Research on Fengjiashan Reservoir Ecological Compensation Mechanism Based on Ecosystem Service Function

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Abstract. The impact of hydropower projects on the ecosystem is dynamic and complex. Constructing a complete ecological compensation mechanism can ensure the effective progress of ecological compensation. The ecosystem service value of the Fengjiashan Reservoir such as water supply, fish farming, hydropower, water regulation, water resources accumulation, biodiversity, and environmental purification, is calculated with market value method, alternative engineering method and other evaluation methods, and the ecological compensation mechanism of the reservoir is studied. The results show that the value of its ecosystem services is 230,912,700 yuan, and the amount of ecological compensation determined on the basis of ecosystem service functions is 101,866,200 yuan. The main sources of compensation funds are taxes, water surcharges and government financial subsidies.

1. Introduction
Reservoirs belong to the wetland ecosystem [1], with functions such as water resources accumulation, environmental purification, water regulation, and maintenance of biodiversity. China has the largest number of reservoirs in the world. In recent years, ecological and environmental problems have become increasingly severe [2,3], especially, the problems of reservoirs have attracted great attention [4,5].

Ecological compensation, a new method of resource and environmental management, which has become a hot research field [6-9], can be used as a way to alleviate the contradiction of environmental pollution, ecological damage and economic development. Xiao [10] and others applied the ecological footprint idea to the compensation of large-scale hydropower project construction, and built an ecological compensation standard evaluation model taking the Three Gorges Project as an example. Cao [11] and others applied the fuzzy analytic hierarchy process to the study of reservoir ecological compensation, and the comprehensive importance of reservoir ecological compensation measures is reasonably allocated. Huang [12] and others introduced the economic correction coefficient $\theta$ to calculate the ecological compensation value of a hydropower project. However, the impact of hydropower projects on the ecosystem is profound and complex [13]. At present, the compensation system is not perfect in China, and the ecological compensation mechanism still needs to be explored continuously.

The Fengjiashan Reservoir is studied to ensure the normal performance of its ecological service functions and alleviate the contradiction between the ecological environment and economic development in this article [14-15]. Based on the ecosystem service value, market value method and
alternative engineering method are used to calculate the ecosystem service value. The ecological compensation mechanism study of the Fengjiashan Reservoir can provide more references for the ecological compensation of reservoirs.

2. Overview and methods of the study area

2.1. Overview of the study area
Fengjiashan Reservoir is located at the junction of Chencang, Fengxiang, and Qianyang counties (districts) in the lower reaches of the Qianhe River. It is a large (II) comprehensive use of agricultural irrigation and urban and industrial water supply as well as flood control, power generation, breeding, and tourism type water conservancy project [16]. The reservoir irrigation area is located in the Weibei loess plateau, which is divided into two parts, east and west, with the Qianhe River as the boundary. It’s from the east bank of the Jinling River in the west, to the west bank of the Qishui River in the east, to the left bank of the main canal of the Baoji Gorge on the edge of the Weibei plateau in the south, and to the foot of Qiaoshan in the north, it is about 80 kilometers from east to west, with a span of 18 kilometers from north to south [17]. Since the reservoir operated, it has played important economic and social benefits. Therefore, in order to maintain and restore the functional value of the ecosystem, the reservoir ecological compensation mechanism is analyzed in this paper [18].

2.2. Research methods
According to the characteristics of Fengjiashan Reservoir’s ecosystem, we have consulted the previous literature, collected various data on the reservoir’s industrial, agricultural and domestic water supply, hydroelectric power generation, fish farming, etc., and then used market value methods, alternative engineering law and other resource environmental economics methods. The value of the ecosystem service function of the reservoir was estimated, and the ecological compensation standard of Fengjiashan Reservoir was determined based on these estimated results, which provided the basis for the ecological compensation policy.

Table 1. The evaluation index system and methods for Fengjiashan Reservoir

| Function type                        | Calculation method          | Method introduction                                                                 |
|--------------------------------------|-----------------------------|--------------------------------------------------------------------------------------|
| Industrial, agricultural and domestic water | Market value method         | Using the market price of the product to measure the change in output value and profit, and to estimate economic losses or benefits |
| Fish farming                         | Market value method         |                                                                                     |
| Hydropower                           | Market value method         |                                                                                     |
| Hydropower                           | Market value method         |                                                                                     |
| Moisture regulation                  | Alternative engineering law| A special form of cost restoration, which uses the cost of constructing the project to estimate the economic loss caused by environmental pollution or damage |
| Water accumulation                   | Alternative engineering law|                                                                                     |
| Biodiversity                         | Alternative engineering law|                                                                                     |
| Environmental purification           | Alternative engineering law|                                                                                     |
3. Evaluation of Fengjiashan Reservoir Ecosystem Service Function

3.1. Direct use value

3.1.1. Industrial, agricultural and domestic water. Fengjiashan Reservoir is rich in water resources, it shoulders the important task of supplying water for urban industrial and agricultural production and living. The value of its water supply function can be calculated according to the following formula:

\[ V_1 = \sum A_i \times P_i \]  

(1)

Where \( V_1 \) is the functional value of water supply; \( A_i \) is the supply of the i-th water, and \( P_i \) is the market price of the i-th water. According to the data, the Fengjiashan Reservoir provides an annual average of 101.45 million m\(^3\) of agricultural irrigation water, an average of 15.62 million m\(^3\) of urban domestic water, and an average of 11.64 million m\(^3\) of industrial water [19]. Affected and restricted by the factors such as water scarcity, project water supply costs, farmers’ affordability, etc., the agricultural irrigation water of Fengjiashan Reservoir irrigation area is 0.2 yuan/m\(^3\) [20]. Industrial and domestic water use is calculated based on the current basic water price in Baoji City, 2.18 yuan/m\(^3\) and 1.78 yuan/m\(^3\) respectively. According to the above formula, the total annual water supply value is 73.468 million yuan.

3.1.2. Fish farming. Fengjiashan Reservoir has a good climate, great water quality and abundant aquatic resources. Since the reservoir operated, many residents have made aquaculture as their main income, and the value of their fish farming can be calculated according to the following formula:

\[ V_2 = u \times P \]  

(2)

Where \( V_2 \) is the value of aquatic products; \( u \) is the average annual aquaculture production; \( P \) is the average price of freshwater fish. According to the 2016 Shaanxi Provincial Statistical Yearbook, the average price of freshwater fish in Shaanxi Province is 14.84 yuan/kg. With the amount of aquaculture in Fengjiashan Reservoir of about 250t[21], the value of fish farming can be calculated to be 3.71 million yuan.

3.1.3. Hydropower. In addition to the functions of irrigation, provision of water for production and living, and breeding, Fengjiashan Reservoir also has the function of hydropower. The total value of hydropower can be calculated according to the following formula:

\[ V_3 = W \times P \]  

(3)

Where \( V_3 \) is the value of hydropower, \( W \) is the annual power generation; \( P \) is the price of hydropower. The total installed capacity of Fengjiashan Reservoir is 4500kw, and the annual power generation is 24 million kw•h. The shadow price of hydropower is 0.4 yuan/kW•h [22]. With the above formula, the total value of hydropower is 9.6 million yuan.

3.2. Indirect use value

3.2.1. Moisture regulation function. The reservoir ecosystem also has the function of water regulation, that is, the function of regulating and storing floods. The value of its water resource regulation function is estimated by the alternative engineering method (also called the shadow engineering method), and the calculation formula is:

\[ V_4 = W_r \times P \]  

(4)
Where $V_4$ is the value of the water resources regulation function of the reservoir, $W_r$ is the flood control storage capacity of the reservoir, and $P$ is the annual cost of the reservoir unit storage capacity. The flood control storage capacity of Fengjiashan Reservoir is 92 million m$^3$, and the annual cost per unit storage capacity of Chian’s reservoirs is 0.67 yuan/m$^3$ [23]. With the above formula, the water regulation function value of the reservoir ecosystem is 61.64 million yuan.

### 3.2.2. Water accumulation.

The reservoir has the function of water storage. The water storage function of Fengjiashan Reservoir is calculated according to the alternative engineering method. The formula is as follows:

$$V_5 = K \times P$$

In the formula, $V_5$ is the storage value of the water resources of the reservoir, $K$ is the flood control storage capacity of the reservoir, and $P$ is the annual cost of the reservoir unit storage capacity. The annual cost per unit storage of reservoirs in Chian is 0.67 yuan/m$^3$ [24]. The water storage capacity of Fengjiashan Reservoir is calculated according to 91 million m$^3$, and the above formula is substituted to calculate the functional value of water resources storage of Fengjiashan Reservoir as 60.97 million yuan.

### 3.2.3. Biodiversity.

The abundant water resources of Fengjiashan Reservoir play a very important role in maintaining biodiversity, and its biodiversity value can be calculated according to the following formula:

$$V_6 = A \times P$$

In the formula, $V_6$ is the biodiversity value, $A$ is the water surface area of the reservoir, and $P$ is the average annual value of biodiversity protection. Xie Gaodi and others have calculated that the average annual value of rivers for biodiversity protection was 1,540.41 yuan/hm$^2$ [25], and the water area of the reservoir was 17.7km$^2$. With the above formula, the water biodiversity value of Fengjiashan Reservoir was calculated to be 2.7265 million yuan.

### 3.2.4. Environmental purification function.

The water body has a certain self-purification function, which can continuously purify the water body through a series of dilution, purification, precipitation, redox, and finally restore the original water quality. The value of water purification function can be calculated according to the following formula:

$$V_7 = V_N + V_P = (P_N \times R_N + P_P \times R_P) \times A$$

In the formula, $V_7$ is the total value of the water purification function, $V_N$ is the value of the nitrogen removal function of the reservoir, $V_P$ is the value of the phosphorus removal function of the reservoir, $A$ is the water area of the reservoir, $R_N$ is the average removal rate of nitrogen per unit area of water, $R_P$ is the unit area the average removal rate of phosphorus in the water area, $P_N$ is the cost of wastewater nitrogen removal treatment, and $P_P$ is the cost of wastewater phosphorus removal treatment [26]. According to the research results of Jin Xiangcan and others, the average removal rate of nitrogen per unit area of water is 398 t·km$^{-2}$·a$^{-1}$, and the average removal rate of phosphorus per unit area of water is 186 t·km$^{-2}$·a$^{-1}$, Fengjiashan Reservoir the water area of the district is 17.7km$^2$, and the cost of sewage nitrogen and phosphorus removal used domestic sewage treatment cost, which is 1500 yuan/t for nitrogen and 2500 yuan/t for phosphorus [27]. According to the above formula, it can be calculated that the functional values of nitrogen and phosphorus removal of the Fengjiashan Reservoir ecosystem are 10.5669 million yuan and 8.2305 million yuan respectively, and the total value is 18.7974 million yuan.
3.3. The total value of the service function of the reservoir ecosystem

Using market value method, shadow price method, alternative engineering method and other resource environmental economics methods to calculate the value of the ecosystem service function of Fengjiashan Reservoir, the total value is 230,912,700 yuan.

| Function type                        | Value amount (ten thousand yuan) | Proportion (%) |
|--------------------------------------|----------------------------------|----------------|
| Industrial, agricultural and domestic water | 7346.88                          | 31.82          |
| Fish farming                         | 371.00                           | 1.61           |
| Hydropower                           | 960.00                           | 4.16           |
| Moisture regulation                  | 6164.00                          | 26.69          |
| Water accumulation                   | 6097.00                          | 26.40          |
| Biodiversity                         | 272.65                           | 1.18           |
| Environmental purification           | 1879.74                          | 8.14           |
| Overall function                     | 23091.27                         | 100.00         |

Table 2. The composing of ecosystem service value for the fengjiashan reservoir

4. Fengjiashan Reservoir Ecological Compensation Mechanism

4.1. Compensation subject and object

Ecological compensation is generally compensated by the destroyer of the ecological environment to the victim, or the beneficiary party compensates the party who has suffered a certain loss due to the ecological environment protection [28]. According to the composition and calculation of the ecosystem service value of Fengjiashan Reservoir, as well as the proportion of each function value, the current ecological compensation subject with relatively significant benefits and the clear object of ecological compensation are considered, except the benefits of fishery breeding, water regulation, water resources accumulation, and biodiversity functions. The main bodies of ecological compensation include hydropower development owners, polluting enterprises, mid- and downstream water users, the central government and local governments. Eco-compensation objects include river ecosystems affected by water pollution in the reservoir area and its upstream, and individuals and units that contribute to the river ecosystem in the upstream.

4.2. Compensation Standard

As the beneficiaries of fishery, water regulation, water accumulation, and biodiversity are not considered for the time being, the value of this part of the function should be deducted correspondingly to 129,046,500 yuan, which accounted for 55.88%. The ecological compensation standard is 101,866,200 yuan/a. The amount of ecological compensation is determined according to the economic value of the beneficiaries. Hydropower development owners (beneficiaries of hydropower products), the central government and local governments jointly bear the compensation amount of 9.6 million yuan. Middle and downstream water users (environmental purification, water supply beneficiaries), polluting enterprises (river ecosystem destroyers), the central government and local governments jointly bear the compensation amount of 92,266,200 yuan.

4.3. Sources of compensation funds

(1) Water fee surcharge. As the beneficiaries of the ecosystem functions of the reservoir, water users in the middle and lower reaches of the water-receiving area can levy water surcharges and use the levied water surcharges as part of the source of funds for maintaining the sustainable development of the reservoir ecosystem.

(2) Taxation. Ecological compensation funds can be collected from the beneficiary units (hydropower development owners, etc.). For some polluting enterprises, while creating benefits for themselves, their awareness of emission reduction and pollution control is weak, causing more or less
damage to the water ecological environment. According to the principle of “who benefits, who compensates”, the polluting enterprises can be expropriated certain ecological compensation fees.

3) Government financial subsidies. Government financial transfer payment is the main source of ecological compensation funds, and the government should increase capital investment.

5. Conclusions and prospects

5.1. Conclusions
The ecological compensation mechanism of the Fengjiashan reservoir ecosystem is studied based on the service function of the reservoir ecosystem. The following conclusions are obtained through the calculation in the article:

1) The reservoir ecosystem has many functions. The seven functions were selected to make an approximate calculation in this paper which account for the large proportions of the functions of the Fengjiashan Reservoir ecosystem. The results show that the ecosystem service value of the Fengjiashan Reservoir is 230,912,700 yuan, and the ecological compensation standard is 101,866,200 yuan/a. This result is equivalent to the compensation standard calculated by determining the compensation coefficient through the local social development comprehensive index, indicating that the compensation standard is relatively reasonable.

2) In order to facilitate the policy implementation, cash compensation is only considered among the many methods of ecological compensation in this paper, and three kinds of sources of the compensation funds are obtained. Compared with relying only on government financial transfer payment as the main source of funds, the government fiscal pressure can be relieved and the source of funds can be expanded through the methods in this article.

3) The protection and compensation of the reservoir ecosystem is a long-term process. Compensating the reservoir ecosystem by expropriating compensation funds is a way to maintain the sustainable development of the ecosystem. At the same time, it is necessary to improve the environmental protection awareness of groups and individuals. And a more complete ecosystem protection mechanism should be established by the related management, which is more conducive to the coordinated development of society, economy and environment.

5.2. Prospects
The ecosystem is dynamic and complex, and its functional value is also dynamically changing. It is difficult to fully evaluate the ecological compensation standards of the Fengjiashan Reservoir due to the imperfect function selection and evaluation methods, and the limitations of data acquisition, and some ecosystem service functions are not considered in this paper. Therefore, the study on the compensation mechanism of the Fengjiashan Reservoir is only a preliminary work. Researches on the selection of reservoir ecosystem functions, value evaluation methods and reservoir ecological compensation still need to be continuously explored and improved.

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