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RESEARCH ARTICLE

Quantitative standard of eco-compensation for the water source area in the middle route of the South-to-North Water Transfer Project in China

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Abstract The Middle Route Project(MRP) of the South-to-North Water Transfer Scheme (SNWT) in China will require a very large financial expenditure to ensure the water supply and the associated water quality to northern China. An eco-compensation mechanism between the water service source areas and its beneficiaries is essential. This paper establishes an analytic framework of eco-compensation standard for the protection of the water source area, including both the calculation of eco-compensation based on opportunity cost method (OCM) and calculation of the burden sharing of eco-compensation between the water source area and the external water reception area based on the deviation square method (DSM). Taking Shiyan City, Hubei Province in China as a case study, our results show that the eco-compensation in the first-phase of MRP for the water source area in Shiyan, Hubei Province should be 1.63×10^{10} CNY, about four times of planned eco-construction investment budget (4.33×10^{9} CNY). In addition, the burden sharing of eco-compensation varied greatly in terms of different methods. It would be better to integrate the results of different single-factor burden sharing methods by determining the corresponding weighting coefficient with DSM and form one unanimous consent result by the interested parties.

Keywords the South-to-North Water Transfer Scheme, eco-compensation standard, opportunity costs, deviation square method

1 Introduction

The Middle Route Project (MRP) of the South-to-North Water Transfer Scheme (SNWT) is a massive inter-basin water diversion project in China, aiming to optimize the allocation of water resources spatially and to mitigate the increasingly tense situation of water resources in two provinces (Henan and Hebei) and two municipalities (Beijing and Tianjin) in northern China. The Danjiangkou Reservoir Area (DRA) which lies mainly in Shiyan City, Hubei Province, is the source of the MRP. According to the first-phase scheme of the MRP, after it is completed in 2014, the water quality in the DRA should be guaranteed above water class II of *Chinese Surface Water Standard* (GB 3838-2002) throughout the year and the annually diverted water volume of 9.50×10^{9} m^3. To ensure a supply of water to meet the requirements of the first-phase scheme of the MRP, a large number of pollution control and ecological construction projects are needed in the water source area around the DRA, which also restricts development space, bringing about an enormous cost in loss of socio-economic development opportunity, and greatly aggravates the local financial burden which adversely affects the local people's living standards. To achieve equitable development of the water source area and the external water beneficiary area of the water transfer project, it is necessary to establish an eco-compensation mechanism between the water service providing zone and the areas of benefit and to promote the eco-environmental construction and socio-economic development of the water source area in Shiyan City.

How to set the eco-compensation standard for the water source area of Shiyan City is the core of the eco-compensation mechanism construction of the giant water diversion project. We assume in the research on the eco-compensation standard for the water source area of the water diversion project, that two issues should be focused on:

1) how much eco-compensation should be given to the water supply area by the beneficiary areas, namely, how to reasonably determine the eco-compensation for the water

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source area, which is the most fundamental issue for the research on the eco-compensation standard;

2) how to calculate the burden sharing of eco-compensation between the water supply area and the water reception area. That is the problem of how to determine the burden sharing ratio of eco-compensation between the water source protection area and the external water beneficiary area. Because the water source area itself, in addition to the external water reception area, is also the beneficiary area of the eco-environment construction, it should be one major participant of eco-compensation mechanism, and should bear the burden of a certain amount of eco-compensation in accordance with its benefit level. This problem is often ignored in many researches on eco-compensation standards in the past. Not only the effect of eco-compensation mechanism but also the effectiveness of the relevant public policy is closely related to those two aspects of the difficulties of setting standards for eco-compensation.

For the first issue, the common methods used are contingent value method (CVM) [1–3], market value method (MVM) [4–6], paying for ecological services value method (PES), and the opportunity cost method (OCM) [7,8], etc. CVM is a common method used to assess the willingness to pay or willingness to accept the eco-compensation of the stakeholders in determining the values, particularly the non-use values of ecological goods and services [9], but the practical application effect of CVM is very controversial [10]. This is mainly because a hypothetical market for the ecological goods and services is adopted to reveal preferences in CVM, and the conclusion drawn from the investigated stakeholders may not conform to their true wishes [11], resulting from the fact that different investigated stakeholders tend to have a different understanding of the eco-compensation, and often interpret it in a manner favorable to themselves [11]. Ecological goods and services provided by the water source area are taken as a commodity in the MVM. A market is established around the commodity with the buyers and sellers of the ecological goods and services in the water source area. However, the premise for this method is that there should be a relatively stable market for ecosystem goods and services.

Because there is no market in many ecological services, such as soil and water conservation, purification of pollutants and so on, it is difficult to satisfactorily apply the method to determine the eco-compensation standard for a water source area, and which method is now mainly used in the eco-compensation for the transfer of water resources [12,13]. The PES is a method to determine the eco-compensation standard with various ecological services value-assessing technology. However, there always lies a major controversy in the technical methods of assessing the value of ecological services, and no countries or regions have incorporated the value of ecological services into the practical economic accounting system, which can only reflect a “virtual value.” So there are some difficulties in applying it to the eco-compensation practice of water source areas [14]. Opportunity cost is defined in economics as something that must be given up to obtain something else. The eco-compensation standards are calculated with the OCM mainly including the eco-environmental construction input costs and the loss of socio-economic development costs as a result of restricted development space in order to achieve the goal of eco-environment construction. Generally, a large number of accurate survey data are required to calculate the eco-compensation with the method, and the true extent of the data determines the accuracy of OCM. Nevertheless, it is a better choice to calculate the eco-compensation amount of the water source area, for that this method is easy to put into practice.

Burden sharing of eco-compensation is another important issue in the research of eco-compensation standards for the water source area of the water transfer project, namely, what proportion of eco-compensation responsibility should the water source area itself and the external beneficiary area bear in the total calculated eco-compensation amount to the water source area? How to achieve the equity and operability of the burden sharing result is the greatest difficulty faced in the process of eco-compensation burden sharing.

Two issues should be focused on:

1) what indicators should be chosen in the eco-compensation burden sharing between the water supply area and the reception area? This is the basis for carrying out the research of eco-compensation burden sharing;

2) what methods should be used to share the eco-compensation burden? By reviewing the existing studies, single-factor burden sharing method (SFBSM) is often used. The factors to consider mainly include the separate water consumption volumes of the water source area and the reception area [15,16], capacity to pay for water use [17], eco-services beneficiary level [18], quality of supply water[19,20] or pollutant flux upstream and downstream of the basin[21,22] etc. However, when different SFBSMs are used, the eco-compensation burden sharing results often vary widely, as stakeholders tend to seek a method favorable for themselves and disagree about the other methods. Therefore it is difficult to implement eco-compensation in practice. To solve this problem, we think we can first share the eco-compensation burden based on several single key factors, then we can reasonably integrate the eco-compensation burden sharing results by determining the weighting coefficient of the selected SFBSM. In this way, the eco-compensation burden sharing result might be easily accepted by all stakeholders.

2 Study area

We focus the study area on the water source area of DRA in

Shiyan City (See Fig. 1). Shiyan City is the water security guarantee zone of Danjiangkou Reservoir of the MRP of the SNWT located between 31°31′–33°16′N and 109°25′–111°35′E in the north-west of Hubei Province with a land area of 2.37×10^4 km^2, with Daba Mountain to the south, Wudang Mountain in the central area, the eastern relic dike of the Qinling Mountains to the north, with the main topographical features being mountains. The mountain area with an elevation of above 500m accounts for about 73.6% of the city's entire land area. The catchment area in Shiyan City is 1.98×10^4 km^2, accounting for 60% of the total catchment area of the DRA. The Han River, the largest tributary of Yangtze River, goes through Shiyan City from Lantankou in Yunxi County to Sanguandian Town, Danjiangkou City, passing Yunxi County, Yun County and Danjiangkou City, with the transit length of 216 km; The annual average water volume flowing into the DRA from Shiyan area is 2.75×10^{10} m^3, accounting for 87.4% of the total reservoir inflow. Du River within the Shiyan City area is the largest tributary of the Hanjiang River and more than 2400 rivers and tributaries of different magnitudes flow into Hanjiang River in Shiyan City.

Shiyan City has a vulnerable eco-environment. It is soil erosion sensitive and with a large eroded area. Before the implementation of Water Pollution Control and Water and Soil Conservation Planning of DRA and Upstream for the first-phase construction of the MRP of SNWT, the eroded area had reached 1.19×10^4 km^2, accounting for 50.25% of the total land area. The soil erosion types mainly include surface erosion, gully erosion and gravity erosion, in which mild erosion accounts for 46.02%, medium accounts for 17.96% and heavy erosion accounts for 33.17%. There are many sloping arable areas, in which those with a slope of greater than 25° account for 42.5% of the total arable land area. Currently, the water quality of Han River flowing into the Hubei section of the DRA on the whole achieved Chinese class II surface water standard after years of

Table 1 Spatial information of the study area

items	detailed information						
land type	hilly area		low mountain relief	middle mountains	high mountain relief	valley flat area	intermountain basin
(proportion)	(23.0%)		(31.2%)	(28.7%)	(13.7%)	(1.65%)	(1.75%)
land use pattern	forest land	farmland	garden land	grassland	water area	residential area of the city, town and countryside, and area for transportation land use	
(proportion)	(57.42%)	(8.13%)	(1.63%)	(7.50%)	(4.31%)	(20.99%)	
population distribution	total population	non-agricultural population	agricultural population	urban permanent population	urban floating population	rural labor population	rural outflow population
(million)	(3.46)	(1.34)	(2.11)	(0.53)	(0.01)	(1.20)	(0.51)
annual average precipitation (billion m^3)				21.50			
catchment area (km^2)				1.98×10^4			
rivers and tributaries	more than 2000 rivers and tributaries flowing into the DRA in Shiyan area, main rivers are as follows: Du Rvier, Tao River, Quyuan River, Tian River, Jinqian River, Guanshan River, Malan River, Lang River, Shending River, Xiangxi River, Yandu River and Nan River. Du Rvier is the largest river and also is the largest tributary of the Han River						
annually water allocation	Shiyan	Henan	Hebei		Tianjin		Beijing
(million m^3)	279	3.77×10^3	3.47×10^3		1.02×10^3		1.24×10^3
water quality	Du Rvier	Shending River	Si River		Jiang River		Jian River
(key monitoring sections)	grade Ⅲ	worsen than grade Ⅴ	worsen than grade Ⅴ		grade Ⅴ		worsen than grade Ⅴ
pollution contribution of Shiyan area to the water quality of DRA					>80%		
water and soil erosion	mild	medium	heavy		total eroded area is 1.19×10^4 km^2		
(proportion)	(46.02%)	(17.96%)	(33.17%)				

Note: 1. except water quality data of the key monitoring sections of Shiyan area cited from *Shiyan Environmental Quality Bulletin* (2009), all the other statistic data cited from *Shiyan Socio-economic Statistic Yearbook* (2006)
2. water quality classification of the key monitoring section of the surface water in Shiyan area is based on the *Chinese Surface Water Environmental Quality Standard* (GB3838-2002)

persistent pollution prevention and control. But the water quality of some tributaries flowing into the *DRA* is still poor. The water quality of Guanshan River, Si River, Jian River, Liang River and a number of other water courses is all below Chinese class III surface water standard, and the quality of some tributaries is even below the Class V standard.

Shiyan City consists of 8 districts, cities and counties, which are Danjiangkou City, Yun County, Yunxi County, Zhushan County, Zhuxi County, Fang County, Zhangwan District, and Maojian District. According to the 2006 Statistical Yearbook of Shiyan City, the total population of Shiyan City is 3.46×10^6, of which 2.11×10^6 people are the agricultural population, 1.34×10^6 people are non-agricultural, and the urbanization level is 26.62%. The industrial structure is relatively undiversified with the automobile industry as the main industry, whose added value accounts for 64.75% of the city's total one of 12.2 billion in 2005. Compared to the external water beneficiary areas, the economic development level of Shiyan is relatively low. By the end of 2005, the per capita GDP in Shiyan was 9353 CNY, and the per capita GDP of the external water reception area of Henan Province, Hebei Province, Tianjin Municipality and Beijing Municipality is respectively 11346, 14782, 35783 and 45444 CNY. Among the 8 districts, cities and counties in Shiyan, 6 counties and cities in Shiyan City are national-level poverty-stricken counties. In 2008, per capital GDP of the 6 counties and cities was 5192 CNY, only 27.8% of that of the national per capita GDP. Most of the farms in Shiyan are in mountainous areas, the conditions of agricultural production are poor, rural economic foundation is weak, so the backward economic conditions forces the government to conclude that it does not have sufficient investment capacity to protect the eco-environment. Shiyan City is affected significantly by the first-phase water transfer project, whose immigrant population accounts for 52% of the total migrant numbers as a result of the DRA construction. Industrial and mining enterprises that have to be relocated account for 74% of the total relocated. The inundated area accounts for 52.4% of the total inundated area of 300 km^2 at the first-phase of the MRP. According to the SNWT, the first-phase water transfer project can supply 9.5×10^9 m^3 water to northern China, and the beneficiary population is about 3.5×10^6; Most of the water is supplied for urban living and industrial production, and some of the water is for agricultural and other uses.

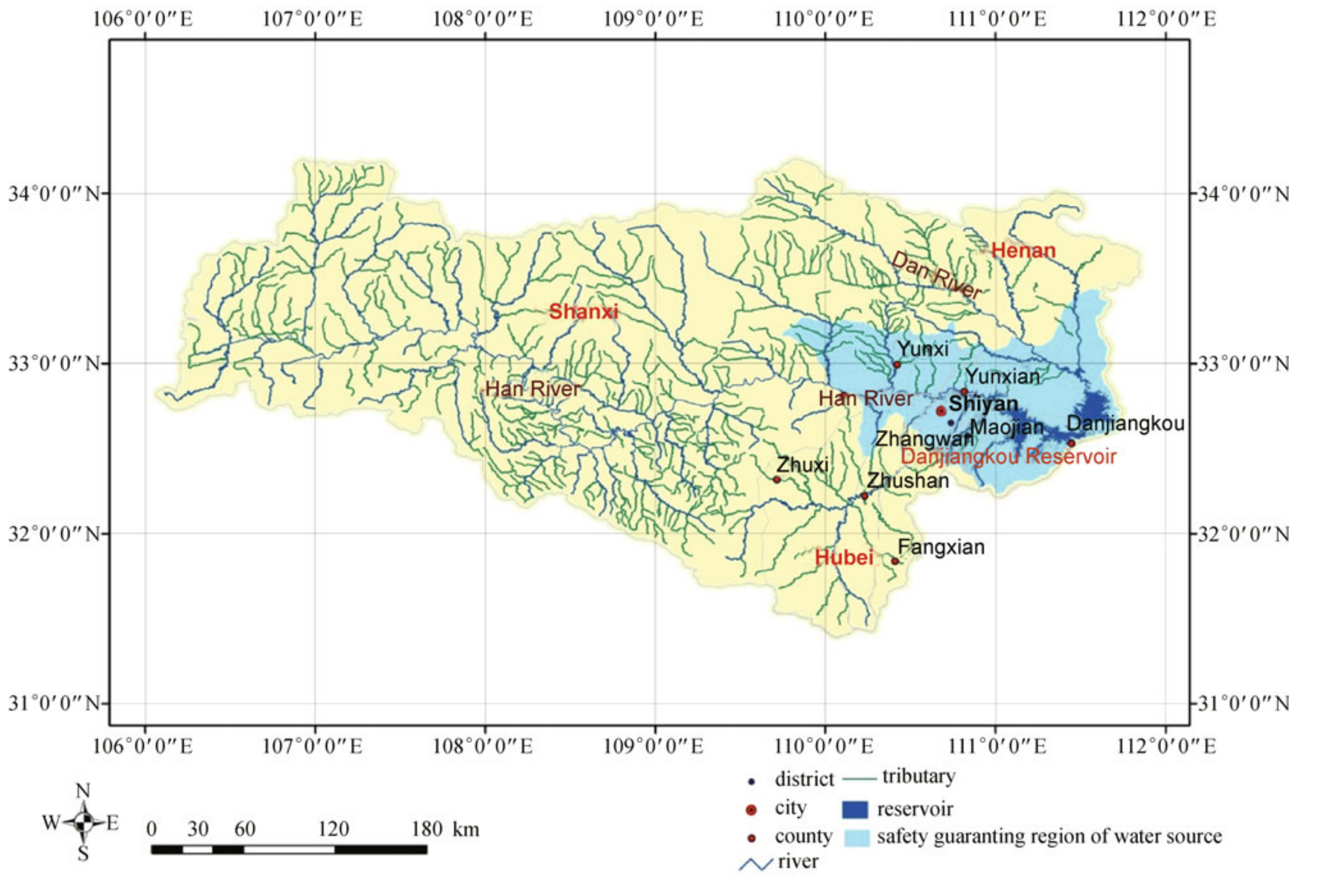

Fig. 1 Location of the study area

3 Analytic framework of eco-compensation to the water source area

The fundamental goal and the biggest benefit of the eco-environment construction of the water source area in Shiyan are to provide high-quality water source for the reception area in north China. For this reason, a large amount of investment is required to implement the eco-environment construction project. Moreover, massive development opportunities are lost because of the restrictions on development. Based on this consideration, the eco-compensation for the protection of the water source area can be calculated from the aspect of eco-environment construction cost as well as the loss of development opportunity cost (See Fig. 2).

3.1 Calculation of the pollution prevention and control cost

To guarantee that the water quality of DRA steadily achieves class II standard throughout the year, the governments in the water source area should strengthen pollution prevention and control. The methods include constructing a certain amount of infrastructural facilities, such as sewage treatment plants and sanitary waste landfill sites, for environmental protection; strengthening the capacity building of environmental supervision and management and monitoring. In addition, the operation and maintenance of the environmental infrastructure must be guaranteed. The detailed list of the calculated costs for pollution control is shown in Table 3. Here, the cost of the sewage treatment plant construction includes the engineering construction costs, ancillary pipe network expenses and the operational maintenance costs and also includes the cost for the construction of sanitary waste landfill sites and the medical waste treatment center including the engineering construction costs and annual maintenance costs. The capacity building cost of water quality monitoring includes that of newly recruited monitoring personnel and monitoring facilities. Because statistical work has not been carried out on the cost of treating

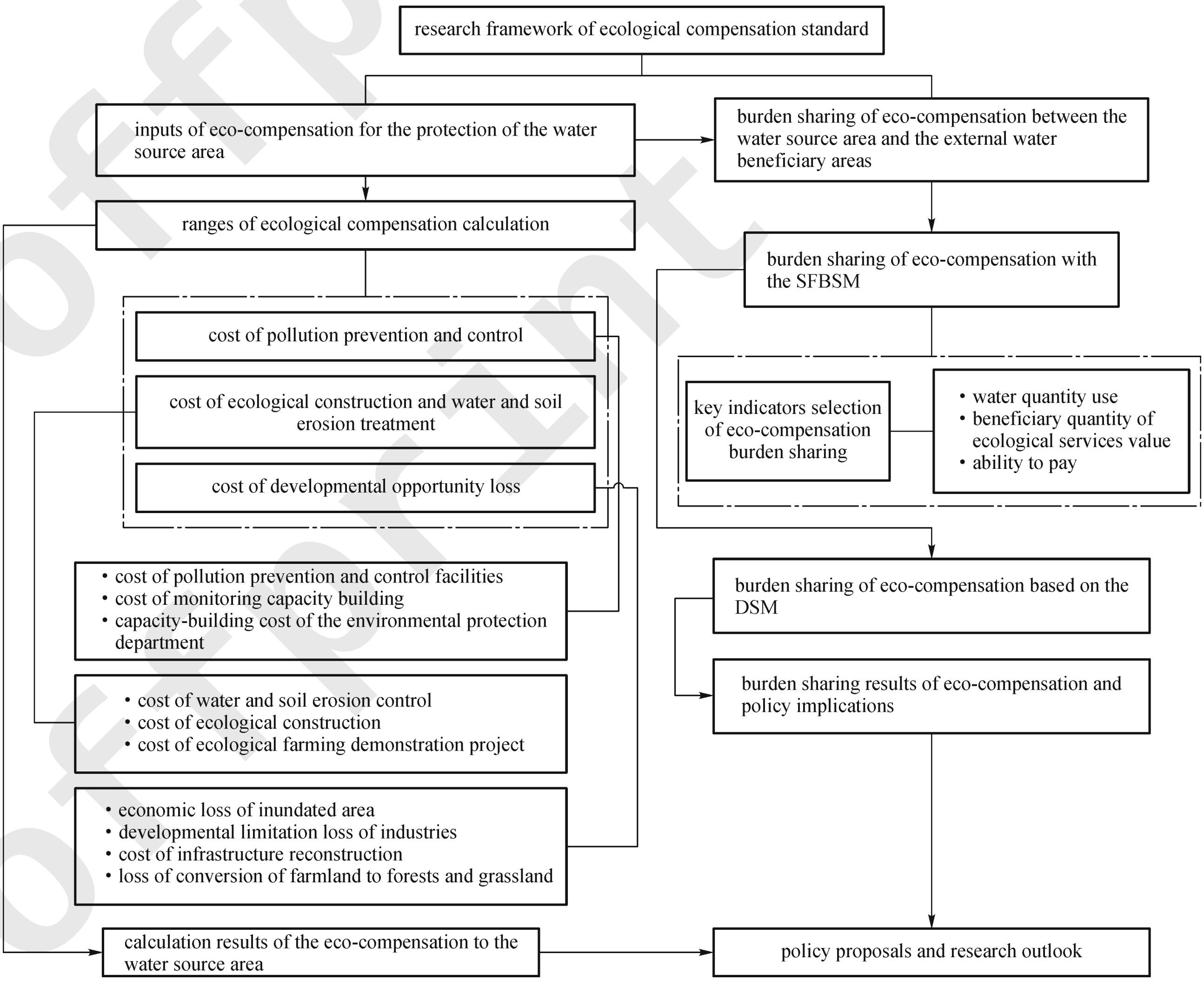

Fig. 2 Analytic framework of the ecological compensation standard

agricultural non-point source pollution in the area, it is not calculated in this research.

3.2 Calculation of the water and soil conservation and the ecological construction cost

Shiyan has a vulnerable ecological background, hence water and soil conservation and ecological construction measures are urgently required to reduce the silting speed of reservoir sediment and ensure the inflow to the DRA. As is required in the ecological construction objective of Water Pollution Control and Water and Soil Conservation Planning of DRA and Upstream for the first-phase construction of the MRP: in the area with serious soil erosion, the treatment level of the small basin should reach 30%–40%; in the area with medium soil erosion, the control rate of the small basin achieves above 60%–70%. The vegetation coverage rate increases by 15%–20% and most of the arable lands with a slope of over 25° needs to be transformed as forestland or grassland. To achieve this goal, it is necessary to make an investment in ecological system construction, such as water and soil conservation and an ecological agriculture demonstration project.

The detailed calculation list is shown in Table 4, including ecological construction investment costs for the forest, grassland and wetland, water and soil erosion control expense and an ecological agriculture demonstration project investment cost. Here, the cost of the construction of ecosystems covers the ecosystem maintenance, conservation expenses and the grassing and forestation expenses on the barren hills amongst other costs. The expense for water and soil erosion control includes the investment cost on the water and soil conservation project such as changing the slope land to terraces, checking dams, the sediment storage dam, the settling basin and so on. Generally speaking, the annual maintenance and improvement expenses for the water and soil erosion control project takes 10%–20% of the construction expense, 15% is chosen in this work [23]; the investment on the construction of ecological agriculture demonstration project is mainly the investment expenses used for developing green non-environmentally damaging agriculture such as Chinese herbal medicine, green vegetables, organic food and so on.

3.3 Calculation of the loss of development opportunity cost for the protection of the water source area

The (lost) development opportunity cost for the water source protection area is one of the most important parts of eco-compensation [24–26]. After the DRA dam heightening project in the water source area is completed, the submerged land area in the water source area of Shiyan City will amount to 158.7 km^2. Therefore the massive loss of the submerged area needs to be accounted for in the eco-compensation assessment. Most regions of Shiyan City are located in the core water resources protection area of the Dangjiangkou Reservoir, so a higher standard for local eco-environment construction is necessary. Not only will some local enterprises be obliged to conform to the national environmental standards and need to adopt cleaner techniques and enhance pollution treatment level, but some will even have to be shut down, thus leading to substantial financial and taxation losses, and a reduction in the employment and income of local residents. Although some development opportunity needs to be given up for the implementation of green development in the water source area itself, considering the equity in the integral socio-economic development environment, the main objective of these works is to guarantee the provision of supplies of increasingly scarce water resource for Beijing, Tianjin and Hebei in Northern China. Consequently the water source area of Shiyan is faced with greater dual pressures of eco-environmental construction and socio-economic development, and it is therefore reasonable that equitable compensation for this disadvantage should also be allowed for. In this research, the calculation of development opportunity cost for the protection of the water source area includes submerged area loss, the restricted industrial development loss, the added infrastructure reconstruction expenses and the loss of returning farmland to forest or grass. The detailed calculation items can be seen in Table 5.

The loss of farming and forest lands and enterprise in the submerged area is calculated for the submergence of the water source area. The loss brought about by the shutting down of enterprises includes the loss of operational income and pre-tax profit income. The item "closed enterprises" calculated in this work refers to those enterprises that are compelled to be closed down for the requirement of eco-environment construction of the water source area although they satisfy the requirements of the national laws, regulations and policies. The losses of these closed enterprises represent an extra income loss of the water source area; the transformation costs of some regulatory compliant enterprises are the extra investments that must be made for the upgrading transformation of the enterprises for the protection of the water source area. The enterprise relocation cost refers to the extra investment cost that is caused by the relocation of the enterprises that have a high environmental pollution risk. The total cost of the relocated and reconstructed infrastructure refers to the relocation and reconstruction expenses of the electricity grid, bridge and some water conservation facilities. The increased infrastructure investment is the newly increased infrastructure investment for the water source protection in the water source area of Shiyan City. Part of the agricultural land in the water source area must be transferred to forest land, the opportunity cost produced by changing the use of this portion of land can be regarded as the product benefit used as arable lands; 44 deformable bodies are thus newly added to the submerged area in the water source area of Shiyan, which will increase the investment in treating against landslide and collapse.

4 Burden sharing method of eco-compensation between the water source area and the external water reception area

In reviewing the existing research literature [15–20], we select the required water consumption volume, the beneficial degree of added ecological service because of the eco-environment construction of the water source area and the economic development level as the burden sharing factor of the eco-compensation between the water source area and the external reception area. First the total eco-compensation is separately apportioned between the water source area and the external water reception areas based on the selected three factors respectively, which is easy to determine.

The next question is how to integrate the results that are obtained with the SFBSM, namely, how to determine the weighting coefficient of each SFBSM? If the weighting coefficients of different burden sharing methods are determined by the subjective factor method such as the Delphi technique, involvement in the artificial factor probably make the fairness of the eco-compensation burden sharing to be questioned by the interested parties, and thereby encumber the implementation of eco-compensation burden sharing. Deviation square method (DSM), belonging to a category of a weighting synthesis method, and is often used in the investment apportionment of water conservancy projects [27–29]. Weighting coefficient of various SFBSM could be determined by counting how close the result of each SFBSM is to the mean value of the result of many SFBSMs. Due to no artificial factors in determining the weighting coefficient of each SFBSM, apportion result of the eco-compensation with this method can be easily accepted by all the interested parties. In this research, a synthetic eco-compensation burden sharing model is constructed based on the principle of DSM, and the burden sharing ratio of eco-compensation between the water source area and the external reception area is analyzed.

The mathematical models of apportioning the eco-compensation with the single factor method and DSM can be seen in Table 2:

1) The burden sharing method based on water consumption. The direct benefit level of the water supply services among various areas could be reflected by the respective proportion of acquired water volume. Thus the burden sharing of eco-compensation between the source area and the external water reception area could be calculated by the average water pricing method [20,29];

2) The burden sharing method based on the benefited ecological service level. The water source area provides many kinds of ecological services through the eco-environment construction, and the benefited proportion of the different ecological services in the water source area itself and the external water reception area is different. Generally the ecological service value is calculated according to the value coefficient of different land utilization types of the ecosystem [30]. The increased ecological service value of various land types such as forest land, grassland, farmland, waters, wetland are determined by carrying out ecological construction in the water source area of Shiyan City before and after the first-phase construction period of the MRP and is analyzed in this research. The calculated value of ecological service includes regulating climate, conserving water and soil, purifying water quality, protecting the biodiversity, producing foods, providing raw materials and recreational environment. The ecological service value coefficient of different land utilization types is referred to the work of Xie Gaodi [31], and the beneficial weighting of various types of ecological services provided by the water source area to the water source area *per se* and the external reception area can be referred to in the work of Cai Bangcheng [18]. With the changed data of land utilization types in the water source area of Shiyan City before and after the first-phase construction period of the MRP, the increased ecological service value provided by Shiyan is analyzed, and then the eco-compensation burden sharing between the water source area and the external benefited area is determined according to the respective benefited proportion of added ecological service value as a result of the eco-environment construction of the water source area;

3) The burden sharing method based on the maximum paying capacity (MPC). The per capital GDP is the most direct and effective parameter to weigh the economic development level of an area. Simultaneously it can also indirectly reflect the ability of the local people to pay for water, the area with low economic level suitably bears the lower eco-compensation expense for the water source area, and the area with high economic level bears the greater compensation expense, therefore the relative proportion of eco-compensation of the various benefited areas could be determined with the per capita GDP as the proportional factor of the various benefited areas set against that of the whole benefited areas [23].

The burden sharing calculation model of eco-compensation based on the DSM is constructed as follows: It is supposed that there are n SFBSMs, whose burden sharing coefficient X_i of the various SFBSMs are independent and non-correlated with each other, the mean value of the burden sharing coefficient of these SFBSMs is expressed as $\overline{X}$, namely $\overline{X} = \frac{\sum_{i=1}^{n} X_i}{n}$. Therefore for the burden sharing coefficient X_k of the k burden sharing method, consequentially the precision of X_k is worse with greater $\left|X_k - \overline{X}\right|^2$, namely, $\left|X_k - \overline{X}\right|^2$ is in the reverse direction with X_k value, accordingly, the burden sharing weighting coefficient W_k is lower. In the following, the function of W_k to $\left|X_k - \overline{X}\right|^2$ is constructed to reflect the degree of this reverse relation.

First the function is constructed as Eq.(1).

$$W_k^* = \frac{V}{V + \left(X_k - \overline{X}\right)^2}, \tag{1}$$

Hereinto,

$$V = \sum_{i \neq k}^{n} \left(X_i - \overline{X}\right)^2. \tag{2}$$

It can be seen evidently from Eq. (1) and (2), W_k^* is in the reverse direction with $\left(X_k - \overline{X}\right)^2$, standardizing W_k^* to W_k, so that $\sum_{k=1}^{n} W_k = 1$, namely $W_k = \frac{W_k^*}{\sum_{i=1}^{n} W_i^*}$;

It is supposed that $s^2 = \frac{\sum_{k=1}^{n} \left(X_k - \overline{X}\right)^2}{(n-1)}$

Therefore:

$$\sum_{k=1}^{n} W_k^* = \sum_{k=1}^{n} \frac{(n-1)s^2 - \left(X_k - \overline{X}\right)^2}{(n-1)s^2}$$

$$= \sum_{k=1}^{n} \left[1 - \frac{\left(X_k - \overline{X}\right)^2}{(n-1)s^2}\right]$$

$$= n - \frac{1}{(n-1)s^2} \sum_{k=1}^{n} \left(X_k - \overline{X}\right)^2 = n - 1.$$

It is derived from Eq. (1) and Eq. (2) that

$$W_k^* = \frac{\sum_{i \neq k}^{n} \left(X_i - \overline{X}\right)^2}{\sum_{i=1}^{n} \left(X_i - \overline{X}\right)^2} = \frac{(n-1)s^2 - \left(X_k - \overline{X}\right)^2}{(n-1)s^2}, \tag{3}$$

thus, the calculation function of the burden sharing weighting coefficient W_k can be acquired,

$$W_k = \frac{(n-1)s^2 - \left(X_k - \overline{X}\right)^2}{(n-1)^2 s^2}. \tag{4}$$

It is supposed that the integrated burden sharing coefficient of n burden sharing methods is expressed with C_c, then

$$C_c = \sum_{i=1}^{n} W_i \cdot X_i. \tag{5}$$

The estimated value of C_c is converged at the expected integrated burden sharing coefficient X following the probability theory [28], namely $C_c \underset{\rightarrow}{P} X$.

Table 2 Burden sharing calculation model of eco-compensation with the SFBSM and DSM

method	calculation model	definition of the parameters
water consumption based model	$E_i = Q_i \times \frac{E}{\sum_{i=1}^{n} Q_i}$ $C_i = \frac{E_i}{E} = \frac{Q_i}{\sum_{i=1}^{n} Q_i}$	C_i: burden sharing coefficient of the i area; Q_i: water reception quantity of the i area; E_i: burden sharing of eco-compensation of the i area; E: total eco-compensation amount; $i \in (1,5)$
ecological services value based model	$C_i = \frac{B_j}{\sum_{j=1}^{n} B_j} = \frac{\sum_{u=1}^{n}\sum_{v=1}^{n} \Delta A_u \cdot g_v \cdot h_{jv}}{\sum_{j=1}^{n}\sum_{u=1}^{n}\sum_{v=1}^{n} \Delta A_u \cdot g_v \cdot h_{jv}}$	B_j: ecological services beneficiary amount of the j regions; j_1: the water source protection area, j_2: the external water reception regions, j_3: the other regions of China, $j \in (1,3)$; ΔA_u: land area changes of the different land utilization type before and after the first-phase construction of the water source area in the MRP; v: various kind of ecological services provided by the water source area; g_v: different ecological services value coefficient of the different ecosystem; h_{jv}: weighting coefficient of the beneficiary level of the j regions
MPC based model	$a_i = \frac{\overline{gdp_i}}{\sum \overline{gdp_i}}$ $C_i = \frac{a_i}{\sum a_i}$	$\overline{gdp_i}$: per capital gdp of the i area; a_i : $\overline{gdp_i}$ of the i water reception area accounts for the total $\overline{gdp}$ of all the water beneficiary areas; $a_i > 1$ indicates the economic development level in the i area is higher than the average of the water beneficiary areas; $a_i < 1$ indicates the economic development level in the i area is lower than the average of the water beneficiary areas; $a_i = 1$ indicates the economic development level in the i area is close to the average of the water beneficiary areas $i \in (1,5)$

5 Data

The time span of the research is the first-phase construction period of MRP of the SNWT from 2004 to 2014. Here, the data of environmental control, ecological construction and development loss of the eight cities, counties or districts in Shiyan, namely Zhangwan District, Maojian District, Danjiangkou City, Yun County, Yunxi County, Zhushan County, Zhuxi County, Fang County from 2004 to 2009 are mainly collected by the relevant departments of the areas. Examples are water conservation, environmental protection, development and reform commission, forestry, agriculture and so on according to their actual situations, and part of the data come from the statistical yearbook of the areas. The data from 2009 to 2014 are estimated by the related departments of the areas in accordance with the goal of eco-environment construction plan of the first-phase of the MRP and the local socio-economic development plan.

The partial basic data are derived from Water Pollution Prevention And Water and Soil Conservation Plan of DRA and Upstream, Shiyan Statistical Yearbook and the regional statistical yearbooks. The basic data such as population, per capita GDP and other details of the receiving areas of Henan Province, Hebei Province, Beijing Municipality and Tianjin Municipality are derived from the statistical yearbooks of their local social economy. Because many data have to be acquired in this research, there might be some problems in the accuracy of the data source. First, although the data involved in the study are obtained through statistics with the help of the relevant governmental departments in the research areas, some data might not conform to the actual situation. Secondly, the related data from 2010 to 2014 are obtained through a forecast of the areas, which might be different from the actual situation in the future. However, this research will clarify the potential eco-compensation standard. In addition, an approximate evaluation of the eco-environment construction costs and the loss of the development opportunity costs in the study area can provide scientific support for further formulation of the eco-compensation public policy. What is more, the established eco-compensation standard analysis framework will also provide reference for further research in the future, and the insufficiency of this research and the research direction to be developed in the future is pointed out, which is favorable for developing research in this aspect in the future.

6 Results and discussion

6.1 Calculation results and analysis of the total eco-compensation

According to the calculation method of eco-compensation standard in section 3, the eco-compensation of the total pollution control cost, ecological construction cost and the lost development opportunity cost is 5.46×10^9, 4.00×10^9 and 6.75×10^9 CNY, respectively. The multi-year average eco-compensation standard is respectively 5.46×10^8, 4.00×10^8 and 6.75×10^8 CNY·a^{-1} (Tables 3–5). The total opportunity cost of eco-environment construction and development loss of Shiyan is obtained as 1.62×10^{10} CNY, the yearly average compensation standard is approximately 1.62×10^9 CNY·a^{-1} (Table 5). The calculation of the eco-compensation of returning farmland to forest is as follows: In the first-phase construction period of the MRP, the total area of returning farmland to forest is 2.08×10^4 ha. If the average output value level of unit agricultural land area of Shiyan City is 3.0×10^4 CNY·ha^{-1} in recent years, then the opportunity cost of returning farmland to forest is obtained as 6.24×10^8 CNY. The inundated area created by the heightened Dangjiangkou Reservoir dam construction in the water source area is mainly located at 37 towns in Danjiangkou City, Yun County and Yunxi

Table 3 Pollution control cost in the water source area (1.00×10^8 CNY)

cost items	Maojian District	Zhangwan District	Danjiangkou City	Yun County	Yunxi County	Zhushan County	Zhuxi County	Fang County
sewage treatment plants	1.50	4.56	7.16	1.21	1.22	0.76	4.99	13.40
sanitary landfill sites	1.20	1.60	0.88	3.90	0.75	0.23	2.65	4.95
medical waste treatment center	0.00	0.21	0.00	0.00	0.00	0.00	0.00	0.12
capability building of water quality monitoring	1.00×10^{-2}	0.00	9.87×10^{-2}	0.27	0.10	1.93×10^{-2}	0.12	0.28
capability building of the environmental protection department	2.30×10^{-2}	5.90×10^{-3}	0.22	0.30	0.10	1.62×10^{-2}	0.28	1.47
overall	54.6							
annual average	5.46							

Table 4 Water and soil conservation and ecological construction cost in the water source area (1.00×10^8 CNY)

cost items	Maojian District	Zhangwan District	Danjiangkou City	Yun County	Yunxi County	Zhushan County	Zhuxi County	Fang County
forestry construction	7.00×10^{-4}	0.00	0.00	2.00	0.30	0.00	0.70	0.00
grassland construction	0.00	0.00	0.00	0.49	0.00	0.00	0.00	0.00
wetland construction	0.00	0.00	0.00	1.32×10^{-8}	0.00	0.00	1.54×10^{-8}	0.00
water and soil erosion treatment	5.80	1.54	5.55	4.11	6.49×10^{-2}	1.10×10^{-2}	0.55	2.28
Ecological farming demonstration construction	0.00	3.36	1.93	2.09	1.25	0.00	3.41	4.56
overall	40.02							
annual average	4.00							

Table 5 Loss of development opportunity cost in the water source area (1.00×10^8 CNY)

calculation items		Maojian District	Zhangwan District	Danjiangkou City	Yun County	Yunxi County	Zhushan County	Zhuxi County	Fang County
submerged area loss	farming and forest lands	0.00	0.00	1.24	0.94	2.58	0.00	0.00	0.00
	enterprise	0.03	0.00	1.00	5.35	4.50	0.00	0.00	0.00
enterprises shutting	operational income	0.00	0.00	0.15	1.41	7.87	0.00	2.26	0.38
down Loss	pre-tax profit income	0.01	6.45×10^{-2}	3.81×10^{-2}	0.32	0.89	0.14	0.41	0.27
transformation costs of the regulatory compliant enterprises		0.00	0.27	0.57	1.92	0.00	0.00	0.00	5.50×10^{-2}
cost of the relocated enterprise		0.00	0.00	2.76	5.25	0.00	0.00	0.00	0.00
cost of the relocated and reconstructed infrastructure		1.20×10^{-2}	0.00	0.00	12.28	0.30	0.00	0.00	0.00
the added infrastructure reconstruction expenses		0.00	0.00	1.00	4.50	0.60	0.00	0.00	0.00
loss of returning farmland to forest or grass		1.75×10^{-2}	0.26	0.64	2.97	0.52	1.48×10^{-2}	1.90	0.42
landslide and collapse controlling expenses		0.00	0.28	0.00	0.91	0.15	0.00	0.00	0.00
overall		67.46							
annual average		6.75							

Table 6 Inputs of eco-compensation to the water source area (1.00×10^8 CNY)

	Maojian District	Zhangwan District	Danjiangkou City	Yun County	Yunxi County	Zhushan County	Zhuxi County	Fang County
the 8 regions respectively	8.60	12.73	23.24	50.22	21.19	1.19	17.27	28.19
annual average of the 8 regions respectively	0.86	1.27	2.32	5.02	2.12	0.12	1.73	2.82
overall	162.63							
annual average	16.26							

County. The area of lost arable land and forest land in the inundated area are altogether 1.59×10^4 ha. There are 3.0×10^3 ha of arable land and 1.08×10^3 ha of economic forest lands to be inundated in Danjiangkou; 2.65×10^3 ha of arable land and 4.92×10^2 ha of forest land to be submerged in Yun County; 8.60×10^3 ha of arable land to be submerged in Yunxi County. The loss of arable land and forest land in the inundated area is also calculated with the opportunity cost of transforming the arable land into the forest land as 4.76×10^8 CNY in total.

According to the Water Pollution Control and Water and Soil Conservation Planning of DRA and Upstream implemented by the State Council in a written reply on February 2006, the central government finances 60% of the costs of eco-environment construction during the first-phase of the MRP. Another 40% needs to be levied locally. The total national investment is approximately 2.60×10^9 CNY, and the total investment budget estimate is 4.33×10^9 CNY. But in fact, according to the calculation in our work, the expense of the eco-environment construction during the first-phase construction period of MRP will reach 9.45×10^9 CNY, so the gap of investment demand and the planned budget is approximately 5.13×10^9 CNY. This is mainly because the necessary investment items such as the matched investment on the capability building of environmental protection departments, the operational maintenance expense of pollution treatment facility, the management and maintenance expense of water and soil conservation etc are not taken into account in the initial eco-environment construction plan of the water source area of the MRP, and that there is inevitably a deviation between the related planning investment and the actual demand of eco-environment construction. In December 2008, the Ministry of Finance of China issued Ministry of Finance's notification on the fiscally transferred payment to the ecological source reserve of Yangtze, Lancang and Yellow River etc in 2008. From this, 3.07×10^8 CNY has been transferred to DRA in Shiyan, Hubei Province for eco-compensation. Even so, the eco-compensation is still insufficient. The protection of the water source area in Shiyan is still faced with a large funding gap for eco-environment construction.

Moreover, the finance paid by the central government is only transferred to the local finance of the eight districts, cities and counties in Shiyan to make up the local fiscal pressure, but how to compensate members of the public who have suffered a greater loss has not yet been considered. In addition, the compensation for the major lost development opportunity cost for the protection of the water source area due to the restricted development space is also not considered in the initial plan period of the MRP, which according to the calculation in this research amounts to 6.75×10^9 CNY. It is noteworthy that the economic development level of the water source area is low. Except for the two districts of Maojian and Zhangwan in Shiyan, the other six counties and cities were national poverty counties. To complete the political task of supplying high quality water, the governments of the water source area have to depend upon their own increased investment and loans to solve the problem. For example, the debt of 1.83×10^8 CNY is owed to the bank in the construction of the local Shengding River Sewage Treatment Plant. Therefore the water source area is faced with huge dual pressures of ecological environmental protection and sustainable development of social economy.

The investment plan of the eco-environment construction project determined in Water Pollution Control and Water and Soil Conservation Planning of DRA and Upstream has already been implemented for more than five years, which should be suitably adjusted according to the actual expense and funding demand of eco-environment construction of the water source area. The fiscally transferred payment policy on eco-compensation of the Ministry of Finance in China for the water source area should be further improved. Scale adjustment should not only be made on the basis of calculating the ecological service value supplied by the eco-environment construction of water source area, but also on how to benefit the people who suffer in the water source area. The central government of China should not only increase fiscal investment on the eco-environment construction of the water source area in Shiyan, but also adopt many other compensation methods, especially increasing the policy compensation for the people affected in the water source area of Shiyan. For example, offering the people free vocational education, implementing skill training to enable them work in new trades with sufficient skills, which can also alleviate Shiyan's eco-environment construction pressure to a certain extent. Moreover, because the water source area of Shiyan loses more industrial development opportunities compared with other places, so it will encounter difficulty and pressure in industrial choices and adjustment. Green development of this place needs to restructure its social economic system. In the meantime, it is well known that industrial adjustment and substitution is a long-term process, which will affect the development of local economy for a long time. Moreover, it should be realized that economic development of the water source area is an important precondition to protect water quality. Without solving the problem of survival and development of the locality, it is hard for the protection of water resources to last long; there are many lessons to learn from this aspect [32–35]. It is suggested that the Chinese government should set up a green economic development fund of the DRA, construct a pilot area of green economic development in the DRA, and promote the depth adjustment of economic structure in the water source area and the development of green industries.

6.2 Results and analysis of eco-compensation burden sharing

According to the Water Pollution Control and Water and Soil Conservation Planning of DRA and Upstream, at the end of the first-phase construction of the water diversion project, the industrial and domestic water consumption in Shiyan City is 2.79×10^8 m^3. The multi-year average annual amount of transferred water is 9.50×10^9 m^3. At the same time, the allocated water quantity of various provinces and municipalities in the water reception area is 3.77×10^9 m^3 in Henan Province, 3.47×10^9 m^3 in Hebei Province, 1.24×10^9 m^3 in Beijing Municipality and 1.02×10^9 m^3 in Tianjin Municipality. Thus, the burden sharing coefficients of the water source area itself and the external water reception area with the water consumption based sharing method can be calculated as 0.03 and 0.97 respectively. With the burden sharing method based on the benefited ecological service level, we can calculate that the newly increased ecological service benefit of the eco-environment construction in the water source protection area totals 3.05×10^8 CNY, of which the ecological service benefit of the water source area amounts to 9.51×10^8 CNY. Therefore, the burden sharing coefficients of eco-compensation of the water source area and the external beneficiary area of ecological service are 0.31 and 0.69. In 2007, the per capita GDP in Shiyan City, Henan Province, Hebei Province, Tianjin Municipality and Beijing Municipality are respectively 11793, 16088, 19967, 45007 and 55151 RMB Yuan. With the eco-compensation burden sharing model based on the maximum paying capacity we can calculate that the burden sharing ratio of Shiyan City to the external water reception area is 0.12:0.88. With the burden sharing coefficient results obtained by the above three single indicator methods, the weighting coefficients W of the water source area and the external water beneficiary calculated with Eq. (4) in section 4 are respectively 0.30 and 0.31, 0.21 and 0.20, 0.49 and 0.49. Thus, the burden sharing ratio of eco-compensation of the water source area and external beneficiary area obtained with DSM is 0.13:0.87 calculated with Eq. (5) in section 4, namely the burden sharing of eco-compensation of the water source area and the external beneficiary area is 2.11 $\times10^9$ CNY and 1.42 $\times10^{10}$ CNY, which indicate that the external beneficiary area should share a larger part of the eco-compensation.

It can be seen from the burden sharing results of eco-compensation of the three SFBSMs based on the water consumption volume, ecological service benefit level and maximum paying capacity greatly differed from each other, so it is easily imagined that it is hard to reach an agreement among the interested parties if the eco-compensation is apportioned with any SFBSM. Therefore, eco-compensation burden sharing based on DSM provides us with a new thought, in which the three key single factors affecting the eco-compensation are comprehensively considered and the weighting coefficient of each burden sharing method is objectively determined.

It is indicated by the burden sharing results based on DSM that the external water reception area is the major beneficiary party of the eco-environment construction of the water source area. As the first-phase construction of the MRP is dominated by the Chinese central government, Henan Province, Hebei Province, Tianjin Municipality and Beijing Municipality, the major beneficiary areas of water supply service, have not participated in the development of the eco-compensation mechanism. The externality indicates the virtual unfairness in existence of the eco-environment construction of the water source area, which does not conform to the 'building and sharing together' principle of the eco-environment construction of the water source area of the water diversion project. In addition, the eco-compensation payment that should be shared by the water source area is comparatively small, which is about 13%. However, as a matter of fact, at present, the eco-environment construction of the water source area is mainly invested by the water source area itself. Therefore, according to the principle of fairness, the external parties should increase the support to the water source area, and the burden sharing ratio of eco-compensation calculated in this research can be referred for making relevant policies. Under China's current policy background, the following proposals can be referred to eco-compensation policies design:

1) The governments of the water reception area compensate the water source area through horizontal fiscal transfer payment;

2) The water reception area raises the compensation fund for the ecological construction of the water supply area through collecting the eco-compensation fee of SNWT;

3) Besides the financial compensation provided by the government of the water reception areas to the water supply area, the coordinated assistance, intellectual support and guidance of the local green capital to be invested into the water source area may be given consideration.

7 Conclusions

In this paper, studies are made on the eco-compensation standard to the water source area of Shiyan City, Hubei

Table 7 Burden sharing coefficient of eco-compensation calculated with the SFBSM and DSM

burden sharing calculation method	burden sharing coefficient of the water source area and the external water reception area
water consumption quantity based method	0.03:0.97
benefited ecological service value based method	0.31:0.69
MPC based method	0.12:0.88
DSM based method	0.13:0.87

Province in the first-phase of the MRP of the SNWT. As there is still no unanimous consent for the calculation method of an eco-compensation standard [11], calculation of the eco-compensation to the water source area is inevitably controversial. Moreover, as mentioned above, a lot of real and effective data are needed to support the calculation of eco-compensation standards. Although much careful data investigation and collection work has been done in this research, it is also inevitable to deviate from the actual situation, which has also affected the precision of calculation of any eco-compensation standards to a certain extent. Even so, this current research can provide certain reference for the government to formulate related policies and a kind of reference for related further research.

In addition, the conceptual boundary of eco-compensation is a controversial topic, either used in both broad or narrow sense. For instance, Pagiola [36] states that ecological compensation can be defined as giving certain subsidy to the managers of natural resources, who offer ecological services so as to enhance their enthusiasm to protect and provide these services. Engel [37] states that any market-based ecological protection mechanism can be considered as eco-compensation. Li [38] states that connotation of eco-compensation includes two aspects, one is the ecological service beneficiaries compensating the ecological service providers for the costs and losses that result from protecting the eco-environment. The other is the eco-environment destroyers should compensate the victims who suffer from the eco-environmental damage. Moreover, even if the concept of eco-compensation is used in a broad or narrow sense, there are also different understandings of the connotation of the concept. In fact, because of the complexity of the ecosystem and diversity of the product and service provided by it, it is inevitable to some extent that understanding and definition of the connotation of eco-compensation by the different researchers with different research goals often differ widely. Therefore, it is very difficult to form an identical understanding of the calculation scope of eco-compensation. But there is an attempt in our work to establish an analytic framework to calculate the eco-compensation standard of the water source area from the viewpoint of the eco-environment construction and the development opportunity cost losses, which can provide a new analytical thought for the related research.

In fact, the opportunity cost that results from the environmental capacity losses brought about by the improved requirement of the water quality in the water source area is also one of the important factors of eco-compensation. The water transfer project requires that water quality in the DRA should conform to Chinese surface water class II Standard, and any branches which converge into the Danjiangkou reservoir should be maintained at least above Chinese surface water class standard III throughout the year. Higher requirement for water quality from the water source area is actually equivalent to meaning that less pollutants are allowed to be discharged in the area. Environmental capacity is a concept to characterize the allowed pollution emission level in an area, so higher requirement for the water quality objectives of the water source area indicates certain environmental capacity loss, and environmental capacity loss restricts the amount of pollution emission in the locality. Seen from another perspective, the water source area loses a certain development space, therefore the reduced value of environmental capacity losses of the water source area should be included in the eco-compensation category. However, only wide scale 'on-the-spot' investigation can confirm the environmental capacity of the water source area. In this research, this problem is not involved, but here we point out that it is also an important problem for the study on the eco-compensation standard, which also makes calculation of eco-compensation standard in this research be underestimated to a certain extent.

Theoretically, the eco-compensation amount to the water source area should be apportioned according to the benefited degree of the ecological product or service by the water source area itself and the external water reception area. But it is usually difficult to operate in practice, the reason being that burden sharing results of eco-compensation often differ greatly when calculated with different methods, so that it is difficult for the interested parties to reach a unanimous consent on the eco-compensation burden sharing scheme. In this research, we make an attempt to study the eco-compensation burden sharing with the theory of DSM that is often used in the apportionment of the construction cost of water conservancy projects. The DSM covers the main factors affecting the burden sharing of eco-compensation, without subjective factors involved in the calculation process of the burden sharing weighting coefficient of the different burden sharing methods, with transparent burden sharing process, and various burden sharing results with the SFBSM can be comprehensively processed better. Therefore the apportionment results determined by this method can be more easily accepted by the interested parties, which is advantageous to the implementation of eco-compensation burden sharing in practice. But even so, just as above-mentioned, that application of this method is only an attempt, which aims at providing a thought for the study on the eco-compensation standard of the water source area in Shiyan, in Hubei in the middle route of SNWT. Moreover, there are still many problems in the details of the method applied in the paper. For instance, water utilization structure of the various industrial sectors in the different areas should be taken into consideration, as the value of water resources differs in the industrial, domestic, agricultural and the ecological water fields, so future research in these aspects still needs to be carried out.

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