Evaluation of the degree of satisfaction of river ecological flow —Taking the Kushui River in Ningxia as an example

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Abstract. In order to comprehensively evaluate the degree of satisfaction of ecological flow in rivers, an evaluation system was constructed based on the daily average flow, monthly average flow, and the lowest monthly flow data of the Kushui River in Ningxia from 2017 to 2019, including indicators such as flow changes, flow satisfaction at different levels, ecological water demand guarantee, and monthly average ecological water demand suitability, to assess the health status of the Kushui River. The results showed that the minimum runoff of the Guojiaqiao hydrological station in the Kushui River during the dry season was relatively small, with a large gap compared to the annual average daily flow, but the degree of ecological flow guarantee was high, reflecting the seasonal and uneven distribution characteristics of the Kushui River. It is recommended to strengthen the research on the dispatching of water storage reservoirs, rationally allocate water, and gradually improve and improve the sustainable guarantee degree of ecological flow in the Kushui River.

Keywords: River, ecological flow, satisfaction degree, Kushui River.

1. Introduction

Ecological flow is an important constraint indicator in the development and utilization of water resources, and is one of the basic basis for water resource development control and optimization, river and lake ecological protection and restoration, as well as regional coordination of water related matters [1-2]. Ensuring the ecological flow of rivers and lakes is a prerequisite and foundation for achieving sustainable utilization of water resources, which is related to the overall construction of ecological civilization and water conservancy reform and development, and is of great significance for maintaining water security [3-4].

River ecological flow assessment is based on basic hydrological data of rivers, reflecting the degree to which ecological water reaches or meets ecological flow, as well as the management and guarantee status and effectiveness of ecological flow [5-6]. In 2015, the State Council and the Ministry of Water Resources deployed ecological flow pilot projects in the Yellow River Basin, which clearly required scientific determination of ecological flow and coordinated efforts in water and sediment regulation in the Yellow River Basin[7]. The Kushui River Basin is located in Wuzhong City, Ningxia Hui Autonomous Region. The seasonal variation characteristics of the river are obvious. With the intensification of human activities such as local agriculture and social development, the law of runoff and confluence and the degree of ecological flow protection have changed[8]. In 2018, the Water Resources Department of Ningxia Hui Autonomous Region formulated an implementation plan for the ecological flow pilot project of the Kushui River in accordance with relevant regulations, and organized the pilot implementation work[9]. In 2019 and 2020, the organization implemented an annual evaluation of ecological flow management and security, gradually exploring an ecological flow management system.

Due to the prominent contradiction between the development and utilization of water resources and ecological protection in the Kushui River Basin, the construction of national ecological civilization has put forward new requirements for the coordinated development of regional

economy, society, and ecological protection. From the perspective of natural resource endowment in the Kushui River Basin, a comprehensive evaluation of the degree of satisfaction with the ecological flow of the Kushui River is of great significance for promoting the continuous improvement of Kushui River resources, water environment, and water ecological health, and comprehensively promoting the social and ecological comprehensive management of the basin.

2. Research Method

2.1 Overview of the Research Area

Kushui River is a primary tributary of the Yellow River in Ningxia, originating from Shapotigou, Huashi Mountain, Tianshuibao Town, Huan County, Gansu Province. It flows through five counties (cities, districts) in Wuzhong City, Ningxia, including Yanchi, Tongxin, Litong, Hongsibao, and Lingwu City, Yinchuan City, and joins the Yellow River at Huayi Village, Xinhua Bridge Town, Lingwu City. The main river has a total length of 223.8km and a drainage area of 5218km^2. Among them, the Kushui River in Ningxia is 202.8km long, accounting for 90.61% of the total river length. The drainage area in Ningxia is 4942km^2, accounting for 94.71% of the total drainage area of the Kushui River[10].

2.2 Data Calculation

2.2.1 Daily average ecological flow satisfaction level

(1) Daily flow deviation degree

This time, the measured daily flow data of the Guojia Bridge section of the Kushui River from 2017 to 2019 were used to analyze the current satisfaction level of the ecological base flow of the Kushui River. Taking the actual daily average flow rate over multiple years as the standard value and the deviation degree between the actual daily average flow rate during the ecological water use process and the standard value as the indicator, it is called the flow deviation rate. This indicator can reflect the deviation degree between the ecological flow rate and the natural flow rate during the same period.

$$C_i = \frac{Q_{ei}}{Q_{di}} \quad (1)$$

In the formula, C_i is the daily flow deviation rate; Q_{ei} is the average flow rate of ecological water demand on the *i*-th day; Q_{di} is the average natural daily flow over the years under the same time series as Q_{ei}.

Due to the closer the ecological flow is to the natural flow, i.e. the closer the C_i is to 1, it indicates a better satisfaction rate of ecological flow and there is no need to recheck the ecological flow. However, when the C_i is smaller, it indicates that the measured flow is much greater than the proposed ecological flow and needs to be rechecked. When the C_i is larger, it indicates a very low degree of satisfaction with ecological flow.

(2) Daily average ecological flow assurance level

The calculation of the degree of ecological flow assurance is to use the actual monitored water volume data of the river to analyze and calculate the daily water volume of the river to meet the degree of ecological flow assurance of the river. The calculation formula is:

$$\mathrm{D} = \frac{q_d}{Q_p} \times 100\% \quad (2)$$

In the formula, q_d is the measured daily runoff of the evaluation year; Q_p is the minimum ecological flow rate; D is the percentage of days exceeding the minimum ecological flow within the evaluation year, which represents the degree of ecological flow assurance.

2.2.2 Monthly average ecological flow satisfaction level

(1) Monthly average ecological water demand guarantee rate

Using the median value of the average natural water inflow for 7 consecutive days from 2017 to 2019 (with days from the following month being used as compensation for insufficient days) as the indicator value, and the guarantee rate of the average continuous flow for 7 consecutive days in the actual ecological water use process exceeding this standard value as the evaluation indicator, reflecting the adequacy of the monthly average ecological flow, the ecological water demand guarantee rate for the *i*-th month, P_i, is:

$$P_i = \frac{N_i}{N_m} \quad (3)$$

In the formula, P_i is the number of days in the *i*-th month that the ecological water supply meets the natural ecological flow for 7 consecutive days, and N_m is the total number of days in the *i*-th month. The value of P_i ranges from 0 to 1, and the larger the value, the more days the ecological flow meets the requirements, that is, the higher the guarantee rate of continuous ecological water demand.

(2) Monthly suitability of ecological water demand

The sum of the dispersion degree between the median and characteristic extreme values of the actual ecological water flow in that month and the median and characteristic extreme values of the natural incoming water flow is defined as the monthly average ecological water demand dispersion coefficient, reflecting the dispersion degree between the ecological flow and the measured runoff in each month.

$$\mathrm{F}_i^{'} = \left(\frac{Q_{mi} - \mathrm{Q}_{mi}^{'}}{\mathrm{Q}_{mi}^{'}}\right)^2 + \left(\frac{Q_{ji} - \mathrm{Q}_{ji}^{'}}{\mathrm{Q}_{ji}^{'}}\right)^2 \quad (4)$$

In the formula, $\mathrm{F}_i^{'}$ is the dispersion coefficient of the average ecological water demand for month *i*, and Q_{mi} is the median ecological water flow for month *i*; $\mathrm{Q}_{mi}^{'}$ is the calculated natural flow median for the *i*-th month; Q_{ji} is the extreme characteristic flow rate of the *i*-th month; $\mathrm{Q}_{ji}^{'}$ is the characteristic extreme value of natural flow in the *i*-th month.

The monthly ecological water demand suitability index is:

$$F_i = 1 - \frac{\mathrm{F}_i^{'}}{10} \quad (5)$$

This indicator can reflect the suitability of the total ecological water demand and the measured total runoff for the month. When F_i is 1, it indicates complete suitability; When $\mathrm{F}_i^{'}$ is negative, it indicates that it is completely unsuitable. When the dispersion degree $\mathrm{F}_i^{'}$ between the ecological water consumption and the measured runoff in that month is greater than 10, it can be considered completely discrete, and $\mathrm{F}_i^{'}$ is taken as 10.

3. Assessment of Ecological Flow Satisfaction in Kushui River

3.1 Dynamic Process of Annual Flow Control Section

(1) Characteristics of Flow Changes in Guojia Bridge Section in 2017

The average annual flow rate of Guojiaqiao section in 2017 was 4.10m^3/s, with a maximum flow rate of 23.9m^3/s, which occurred on August 2nd; The minimum flow rate is 1.01m^3/s, which occurred on December 9th. The average flow rate during dry season is 1.549m^3/s, the average flow rate during non flood season is 2.593m^3/s, and the average flow rate during flood season is 6.197m^3/s.

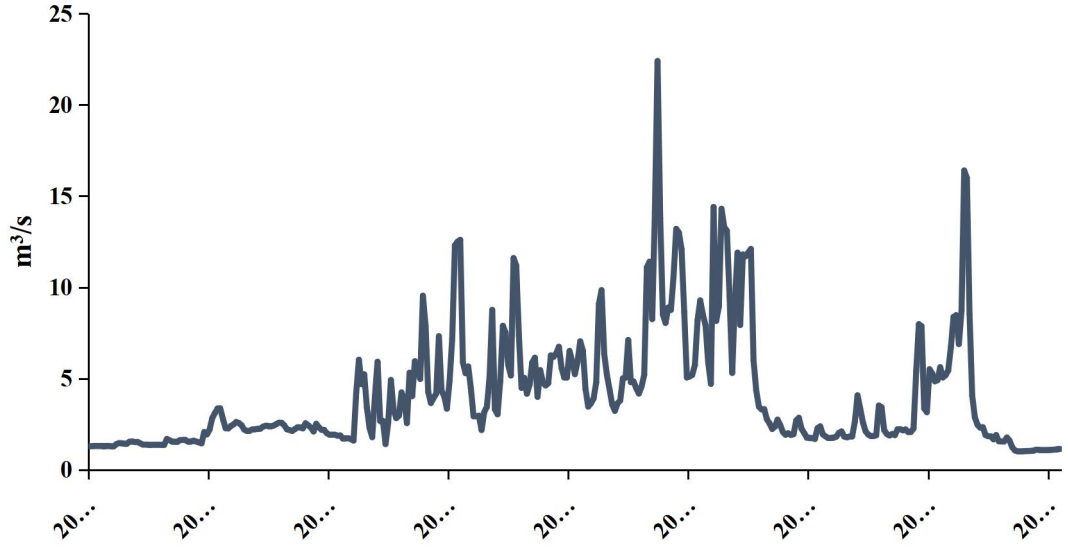

Fig. 1 Daily Average Flow Process of Guojia Bridge Section in 2017

(2) Characteristics of Flow Changes in Guojia Bridge Section in 2018

The average annual flow rate of Guojiaqiao section in 2018 was 4.98m^3/s, with a maximum flow rate of 23.9m^3/s, which occurred on July 8th and a minimum flow rate of 0.275m^3/s, which occurred on December 13th. The average flow rate during the dry season was 1.326m^3/s, the average flow rate during the non flood season was 3.120m^3/s, and the average flow rate during the flood season was 8.683m^3/s

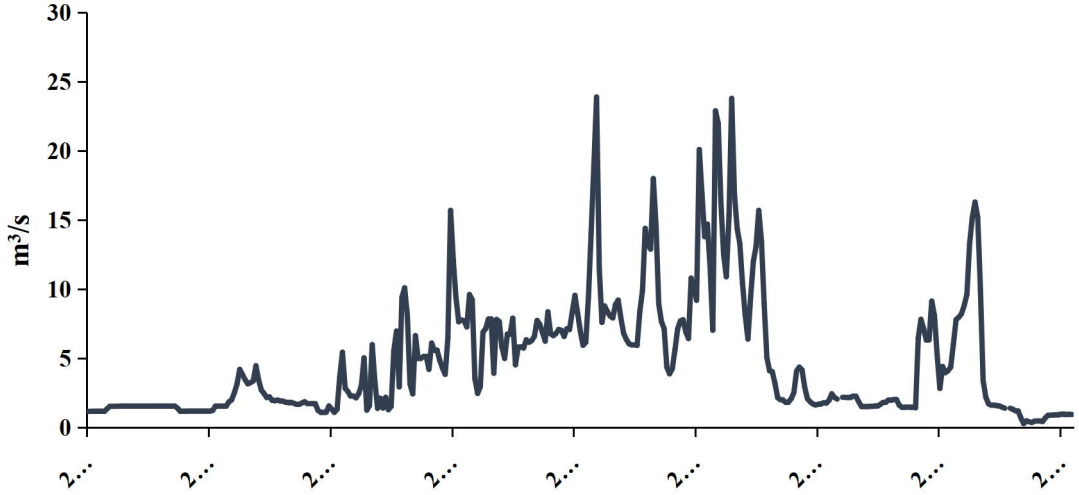

Fig. 2 Daily Average Flow Process of Guojia Bridge Section in 2018

(3) Characteristics of Flow Changes in Guojia Bridge Section in 2019

As of the end of October 2019, the average flow rate of Guojiaqiao section was 5.68m^3/s, with a maximum flow rate of 25.7m^3/s, which occurred on June 27th and a minimum flow rate of 1.225m^3/s, which occurred on January 1st. The average flow rate during the dry season was 1.43m^3/s, the average flow rate during the non flood season was 3.69m^3/s, and the average flow rate during the flood season was 8.34m^3/s

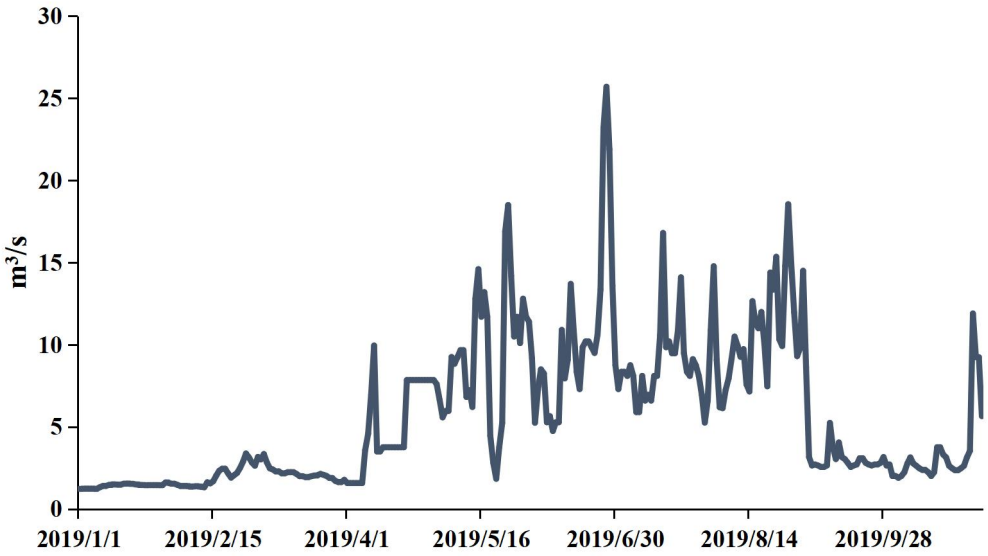

Fig. 3 Daily Average Flow Process of Guojia Bridge Section in 2019

3.2 Daily Average Ecological Flow Satisfaction Level

3.2.1 Daily flow deviation degree

An analysis of flow deviation rate was conducted on the daily flow in 2017, as shown in Fig. 4. The daily average flow deviation rate in 2017 was all less than 1, but the change was significant, ranging from 0.1 to 0.9. The ecological flow was satisfied. Among them, the ecological flow satisfaction rate was better in September and December, and the C_i ratio was close to 1. It can be seen that the daily average ecological flow satisfaction rate in 2017 was better.

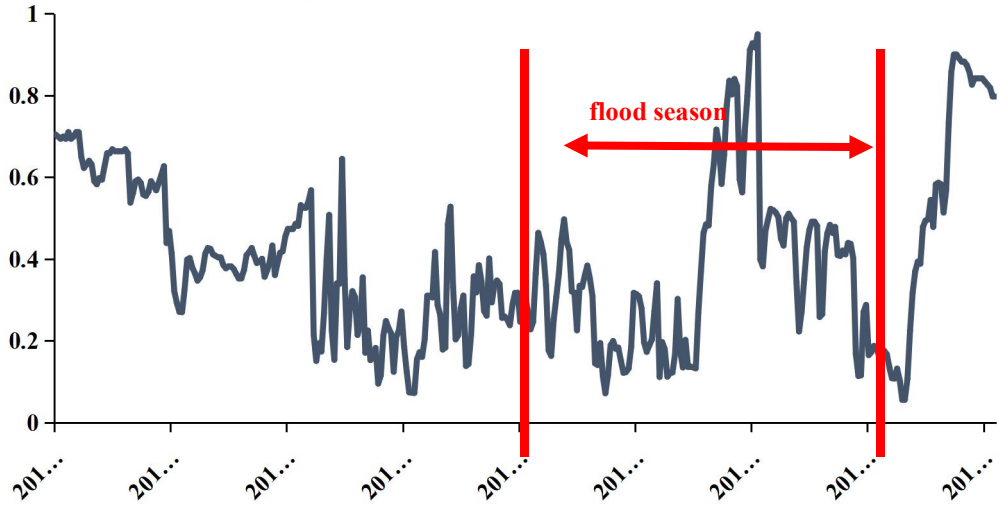

Fig. 4 Deviation rate of daily average flow rate of Guojia Bridge section in 2017

The flow deviation rate analysis was conducted on the daily flow in 2018, as shown in Fig. 5. The daily average flow deviation rate in 2018 was all less than 1, and the annual flow deviation rate was basically around 0.2. However, the ecological flow deviation rates in September and December were relatively close to 1, indicating that the ecological flow satisfaction rate was good throughout the year.

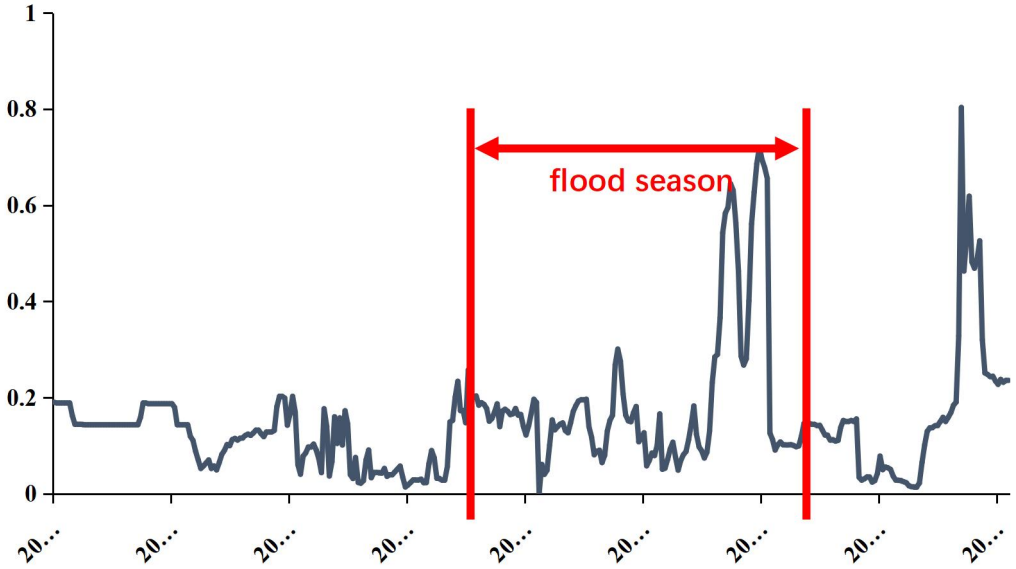

Fig. 5 Deviation rate of daily average flow on Guojia Bridge section in 2018

A flow deviation rate analysis was conducted on the daily flow from January to October 2019, as shown in Fig. 6. The daily average flow deviation rate in 2019 was all less than 1, and the annual flow deviation rate was basically around 0.34. However, the ecological flow deviation rates in September and January were relatively close to 1, indicating that the ecological flow satisfaction rate was good throughout the year.

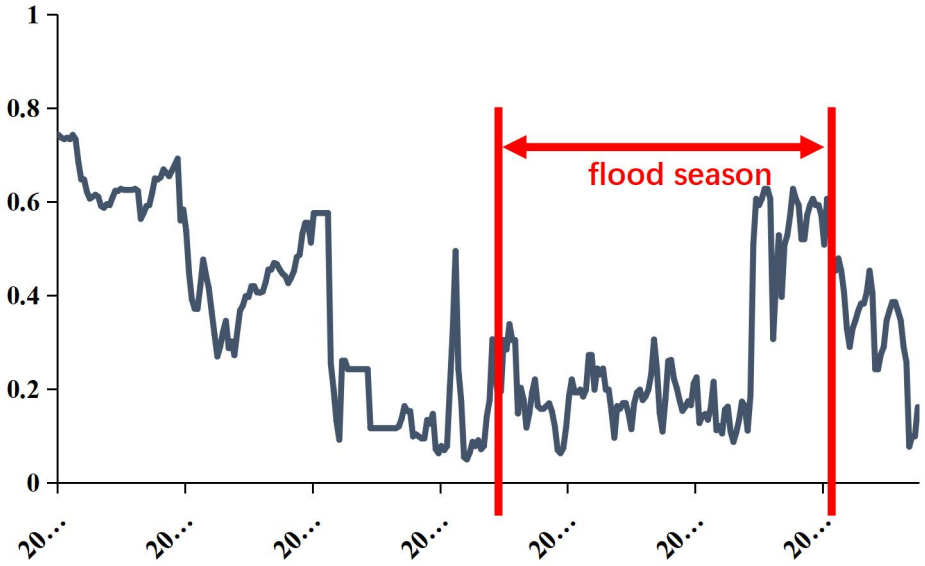

Fig. 6 Deviation rate of daily flow rate of Guojia Bridge section in 2019

3.2.2 Daily average ecological flow assurance level

According to formula (2), calculate the daily ecological flow guarantee levels for 2017, 2018, and 2019 respectively. Within three years, the daily average ecological flow guarantee rate is met, and the daily average ecological flow guarantee rates for the entire year of 2017, 2018, and 2019 are 100%, 100%, and 100%, meeting the basic requirements.

3.3 Monthly Average Ecological Flow Satisfaction Level

3.3.1 Monthly average ecological water demand guarantee rate

Fig. 7 shows the median daily flow rate variation curve of Guojiaqiao section from 2017 to 2019. According to formula (3), the monthly ecological water demand guarantee rate from 2017 to 2019 reached 1, and the monthly ecological flow rate was met, indicating a high continuous ecological

water demand guarantee rate. The monthly ecological water demand guarantee rate from 2017 to 2019 is shown in Table 1.

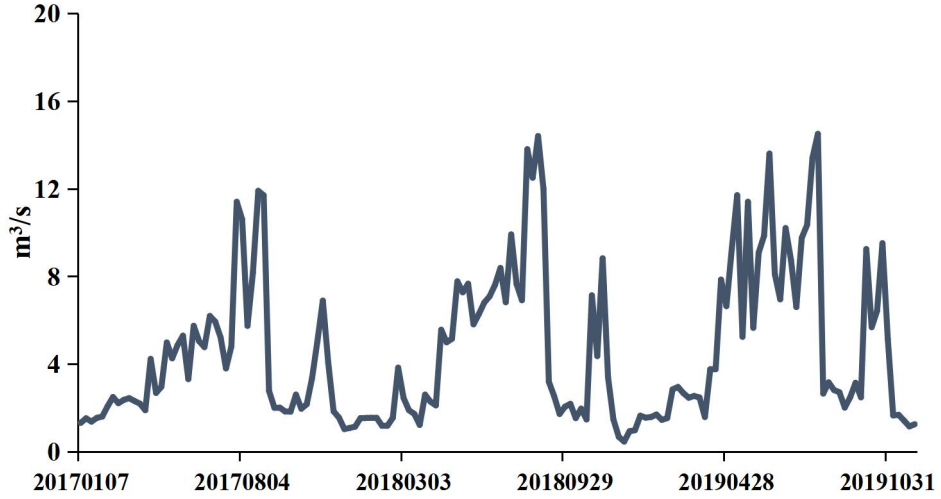

Fig. 7 Median daily average flow of Guojia Bridge section from 2017 to 2019

Table 1 Monthly Ecological Water Demand Guarantee Rate

Month	2017	2018	2019
1	1	1	1
2	1	1	1
3	1	1	1
4	1	1	1
5	1	1	1
6	1	1	1
7	1	1	1
8	1	1	1
9	1	1	1
10	1	1	1
11	1	1	-
12	1	1	-

3.3.2 Monthly suitability of ecological water demand

Based on monthly flow calculations, the monthly average ecological water suitability for 2017-2019 was above 0.9. Among them, the monthly average ecological water suitability for 2019 was significantly higher than that of 2017 and 2018, indicating that the ecological flow in 2019 was fully met.

3.4 The degree of ecological flow satisfaction at different levels

Based on the actual situation of the Kushui River and referring to the relevant requirements for the division of water periods in the third water resources survey and evaluation, the flood season of the Kushui River is from June to September each year, the non flood season is from October to May of the following year, and the freezing period is from December to February of the following year. The ecological water volume of the Guojiaqiao section during the flood season is 1.23 million m^3, which is equivalent to a daily flow rate of 0.1167 m^3/s. According to the statistical results of flow data, the average daily flow rate of the Guojiaqiao section during the flood season in 2017 was 6.395 m^3/s, and the minimum daily flow rate was 1.73 m^3/s; The average daily flow rate of Guojiaqiao section during the 2018 flood season was 8.392 m^3/s, and the minimum daily flow rate was 1.7 m^3/s; The average daily flow rate of Guojiaqiao section during the 2019 flood season was

7.438m^3/s, and the minimum daily flow rate was 2.01m^3/s. The ecological flow of the Guojiaqiao control section during the flood season was fully met in 2017, 2018, and 2019, respectively.

The non flood season belongs to the dry season, with low water levels and low flow. Its ecological flow meets the requirements and is a key guarantee object for maintaining the basic ecological water demand of the Kushui River. The ecological water volume of Guojiaqiao section during non flood season is 440000 m^3, which is equivalent to a daily flow rate of 0.05 m^3/s. According to the statistical results of flow data, the average daily flow rate of Guojiaqiao section during non flood season in 2017 was 2.95 m^3/s, and the minimum daily flow rate was 1.01 m^3/s; The average daily flow rate of Guojiaqiao section during non flood season in 2018 was 3.11 m^3/s, and the minimum daily flow rate was 0.275 m^3/s; The average daily flow of the Guojiaqiao section during the 2019 flood season was 3.4m^3/s, and the minimum daily flow was 1.58m^3/s. The non flood season ecological flow of Guojiaqiao control section was fully met in 2017, 2018, and 2019, respectively.

4. Summary

This ecological flow assessment is based on the daily average flow data from 2017 to 2019, and evaluates the degree of ecological flow satisfaction of the Kushui River from the aspects of continuous flow process, ecological water demand satisfaction, and ecological water demand suitability. The results indicate that the minimum runoff of Guojiaqiao Hydrological Station on the Kushui River during the dry season is relatively small, with a significant difference from the annual average daily flow. However, the degree of ecological flow assurance is very high, reflecting the seasonal and significant changes in the Kushui River, with extremely uneven distribution throughout the year. After calculation and analysis, the ecological flow of Kushui River at both daily and monthly scales, as well as during flood and non flood seasons, has been fully met.

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