Analysis of hydrological changes in the main stream of Chishui River before and after hydropower construction

Wentong Wang, Jing Zhang, Qi Wang, Jinyong Zhao*

Department of Water Ecology and Environment China Institute of Water Resources and Hydropower Research, Beijing 10038, China

*Corresponding author's e-mail: zhaojy@iwhr.com

Abstract. Based on flow data from the Luodian River Hydrological Station, the RVA analysis method was first used to measure the degree of hydrological change of the five groups of indicators in the IHA index system. The improved RVA method combined with the Nemerow index was then used to calculate the overall degree of hydrological change and the comprehensive degree of hydrological change of each indicator group. The study found that the overall degree of hydrological change of the main channel of the Chishui River was low. Except for the frequency and duration of high and low flows, which were moderately changed, the other four index groups were all low-level changes. Most of the hydrological index changes were low-level, there are no high-level changing indicators; after the establishment of Yudong Hydropower Station, the discharge tends to be uniform, the frequency and duration of high and low flows and the annual extreme flow index group have relatively large changes, the rate and frequency of flow conditions rate and frequency of water condition changes have decreased, low flow occurs significantly earlier.

Keywords: Hydrological regime; Degree of hydrological change; Chishui River; RVA method

1 Introduction

Hydrology is a key element in maintaining the integrity of aquatic ecosystems and has a major impact on river and lake ecosystems [1]. Understanding and accurately assessing changes in river hydrological regimes is a necessary condition for restoring and maintaining river ecological functions and ensuring river health. It is also the basis for ensuring the ecological health of rivers [2].

Many studies have been conducted by a large number of scholars on the assessment of hydrological conditions of rivers. Richter et al. first constructed a hydrological change index system (IHA) to describe the changes in river hydrological conditions [3-4]. At the same time, they proposed the range of change method (RVA) to quantitatively evaluate the impact of river conservancy project construction on hydrological conditions. At present, many scholars at home and abroad have analysed the impact of water conservancy project construction on river hydrological conditions based on the IHA

D. Li et al. (eds.), *Proceedings of the 2023 9th International Conference on Architectural, Civil and Hydraulic Engineering (ICACHE 2023)*, Advances in Engineering Research 228,
https://doi.org/10.2991/978-94-6463-336-8_67

index system and the RVA method. At the same time, many scholars believe that the indicator group of RVA and the method of calculating the overall hydrological change are insufficient, and the method of RVA has been improved and applied to the analysis of the hydrological situation of rivers [5-7].

Based on the existing studies, this paper analyses the hydrological situation of the mainstream of the Chishui River before and after the construction of the hydropower plant based on the IHA indicator system and using the improved RVA method, with the aim of gaining a more comprehensive understanding of the hydrological changes of the Chishui River before and after the construction of the hydropower plant.

2 Research background and research methods.

2.1 Overview of the study area

The total length of Chishui River is 1138.31 km, including the mainstream of Chishui River, the first-level tributaries such as Yudong River and Tongche River, and the second-level tributaries such as Muxiang River and Bitter Pig River. Yudong Power Plant was built in 1998, located in the Yudong River section of the main stream of Chishui River in Guozhu Township（Figure 1）, with an installed capacity of 2×800kw, and a distance of 4km from the water intake dam (105°01′16.28″, 27°38′29.31″) to the power plant (105°01′34.30″, 27°40′2.81″).

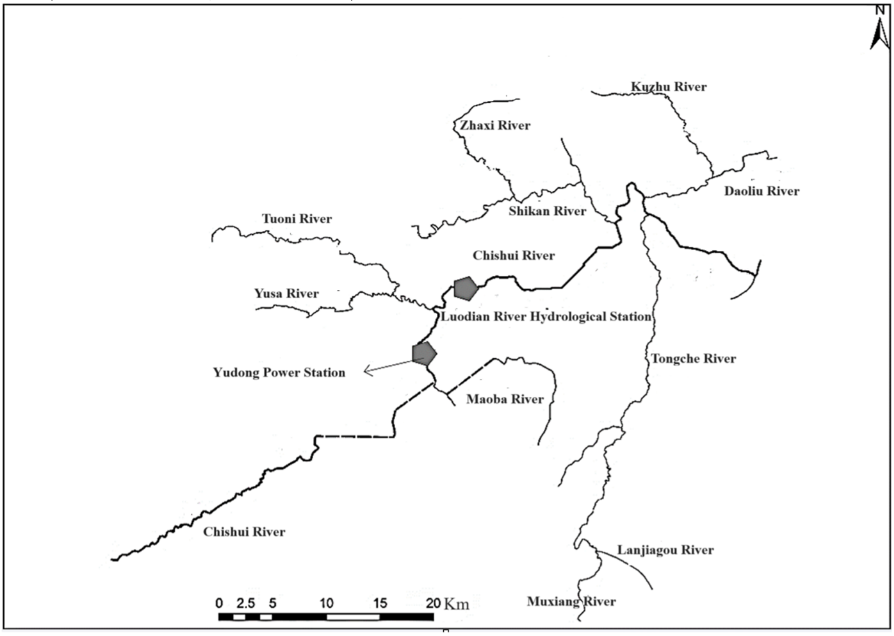

Fig. 1. Chishui River source section watershed map

2.2 Data Sources

The Luodian River Hydrological Station was built in 1960 and is located in Dahe Village, Dawan Town, Zhenxiong County. On the mainstream of the Chishui River, the Yudong Hydropower Station is the only one upstream of the Luodian River Hydrological Station. Before the construction of Yudong Hydropower Station, there were no power stations on the mainstream and tributaries of the Chishui River upstream of the Luodian River Hydrological Station. This paper analyses and discusses the changes in the hydrological situation of the mainstream of the Chishui River before and after the construction of the hydropower plant, using the flow data of the mainstream of the Chishui River at the Luodian River Hydrological Station as a representative.

2.3 Research methods

Based on the existing discharge observation data (1976-2019) from the Luodian River Hydrological Station, the 10-year daily discharge sequence from 1976 to 1985 was selected as the natural hydrological situation of the mainstream of the Chishui River without the hydropower station, and the 13-year daily discharge sequence from 2006 to 2019 (excluding the year 2011) was selected as the hydrological situation of the mainstream of the Chishui River disturbed by the hydropower station after its construction.

IHA Indicator System.

The IHA indicator system is an internationally recognised evaluation indicator system that can respond to changes in the hydrological situation and has been widely used around the world. The analytical approach of the IHA system has been applied by many scholars in analysing changes in the hydrological situation of rivers in different countries and in assessing their impacts. [7-9]. In this paper, the IHA indicator system is used to analyse the hydrological situation of the main stream of the Chishui River, which includes five groups of indicators, including the magnitude of monthly water conditions, the annual extreme flow, the time of occurrence of annual extreme flows, the frequency and duration of high and low flows, and the rate and frequency of water condition changes.

Improved RVA methodology.

- Calculation of hydrological change of individual indicators

Based on the basic concept of the RVA threshold proposed by Richter et al. in 1997, this paper takes the interval range of the mean plus or minus the standard deviation of each indicator parameter in the hydrological series before the construction of the Yudong Hydropower Station in the mainstream of the Chishui River as the threshold of the hydrological target, and thus obtains the upper and lower bounds of the RVA target for the hydrological indicators of the two time periods in the mainstream of the Chishui River [9].

The degree of hydrological change degree of individual IHA indicators is calculated as follows:

$$D_i = (N_{oi} - N_{ei})\ N_{ei}^{-1} \times 100\% \tag{1}$$

Here, D_i is the degree of change of the ith indicator; N_{oi} is the actual number of years that the ith indicator falls within the RVA target after being affected by human activities; N_{ei} is the expected number of years that the ith indicator falls within the RVA target after being affected by human activities. In order to more accurately assess the degree of hydrological change, reference has been made to the existing literature, which stipulates that if $0 < D_i \leq 33$ per cent, it is considered as a low level of change; if 33 per cent $< D_i \leq 67$ per cent, it is considered as a medium level of change; and if 67 per cent $< D_i \leq 100$ per cent, it is considered as a high level of change [8].

- Improved indicator groups and calculation methods for total hydrological change

In the current study, the calculation method of overall hydrological change degree of RVA is mainly to take the root-mean-square or average value of all indicators [7-10], which will ignore the influence of the height change value on the hydrological situation, resulting in narrowing the importance of the ecological impact of the height change indicators [11]. In order to avoid this problem, this paper refers to the existing literature combined with the Nemero index method, considering the effect of the maximum value, the calculation of hydrological change degree is amended accordingly, and the improved formula for the calculation of indicator group and overall hydrological change degree is proposed [12], through which the importance of the height change indicator on the ecological impact is better reflected. The following is the improved formula for the calculation of group hydrological change degree D_j and overall hydrological change degree D_0 :

Indicator Group hydrological change degree formula is:

$$D_j = \left[\frac{1}{2}\ (D_q{}^2 + D_{jr}{}^2)\ \right]^{0.5} \tag{2}$$

$$D_q = \frac{1}{2}\left(|D_j|_{max} + D_{jr}\right) \tag{3}$$

$$D_{jr} = \left(\frac{1}{n}\sum_{i=1}^{n} D_{ji}{}^2\right)^{0.5} \tag{4}$$

Here D_j is the overall hydrological change degree of the indicators in group j, $|D_j|_{max}$ max is the maximum value of the absolute value of hydrological change in the jth group of indicators. D_{jr} is the root-mean-square of the absolute value of hydrological change of the jth group of hydrological indicators. D_{ji} is the value of the hydrological change parameter of the ith indicator in the jth group, and n is the number of indicators in the indicator group.

The overall hydrological change degree D_0 is calculated as:

$$D_0 = \left[\frac{1}{2}\left(D_g{}^2 + D_r{}^2\right)\right]^{0.5} \tag{5}$$

$$D_g = \frac{1}{2}(|D|_{max} + D_r) \tag{6}$$

$$D_r = \left(\frac{1}{33}\sum_{i=1}^{33} {D_i}^2\right)^{0.5} \tag{7}$$

Here $|D|_{max}$ is the maximum value of the absolute value of hydrological change degree among all indicators, and D_r is the root mean square of the hydrological change degree of 33 hydrological indicators. If $0 < D_0 \leq 33\%$, it is regarded as low degree of alteration; if $33\% < D_0 \leq 67\%$, it is medium degree of alteration; if $67\% < D_0 \leq 100\%$, it is high degree of alteration [8].

3 Analysis of results

3.1 Analysis of hydrological change degree of single indicator

The 33 indicators in the IHA indicator system are named Q1-Q33, and the degree of hydrological change of each indicator in the main stream of the Chishui River before and after the construction of the Yudong Power Plant is analysed and calculated based on the IHA indicator system and the RVA method, as shown in Table 1 and Figure 2.

Table 1. Summary of IHA Indicator Hydrological change Results

IHA Indicators			Mean		RVA boundry		Hydrologic Alteration (%)
			pre	post	Low	High	
Magnitude of monthly water conditions	Q1	January	5.5	5.9	3.5	7.4	1 (L)
	Q2	February	7.0	5.8	3.8	10.3	28 (L)
	Q3	March	7.1	6.1	3.2	11.0	12 (L)
	Q4	April	7.2	7.3	3.7	10.8	15 (L)
	Q5	May	15.9	9.2	5.7	26.0	28 (L)
	Q6	June	21.6	20.0	9.0	34.3	6 (L)
	Q7	July	23.8	27.1	8.1	39.4	21 (L)
	Q8	August	29.3	23.2	13.4	45.1	15 (L)
	Q9	September	21.3	16.8	3.8	38.9	32 (L)
	Q10	October	10.1	13.6	4.9	15.2	12 (L)
	Q11	November	7.0	7.6	5.1	8.8	33 (L)
	Q12	December	5.5	6.2	3.4	7.6	42 (M)
Annual extreme flow	Q13	Annual minimum 1-day means	2.0	1.8	1.0	2.9	36 (M)
	Q14	Annual minimum 3-day means	2.5	2.7	1.4	3.6	23 (L)
	Q15	Annual minimum 7-day means	2.6	2.9	1.5	3.8	34 (M)
	Q16	Annual minimum 30-day means	3.4	3.5	2.1	4.6	34 (M)

	Q17	Annual minimum 90-day means	5.3	5.1	3.4	7.2	3 (L)
	Q18	Annual maximum 1-day means	198.6	148.6	126.8	270.4	45(M)
	Q19	Annual maximum 3-day means	135.3	108.5	92.6	194.1	23(L)
	Q20	Annual maximum 7-day means	91.1	76.1	64.5	125.4	12(L)
	Q21	Annual maximum 30-day means	47.0	42.4	34.7	59.2	23(L)
	Q22	Annual maximum 90-day means	30.3	26.5	20.3	40.3	4(L)
	Q23	Number of zero days	0.0	0.4	0.0	0.0	23(L)
	Q24	Base flow index	0.2	0.2	0.1	0.3	41(M)
Time of occurrence of annual extreme flows	Q25	Date of minimum	204.5	94.5	91.2	317.8	10(L)
	Q26	Date of maximum	202.7	221.2	170.2	235.2	3(L)
Frequency and duration of high and low flows	Q27	Low pulse count	7.0	7.6	3.7	10.3	36(M)
	Q28	Low pulse duration	14.9	9.6	6.2	33.1	3(L)
	Q29	High pulse count	8.3	6.8	5.5	11.1	12(L)
	Q30	High pulse duration	3.2	3.3	2.3	4.0	45(M)
Rate and frequency of water condition changes	Q31	Rise rate	6.9	5.4	4.4	9.3	13(L)
	Q32	Fall rate	3.5	2.7	2.3	4.6	13(L)
	Q33	Number of reversals	105.4	102.2	96.1	114.7	28(L)

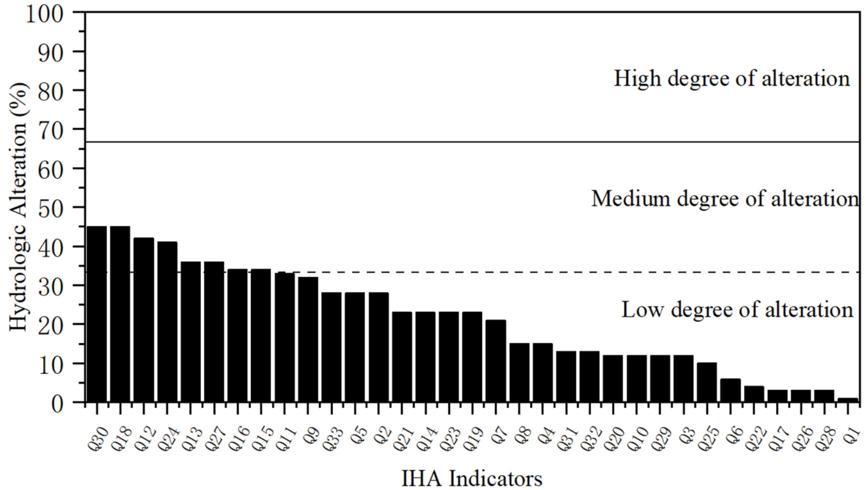

Fig. 2. Ranking of results of absolute changes in hydrological change degree for IHA indicators

From Table 1 it can be concluded that the degree of hydrological change of 33 indicators in the IHA indicator system is between 3% and 45%, all of which are medium-low.

From Figure 2, it can be seen that: there are 8 indicators with medium degree of hydrological change, accounting for 24.2%; there are 25 indicators with low degree of hydrological change, accounting for 75.8%; there are no highly altered indicators; and the hydrological change degrees in the top five are Q30 (high pulse duration), Q18 (maximum flow on 1 day of the year), Q12 (flow in December) and Q24 (base flow index), Q13 (lowest flow on 1 day of the year).

The monthly average hydrological flow change of the main stream of the Chishui River ranges from 1% to 42%. Among them, the flow changes in the dry season (November and December) after the establishment of the station are larger than those in other months, at 33% and 42%. After the completion of Yudong Hydropower Station, the discharge showed a trend of homogenisation, the annual flood showed an overall downward trend, and the duration of the annual flood increased. At the same time, the main flow of the Chishui River decreased after the construction of Yudong Hydropower Station. The rate of water rise, the rate of precipitation and the number of rises and falls have all decreased. The main reason is that the flow regulation of the power station affects the flow extremes in the hydrological process and makes the hydrological process more uniform. This reduces the rate and frequency of changes in flow conditions.

3.2 Overall hydrological change analysis

The improved RVA method calculates the degree of hydrological change for each group and for the whole, as shown in Table 2. It can be seen from Table 2 that the overall hydrological change degree is 31%, which is a low degree of change; the frequency and duration of high and low flow The hydrological change degree of the group is 34%, which is a moderate change, and the hydrological change degree of other groups is a low change.

Table 2. Indicator groups and overall hydrological change degree

Hydrological change degree of each group					overall
1	2	3	4	5	
29（L）	33(L)	8(L)	34(M)	22(L)	31(L)

4 Conclusion

The discharge of the main stream of the Chishui River has shown a trend of uniformity after the completion of Yudong Hydropower Station. The overall rate of change and frequency of flow conditions have decreased. The frequency and duration of high and low flows and the annual extreme flow have changed significantly.

The overall hydrological change degree of the main stream of the Chishui River did not change much before and after the construction of the Fishery Hole Hydropower Plant, and the ecosystem was relatively stable.

The hydropower construction should take reasonable measures to reduce the impact on the hydrological conditions and ecology of the river.

References

1. Dong Z R, Sun D Y, Zhao J Y, et al. Progress and prospect of eco-hydraulic engineering[J]. Journal of Hydraulic Engineering, 2014, 45(12): 1419-1426.
2. Shi W D. Hydrological Regime Assessment Method Considering the Periodicity of IHA Indexes [J]. Yellow River, 2019, 41(9).
3. RICHTER B D, BAUMGARTNER J V, POWELL J, et al. A Method for Assessing Hydrologic Alteration within Ecosystems[J/OL]. Conservation Biology, 1996, 10(4): 1163-1174.
4. A spatial assessment of hydrologic alteration within a river network - Richter - 1998 - Regulated Rivers: Research & Management - Wiley Online Library[EB/OL]. [2023-06-30].
5. Zhang R Q, Liu J G, et al. Flow regime alterations of upper Heihe River based on improved RVA [J/OL]. Arid Zone Research, 2021, 38(1): 29-38.
6. Zhu D, Mei Y D, et al. Calculation of overall hydrologic alteration in middle and lower reaches of Ganjiang River based on grouping weighting and improved Nemerow index [J/OL]. Engineering Journal of Wuhan University, 2019, 52(12): 1048-1055.
7. Ju Q, Wu J J, Yao T Y, et al. Analysis of Hydrological Regime Change in Weihe River Basin Based on IHA-RVA Method [J/OL]. Journal of China Hydrology, 2022, 42(4): 76-82.
8. Dong Y T, Wang S Y, Mu X M, et al. Assessment on Impact of Ecological Management on Runoff Evolution Based on IHA-RVA Method [J/OL]. Research of Soil and Water Conservation, 2023, 30(2): 193-200.
9. Singh R K, Jain M K. Reappraisal of hydrologic alterations in the Roanoke River basin using extended data and improved RVA method[J]. International Journal of Environmental Science and Technology, 2021, 18: 417-440.
10. Wu X J, Ge J J, Qi X M, et al. Assessment of flow regime of Zhoukou Section based on RVA method [J/OL]. South-to-North Water Transfers and Water, 2019, 17(5): 71-80.
11. Xue L Q, Zhang H, Zhang L C, et al. Impact of water conservancy projects on eco-hydrological regime of Tarim River based on improved RVA method [J]. Journal of Hohai University (Natural Sciences), 2017, 45(3): 189-196.
12. Li Y S, Zhang J Z, Fei Yh et al. Improvement of Nemerow index method and its application [J]. Water Resources Protection, 2009,25(06):48-50.