Ecological risk assessment based on IHA-RVA in the lower Xiaolangdi reservoir under changed hydrological situation

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Abstract. Ecological risk assessment of river is an important content for protection and improvement of ecological environment. In this paper, taking Xiaolangdi reservoir for example, ecological risk assessments are studied based on the 1956-1997 and 2002-2008 dairy runoff data as the pre and post of construction of Xiaolangdi reservoir. Considering pre and post hydrological regime of construction of Xiaolangdi, ecological risk assessment index systems of downstream are established based on Index of Hydrologic Alteration-Range of Variability Approach method（IHA-RVA）, which considering characters of flow, time, frequency, delay and change rate. Then ecological risk fuzzy comprehensive evaluation assessment model downstream is established based on risk index and RVA method. The results show that after the construction of Xiaolangdi reservoir, ecological risk occurred in the downstream of Yellow River for changed hydrological indexes, such as monthly average flow, frequency and duration of extreme annual flow and so on, which probably destroy the whole ecosystems of the river. For example, ecological risk downstream of Xiaolangdi reservoir upgrade to level two in 2008. Research results make reference values and scientific basis both in ecological risk assessment and management of reservoir after construction.

1 Introduction

River is the key to material and energy circulation for a regional or a nation. The hydrological situation of the river plays an important role in maintaining the health of the river and the integrity of the aquatic ecosystem [1]. In recent years, with the background of global environmental change, the developments and constructions of the major watersheds in China have changed the hydrological situation of the rivers and greatly affected the ecological environment of the rivers [2]. As the mother river of the Chinese nation, Yellow River undertakes a great deal of mission. With the contradiction between supply and demand, the Yellow River basin has become increasingly prominent, especially in the lower Yellow River. Large-scale dam, irrigation and other human activities caused the Yellow River hydrological situation has undergone major changes [3].

At present, most of them at home and abroad establish the hydrological and ecological index system and quantify the degree of hydrological factors or analyze the relationship between hydrological factors and hydrological factors to study the ecological risks. The Index of Hydrologic Alteration (IHA), proposed by American ecologist Richter in 1996, is one of the methods of covering the concept of hydrological situation in recent years, including 32 indicators such as river runoff value, frequency, time of occurrence, duration and rate of change and so on[4]. Later, Richter proposed the Range of Variability Approach (RVA) basing on IHA [5]. After that, IHA and RVA are widely used in hydrological situation changes at home and abroad [6-13]. On the issue of ecological risk assessment, many domestic scholars analyze the ecological problems of water quality problems, and there is little ecological risk assessment based on the change of hydrological situation in the downstream river.

Based on the hydrological situation change pre and post the reservoir construction, the fuzzy comprehensive evaluation model of ecological risk in the middle and lower Yellow River is established to quantitatively evaluate the ecological risk. The research results are of great significance and application value for the scientific decision making of reservoir ecological environment management [17].

2 Assessment System of Ecological Risk

Reservoirs and other water conservancy projects in the construction and operation have a positive impact, but also negative impact on natural ecological environment. The current researches have not yet fully defined the clear boundaries of positive and negative effects of the ecological environment. However, the ideas of protect river ecology in the future has the ideas to protect river ecology in the future. Protecting the natural species and biological evolution processes to maintain the integrity of the ecosystem of species diversity is our way to protect the environment in the future [18]. In this study, the RVA is used to the ecological risk assessment of the lower reaches of the reservoir. Based on the analysis of the impact of IHA and ecology, the ecological risk assessment system of downstream river is established. The meanings of indicators for each group of hydrological indicators like [19].

3 Ecological Risk Assessment Model

3.1 Risk Index Calculation

Due to the different meaning and dimension of the ecological risk assessment index, it is necessary to use the reasonable mathematical method to deal with it without any dimension to make it comparable. The ecological risk assessment index defined changes within the RVA threshold. In this paper, the risk index of ecological risk in healthy rivers fluctuated within the upper and lower range of RVA threshold. The closer the index value is to the natural hydrological characteristic value, the healthier the river may be. That means that the risk assessment index is an intermediate optimal index. The risk indexes calculated like [20].

3.2 Fuzzy Comprehensive Evaluation Model

The ecological risk assessment index of river has no clear boundary, and it has some ambiguity. Therefore, ecological fuzzy comprehensive evaluation model about the river established in this paper quantified the risk evaluation index, and ensure the rationality and accuracy of the evaluation results. The flow chart of ecological risk assessment is shown in Figure 1.

4 Case Study

4.1 Study Region and Data

Xiaolangdi reservoir is located at the exit of the last valley in the middle reaches of the Yellow River. It is the only major control project in the Yellow River, which can obtain a large storage capacity under the Sanmenxia reservoir. Xiaolangdi Reservoir is the nearest reservoir from the lower Yellow River. Therefore, it is the most influential and sensitive to the lower reaches of the Yellow River.

In this paper, the Xiaolangdi Reservoir in the lower the Yellow River is chose as the object of study. The daily runoff data from 1957 to 1997 are chose as the daily runoff series before the impact. The daily outbound runoff from 2002 to 2007 are chose as influencing data after the impact, and the year of 2008 as the object of river ecological risk assessment.

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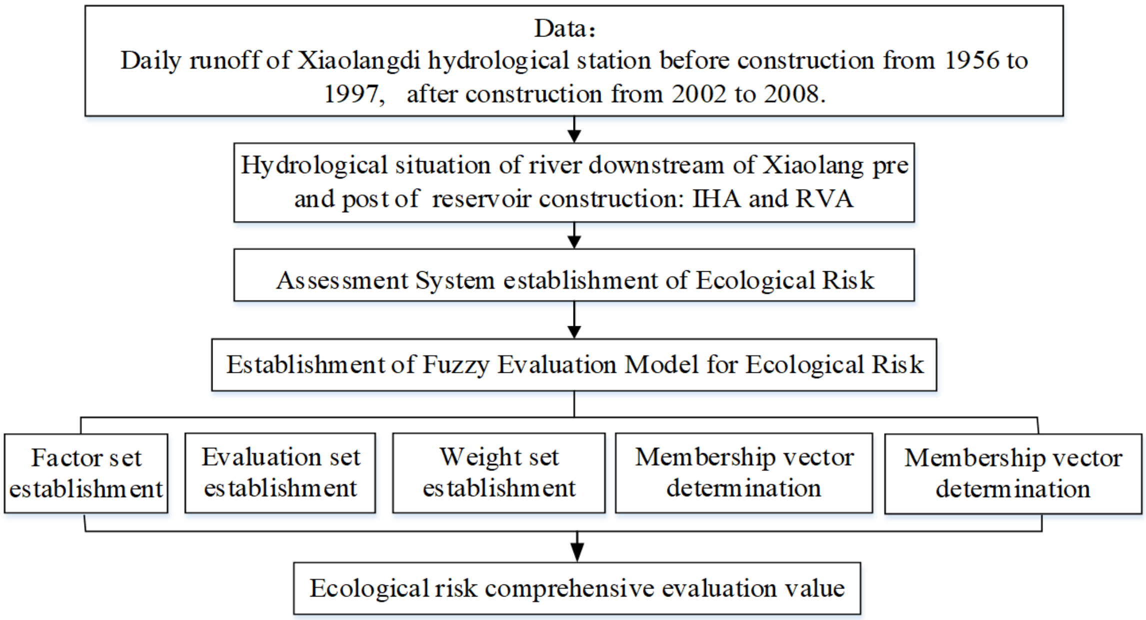

Figure 1. Flow chart of ecological risk assessment

4.2 Risk level determination

Combining the data parameters of RVA of Xiaolangdi reservoir, the ecological risk level about the lower Xiaolangdi Reservoir of 2008 is 2-level, which means the low risk.

Before and after the construction of the Xiaolangdi reservoir, the coordination and integrity of the river ecosystem in the lower Xiaolangdi damaged to varying degrees, the river landscape, the biological habitat destruction, the fish migration and spawning pulse reduced and the number of pulses decreased, transportation and transportation sediment, and the flow of nutrients, and so on. The hydrological situation of the river is highly changed and the stability of the river ecosystem is the main reason for the increase of the ecological risk of the river in 2008.

4.3 Change degree

The change of hydrological situation pre and post of Xiaolangdi Reservoir construction is the starting point of the study. This section mainly analyzes the calculation results of four aspects. In order to analyze the causes of the ecological risk of the lower Xiaolangdi.

4.3.1 Monthly average flow

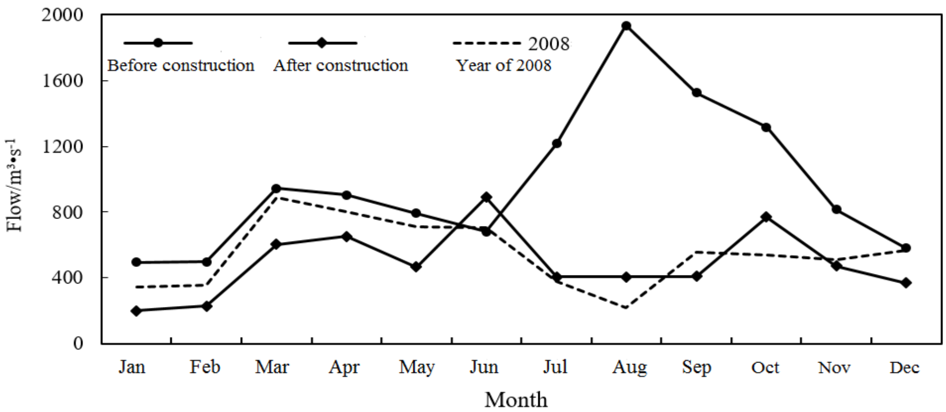

Figure 2. Average flow of month with pre and post of Xiaolangdi Reservoir construction

Table 1 Average flow change of month with pre and post of Xiaolangdi Reservoir construction

Month	Mean before construction	Mean after construction	Year 2008	Changes pre and post of construction	Changes before and year 2008 construction	Change degree
Jan	493.5	200.5	343.0	293	150.5	High
Feb	497.3	229.5	357.0	267.8	140.3	High
Mar	945.0	603.5	889.0	341.5	56.0	Medium
Apr	904.0	653.3	800.0	250.7	104.0	Medium
May	793.0	465.0	710.0	328.0	83.0	Medium
Jun	681.5	890.5	706.5	-209.0	-25.0	Medium
Jul	1215.0	406.5	380.0	808.5	835.0	Medium
Aug	1935.0	406.5	218.0	1528.5	1717.0	High
Sep	1525.0	408.8	554.0	1116.2	971.0	High
Oct	1315.0	769.0	539.0	546.0	776.0	Medium
Nov	814.8	472.3	510.0	342.5	304.8	High
Dec	580.0	369.5	566.0	210.5	14.0	Medium

Table 1 and Figure 2 illustrate average flow changes of month with pre and post of Xiaolangdi Reservoir construction. The conclusions are as follows:

(1) After the construction of the Xiaolangdi Reservoir, the flow rate increased in June, which is moderate change. The water storage capacity in January, February, August, September and November significantly reduced, which are height change. The flow of the remaining months reduced, which are moderate changes due to the storage capacity of the reservoir. The change degree of dry season in January to May, and in October to December is smaller than that in July to September, which corresponds to the water storage period of Xiaolangdi Reservoir. In general, the Xiaolangdi Reservoir plays the role of water storage, water supply, reserve flood storage capacity, detention and so on. The monthly average flow rate changed greatly, which affects the aquatic habitat and soil water content, resulting in certain ecological risk.

(2) The mean monthly flow in 2008 changes in varying degrees. Including the average monthly flow, distribution uniform and July to September the degree of change are higher than the rest month. It concluded that the monthly average flow is one of the causes of the ecological risk of the river.

4.3.2 Extreme flow and duration

Table 2 Extreme flow change of year with pre and post of Xiaolangdi Reservoir construction

Indicators	Mean before construction	Mean after construction	Year 2008	Changes pre and post of construction	Changes before and year 2008 construction	Change degree
Minimum 1-day flow	128.0	114.0	108.0	14.0	20.0	High
Minimum 3-day flow	173.8	155.8	149.3	18.0	24.5	High
Minimum 7-day flow	190.0	163.3	154.3	26.7	35.7	High
Minimum 30-day flow	325.5	182.0	210.6	143.5	114.9	High
Minimum 90-day flow	615.4	275.1	391.0	340.3	224.4	High
Maximum 90-day flow	4915.0	3385.0	4040.0	1530.0	875.0	Medium
Maximum 30-day flow	4148.0	3187.0	3967.0	961.0	181.0	Medium
Maximum 7-day flow	3926.0	3049.0	3767.0	877.0	159.0	Medium
Maximum 3-day flow	2791.0	1938.0	1819.0	853.0	972.0	Low
Maximum 1-day flow	2081.0	1203.0	1102.0	878.0	979.0	Low

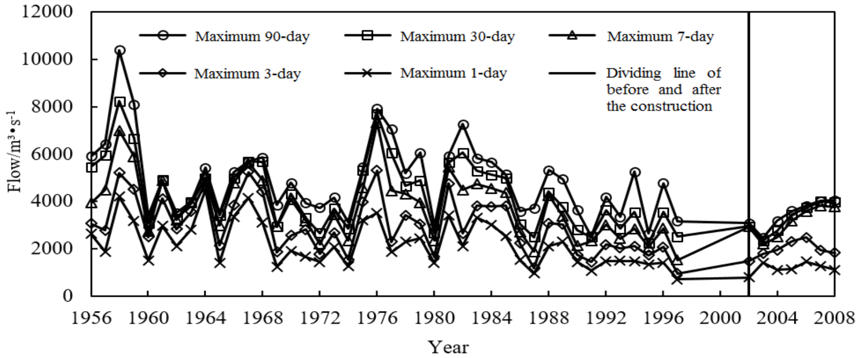

Figure 3. The largest extreme flow of year with pre and post of Xiaolangdi Reservoir construction

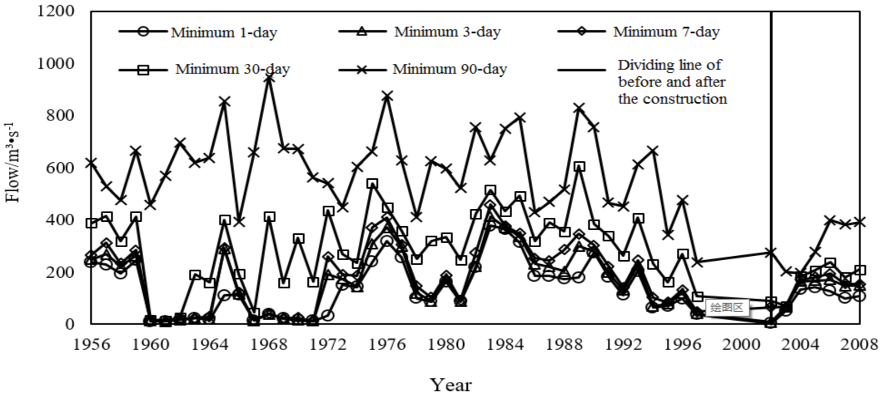

Figure 4. The smallest extreme flow of year with pre and post of Xiaolangdi Reservoir construction

Table 2, Figure 3 and Figure 4 show extreme flow change of year with pre and post of Xiaolangdi Reservoir construction. The resulting conclusions are as follows:

(1) After the construction of the Xiaolangdi Reservoir, the maximum flow of 90-day changes dramatically. The maximum extreme flow in 2008 are moderate change, in addition to the severe change of the flow of 90-day. After the construction of the Xiaolangdi Reservoir, the minimum annual extreme flow reduces. The change of the minimum 90-day flow is large. The change of the minimum 1-day flow is the small. The annual minimum extreme flow also changes. In 2008, the minimum extreme flow reduces, the change of the minimum 90-day of flow is small. Year minimum 1-day flow reduced by 15.63%, which is the small change.

(2) After the construction of Xiaolangdi Reservoir, the annual maximum extreme flow has a decreasing trend. The maximum extreme flow rate is also one of the reasons for the ecological risk of the river，leading to poor transport of nutrients in the river and the detention area, which seriously affects the growth of aquatic organisms and surrounding vegetation in the detention area. At the same time, the minimum annual extreme flow has a decreasing trend, and the change of the minimum extreme flow rate affects the fragile ecological environment. Therefore, the minimum annual extreme flow is also one of the main causes of river ecological risk.

(3) In the year of 2008, the extreme maximum and lowest flow exceedes the RVA threshold, which changed compared with that before the construction, threatening a variety of migratory and spawning fish, as well as destroying the cycle of reproduction.

4.3.3 Frequency and duration of annual high and low flow

Table 3 High low flow change of year with pre and post of Xiaolangdi Reservoir construction

Indicators	Mean before construction	Mean after construction	Year 2008	Changes pre and post of construction	Changes before and year 2008 construction	Change degree
Low flow times	8	20.5	34	12.5	26	High
Low flow days	4.5	2	1	-2.5	-3.5	High
High flow times	9	20.5	32	11.5	23	High
High flow days	3.5	1.8	1	-1.7	-2.5	High

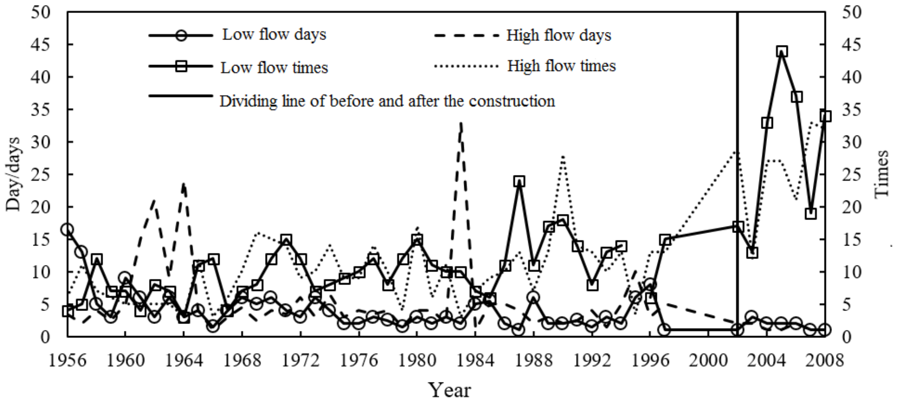

Figure 5. Frequency and diachronic of high low flow change of year with pre and post of Xiaolangdi Reservoir construction

Table 3 and Figure 5 illustrate the frequency and duration of high and low flow change of year with pre and post of Xiaolangdi Reservoir construction. The conclusions are as follows:

(1) Before and after the construction of Xiaolangdi Reservoir, the times and the number of days of high and low flow occurred have changed. The number of low flow days reduces from 4.5 days to 2 days after construction, and the degree of hydrological change is 70%. After the reservoir is established, the number of low flow increases from 8 to 20.5 times and high flow increases from 9 to 20.5 times, the high flow days decrease from 3.5 days to 1.8 days, All in all, the hydrological change of each factor is 100%.

(2) The number of times the high and low flows occur has changed since the establishment of the reservoir. High and low, flow is an indispensable factor in river ecology, with the role of promoting the transport of sediment and nutrients. The change of annual high and low flow threatens the ecological environment of rivers and is not conducive to the growth of surrounding vegetation. It is one of the main causes of ecological risk of rivers.

(3) In 2008, the number of times and days of high and low flow seriously deviated from the RVA threshold. Among them, the number of high flow changes 23 times and low flow changes 26 times, the number of high flow days changed by 2.5 and low flow days changed by 3.5, the hydrological change of each element is a high degree of change. The high changes of the high and low flow destroy the growth environment of the surrounding plants and the coordination of the ecosystem, which also is one of the main causes of the ecological risk escalation in Xiaolangdi Reservoir.

4.3.4 Reverse Times of Flow

Table 4 Reverse times of flow change pre and post of Xiaolangdi Reservoir construction

Indicators	Mean before constructio n	Mean after constructio n	Year 2008	Changes pre and post of construction	Changes before and year 2008 construction	Chang e degree
Flow increase	57.8%	75.5%	112.0%	17.7%	54.2%	Low
Flow reduction	55.0%	70.5%	128.0%	15.5%	73.0%	High
Reverse Times	142.5	225.0	231.0	82.5	88.5	High

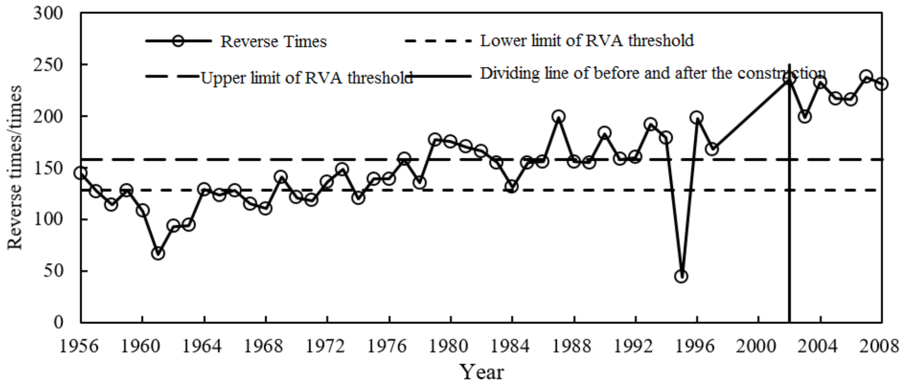

Figure 6. Reverse times of flow pre and post of Xiaolangdi Reservoir construction

Figure 6 and Table 4 shows the number of reversals of the flow before and after the construction of Xiaolangdi, which can draw the following conclusions:

(1) The rate of waterfall increases from 57.8% and 55% to 75.5% and 70.5% respectively after 17.5% and 15.5% respectively. The degree of hydrological change is low and height and the number of reversal of flow increases from 142.5 times before construction to 225 times of construction, an increase of 82.5 times, and the hydrological index changes greatly.

(2) The number of reversal times of flow after the construction of Xiaolangdi Reservoir falls under the RVA threshold, and the number of reversal of traffic has a significant upward trend. The number of river flow reversal will endanger the habitat of biological habitat, is not conducive to biological growth.

(3) In 2008, the hydrological change degree is above the RVA threshold, which increases from 142.5 times to 231 times before the building, increasing by 88.5 times. The flow rate and water drop rate increases by 54.2% and 73.0% respectively. The hydrological change degree for the high degree of change, a serious threat to the habitat of the environment, breaking the stability of the ecosystem. Therefore, the rate of change in flow rate, frequency and the number of reversal is also the occurrence of two levels of ecological risk in 2008 one of the reasons

4.4 The Overall Change Degree.

The main influencing factors of hydrological situation is analyzed, including monthly average flow rate, annual extreme flow frequency and duration, year and high flow rate and duration, flow reversal. Based on the comprehensive analysis of the results, the overall hydrological change degree of the lower reaches of the Yellow River is 67.6% after the operation of Xiaolangdi Reservoir, and the hydrological situation has changed greatly. This shows that the river hydrological situation changes after the operation of the reservoir will occur a certain degree of ecological risk.

In summary, after the construction of Xiaolangdi, the river hydrological situation has changed greatly, resulting in the destruction of the river ecosystem, exacerbated the ecological risk of Xiaolang lower reaches of the river.

5 Conclusions

(1) This study makes the ecological risk assessment ,which hierarchical structure is complex and the data are not easily collected by the reservoir downstream of the river, can be calculated simply on the base of the river hydrological situation before and after the building ,and also get a series of related quantitative results.

(2) This paper concludes that the ecological risk level of Xiaolangdi Reservoir in 2008 is Grade 2 by establishing the ecological risk assessment index system and risk comprehensive evaluation model of Xiaolangdi Reservoir. The main reason for this result is the change of hydrological situation in the lower reaches of the reservoir after Xiaolangdi reservoir construction, Changes in the degree of change, destruction of ecological harmony, triggering river ecological risk.

(3) Human should follow the objective laws, coordination of water, soil, and ecology, human relationship between the four when they develop and use the water resources, so that the water conservancy facilities operate ecologically. We must take the actively measures to reduce the impact of the high hydrological situation changes which has occurred, so it is difficult and hot to carry out the ecological maintenance of the river to maintain the ecological health of the river for future work.

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