Assessment of indirect agricultural losses caused by river ecological base flow protection

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Abstract. In order to coordinate the relationship between ecological base flow guarantee and agricultural water use, and promote the development of ecological base flow guarantee and compensation, this paper established an evaluation system of indirect agricultural losses caused by ecological base flow guarantee. Taking the Baojixia irrigation area as an example, the substitution method was used with the social security value of urban residents as a reference, and the coefficient in combination with the income ratio of urban and rural residents was modified to obtain the social security value of rural residents’ cultivated land, then the agricultural irrigation before and after the ecological base flow guarantee was combined. The amount of water diversion was changed, finally the indirect agricultural loss caused by the protection of ecological base flow was calculated. The results show that the upper and lower limits of total agricultural indirect losses in a typical year are 420 million yuan and 122 million yuan, respectively. Actually, since the Baoji Gorge Irrigation District undertakes the task of food supply in the Guanzhong area and even in Shaanxi Province, it is necessary to consider other factors such as food security when implementing the policy of guaranteeing the base flow.

1. Introduction

Water resources are irreplaceable [1]. Agriculture, industrial production, and residents' lives are inseparable from water. The rapid social and economic development and rapid population growth have led to a sharp increase in the demand for industrial and agricultural water. A large amount of water diversion from rivers has caused production water to squeeze the ecological water use of the river, making a series of ecological and environmental problems such as the shrinkage of the river [2-6]. With the improvement of people’s material living standards, people gradually pay more attention to the ecological environment. To make rivers have ecological function value, the rivers must have corresponding water volume [7], so the river ecological base flow guarantee is essential for the normal performance of the river’s ecological functions and the river’s life and health.

In order to ensure the ecological base flow, it will inevitably reduce the amount of water drawn from the river by other water-using departments, which will lead to certain economic losses in other water-using departments. With the advancement of ecological base flow protection, many scholars at home and abroad have researched on the cost and compensation of ensuring ecological flow, and most of them mainly focus on the agricultural losses and compensation caused by ecological base flow protection. Qureshi [8] focused on the agricultural losses when the Murray Basin in Australia protect ecological water. Jones [9] used a stochastic dynamic model to determine the agricultural economic loss when the agricultural water is reduced in order to protect the ecological water. Zhang Qian[10] used the water
production function model to calculate the agricultural losses in the Baojixia Irrigation Area and Jiaokou Weihe Irrigation Area caused by the protection of ecological base flow in the middle section of the Weihe River. The above researches mainly calculate the direct economic loss of agriculture caused by the protection of ecological base flow. As the value of ecological base flow protection continues to increase, agricultural irrigation water decreases accordingly, resulting in a decline in the quantity and quality of farmers’ arable land, which cause certain losses to farmers’ direct economic income, and at the same time, the social security function value of arable land is also affected. Certainly, the indirect losses caused by the protection of ecological base flow to farmers cannot be ignored. At present, there is little research on the indirect loss caused by ecological base flow protection. The main research direction is to calculate the social security value of farmers’ cultivated land, and seldom consider the indirect loss to agriculture caused by ecological base flow protection, such as Zuru [11], she summarized the value evaluation methods of agricultural land based on the definition of agricultural land, and proposed that the social security value of agricultural land needs to consider the value of endowment insurance, medical insurance and employment insurance. Liu Xinghua [12] started from the social security function of cultivated land, and calculated the social security value of cultivated land resources by using the market method and the decomposition and sum method.

In recent years, the social security system for urban residents in China has been gradually improved, but the rural social security system is still in its infancy, and the employment, pension, and medical security systems for farmers have not yet been perfected. Cultivated land is the basic means of production for farmers, and it is also the basis for their basic life [13]. The social attributes of cultivated land determine that cultivated land not only has the value of ensuring food security, but also provides basic social security for farmers [11]. Current farmland evaluation methods and theories focus more on the economic value evaluation of farmland, and less consider its social security value, which is very unfavorable for accurately understanding the actual value of agricultural farmland. In order to more accurately understand the actual impact of ecological base flow protection on farmers’ cultivated land, this paper first clarifies the social security value of cultivated land to farmers, and then combines the ecological base flow protection and the reduction in agricultural irrigation water to quantitatively assess the indirect losses caused by ecological base flow protection (that is, social security losses), that can provide a theory and basis for the establishment of a scientific, reasonable and fair ecological compensation system.

2. Overview of the research area
The Guanzhong section of the main stream of the Weihe River is located in the middle and lower reaches of the Weihe River Basin, in the arid and semi-arid area of Northwest China, including 6 administrative regions of Baoji, Xianyang, Xi'an, Weinan, Tongchuan, and Yangling[14]. Water resources are scarce in this area, the natural runoff of the rivers alternates between high and low levels, and the distribution of water resources is not balanced with the needs of social development, which constantly restricts social development. Especially in the dry season, the natural inflow of water from the river is limited, and the water consumption of various water departments along the coast is relatively large, resulting in a more prominent contradiction between the supply and demand of ecological water and production water in the river. Especially after the completion of the Baoji Gorge Irrigation District, the irrigation area draws a large amount of water from the Baoji section of the main Weihe River, that it squeezes out the ecological water of the river, causing ecological environmental problems such as the inability to guarantee the ecological base flow of the river in the Baoji section of the Weihe River.
3. Research methods and data sources

3.1. Calculation method for reduction of water diversion outside the channel under base flow guarantee

There are two main factors that make the ecological base flow cannot be guaranteed: natural factors and man-made factors. Natural factors are caused by insufficient river natural water, which is difficult to change. Human factors are mainly caused by human activities such as excessive water diversion from the river. Therefore, if the ecological base flow is to reach the target value in the short term, it can be solved by reducing the water use of other production departments and reducing water diversion outside the river.

Linjiacun (He) station reflects the natural inflow of the Baoji section of the Weihe River, and Linjiacun (3) station monitors the river flow after the diversion of the Baoji Gorge Canal. When the flow of Linjia Village (3) Station is greater than the target regulation value, there is no need to reduce the water supply of the production department. When that is less than the target regulation value, in order to ensure that the ecological base flow reaches the target value, it is necessary to reduce the water supply of the production department. In addition, it is also necessary to consider whether the natural inflow of river can meet the target regulation value requirements. When the natural flow of the river is greater than or equal to the target control value, the reduced water supply of the production department under the protection of the ecological base flow can be obtained directly by the ecological base flow control value minus the measured flow of Linjiacun (3) Station. When that is less than the target control value, even if the water diversion amount of Baoji Gorge is zero, the target adjustment value requirement cannot be achieved. At this time, the reduced water supply of the production department can be based on the natural water inflow of the river minus the actual flow of Linjiacun (3) Station, the calculation formula can be expressed as:

$$Q_1 = \begin{cases} Q_2 - Q_3 & Q_4 > Q_2 \\ Q_4 - Q_3 & Q_4 \leq Q_2 \end{cases}$$

$$W_1 = 8.64 \times Q_1$$

Where $Q_1$ is the amount of daily diversion out of the river that need to be reduced, $m^3/s$; $Q_2$ is the natural discharge of Linjiacun section, $m^3/s$; $Q_3$ is the measured discharge of Linjiacun (3) station, $m^3/s$; $Q_4$ is ecological base flow regulation value, $m^3/s$; $W_1$ is the amount of daily diversion out of the river that need to be reduced, $10^3 m^3$.

3.2. Calculation method of indirect loss caused by base flow support

Social security includes employment, medical treatment, endowment and lowest living guarantee. From the comparison of nearly ten years of Shaanxi guanzhong region agriculture per capita net income of farmers and rural per capita annual net income, agricultural income accounts for less than 30% of the total average annual net income of farmers, the rest of the net income from non-agricultural income is more than 70%, so the cultivated land change has less effect on their lowest life security, and the loss of job security can indirectly reflect the farmers' minimum living allowance, so this paper chooses employment, medical care and old-age security loss as the main indirect loss index, and convert the reduced the farmers income security coefficient to calculate.

Due to the rural social security system isn’t perfect, this paper used the substitution method to obtain the social security value of farmer arable land. Which makes the urban social security value as reference, the rural residents social security value of cultivated land is obtained by correcting coefficient according to the ratio of urban and rural residents income, then combining the ecological base flow changes before and after the agricultural irrigation diverted to calculate the farmers' social security loss after the ecological base flow guarantee.
3.2.1. Loss of employment security. The rural residents who make a living on agriculture in China generally suffer from serious aging phenomenon, with low education level and less professional skills guidance and training. The decrease of agricultural water consumption leads to the decrease in the quantity and quality of farmland for rural residents and the decrease in the number of labor force needed, which increases the employment pressure of farmers with low educational level and less professional training, even leads to their unemployment and loss of basic economic sources. Therefore, the value of employment security can be calculated by the minimum living security fund and the guarantee coefficient of agricultural annual income of rural residents. On this basis, the loss of employment security can be calculated by the reduced amount of agricultural irrigation water after the ecological base flow guarantee. The calculation formula is as follows:

\[ v_1 = \frac{k}{s} \times c \quad (3) \]

\[ c = \frac{c_1}{c_2} \quad (4) \]

\[ V_1 = v_1 \times S \quad (5) \]

\[ V'_1 = V_1 \times \frac{W_1}{W_2} \quad (6) \]

Where \( v_1 \) is employment security value per unit area, yuan/hm\(^2\); \( k \) is the minimum subsistence allowance for rural residents, yuan/person; \( s \) is farmer's arable land per capita, hm\(^2\)/person; \( c \) is security coefficient; \( c_1 \) is farmers' per capita annual net agricultural income, yuan; \( c_2 \) is farmers' per capita annual net income, yuan; \( V_1 \) is value of employment security, yuan; \( S \) is cropland area, hm\(^2\); \( V'_1 \) is loss of employment security caused by ecological base flow guarantee, yuan; \( W_1 \) is reducing amount of water diversion from river channel after ensuring ecological base flow, \( 10^3 \)m\(^3\); \( W_2 \) is The amount of agricultural irrigation water without considering the ecological base flow guarantee, \( 10^3 \)m\(^3\).

3.2.2. Pension insurance loss. At present, China’s old-age security system is mainly for urban residents. Therefore, the pension insurance fund of urban residents is as a reference, and the income ratio of urban and rural residents is introduced for correction, so as to identify the value of rural residents’ old-age security and calculate the old-age insurance loss after the ecology base flow guarantee based on this. The calculation formula is:

\[ v_2 = \frac{E_1}{s} \times c \quad (7) \]

\[ E_1 = \frac{I_1}{I_2} \times E_2 \quad (8) \]

\[ V_2 = v_2 \times S \quad (9) \]

\[ V'_2 = V_2 \times \frac{W_1}{W_2} \quad (10) \]

Where \( v_2 \) is pension insurance value per unit area, yuan/hm\(^2\); \( E_1 \) is pension for rural residents, yuan; \( E_2 \) is pension provided by the government for urban residents, yuan; \( I_1 \) is per capita net income of farmers, yuan; \( I_2 \) is per capita disposable income of urban residents, yuan; \( V_2 \) is old-age security value, yuan; \( V'_2 \) is old-age security value, yuan; \( V'_2 \) is old-age security loss caused by ecological base flow security, yuan.

3.2.3. Medicare loss. The rural residents' medical security system has been not yet complete, and the number of agricultural laborers has decreased, which has increased the burden of rural residents' medical security. The medical security value of cultivated land can be calculated from the per capita medical expenditure of rural residents. After the medical value of cultivated land is clarified, the medical security loss is calculated based on the reduced water volume of agricultural irrigation. The calculation formula is:
v₃ = \frac{E₃}{s} \times c \quad (11)

V₃ = v₃ \times S \quad (12)

V₃′ = V₃ \times \frac{W₁}{W₂} \quad (13)

Where \( v₃ \) is medical insurance value per unit area, yuan/hm²; \( E₃ \) is annual medical expenditure per capita of rural residents, yuan; \( V₃ \) is medical value, yuan; \( S \) is cropland area, hm²; \( V₃′ \) is loss of medical security caused by ecological base flow security, yuan.

4. Results and discussion

4.1. Calculation of reduction of water diversion outside the channel under base flow guarantee

In order to better study the reduction of water diversion outside the river channel caused by the ecological base flow under different inflow frequencies, typical years are selected for analysis based on the natural inflow of the river channel. Because the Weihe River is a seasonal river, and the lack of ecological base flow in non-flood seasons is serious, this paper selects typical hydrological years based on the average runoff data of Linjiacun (He) Station from 1960 to 2016 in non-flood seasons, and regarded 1981, 2004, and 2011 as normal years (50%), dry years (75%), and extremely dry years (90%) respectively.

The Weihe River Basin Administration of Shaanxi Province has set 5 m³/s as the current ecological base flow guarantee value at the Linjia Village section of the Weihe River. Based on this, this paper uses 5 m³/s as the low-limit regulation value of the ecological base flow at the Linjiacun section of the Baoji section of the Weihe River. The ‘Weihe River Basin Key Management Plan’ sets 10 m³/s as the ecological base flow control value of the Linjia Village section in the middle section of the Weihe River, so 10 m³/s is used as the upper limit control value of the ecological base flow of the Linjia Village section of the Weihe River. This paper will sequentially calculate the reduction of water diversion outside the river channel and the indirect loss when the ecological base flow regulation value is between 5 and 10 m³/s.

According to the daily flow data of Linjiacun (3) station and the daily flow of Linjiacun (He) station in normal years (50%, 1981), dry years (75%, 2004), and extremely dry years (90%, 2011), the amount of water diversion outside the river channel that need to be reduced are calculated with formulas (1) and (2). The calculation results are shown in Tables 1.

| Typical year | 5 m³/s | 6 m³/s | 7 m³/s | 8 m³/s | 9 m³/s | 10 m³/s |
|--------------|--------|--------|--------|--------|--------|---------|
| 1981         | 0.90   | 1.09   | 1.29   | 1.49   | 1.69   | 1.88    |
| 2004         | 0.92   | 1.18   | 1.42   | 1.66   | 1.90   | 2.13    |
| 2011         | 0.66   | 0.82   | 0.97   | 1.14   | 1.31   | 1.46    |

It can be seen from Tables 1 that as the set ecological base flow target regulation value increases under the same typical year, the amount of water diversion that needs to be reduced increases. When the target regulation value is same, the amount of water diversion that can be reduced in an exceptional dry year is the smallest, a normal year followed, and the amount of water diversion that can be reduced in a dry year is the largest. The main reason is that in the extremely dry year, the natural water inflow is insufficient and the water diversion amount of Baoji Gorge canal is small, so the amount of water diversion that can be reduced is small. While in normal and dry years, the natural water inflow is sufficient and the water diversion amount of Baoji Gorge Canal is larger. Therefore, when considering
the protection of ecological base flow, the amount of water diversion that can be reduced by Baoji Gorge Canal is greater.

4.2. Calculation of indirect loss caused by base flow guarantee

The large amount of water diversion in the Baoji Gorge canal directly leads to the ecological base flow of the Baoji section is difficult to guarantee. To ensure the ecological base flow of this section, it is necessary to reduce the amount of water diversion of the Baoji Gorge Canal, while it will directly cause the coastal water sector to suffer economic losses. The diversion of the Baoji Gorge Canal mainly provides water for power generation of the Weijiabao Hydropower Station and agricultural irrigation in the upper irrigation area of the Baoji Gorge. Due to the limitation of the water diversion data of the hydropower station, this article does not consider the economic loss of the hydropower station caused by the reducing diversion of the channel, but only considers the indirect losses to farmers when the amount of agricultural irrigation diversion decreases.

Refer to the ‘Statistical Yearbook of Shaanxi Province’ in the past 10 years, the per capita annual net income of farmers and the per capita annual agricultural net income of farmers, the agricultural income guarantee coefficient of rural residents from 2006 to 2016 are calculated according to formula (4). The calculation results are shown in Table 2.

| Yeas   | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 |
|--------|------|------|------|------|------|------|
| Coefficient | 0.37 | 0.35 | 0.31 | 0.31 | 0.32 | 0.26 |

According to the above table, this paper uses the average value of the calculation results in the past 10 years when calculating social security. In order to better study the impact of changes in the amount of natural water on the value of social security, this paper selects normal years (50%, 1981), dry years (75%, 2004), and extremely dry years (90%, 2011) for analysis. The social security loss in typical years after the change in the amount of agricultural irrigation water diversion is calculated according to formulas (3) ~ (13), and the results are shown in Table 3.

Table 3. Annual social security loss in typical years

| Typical year | 5 m³/s | 6 m³/s | 7 m³/s | 8 m³/s | 9 m³/s | 10 m³/s |
|--------------|--------|--------|--------|--------|--------|---------|
| 1981         | 1.22   | 1.48   | 1.75   | 2.02   | 2.29   | 2.55    |
| 2004         | 1.50   | 1.91   | 2.30   | 2.69   | 3.09   | 3.46    |
| 2011         | 1.90   | 2.35   | 2.81   | 3.28   | 3.77   | 4.20    |

In order to more clearly see the characteristics of the loss changes in typical years, this paper draws a diagram of the total social security loss change process under different security values in each typical year, as shown in Figure 1.
Figure 1. The Process of Change in Total Social Security Loss With Different Guaranteed Values in Typical Years

It can be seen from Figure 1 that the natural inflow in each typical year is different. The natural inflow in normal water years is the largest, and the water in the river is relatively full. So that the ecological base flow guarantee value of the river is easier to meet, and the amount of agricultural water that needs to be reduced is small. Therefore, the total social security loss is the smallest in a normal year, a dry year followed. The natural water inflow of the river is the smallest in the extremely dry year, and the river is dry and dry. The ecological base flow control value of the river is relatively difficult to meet. Therefore, the amount of agricultural water that needs to be reduced is large, and the social security loss is also increased. The total social security loss in this year is the largest.

4.3. Analysis of the rationality of the loss

In terms of indirect loss calculation, the typical annual indirect loss calculated in this article is between 1.22 and 420 million yuan, and the average inter-annual indirect loss is between 135 million and 328 million yuan. According to the calculations by Gao Zhiyue [15], the loss of agricultural water supply and social security for the ecological base flow guarantee of the Linjia Village section is between 2.19-503 million yuan, and the multi-year average agricultural society guaranteed loss calculated by Zhang Qian [16] is between 0.59-101 million yuan. The calculation result of this paper is between the above results, so it is reasonable.

5. Conclusion

(1) Based on the ecological base flow guarantee target value, this paper proposes a calculation method for water reduction in other production sectors, and calculates the water reduction in other production sectors caused by the protection of the river ecological base flow in typical years.

(2) The upper and lower limits of indirect agricultural losses in the typical year are 420 million yuan and 122 million yuan respectively. The quantitative assessment of agricultural social security losses caused by ecological base flow guarantee can provide a theory and basis for the establishment of a scientific, reasonable and fair ecological compensation system.

(3) In the actual guarantee process, as the Baoji Gorge Irrigation District undertakes the task of food supply in the Guanzhong area even Shaanxi Province, it is necessary to consider factors such as food security when implementing the base flow guarantee policy, the control value can be adjusted appropriately or reduced under the premise of ensuring food security.
This article is preliminary to the study of social security losses caused by ecological base flow security, and it needs to be further deepened and improved in the future.

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