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Study on Ecological Compensation Mechanism of Xin’an Spring Water Source Protection Zone in Shanxi Province, China

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Abstract

As one vital function of water resource for human beings, providing drinking water has become a big problem nowadays, in cases that water resource faces a serious quality and quantity problem. To resolve this issue, one major measure is to establish water resource protection zone. Thus, the ecological compensation mechanism should be coupled with the protection zone construction, because this, according to studies on economics and environment field by many scholars, is an effective and essential measure to maintain the passion of residents and government in water source area to protect the water quality and the ecology there. In this paper, we discussed and promoted one approach to constitute and consummate the ecological compensation mechanism, in order to fulfill a win-win situation between water source protection and economic development. According to the general ecological compensation standard literatures and the specific situation of Xin’an Spring area, we selected ecological service providing cost and ecological value as the calculation basis in this paper. By calculating and analyzing, we got the compensation value for Xin’an Spring water source protection area should be 22.9495 million yuan, and the results could be a little modified under different premises of taking the benefit modifying coefficient.

Keywords: ecological compensation mechanism; water source protection zone; ecological service providing cost; ecological value; compensation adjustment

1. Introduction

The concept of ecological compensation was first illustrated in the natural world perspective. With the development of the society, more and more scholars started to do research on it from the economic perspective. Rather than ecological compensation, scholars abroad always applied the concept of Payment for Ecological Services (PES) or Payment for Ecological Benefit (PEB) in their studies and practice [1-2]. Before the early 1990s in China, researchers took the fee which was to pay for the environmental pollution as kind of responsibility. Thus, the
fee was taken as an economic means to stimulate the pollution makers to reduce the damage to environment and ecology\cite{3-4}. Since the late 1990s, the economic meaning of ecological compensation has been enlarged from the fee for the pollution only to the compensation of environmental conservation as well\cite{5}.

At present, the study on ecological compensation in China is mainly based on the methods of evaluation on ecosystem service, which usually includes market value approach, willingness to pay approach, opportunity cost approach and cost analysis approach\cite{6-8}. In some other countries, study on ecological compensation pays more attention to the willingness to pay and the configuration of the compensation\cite{9-10}.

As to the specific calculation of ecological compensation, the present research mainly concentrated in the following aspects\cite{10-13}.

First, calculate according to the ecological service providing cost. The cost includes the direct input to protect ecology and the opportunity cost. Theoretically, the ecology service providing cost should be the minimum standards of the compensation.

Second, calculate according to the benefit gotten. Ecological beneficiaries should pay the cost of ecological conservation activities, which is in order to initiate the externality. This part of calculation could be done based on the data of market price and volume of the related products or services.

Third, calculate according to the cost of ecology damage recovery. The damage, like the destruction of water resources and vegetation and soil erosion, caused by resource development, would affect some eco-system service function like the water and soil conservation, landscaping and climate regulation. Therefore, the cost of ecology damage recovery can be one database of compensation calculation.

Fourth, calculate according to the ecosystem value. The result got by this way is usually taken as the reference of the theoretical maximum value of compensation. To calculate this value, we usually concern the eco-system service functions like water and soil conservation and climate adjustment caused by the environmental and ecological protective producing and operating mode.

As to the study on ecological compensation in water source protection zone, most relevant content is called PES (Payment for Environmental Service or Payment for Ecosystem Service), or PEB (Payment for Environmental Benefit), which is to express a trade on environmental service value between the two of enterprises, farmers and government. In other words, ecological compensation researches are mainly based on market rather than government intervention or other means, especially in other countries\cite{14}.

The theories of ecological compensation in water source area are mainly including ecological environment value theory, public goods theory and externality theory\cite{9,15-18}.

In this paper, we concentrated on the area of Xin’an Spring water source, trying to promote one approach to constitute and consummate the ecological compensation mechanism, especially for the water source area.

2. Overview of the Study Area

2.1. Survey of Xin’an Spring water source protection zone

Xin’an Spring, located northeast of Changzhi City in Shanxi Province, is the second largest spring in Shanxi Province, with the area of 10,950 km². The annual average flow of Xin’an Spring is 10.10 m³/s.

The main river in the spring area is Zhuozhang River, which belongs to Wei River System (see Figure 1). In the upstream of Zhuozhang River, there are three tributaries. The three tributaries flow together in Xiaojiao village and then flow from north to south till Xin’an village, then flow to east across Hebei Plain. Xin’an Spring water source area is important to supply drinking water for residents of Changzhi City, with the total water supply capacity of 172,800 m³/d.
Figure 1: Xin’an Spring area
The main spring exposed area and the main protection zone area is Lucheng, which is a county-level city of Changzhi.

The total population of Lucheng in the year 2007 is 21.89 million, including agricultural population of 17.50 million, which is 79.95 percent of the total population, and non-agricultural population of 4.39 million, which is 20.05% of the total. The GDP of Lucheng reached 5.65 billion yuan in 2007; Per capita GDP is 25,428 yuan. Among them, the agricultural output value is 236 million yuan; forestry output value is 800 million yuan; animal husbandry output value is 119 million yuan; fisheries output is 1.65 million yuan.

2.2. Status and problems of water resources

Through literature review and field research, we found some major problems in Xin’an Spring water source protection area as following: karst groundwater level declining, drying up of some springs, karst water pollution, and water ecological environment serious damaging. Meanwhile, all the reservoirs in the basin has played only a small part of role of flood control and agricultural water; the surface water is not used effectively, even when river water volume increases at the time the reservoirs abandoning water in January-February each year, the amount of surface water use is also small, thus, a large number of high-quality groundwater is exploited.

Because of the problems above, the ecological compensation mechanism of Xin’an Spring water source protection area should be established to limit irrational water and land resource exploitation activities, and to encourage ecological and environment protection activities. This is significant to make the water ecological environment good and healthy in Xin’an Spring area, and to make the regional economic a sustainable development.

3. Modeling Formulation

When doing ecological compensation of water conservation and protection area, we should first determine the scope, subject and object of ecological service, and then considerate comprehensively combined with the supply and demand for the ecological service.

3.1. Research scope determination of ecological compensation mechanism in Xin’an Spring water source protection zone

According to the natural and social survey analysis above, coupled with the clear prescription to the 19 Karst Spring in Shanxi Province protection given in Water Resources Protection Ordinance in spring area in Shanxi Province, we designated the key protection area. However, water source protection zone, in practice, has not been designated particularly yet.

In 2008, Shanxi Academy of Environmental Sciences and Environmental Protection Bureau of Changzhi City did some research on Xin’an Spring protection zone designation, and designated the preliminary delineation of the drinking water source protection areas the spring area (Figure 2 ).
Figure 2: preliminary Xin’an Spring water source protection area
Based on Xin’an Spring Water Resource Protection Area boundaries, the research scope, in this paper, is initially determined as part of Xin’an Spring Water Source Protection area, which is in Lucheng.

3.2. Subject and object analysis of the ecological compensation in Xin’an Spring Water Source Protection Zone

The analysis on subject and object of the compensation is shown below.

![Flowchart showing subject and object analysis]

3.3. The ecological compensation standard determination of Xin’an Spring water source protection zone

According to the general ecological compensation standard literatures and the specific situation of Xin’an Spring area, in this paper, we selected ecological service providing cost and ecological value as the calculation basis.

In the relevant elements of ecological compensation, increment the ecological service value includes water quality improvements, water volume increasing, soil erosion reduction, etc.; the cost estimates include ecological and environmental protection investment, the losses in economic and social development; water resource value refers to the water quality and quantity provided by water source area to downstream, and its contribution to social and economic development in the downstream area; the greatest willingness to pay is the maximum value that benefactors or the destructionists of water sources are willing to pay for improving ecosystem services; ability to pay means the local financial ability and income level.

When calculating ecological value, we should first consider various aspects to estimate the economic value of the water, including domestic, industrial and agricultural water use, aquatic production, recreation, flood control, soil conservation, water purification, biodiversity maintenance and so on; and then sum them up to get the total economic value.

\[ V = \sum_{i=1}^{N} \sum_{j=1}^{n} P_{ij} \times W_i \]

In the formula, \( V \) refers to ecosystem service value; \( i \) means all the ecological environmental elements in the ecology - economy - Society System; \( j \) is every specific ecosystem service, \( P_{ij} \) refers to the unit value of the specific ecosystem service, say each \( j \), in each ecological environmental element, say each \( i \). \( W_i \) means the total area, volume or weight of each \( i \).

The direct and the indirect cost of water conservation and ecological protection together constitute the total cost, namely, \( C = DC_t + IC_t \).

1. The direct cost (\( DC_t \)) is all the direct input that the measures of water and ecological conservation cost, including the direct protection cost in the water source protection zone (\( DPC_t \)), direct forest ecology protection cost (\( DFC_t \)), direct managing cost (\( DMC_t \)) and other direct cost (\( DOC_t \)).

Then, \( DC_t = DPC_t + DFC_t + DMC_t + DOC_t \).
The indirect cost ($IC_t$) refers to the potential development loss from limiting the development of some local industries, which is to conserve water and ecology in the water source protection area. The $IC_t$ includes indirect soil cost ($ISC_t$, which refers to defarming loss), indirect resettlement cost ($IRC_t$), indirect economic cost ($IEC_t$, which refers to the economic loss from the development limitation) and other indirect cost ($IOC_t$). In this paper, we considered the development limitation loss of Lucheng and the opportunity cost of conserving the water source. We chose Changzhi City as a reference, and selected the statistics of 2007 to doing calculation.

In this paper, we determined the compensation standard based on ecological service providing cost ($C_t$) and the ecosystem service value ($V$), and the standard should be a value between $C_t$ and $V$. As the ecological compensation is mainly done by government at present, the standard should be a little greater than ecological service providing cost.

(1) Compensation adjustment coefficient ($KD_t$): based on the ecosystem service value ($V$), ecological service providing cost ($C_t$), and the willingness and ability to pay, combining with multi-consultation, gaming and balancing, we set $KD_t$ ($0 < KD_t < 1$) as 0.5, and initially set the compensation base, say $M_b$.

$$M_b = C_t + KD_t(V - C_t)$$

(2) Water supply adjustment coefficient ($KV_t$), refers to the proportion that the water supply to reception region or industry from the water source area ($W_r$) counted from the total water supply ($W_t$), thus the compensation value that reception area should take is $M_b \times KV_t$.

$$KV_t = \frac{W_r}{W_t} \quad (0 < KV_t < 1)$$

Then, here,

(3) Water quality adjustment coefficient ($KQ_t$), means the subsidies that the water source area got because of providing reception area better water than that required in the water quality standard. Here, we took COD concentration as indicators of administrative border section. Suppose the water quality standard required in the section is $S$ (mg / L), when water quality in the section $Q_t$ is worse than $S$, despite of $M_b$, the cut down COD when the water quality is $Q_t$ rather than $S$, say $P_t$, should be compensated. Setting the input of annual unit COD emission reduction as $M_t$, then the subsidies should be $P_tM_t$.

$$KQ_t = 1 + \frac{P_tM_t}{M_b}$$

Then,

(4) Efficiency adjustment coefficient ($KE_t$) refers to the extra subsidy when income or benefit of ecological construction is greater than anticipation input. $KE_t$ varies of different industries, and the ecological construction positivity could be maintained only when the coefficient is greater than 1.

(5) Regional differences coefficient ($KL_t$): the benefit bringing from different cube water or different quality of one cube water varies in different regions, so that the comparative losses (the opportunity cost) are different. According to the local economic development level, volume of local water or ecological environment frangibility, we evaluated based on various combination to determine $KL_t$.

Table 1. Regional differences coefficient
In summary, the compensation calculation formula should be:

\[
M_j = [C_t + KD_t(V - C_v)] \times \frac{W_t}{W_v} \times (1 + \frac{PM_c}{M_c}) \times KE \times KL
\]

3.4. Ecological value calculation

When calculating ecological value, we should first consider various aspects to estimate the economic value of the water, including domestic, industrial and agricultural water use, aquatic production, recreation, flood control, soil conservation, water purification, biodiversity maintenance and so on; and then sum them up to get the total economic value. Theoretically, the market value of ecosystem service function is the real basis and standard of compensation. However, people’s willingness to pay vary widely because of the immature valuation method. Thus, most quantitative results, in consequence, can not be applied to relevant policy-making and practice directly. Therefore, we mainly considered the ecological value which can be determined in this paper, including the domestic, industrial and agricultural water use value, water purification value, and recreation value of the water resource of Xin’an Spring water source area.

Thus, the domestic water use value = 2.5 yuan \times 26.6364 million m^3 = 66.591 million yuan; the industrial and agricultural water use value = 4 yuan \times 9.3936 million m^3 = 37.5744 million yuan. (data source: Water Supply Corporation of Changzhi City)

Water purification value here was estimated according to the cost of reducing COD emission to the standard level. In accordance with the model of pollutants reduction cost of the sewage treatment plant, unit cost of COD emission reduction is 0.79 yuan/kg. And according to the water quality standard in water source protection area, say Class II, and the emissions in Xin’an Spring area, the current exceeded COD emission is 1428.675 t/a. Therefore, we got the cost of reducing COD emission to the standard level, which is 1.1429 million yuan.

\[
V = \sum_{i=1}^{m} \sum_{j=1}^{n} P_{ij} \times W_{ij}
\]

= domestic water use value + industrial and agricultural water use value + water purification value + recreation value = 66.591 + 37.5744 + 1.1429 + 0.2 = 105.5083 million yuan
In the formula, $V$ refers to ecosystem service value; $i$ means all the ecological environmental elements in the ecology - economy - Society System; $j$ is every specific ecosystem service, $P_j$ refers to the unit value of the specific ecosystem service, say each $j$, in each ecological environmental element, say each $i$. $W_i$ means the total area, volume or weight of each $i$.

3.5. Ecological service providing cost calculation

The direct and the indirect cost of water conservation and ecological protection together constitute the total cost, namely $C_t = DC_t + IC_t$.

(1) The direct cost ($DC_t$) is all the direct input that the measures of water and ecological conservation cost, including the direct protection cost in the water source protection zone ($DPC_t$), direct managing cost ($DMC_t$) and other direct cost ($DOC_t$). After calculating, we got: $DC_t = 22.3064$ million yuan

(2) The indirect cost ($IC_t$) refers to the potential development loss from limiting the development of some local industries, which is to conserve water and ecology in the water source protection area. The $IC_t$ includes indirect soil cost ($ISC_t$, which refers to defarming loss), indirect resettlement cost ($IRC_t$), indirect economic cost ($IEC_t$, which refers to the economic loss from the development limitation) and other indirect cost ($IOC_t$). In this paper, we considered the development limitation loss of Lucheng and the opportunity cost of conserving the water source. We chose Changzhi City as a reference, and selected the statistics of 2007 to doing calculation.

Then, we got $IC_t$.

$$IC_t = \frac{\bar{\text{per capital disposable income of urban residents of Changzhi}} - \bar{\text{per capital disposable income of urban residents in Lucheng}}}{\text{population of urban residents in Lucheng}} \times \frac{\bar{\text{per capital net income of rural residents in Changzhi}} - \bar{\text{per capital net income of rural residents in Lucheng}}}{\text{agricultural population of Lucheng}}$$

$$= (12418.5 - 9413) \times 43955 + (5226 - 4769) \times 175000$$

$$= 21,208,200 \text{ yuan} = 21.2082 \text{ million yuan}$$

(3) Then, the total cost is

$$C_t = DC_t + IC_t = 43,514,600 \text{ yuan} = 43.5146 \text{ million yuan}$$

4. Results and Discussion

4.1. Calculation results on ecological compensation

(1) Based on the ecosystem service value ($V$), ecological service providing cost ($C_t$), and the willingness and ability to pay, combining with multi-consultation, gaming and balancing, we set $KD_t$ (compensation adjustment coefficient, and $0 < KD_t < 1$) as 0.5, and initially set the compensation base, say $M_b$.

$$M_b = C_t + KD_t(V - C_t)$$

$$= 43.5146 + 0.5(105.5083 - 43.5146)$$

$$= 74.51145 \text{ million yuan}$$
(2) Water supply adjustment coefficient ($KV_t$), refers to the proportion that the water supply to reception region or industry from the water source area ($W_r$) counted from the total water supply ($W_t$), thus the compensation value that reception area should take is $M_b \times KV_t$. Then, here, $KV_t = \frac{W_r}{W_t} = \frac{4.3}{15.3} = 0.28$, ($0 < KV_t < 1$)

(3) Water quality adjustment coefficient ($KQ_t$). According to the formula $KQ_t = 1 + \frac{P_M}{M_b}$, and as the water quality of water resource has not reached Class II water quality standard, we set the water quality adjustment coefficient as 1.0.

(4) Efficiency adjustment coefficient ($KE_t$) obtained 1.1 (Delphi)
(5) Regional differences coefficient ($KL_t$) took 1.0.

In summary, the compensation calculation formula should be:

$$M_f = \left[ C + KD_t(V - C_v) \right] \times \frac{W_r}{W_t} \times (1 + \frac{P_M}{M_b}) \times KE_t \times KL_t$$

$$= [43.5146 + 0.5 \times (105.5083 - 43.5146)] \times 0.28 \times 1.0 \times 1.1 \times 1.0$$

$$= 22.9495 \text{ million yuan}$$

4.2. Discussion

The present result, 22.9495 million yuan, is got under the premise of taking the benefit modifying coefficient $KE_t$ as 1.1 and the compensation adjustment coefficient $KD_t$ as 0.5 ($KE_t$ and $KD_t$ are set by multi-consultation, gaming and balancing).

If $KD_t=0.6$, we can get the final compensation result as 24.85877 million yuan;
If $KD_t=0.7$, we can get the final compensation result as 26.76834 million yuan;
If $KD_t=0.8$, we can get the final compensation result as 28.67774 million yuan.

The results are gotten based on the data of the year 2007 and before, which can be a reference of other ecological compensation program in the recent years. When doing calculation, part of the direct cost is one-off input, so this part should be compensated first in the beginning of the compensation implementing. Despite of the one-off capitalized input, there is some current input, such as management input and other, which should be compensated in a long term. Therefore, when implementing compensation program in the later years, the compensation should be converted into the effective local public service stepwised.

5. Conclusion

By calculating and analyzing, we got the compensation value for Xin’an Spring water source protection area should be 22.9495 million yuan, and the discussion and modifying of the result is shown above as well. Based on the results, for such water source protection areas like Xin’an Spring water source protection zone, the ecological compensation mechanism can be modeled as the modeling formulation stated in this paper. The method and formulation can be used as a reference, because Xin’an Spring water source protection zone is a representational area.

Ecological compensation mechanism constitution is complicated and systematical. To determine the ecological standard is the key and difficulty. There is not yet a unitive calculation method at present. In this paper, we
discussed and promoted one approach to constitute and consummate the mechanism, in order to fulfill a win-win situation between water source protection and economic development.

Reference