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Calculation of ecological compensation for water sources for water diversion projects

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Abstract. This study considers the compensation of water diversion projects for the values of the terrestrial biological resources, water environment, and aquatic biological resources in water sources. An analysis of capital dynamics was conducted, and the economic development coefficient was used to correct the current method for calculating ecological compensation. A model was constructed to calculate the ecological compensation for the water sources for water diversion projects. This model was used to calculate the ecological compensation for the Niulanjiang River provided by the Niulanjiang River to the Dianchi Lake water diversion project, which was calculated to be 136,799,400 RMB. As long as we know the occupying area of the project, the change of the river net flow after diversion and the local average GDP, the ecological compensation for water sources could be calculated by the model. The proposed model for calculating the ecological compensation for water sources is simple and incorporates the compensation provided by water diversion projects for the various environmental effects on water sources. It provides a guarantee for the capital to be used for the environmental protection of water sources and facilitates the sustainable development of the ecological environments of water sources.

1. Introduction

Water diversion projects use water resources to satisfy needs [1]. These projects often destroy ecological integrity because their implementation occupies a great deal of farmland, destroys forest vegetation, and affects the animal habitats around the water sources. In particular, the decrease in the amount of available water resulting from water diversion has affected the water volume, quality of rivers, and aquatic organisms in rivers, which has given rise to eco-environmental problems [2]. The smooth implementation of water diversion projects requires ecological compensation for the ecological losses experienced by the water sources. This compensation not only resolves the conflict between engineering construction and environmental protection, but also eases the shortage of capital required for environmental protection. The majority of cost-benefit analyses of environmental protection measures of water conservancy projects fail to consider the loss and gain of the functional value of the life support system provided to human beings from the ecosystem. This lack of consideration leads to incomplete calculations of the investment costs of projects. Domestic scholars have conducted an exploratory study on ecological compensation for basins and reservoirs [3] [4], and some methods have been proposed for proper calculation [5]. However, the ecological compensation for water sources in water diversion projects involves the quality of rivers and the aquatic organisms in rivers, and this is also calculated using a different method. This paper establishes a model for the calculation of the ecological compensation for water resources for water diversion projects that then also calculates ecological compensation for the water resources of the Niulanjiang River, provided by the Niulanjiang River to Dianchi Lake water diversion project. This calculation avoids the one-sidedness of the conventional ecological compensation calculation of water diversion projects and ensures proper implementation of water diversion projects.

2. Model for calculation of ecological compensation for water sources for water diversion projects

The expenses spent on protective measures reduce the adverse effects of a project on the environment are used to reflect the loss incurred by the project due to its environmental effects, the calculated value of which is the ecological compensation for the environment. The water sources for water diversion projects are primarily affected by the land occupation of the projects, which leads to decreased terrestrial biological resources, decreased water in rivers due to diversion, and poorer water quality. Dams are often built as well to block the activity of aquatic organisms. Thus, the ecological compensation for a water resource consists of the compensation for the values of its terrestrial biological resources, water environment, and aquatic biological resources.

2.1. Calculation of compensation for the value of terrestrial biological resources

The corrected method for calculating ecological value was used. Xie gaodi listed the value of the ecological services provided per unit area of China's terrestrial ecosystems [6], as shown in Table 1.

Table 1. Value of the ecological services provided per unit area of China's terrestrial ecosystems.

Unit: RMB/ hm^2.a.

Ecosystem services and functions	Forest	Grassland	Farmland	Wetland	Water	Desert
Gas regulation	3097.0	707.9	442.4	1592.7	0	0
Climate regulation	2389.1	796.4	787.5	15130.9	407.0	0
Water conservation	2831.5	707.9	5 30.9	13715.2	18033.2	26.5
Soil formation and protection	3450.9	1725.9	1291.9	1513.1	8.8	17.7
Waste disposal	1159.2	1159.2	1451.2	16086.6	16086.6	8.8
Biodiversity protection	2884.6	964.5	628.2	2212.2	2203.3	300.8
Food production	88.5	265.5	884.9	265.5	88.5	8.8
Raw material	2300.6	44.2	88.5	61.9	8.8	0
Entertainment	1132.6	35.4	8.8	4910.9	3840.2	8.8
Total	16237.0	5698.6	5672.6	53896.3	40676.4	371.4

Table 1 shows the unit price of the average value of the ecological services provided by China's ecosystems. The unit prices of the service values of the ecosystems in different regions depend on local and national economic development. Moreover, the value natural resources constantly changes. With the development of the social economy, the increase in average income, and the decrease in natural resources over time, the value of nature will increase, resulting in a general increase in willingness to pay for these resources. Therefore, an area more economically developed requires higher ecological compensation. The unit price of the service value of an ecosystem in an area must be multiplied by the local economic development factor. The economic development factor can be expressed by the ratio of the local gross domestic product (GDP) to the national average GDP. Additionally, the land occupied by a project has a time value. Land not only has current biological value, but it will also constantly produce ecological value in the future. Therefore, the compensation for the ecological value of the occupied land must be calculated through an analysis of the capital dynamics by converting the ecological value that the land cannot gain after being occupied into the current ecological value at a discount rate. The corrected unit price of the service value of an ecosystem and the ecological compensation for terrestrial resources are defined as [7]:

$$w_i = a_i[\frac{1}{1+r} + \frac{1}{(1+r)^2} + \cdots + \frac{1}{(1+r)^n}] = \frac{a_i}{r}[1 - \frac{1}{(1+r)^n}] \tag{1}$$

$$D_i = e\ w_i = e\frac{a_i}{r}[1 - \frac{1}{(1+r)^n}]$$

A project occupies land permanently, meaning $n \to \infty$. The above equation can thus be corrected to:

$$D_i = \lim_{n\to\infty} e\frac{a_i}{r}[1 - \frac{1}{(1+r)^n}] = e.\frac{a_i}{r} = \frac{g}{G}\cdot\frac{a_i}{r} \tag{2}$$

$$F_l = \sum_{i=1}^{6} D_i A_i \tag{3}$$

where wi represents the present value of the ecological services provided by unit area of an ecosystem (RMB); a_i represents the unit price of the service value (RMB/hm2.a) of the different ecosystems listed in Table 1; Di represents the corrected unit price (RMB/hm2.a) of the service value of the ecosystems; e represents the economic development factor; g represents the local GDP per capita (RMB/person); G represents the national GDP per capita (RMB/person); r represents the discount rate; n represents the number of years of land use (a); Ai represents the area of land (hm2); Fl represents the ecological compensation for terrestrial resources (RMB); and i represents the six ecosystem types shown in Table 1.

2.2. Calculation of compensation for the value of water environment

Utilization of more than 20% of runoff after water diversion is generally believed to result in significant effects on the environment. Water diversion can lead to a decrease in both the percentage of a river's flow in a non-flood season and the river's self-purification capacity, which results in an increase in the expenses required for further processing of the wastewater along the river's bank. Rivers exhibit low self-purification capacities primarily in non-flood seasons. The dilution ratio is the ratio of the amount of wastewater discharged to the amount of water contained in the water body that contains the wastewater. The compensation for the water environment of a river consists of the pollution abatement expenses required for a river from which water is diverted in a non-flood season to achieve a dilution ratio that is the same as the dilution ratio prior to water being diverted. This calculation is performed according to the following steps [8]: (1) calculate the dilution ratio of a river in a non-flood period before and after water diversion; (2) determine the amount of wastewater that must be reduced for the dilution ratio of the river after water diversion to be equal to the dilution ratio of the river before water diversion; (3) use the shadow engineering method to construct a wastewater treatment plant for treating the amount of wastewater that must be reduced. The incurred expenses are therefore the compensation for the water environment of the river. The calculation of compensation for the water environment of the river is defined as:

Then, $Q_{yw} = \frac{Q_w}{Q_j}\cdot Q_{yj}$ can be obtained from $b = \frac{Q_w}{Q_j} = \frac{Q_{yw}}{Q_{yj}}$.

$$\Delta Q_w = Q_w - Q_{yw} = \frac{Q_w}{Q_j}\cdot\Delta Q_j \tag{4}$$

$$F_S = C \times \Delta Q_w \times N \tag{5}$$

where *b* represents the dilution ratio; Q_w represents the amount of wastewater discharged from the river before water diversion (m^3/a); Q_j represents the river runoff before water diversion (m^3/a); Q_{yj} represents the river runoff after water diversion (m^3/a); Q_{yw} represents the amount of wastewater discharged from the river after water diversion (m^3/a); ΔQ_w represents the amount of water required to be processed (m^3/a); ΔQ_j represents the decrease in the river runoff (m^3/a); F_S represents the compensation for the water environment of the river (RMB); *C* represents the wastewater treatment plant's cost for processing the wastewater (RMB/m^3); and *N* represents the life of the wastewater treatment plant (a).

2.3. Calculation of compensation for the value of aquatic biological resources

The decrease in the amount of water caused by a water diversion can result in a decrease in the quantity of fish. Building a dam on a river for a reservoir can also result in the division of the habitat for fish, which prevents fish species from genetic exchange and leads to decreased genetic diversity and increased probability of species extinction. The raised water level resulting from dam construction can lead to the disappearance of the natural fish spawning area. The cost of protecting rare fish from extinction is the ecological value of fish. The effects and damage to natural fish caused by a project are irreversible. As the quantity of rare fish continues to decrease, people will become more willing to pay for them, and their value will increase. Therefore, the protection expenses must be discounted indefinitely and multiplied by the local economic development factor. Based on Equation (2), the compensation for the ecological value of rare fish can be calculated as follows:

$$F_y = e \cdot \frac{b}{r} = \frac{g}{G} \cdot \frac{b}{r} \tag{6}$$

where Fy represents the ecological compensation for rare fish (RMB) and b represents the cost of protecting rare fish (RMB/a).

3. Calculation of ecological compensation for Niulanjiang River provided by the Niulanjiang River to Dianchi Lake water diversion project

3.1. Overview of the Niulanjiang River to Dianchi Lake water diversion project

The Niulanjiang River to Dianchi Lake water diversion project is a recent key project that diverts water to the central Yunnan Province. It is designed to fill Dianchi Lake with ecological water, improve the water environment of Dianchi Lake, offer water to Kunming City for urban, domestic and industrial uses in case of a water supply crisis in 2020, and supply water to Qujing City for production and living in 2030. This project diverts water from Niulanjiang River, which is a tributary of the Jinsha River, originates in Xundian County of Kunming City in the northeast of Yunnan Province, and has a mouth located within the borders of Zhaotong City. Niulanjiang River has a mainstream length of 440 m and an average runoff of 4.35 billion m3 per year. This project consists of the Deze reservoir, the Ganhe river pumping station in Deze, and the line for delivery of water from the Ganhe river pumping station to Kunming.

3.2. Assessment of the ecological compensation for the terrestrial biological resources in Niulanjiang River

The land in Niulanjiang River occupied by the project is shown in Table 2 according to the 2010 feasibility study report on the Niulanjiang River to Dianchi Lake water diversion project. The GDP in Niulanjiang River in 2007 was 3,469 RMB per capital. Based on the fact that the national GDP in 2007 was 18,934 RMB per capital [9], the economic development factor of Niulanjiang River was calculated to be 0.18. The discount rate, r, was assigned a value of 2.79%, the one-year term deposit rate.

Table 2. Land in Niulanjiang River occupied by the project.

Farmland (hm^2)	Woodland (hm^2)	Grassland (hm^2)	Waters (hm^2)	Bare land (hm^2)	Total (hm^2)
218.51	1034.50	468.17	103.87	91.76	1916.81

According to the above data and Equations (2) and (3), the ecological compensation in Niulanjiang River granted for the Niulanjiang to Dianchi Lake water diversion project is 136,460,000 RMB for the terrestrial biological resources, 7,990,000 RMB for farmland, 108,340,000 RMB for woodland, 17,200,000 RMB for grassland, 2,720,000 RMB for waters, and 210,000 RMB for bare land. The ecological compensation for woodland is the greatest.

3.3. Assessment of the ecological compensation for the water environment of Niulanjiang River

According to the Plan for Protection of the Water Environment of Niulanjiang River (2009), it costs 2000,000 RMB to build a wastewater treatment plant with a capacity of 500 m^3/a. The life of a wastewater treatment plant is generally thirty years. The cost of treating wastewater by building a wastewater treatment plant is expressed as:

$$C = \frac{T}{G \times N} \tag{7}$$

where C represents the cost of treating wastewater by building a wastewater treatment plant (RMB/m^3); G represents the amount of wastewater to be treated (m^3/a); T represents the cost of building a wastewater treatment plant (RMB); and N represents the lifespan of a wastewater treatment plant.

According to Equation (7), the cost of treating wastewater by building a wastewater treatment plant in Niulanjiang River is 133.33 RMB/m3. According to the 2010 feasibility study report on the Niulanjiang River to Dianchi Lake water diversion project, the average annual runoff of Niulanjiang River is 59.5 m3/s in a dry season and 36.5 m3/s after water diversion, with a reduction of 23 m3/s. Niulanjiang River discharges wastewater at a rate of 239.58 m3/a. According to Equations (4) and (5), the ecological compensation for the value of the water environment of Niulanjiang River is 37,000 RMB.

3.4. Assessment of the ecological compensation for the rare fish in Niulanjiang River

Deze Reservoir, having a dam height of 142 m, was built for the Niulanjiang River to Dianchi Lake water diversion project. The dam and runoff regulation have resulted in a change in the downstream hydrology. The fish affected are primarily the rare fish that spawn in torrents, including Sinocyclocheilus graham, Sinogastromyzon dezeensis, Jinshaia niulanjiangensis, and Paraprotomyzon niulanjiangenssis. It is necessary to build a fish proliferation station in the Niulanjiang River basin for long-term artificial population propagation in order to protect these rare fish. In order to compensate for the effects caused by water conservancy projects to rare fish, American fish ecologists have studied the protection of Oncorhynchus nerka, a rare species of fish and built a fish spawning area at a cost of 7,440.62 USD/a[10], or 46,875.90 RMB/a (at a USD to RMB exchange rate of 6.3). The discount rate r was assigned a value of 2.79%, and the economic development factor of Niulanjiang River was assigned a value of 0.18. Based on Equation (6), the ecological compensation for the rare fish in Niulanjiang River provided by the water diversion project is 302,400 RMB.

3.5. Assessment of the total ecological compensation for Niulanjiang River

The ecological compensation for Niulanjiang River is equal to the sum of the ecological compensation for its terrestrial biological resources, water environment, and rare fish:

$$F = F_l + F_s + F_y = 136{,}799{,}400 \text{ RMB} \tag{8}$$

4. Conclusions

The Niulanjiang River to Dianchi Lake Water Diversion Project provided 136,799,400 RMB for Niulanjiang River water sources as ecological compensation. Among all of the ecological compensation, the most expensive compensation is for woodland, which is 108,340,000 RMB. In order to minimize the water diversion project's adverse effects on the ecological environment of water sources, during the construction, it is necessary to protect some remaining native species that survive in the steep environment. Since Niulanjiang River water sources are located on the plateau of the central region of Yunnan Province, they have sufficient water content and appropriate heat quantities to endow vegetation with strong self-repairing capabilities. Thus, the remaining native species could be effectively used for vegetation restoration after the construction.

The proposed method for calculating the ecological compensation for water sources for water diversion projects considers the compensation for the various environmental effects on water sources provided by water diversion projects and local social development. This method enables the ecological compensation to cover the environmental protection and ecological restoration in water sources while facilitating the implementation of water diversion projects.

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