Comparisons and improvements of eco-compensation standards for water resource protection in the Middle Route of the South-to-North Water Diversion Project

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ABSTRACT

Reasonable eco-compensation standards are conducive to increasing the enthusiasm of residents in the water source area of the water diversion project for ecological environmental protection and maintenance and for improving the water quality security of the water receiving area. In this paper, a comparative analysis of calculation mechanisms, formulas, and results of 7 types of eco-compensation standard methods for the Middle Route Project of the South-to-North Water Diversion Project in China is conducted. The research shows that the calculated results for the 7 types of methods differ greatly and considers that the cost and ecological service value methods are appropriate. Using this as the basic method to consider introducing market value of water resources, internal income of water source area, and government financial support for method improvement, the results show that the improved methods can reduce the gap between the per capita income of the water source area and the reference area, increase the satisfaction of both the water receiving area and the water source area, and provide support for overall socioeconomic development.

Key words | ecological compensation, south-to-north water diversion, water transfer project

HIGHLIGHTS

- Improve existing ecological compensation formula.
- The improved methods can reduce the gap between the per capita income of the water source area and the reference area, increase the satisfaction of both the water receiving area and the water source area, and provide support for overall socioeconomic development.

INTRODUCTION

The Middle Route Project of the South-to-North Water Diversion Project in China, with a total length of 1,432 km, provides water for residents, industry and agriculture (Construction and Administration Bureau of South-to-North Water Diversion Middle Route Project 2019) to 19 large and medium-sized cities including Beijing, Tianjin and more than 100 counties (county-level cities), and is a major infrastructure project to alleviate the severe shortage of water resources in northern China (Ministry of Water Resources of the People’s Republic of China). The water source area refers to the Danjiangkou Reservoir area and the upstream area, which are located between 31°30’–54°N and 106°–110°40’E. The landforms are mostly mountains, hills, and river valleys and involve 14 cities and 46 counties (cities and districts) in Hubei, Henan and Shaanxi provinces and some townships in Sichuan, Chongqing, and Gansu provinces. The catchment area is approximately $9.5 \times 10^4$ km$^2$, as shown in Figure 1. To deliver high-quality drinking water to the water receiving area of the Middle Route Project of the South-to-North Water Diversion Project, the water source area shut down more than 500 enterprises with severe pollution, banned more than one thousand
‘ten small’ companies, stopped more than 300 new projects, and the area of soil erosion controlled exceeded $2 \times 10^4$ km$^2$ during the period from 2011 to 2015. The water quality in the water source area is maintained at Class II as a whole (National Development and Reform Commission et al. 2011). The population directly benefiting from the project is over 58.59 million people (Ministry of Water Resources of the People’s Republic of China). It can be seen that the input cost of the water source area to maintain the water source has forcibly interrupted the traditional industrial structures and economic growth modes and has caused the socioeconomic development of the water source area to lag. For example, in 2015, the total population of the water source area was approximately 13.74 million and the average per capita income of these urban and rural residents was 16,999 CNY, which was less than the national average per capita income of 17,310 CNY (National Development and Reform Commission et al. 2017). The imbalance between water resource protection and the people’s spiritual and material lives in the water source area requires the government to introduce ecological compensation mechanisms to intervene to achieve a win-win situation of high-quality water resource protection and social and economic development in the water source area.

Research on eco-compensation began at the end of the 20th century. The internationally accepted concept is PES (Payment for Ecosystem Services) or PEB (Payment for Ecological Benefit); these terms mean that beneficiaries pay fees...
to the ecological service provider. Pagiola et al. (2005) believe that eco-compensation should be applied by a market mechanism so as to achieve effective allocation of resources. Landell-Mills et al. (2002) considered eco-compensation as an economic stimulus with the main purpose of improving the efficiency of natural resource management. The eco-compensation approach studied in this paper mainly refers to the compensation of the water source area’s transfer of the right to use water sources by the water receiving area to protect the local ecological environment and the development losses of the water source area (Zeng 2014). Eco-compensation includes various methods such as capital compensation, policy compensation, industrial compensation, and counterpart assistance (Wang et al. 2012) but direct economic compensation or other forms of direct economic compensation are used to measure the strength of compensation. The cost of direct economic eco-compensation is related to the success or failure of the Middle Route Project of the South-to-North Water Diversion Project. Therefore, determining the eco-compensation standard is the core content of eco-compensation and is a controversial point for resolving related problems. The determination of the eco-compensation standard has a game relationship between the water receiving area and the water source area. Insufficient compensation will affect the enthusiasm for water source protection in the water source area. However, if the compensation is too large, it may exceed the water receiving area’s ability to pay. However, there are currently many methods for calculating eco-compensation standards and no unified measurement standard has been established. The methods mainly include ecosystem service value methods, cost-based methods, demonstrative preference methods, and declarative preference methods (Dai et al. 2012). Internationally, Gallagher (2015) has calculated eco-compensation standards according to the species of organisms and the ecological function of the region. In the view of Whiley (2016), it is considered that the eco-compensation standard should be calculated after the value budget of ecosystems such as forests, wetlands, minerals, etc. Shaozhuo et al. (2020) proposed an emergy-based eco-compensation accounting framework by linking it with the InVEST model and ArcGIS to calculate the eco-compensation standard from the perspective of ecosystem service improvement. There are many studies on eco-compensation standards in typical watersheds in China. For calculating the eco-compensation standards of the water source area of the Middle Route Project of the South-to-North Water Diversion Project, Zhu (2017), Chen (2018), and Cheng (2022) all used the ecosystem service value method and cost method to calculate the upper and lower limits of the eco-compensation standard, and used the average value as the eco-compensation standard; the calculated amounts were 13.326 billion CNY, 81.84 billion CNY, and 61.891 billion CNY, respectively. Zheng et al. and others used the cost analysis method to calculate the direct costs and opportunity costs of the Middle Route Project of the South-to-North Water Diversion Project in Shiyan, Hubei, from 2003 to 2050. Based on this, the annual eco-compensation standards for Shiyan City in the four periods from 2014 to 2050 were 2.176 billion CNY, 0.533 billion CNY, 0.44 billion CNY, and 0.41 billion CNY, respectively (Zheng et al. 2011). Wang et al. calculated the annual eco-compensation standard amounts of the water source area to be 24.004 billion CNY by using the protection input cost and development opportunity cost (Wang et al. 2012). Yang et al. used the opportunity cost method as the upper limit and the willingness-to-pay method as the lower limit to calculate the horizontal eco-compensation standard of the Middle Route of the South-to-North Water Diversion Project and concluded that the total compensation amount was 22–2.52 billion USD every year (Yang et al. 2018); Wang (2011) calculated the eco-compensation standard for Xichuan county to be 4.424 billion CNY by using the ecosystem service function value accounting method.

There are many calculation methods for eco-compensation standards in the water source area of the Middle Route Project of the South-to-North Water Diversion Project and the calculation results from the same measurement methods still differ greatly, which will directly affect the implementation of eco-compensation standards in the water source area. Therefore, this paper, by comparing a variety of commonly used calculation methods of eco-compensation standards from the literature, reveals the advantages and disadvantages of each method from the principle of eco-compensation standards. Combined with the characteristics of the water source area, analyze the calculation method mechanisms of the eco-compensation method, find the main reason for the difference in the calculation results,
improve the eco-compensation method on this basis and put forward more reasonable suggestions for improving eco-compensation standards to provide support for promoting water source protection and ensure the comprehensive benefits of the water diversion project.

**ANALYSIS OF ECO-COMPENSATION STANDARD CALCULATION METHODS**

**Analysis of calculation process differences**

A total of seven methods for calculating eco-compensation standards in the water source area of the Middle Route Project of the South-to-North Water Diversion Project have been compiled. Table 1 shows the formulas and data requirements for the calculation processes. The calculations of the eco-compensation standard for the water source area of the Middle Route Project of the South-to-North Water Diversion Project are mainly calculated from the perspective of ecological service values and cost-benefit but the same variable has different perspectives and quantitative representations; Table 1 shows that the calculation formula of the ecological service value method has three forms and the costing calculation formula has three forms. The parameters involved in each calculation method in Table 1 were analyzed to find the common and uncommon parameters of these methods, so as to analyze the reasons for the large differences in the calculation results of eco-compensation in the same study area, as shown in Table 2.

| Method number | Method type | Calculation process | Data sources |
|---------------|-------------|---------------------|--------------|
| 1 Zhu (2017)  | Ecological service value and cost method | $A_{pes} = \frac{B_{max} + B_{min}}{2}$ | Statistical Yearbook, socio-economic development bulletin, and land survey results |
| 2 Chen (2018) | Cost method | $A_{pes} = \frac{\text{Total water resources of the water source area} - \text{Internal benefit of water source area}}{\text{Opportunity cost}}$ | Statistical Yearbook and literature |
| 3 Cheng, (2012) | Opportunity cost and willingness-to-pay method | $Q_C = \mu \times (U_O - U_i) + \mu \times (R_O - R_i) \times P_R$ | Statistical Yearbook and related planning documents and literature |
| 4 Zheng et al. (2011) | Ecosystem service function core algorithm | $A = V - Ca$ | Questionnaire and Statistical Yearbook |
| 5 Wang et al. (2012) | | | |
| 6 Yang et al. (2018) | | | |
| 7 Wang (2011) | | | |

$A_{pes}$—Ecological service function core algorithm; $B_{max}$—Ecological service value; $B_{min}$—Cost; $C_O$—Direct cost; $C_P$—Opportunity cost; $C_a$—Amount of cost of agricultural ecological environment in water source area; $E_i$—Ecological benefits of water demand area; $E_W$—Water market value; $E_C$—Internal benefit of water source area; $E_Q$—Willingness to pay adjustment factor; $G$—Total water resources of the water source area; $i$—Impacts of secondary and tertiary industries on development of the economy; $P_W$—Water value; $Q$—Quantity of water diversion; $O$—Opportunity cost; $P_{10}$—the averages of the ten-year urban and rural populations in the supplier area; $P_i$—the possibility of the $i^{th}$ bid value; $R_{10}$—the averages of the ten-year rural citizens disposable incomes per capita in the reference and supplier area, respectively; $R$—Water quality correction factor; $U_O$—the averages of the ten-year urban citizen disposable income per capita in the reference and supplier area, respectively; $V_{i}$—the $i^{th}$ bid value of the respondents; $V$—Economic value of the ecological service function of water source; $W$—Water allocation factor.
Analysis of difference in calculation results

Before construction of the Middle Route Project of the South-to-North Water Diversion Project, urban areas with similar social and economic development degrees as the water source area were selected as the reference areas and the per capita income of residents in the water source area after eco-compensation was calculated. This was then compared with the per capita income of residents in the selected reference areas to judge whether the compensation standard was conducive to developing the water source area. The selection principles for the reference areas were: (1) they were located in the same province with similar geographical locations, as is shown in Figure 1, and (2) the per capita GDP, urban per capita annual income and rural per capita annual income were similar. The study proposes that the economic development reference areas for the water source areas of Shaanxi, Henan and Hubei provinces be selected as Weinan, Jiaozuo and Xiangyang. Since construction of the Middle Route of the South-to-North Water Transfer Project started at the end of 2003, data from 2005 to 2006 were selected to provide a basis for the selection of reference areas for the economic development background of the water source area; the mean per capita GDP and percentage deviation between the water source area and the reference area in 2005–2006 were calculated, as shown in Figure 2. The water source area was 10–24% lower than the corresponding reference area’s per capita GDP, and Hubei Province had the largest deviation.

Considering that the calculation results and statistical data correspond to years that used 7 types of calculation methods, the per capita annual income of each literature study area was calculated and compared with the per capita income of the reference area in the corresponding year, as shown in Table 3. The formula for calculating per capita annual income after compensation in the water source area is shown in formula (1) and the formula for calculating per capita annual income is shown in formula (2). In method number 1, the calculation results of eco-compensation include Xi'an city, Baoji City and Dazhou City, so this study only takes the ecological compensation data of water

| Parameter method | Ecological service value perspective | Cost method (upper limit) | Cost method (lower limit) | Cost method | Willingness to pay method | Ecological service value function perspective | Ecosystem service function core algorithm |
|------------------|-------------------------------------|---------------------------|---------------------------|-------------|--------------------------|-----------------------------------------------|-----------------------------------------|
| Common parameter | 1. The quantity of water diversion  | 1. Direct cost             | 2. Opportunity cost       | 1. Direct cost | /                        | 1. Economic value of ecological service function of water source area |
|                   | 2. Water value                      |                           |                           | 2. Opportunity cost |                         | 2. Amount of cost of agricultural ecological environment in water source area |
|                   | 3. Ecological benefits              |                           |                           | 3. Government financial subsidy |                       |                                               |
|                   | of water demand area                |                           |                           |                           |                         |                                               |
| Uncommon parameter| 1. Non-market part value of water   | 1. Water quality correction factor | 2. Water allocation factor | 1. Internal benefit of water source area | 1. Quotation of respondents |                                               |
|                   | ecosystem service value             |                           |                           | 2. The impacts of secondary and tertiary industries on development of the economy | 2. The possibility of the i<sup>th</sup> bid value |                                               |
|                   | 2. Water quality correction factor  |                           |                           |                           |                         |                                               |
|                   | 3. Total water resources of the     |                           |                           |                           |                         |                                               |
|                   | water source area                   |                           |                           |                           |                         |                                               |
resource areas.

\[ PCI = \frac{E}{P} + PCIC \]  
(1)

\[ PCIC = \frac{(It + Ia)}{2} \]  
(2)

Among these, \( PCI \), the per capita annual income of residents in the water source area after eco-compensation, CNY/(person-year); \( PCIC \), the per capita annual income of residents in the water source area/reference area, CNY/(person-year); \( E \), the eco-compensation standard of the study area, 0.1 billion CNY a year; \( P \), the total population of the study area, ten thousand people; \( It \), the per capita disposable income of urban residents in the study area/reference area, CNY/(person-year); and \( Ia \), the per capita income of rural residents in the study area/reference area, CNY/(people-year).

Table 3 shows that the study area, by five methods, is the water source area, but the calculated eco-compensation amounts range between 13.3 and 81.8 billion yuan and the difference in compensation amounts is very large. At the same time, Table 3 also illustrates the dynamic correspondence between the calculation results of each method and the corresponding reference area, in which the difference of per capita income is positive and thus indicates that the per capita income after compensation is higher than that of the reference area, and the eco-compensation calculated by this method is relatively large. If it is negative, it indicates that the per capita income after compensation is lower than that of the reference area, and the eco-compensation calculated by this method is relatively small. The smaller the difference, the more reasonable the amount of compensation. Table 3 shows that the differences in per capita income calculated by the seven methods are quite different and four have positive deviations in per capita income and three have negative deviations. The percentage difference between the per capita income of the water source area after compensation and the per capita income of the reference area is as high as 29.6%.

Analysis of calculation method mechanisms

Ecosystem services refer to products and services provided by ecosystems that can directly or indirectly enhance human lives (Tognetti et al. 2002). The ecosystem services value method is an evaluation of the value provided by ecosystem services but this method has great limitations for counting, as most ecosystem services are public goods or quasi-public goods that cannot enter the market and cannot truly reflect their actual values. The cost method refers to eco-compensation based on the cost of providing high-quality water in the source area, which mainly includes the direct costs of protecting and maintaining the ecological environment and the costs of development opportunities lost by protecting the water from pollution. The cost method can objectively and comprehensively reflect the economic loss from ecological protection in the water
| Method number | Eco-compensation (study area, study years) (1) | Regional population (ten thousand people) (2) | Per capita compensation (CNY/person) (3) | Regional per capita income (CNY) (4) | Per capita income after compensation (CNY/person) (5) – (3) + (4) | Per capita income of the reference area (CNY/person) (6) | Income per capita difference (CNY/person) (7) – (6) | Deviation (%) (8) = (7)/(6) *100% |
|---------------|-----------------------------------------------|-----------------------------------------------|---------------------------------------|-----------------------------------|-----------------------------------------------------|------------------------------------------|---------------------------------|----------------------------------|
| 1 Zhu (2017)  | 12.176 billion (the water source area, 2014)  | 1,198                                         | 1,016                                 | 16,063                            | 17,079                                              | 18,067                                   | – 988                      | – 5.5                            |
| 2 Chen (2018) | 81.84 billion (the water source area, 2016)   | 1,198                                         | 6,831                                 | 15,963                            | 22,794                                              | 20,363                                   | + 2,431                     | 11.9                             |
| 3 Cheng (2012)| 61.891 billion (the water source area, 2010) | 1,198                                         | 5,166                                 | 8,547                             | 13,713                                              | 10,606                                   | + 3,107                     | 29.3                             |
| 4 Zheng et al. (2011) | 2.176 billion (Shiyang City, 2014) | 347                                           | 627                                   | 14,595                            | 15,222                                              | 18,066                                   | – 2,844                     | – 15.7                           |
| 5 Wang et al. (2012) | 24.004 billion (the water source area, 2010) | 1,476                                         | 1,626                                 | 9,132                             | 10,758                                              | 10,396                                   | + 362                      | 3.5                              |
| 6 Yang et al. (2018) | 15.667–17.717 billion (the water source area, 2016) | 1,198                                         | 1,291–1,478                          | 17,950                            | 19,241–18,428                                      | 20,363                                   | – 1,122~ – 935               | – 4.6~ – 5.5                     |
| 7 Wang (2011)  | 4.424 billion (Xichuan County, 2010)          | 66.25                                         | 6,677                                 | 10,764                            | 17,441                                              | 13,453                                   | + 3,988                     | 29.6                             |
source area with high credibility but it cannot directly reflect the value provided by ecological services. The willingness-to-pay method uses a direct questionnaire survey of the residents of the water receiving area to obtain their valuation or the price they are willing to pay for the products provided by the Middle Route Project of the South-to-North Water Diversion Project. It can truly reflect the willingness of the water receiving area to provide eco-compensation to the water source area, but the results are influenced by individual subjectivity. Research has shown that consumers tend to choose lower compensation fees so the results of the survey can be used as the lower limit of the eco-compensation standard.

Each method has the following differences in its mechanisms:

1. The value of ecological services provided by the water resource area can be divided into market value and non-market value. The market value contributes to the development of the water source area. This part does not need compensation by the water receiving area. The non-market value includes climate regulation and soil and water conservation (Zhu 2017); with these factors being severely damaged during the water diversion project, this is an important part that needs to be compensated by the water receiving area. However, what the water source area loses is not only the non-market value of the water body but also the high-quality water resources. Therefore, the cost of the water resources should be added to the calculation in method 1 (Zhu 2017). At the same time, when calculating the value of the water resources in the project, the corresponding water quality adjustment factor must be adjusted. If the water source area provides water quality which is inferior to class III, the water receiving area needs to deal with the water resource quality by itself. The cost of this activity is reflected in the water quality adjustment coefficient.

2. Table 2 shows that the common parameters in the calculation formula of the cost method are direct cost and opportunity cost and the non-shared parameters involve more variables. In theory, the lowest cost to provide qualified water is the sum of the opportunity costs and direct costs and, therefore, the amount of eco-compensation to be provided must also be based on this standard but the amount of compensation for horizontal eco-compensation must be deducted from the fiscal longitudinal compensation funds (Zhang 2016). Additionally, method 5 (Wang et al. 2012) deducts government subsidies when calculating direct costs. Table 4 shows that the deviation of per capita income calculated by method 5 (Wang et al. 2012) is smaller than that calculated by the other methods. At the same time, when environmental protection and maintenance are conducted in the water source area, these also bring certain internal benefits to the water source area and should be deducted from the costs.

3. Method 7 (Wang 2011) in Table 1 directly uses the calculation method of the value of the ecosystem service function, which covers the sum of the nine types of values of the agricultural ecosystem in the water source area, such as gas regulation, water conservation, waste treatment, and leisure and entertainment. The value of the ecosystem in the water source area is fully displayed. The mechanism of this type of method is clearer. It calculates an ideal amount of compensation. The per capita income is higher than the reference area value of 3,988 CNY but the error for each item in this method is too great. It does not consider the current development status of the water source area or the acceptance capacity and willingness of the water receiving area.

**IMPROVEMENTS OF ACCOUNTING METHODS FOR ECO-COMPENSATION STANDARDS**

**Calculation method**

In this paper, the compensation mechanisms of the ecological service value and cost-benefit methods are clear and there is high availability of required data. Based on this method, the market value of water resources, internal income of the water source, and financial support factors are introduced to promote the rationalization of the mechanism and to improve the methods. The improved eco-compensation standard calculation formulas are
| Method number | Years of study | Study area | $H$ (billion CNY) (1) | $I_N$ (billion CNY) (2) | $G_N - V_N$ (billion CNY) (3) | $B_{max}$ (billion CNY) (4) $-$ (1) $-$ (3) | $B_{min}$ (billion CNY) (5) | $A_{EC}$ (billion CNY) (6) $-$ [(4) $-$ (5)]/2 | Income per capita difference CNY/people | Deviation (%) |
|---------------|----------------|------------|-----------------------|--------------------------|-------------------------------|---------------------------------------------|-----------------|-------------------------------------------------|----------------|---------------|
| 1 Zhu (2017)  | 2014           | The water source area | 11.4                  | 4.0                      | 17.96 (Zhu 2017)              | 29.36                                        | 2.385            | 15.8725                                          | −679           | −3.8          |
| 2 Chen (2018) | 2016           | The water source area | 11.4                  | 3.92 (N.D and R.C 2017) | 38.895 (Chen 2008)            | 50.295                                      | 72.975           | 61.635                                          | +744           | 3.6           |
| 3 Cheng (2012)| 2010           | The water source area | 11.4                  | 4.0 (Zhang 2016)         | 38.895 (Cheng 2012)          | 50.295                                      | 42.887           | 46.591                                          | +1,830         | 17.3          |
| 4 Zheng et al. (2011) | 2014 | Shiyen City | 2.4                   | 0.138 (Cheng 2012)       | 3.865 (Zhu 2017)             | 6.265                                       | 3.863            | 5.064                                           | −2,012         | −11.1         |
| 5 Wang et al. (2012) | 2010 | The water source area | 11.4                  | 4.0 (Zhang 2016)         | 38.895 (Cheng 2012)          | 50.295                                      | 20.004           | 35.1495                                         | +1,117         | 10.7          |
| 6 Yang et al. (2018) | 2016 | The water source area | 11.4                  | 3.92 (N.D and R.C 2017) | 38.895 (Chen 2018)           | 50.295                                      | 11.547 $-$ 13.797 | 30.921 $-$ 32.046 | +168 $-$ +261 | 0.8 $-$ 1.3 |
| 7 Wang (2011)  | 2010           | Xichuan County | 0.37                  | 0.02 (Zhang 2016)        | 0.95 (Zhu 2017)              | 1.32                                        | 0.404            | 0.862                                           | −1,388         | −10.3         |
shown in Equations (3), (4) and (6).

\[ A_{\text{PES}} = (B_{\text{max}} + B_{\text{min}})/2 \]  

\[ B_{\text{max}} = \frac{G_s \cdot V_{IS}}{G} + H \]  

\[ H = G_s \cdot P_r \cdot W \]  

\[ B_{\text{min}} = C_D + C_o - I_N - E_E \]  

\[ H \text{- market value of the water resources;} \]
\[ G_s \text{- total amount of water diversion;} \]
\[ P_r \text{- market price of water resources;} \]
\[ W \text{- water quality adjustment factor.} \]

**Analysis of calculation results**

At present, the average water price for Beijing and Tianjin in the water receiving area of the Middle Route Project of the South-to-North Water Diversion Project is 1.2 yuan/m³ (Cheng 2012) and most of the water quality provided by the water source area is class II (National Development and Reform Commission et al. 2017) and above, so \( W \) is taken as 1; in 2010, the calculation base of the water transfer volume was 9.5 billion m³ and the water resource cost in water source area calculated by formula (5) is:

\[ H = G_s \cdot P_r \cdot W = 9.5 \cdot 1.2 \cdot 1 = 11.4 \text{ billion} \]

The Middle Route Project of the South-to-North Water Diversion Project has been operational since the end of 2014. In the initial stages of operation, the internal benefits of water diversion in the water source area were almost negligible, so \( E_E \) is 0. To test the rationality of the improved method, according to the original data of the research method in Table 1 and the improved calculation formula of the eco-compensation standard, recalculate the amount of eco-compensation in the year of 7 methods in Table 1. The parameters of each method are taken from the original data of the research method in Table 1, for the newly added parameters in the improved method, if the original research method does not have them, the data of the same research year shall be taken. The results are shown in Table 4. The calculation method of per capita income difference and income deviation in the table is the same as that in Table 3. This method is affected by the inconsistency of the calculation data and years in the research literature. Therefore, the phenomenon of the same research area, the same research period and different eco-compensation amount appears in Table 4. This study did not analyze the accuracy of the method parameters, so it is suggested that the data accuracy should be further improved in the calculation of eco-compensation amount to ensure the use of reasonable parameters for the calculation of eco-compensation.

When compared with Table 3, the per capita difference in Table 4 greatly decreases the income gap relative to the reference area and thus indicates that the relative interests of the water source area and the water receiving area can be balanced and the two sides are more accepting. According to Figure 3, we can see, in addition to research method 5, the deviation of the eco-compensation income difference is lower than before the adjustment, which indicates that the adjusted calculation formula is feasible and practical.

Table 4 shows that the amount of eco-compensation in the same research area as the water resource area is different in different years, which indicates that the eco-compensation standards are not fixed; it is necessary to dynamically adjust the compensation standards.

**Dynamic adjustment of compensation standards**

The eco-compensation standards for the water source area of the Middle Route Project of the South-to-North Water Diversion Project should be dynamically changed. With the gradual improvement of compensation standards and the gradual formation of the water source area’s industrial development in a stable manner, the economic growth rate of the water source area will gradually increase and possibly reach or exceed the economic growth rate of the reference area so the amount of eco-compensation may show a trend of first increasing and then decreasing; finally, there is no direct economic compensation. The economic development of the water source area alone can make up for the losses caused by the water diversion project and even due to the characteristics of the water source area, good economic communities in both the water source area and the water receiving area are formed. Therefore, it is
suggested that the eco-compensation standards of the water source area should be calculated in detail every 5–10 years and that the eco-compensation standard be adjusted according to the economic development progress of the reference area and the development status of the water source area in recent years.

Eco-compensation implementation suggestion

In order to ensure eco-compensation can be implemented smoothly, this paper puts forward the following suggestions.

(1) Increase the protection of eco-compensation. In China, the Environmental Protection Law, the Water Pollution Prevention and Control Act, and the Regulations of Henan Province on the Prevention and Control of Water Pollution have all proposed to establish and improve the water environment eco-compensation mechanism in drinking water source protection areas. However, there are no clear regulations on specific implementation and supervision. The lack of legal protection hinders the effective implementation of eco-compensation. Therefore, laws and regulations on eco-compensation should be further improved to enhance the legal protection of the eco-compensation system.

(2) Establish a system of joint meetings. The establishment of a cross-regional, cross-department and cross-industry joint meeting system is conducive to actively handling various issues arising from eco-compensation, implementing eco-compensation, and ensuring the normal play of project benefits.

The implementation of eco-compensation cannot be carried out without the promotion of the government. Therefore, the authors believe that the government should participate in eco-compensation as the main manager.

CONCLUSIONS

There are many studies on eco-compensation of water resources. As for the Middle Route of the South-to-North Water Diversion Project in China, there are many calculation methods for eco-compensation in the water resource area, and the calculation results in the same area differ greatly, which seriously hinders the effective implementation of eco-compensation. So, in this paper, through a comprehensive analysis of the similarities and differences in the calculation process, the results and mechanisms of the seven types of eco-compensation calculations for the water source area of the Middle Route Project of the South-to-North Water Diversion Project it was found that the calculation mechanism is more reasonable from the perspective of ecological service value and cost-benefit calculation, and the required data for this method is easy to obtain. Therefore, the calculation formula of ecological compensation was improved on the basis of this method. Through the mechanism analysis, it was found that the ecological service value provided by the water
source area includes the market value of the water resource in the non-market value, and the cost benefit is the direct cost and opportunity cost caused by water transfer, so the internal revenue and financial support of the water resource area should be deducted. Seven studies are recalculated using the improved calculation formula, and the results show that the improved method can reduce the absolute difference in per capita income between the water source area and the reference area and improve eco-compensation standards for both the water source area and the water receiving area.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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