, which is totally in morbid state.

5 Influence factor

5.1 Industrial and agricultural water consumption of the upper reaches of Yellow River

There are 9, 12 and 14 diversion ports of Qinghai, Gansu and Ningxia respectively above Shizuishan section, which were approved to establish by Yellow River Conservancy Commission. The average annual industrial and agricultural water consumption above the Shizuishan section from 1956 to 1968 is 39.7 billion m^3 (shown in Figure 6), accounts for 11.5% of annual average natural runoff of this period (shown in Figure 7). During the same period, the average annual industrial and agricultural water consumption above the Toudaoguai section is 92.7 billion m^3 (shown in Figure 8), accounts for 27.1% of annual average natural runoff (shown in Figure 9).

From the year 1969 to 1986, the average annual industrial and agricultural water consumption above the section of Shizuishan and Toudaoguai are respectively 52.9 billion m^3 and 110.7 billion m^3, accounts for 15.2% and 31.7% respectively of annual average natural runoff. From the year 1987 to 2013, the average annual industrial and agricultural water consumption above the section of Shizuishan and Toudaoguai are respectively 69.7 billion m^3 and 128.8 billion m^3, accounts for 22.8% and 42.1% respectively of annual average natural runoff.

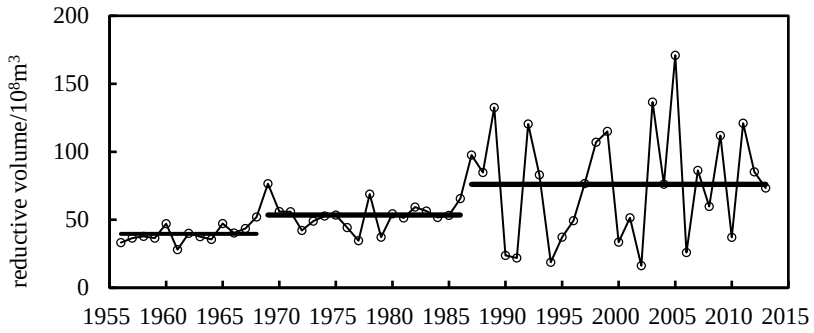

Figure 6. The reductive water volume of Shizuishan section in 1956~2013

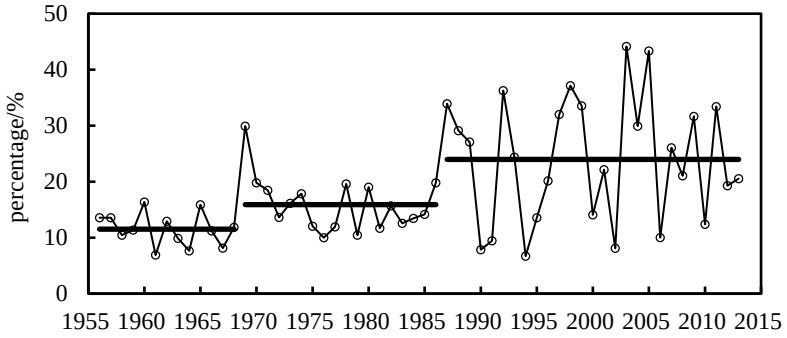

Figure 7. The percentage of reductive volume accounts for the natural runoff of the Shizuishan section from 1956 to 2013

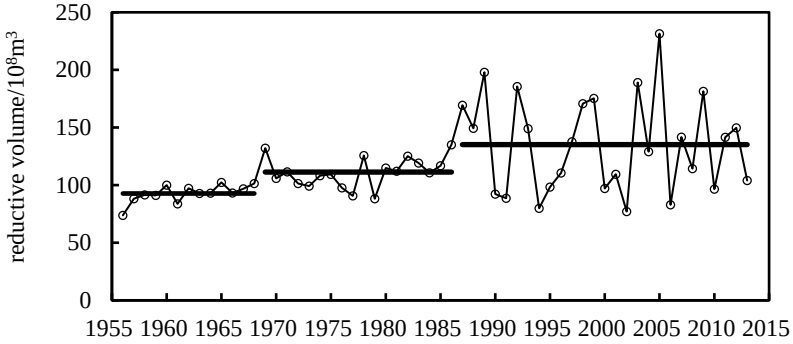

Figure 8. The reductive water volume of Toudaoguai section in 1956~2013

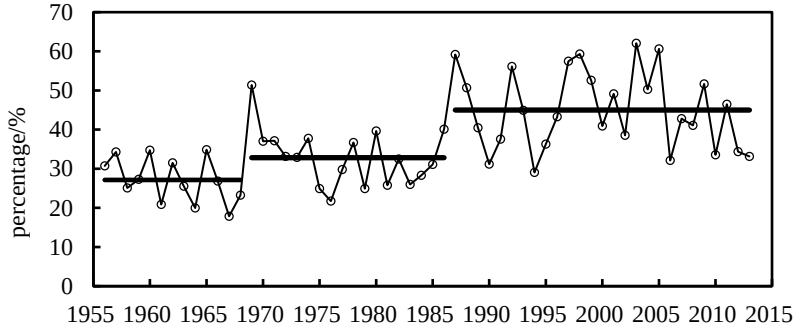

Figure 9. The reductive volume accounts for the percentage of natural runoff of the Toudaoguai section from 1956 to 2013

Industrial and agricultural water consumption of the upper reaches of the Yellow River are greater during the three phases from 1956 to 2013. The water consumption of the irrigation district of Weining and Qingtongxia mainly take place in April to August and November, and the water

consumption of the Hetao irrigation district mainly take place in April to November, which have an obvious effect on the flow process variation degree.

5.2 The reservoir operation of Longyangxia and Liujiaxia

Liujiaxia reservoir operated on October 15, 1968, belongs to a partial annual regulation reservoir. The flood control of the upper Yellow River is undertaken by the Longyangxia reservoir since its operation in October, 1986, and the Liujiaxia reservoir is mainly combining to compatible operation. Two stages are divided in terms of the operation time of Longyangxia reservoir, which are respectively the single operation of Liujiaxia reservoir and the joint operation of the two reservoirs.

5.2.1 The separate operation of Liujiaxia reservoir. The year 1969 to1986 is a period of separate operation of Liujiaxia reservoir. The operation of the year is divided into two stages: the discharging period is from November to next May, in order to meet the water demand of downstream irrigation and the generating stations of Yanguoxia and Qingtongxia, as well as meet the requirement of ice prevention of Inner Mongolia reaches. The annual average water discharge is 28.04 billion m^3; the water storage period of the year is June to October and the annual average impoundage is 28.65 billion m^3 (shown Figure 10).

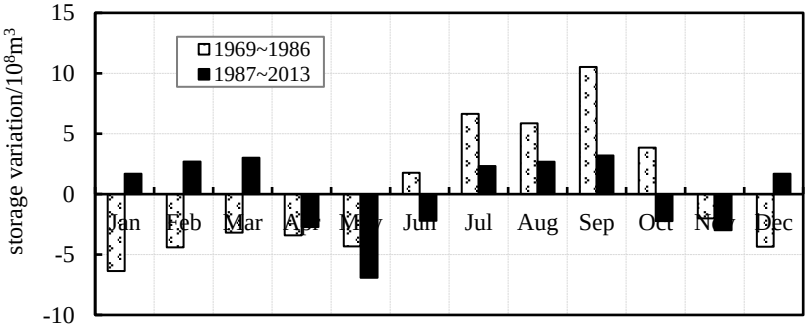

Figure 10. The monthly storage variation of Liujiaxia reservoir

The storage variation of Liujiaxia reservoir directly affected the outflow progress, caused the peak discharge reduced, the outflow progress balanced, the monthly runoff homogenized and the annual water distribution changed. Therefore, the flow process variation degree of the section of Shizuishan and Toudaoguai in the year 1969 to 1986 changed greater than the flow process variation degree from 1956 to 1968.

5.2.2 The joint operation of Longyangxia and Liujiaxia reservoir. The storage progress of the Liujiaxia reservoir has changed a lot since the joint operation of Longyangxia and Liujiaxia reservoir in 1987.The water storage process in the year is generally takes place in July to September and December to next March, other months are water discharge process. Considering the absolute value of the storage variation amount, the water discharge is maximum in May (6.92 billion m^3) and changes little in other months (shown in Figure 10).

The year 1987 to 2013 of the joint operation of Longyangxia and Liujiaxia reservoir, the annual average impoundage is 50.50 billion m3, the annual average water discharge from November to next May is 44.14 billion m3. Among them, the annual average impoundage of Longyangxia reservoir from June to October is 50.50 billion m^3 and the annual average water discharge from November to next May is 40.59 billion m^3(shown in Figure 11).

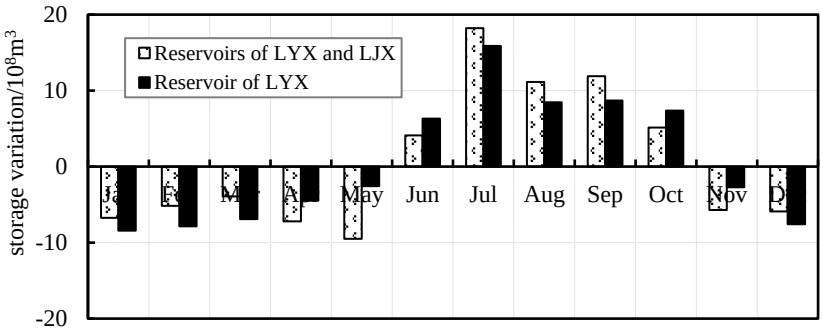

Figure 11. The monthly storage variation of joint operation of the Longyangxia and Liujiaxia reservoir from 1987 to 2013

Floods impounded and the peak discharge reduced since the joint operation of the two reservoirs, the annual runoff distribution of lower reaches of Yellow River was changed, which made the flow process variation degree of the sections of Shizuishan and Toudaoguai in the year 1987 to 2013 changed greater than the flow process variation degree from 1969 to 1986.

6. Conclusion

(1) The result shows that there are three phases of the flow process variation degree of the Inner Mongolia reaches of the Yellow River, namely the year 1956 to 1968, 1969 to 1986 and 1987 to 2013, and which increase by phases. The scorings appear to decrease by phases.

(2) The key reasons of the significant and phased change of the flow process variation degree of the Inner-Mongolia reaches are water consumption of industry and agriculture along the river and reservoir operation of Longyangxia and Liujiaxia.

References

[1] The Upper and Middle Yellow River Bureau 2011 Data compilation of the water drawing permit supervision and management of the middle and upper reaches of the Yellow River, pp 80-87.

[2] Jin S Y, Zhang S Y, Ma Z J and Zhang P 2015 Water consumption in Inner Mongolian reach of the Yellow River since integrated water regulation, *Acta Geographica Sinica*, 70(3**)** pp 501-508.

[3] Hydrology Bureau of the Ministry of Water Resources of the People's Republic of China 1956-2013 The hydrological yearbook of the People's Republic of China-the hydrological data of the Yellow River basin.

[4] The technical documents of the assessment of the national rivers and lakes health 2010 The indicators, criteria and method for evaluation of river health, p 23.

[5] Jin S Y, Zhang P Zhang C L, and Ma Z J 2015 Analysis of water consumption in Ningxia reach of Yellow River since integrated regulation, *Hydrology*, 35(6) pp 82-86.

[6] J Hou S Z, Hou K, Wang P and Chu W B 2015 Analysis on impact of Liujiaxia Reservoir on variation of water and sediment, *Water Resources and Hydropower Engineering*, 46(10) pp 31-35.

[7] Hou S Z, Wang P , Guo Y and Chu W B 2013 Analysis of water and sediment regulation of Longyangxia reservoir, *Journal of Hydroelectric Engineering,* 32(6) pp 151-156.

[8] Zhao Y A, Pan X D, Han S F and Qi P 1989 Effects of operation of Liujiaxia Reservoir on scouring and silting in the lower course of the Yellow River,*Yellow River*, 11(5) pp 23-27.

[9] Guo W N, Zhang B D and Wang H 2015 Study on the operation mode of the Liujiaxia reservoir in the break-up days of the Ningmeng reaches of Yellow River,*China Flood & Drought Management*, 25(1) pp 77-79.