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A Framework for Ecological Compensation Assessment: A Case Study in the Upper Hun River Basin, Northeast China

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Received: 26 January 2019; Accepted: 18 February 2019; Published: 25 February 2019

Abstract: With the rapid socio-economic development, human disturbances are believed to have resulted in the degradation of the watershed ecosystem. The ecological damage to and environmental pollution of river basins have caused great losses. It is widely agreed upon that the protection and restoration of river ecosystems should be on the agenda. Ecological compensation, an important tool to prevent the deterioration of water environments and achieve sustainable watershed development, has attracted increasing interest as a research subject. In this study, the upper reach of Hun River basin was selected as a typical study area. The primary purpose was to determine the allocation costs of ecological compensation in different regions for the river basin. The amount of willingness-to-pay (WTP) for the eco-compensation was estimated at 3.2 million dollars by the Contingent Valuation Method (CVM). Based on linear programming techniques, a Data Envelopment Analysis (DEA) created a primary value of the allocation costs. Considering the different weights of each region, a modified coefficient was introduced to correct the primary result on the basis of a questionnaire survey of river ecological protection and construction.

Keywords: ecological compensation; river basin; Data Envelopment Analysis (DEA); allocation value

1. Introduction

Due to many factors, such as social and economic development and water project construction, numerous river ecosystems have been degraded. Given the common recognition of degradation in the quantity and quality of water resources, many international organizations and agencies from numerous countries have taken multiple measures in recent years. For example, the European Water Framework Directive, one of the most prominent statutes on water resources in Europe, focuses on obtaining a "good ecological status" in both surface and subsurface waters [1,2]. China has become increasingly concerned with biological measures, engineering solutions, and management actions to address multiple resource constraints and eco-environmental challenges. It has been found that ecological compensation is a useful approach to balance and deal with regional water conflicts and ecological destruction. In both the 11th 5-year Plan for National Environmental Protection and the Resolution on Implementing the Science-based Development Perspectives to Enhance Environmental Protection, the State Council has proposed to accelerate the building of ecological compensation [3].

In 2008, the ecological compensation of rivers turned into an amendment in the Laws of the People's Republic of China on Prevention and Control of Water Pollution [4].

Ecological compensation, an economic measure to offset environmental loss, is described as a population, organism, community, or ecosystem disturbance, revealed by some certain disturbance, that adjusts its status to survive for a service capacity [5]. With the study of ecological restoration, ecological compensation has become popular, and is widely used in a variety of domains, such as agricultural systems [6,7], forest ecosystems [8], river/lake ecosystems [9], and soil and water conservation [3]. For a river basin, eco-compensation is considered at three spatial scales: a large watershed's upstream and downstream compensation, a medium-sized river basin's trans-boundary compensation across provinces, and a small watershed's local administrative jurisdiction compensation. According to different objects, the compensation can be classified into two categories: (1) an ecological resources protection type (an upstream area protects vegetation at the cost of economic development, and the downstream area benefits from the upstream area, which shows that the beneficiary of the downstream area should compensate the protector of the upstream area); and (2) an environmental pollution loss type (the discharged waste from an upstream area for economic growth causes harm to a downstream area, which shows that the polluter of the upstream area must compensate for the losses suffered in the downstream area). Ecological compensation is a useful way to protect the environment and promote the coordinated development of the upper and lower reaches. In this paper, we consider the ecological resources protection type of eco-compensation for the study area.

Ecological compensation relates to many fields, such as resources, the environment, economics, policy, and community participation. Moran et al. [10] compared two methods, Analytical Hierarchy Process (AHP) and Choice Experiments (CE), to quantify residents' preference on agricultural and environmental policy, which suggested that payments must be considered in terms of environmental and social performance. Wünscher et al. [11] constructed an applied site selection tool to increase the efficiency of flexible payments and analyzed spatial changes in three variables: participation costs, environmental services, and the risk of services loss. The safety and reliability of water infrastructure should also be considered in ecological compensation [12]. Xu et al. [13] developed an eco-compensation framework according to the willingness-to-accept (WTA) for drinking water sources. However, because the inter-regional ecological compensation for a river basin involves different administrative divisions, it is difficult to precisely measure the allocation cost of the upstream and downstream regions.

With the efforts towards, and research of, river ecosystem restoration, an appropriate eco-compensation technique should be developed and employed based on the local economic and environmental conditions. Every economic activity is a combined production process, which makes use of resource and non-resource inputs to obtain desirable outputs with pollutant emissions [14], even in a river ecosystem. The Data Envelopment Analysis (DEA) method is widely used in a variety of domains to value the efficiency of inputs and outputs [15]. In this study, we utilize a DEA cooperative game to calculate the allocation cost (ecological compensation) to all decision-making units (DMUs) for the upper reach of the Hun River basin. In view of the deficiency of the classic Shapley value in cooperative games, the result is revised by modified weights to make the eco-compensation for the river basin more reasonable.

The main goal of this study is to find an appropriate theoretical system and technical methods for allocating the ecological compensation. We calculate the amount of ecological compensation and determine the allocation value of each DMU of the upper reach of the Hun River basin by combining the willingness-to-pay (WTP) and DEA methods, which have been proven to be feasible and effective. The paper is organized as follows. Section 2 presents the study area and assessment framework. In Section 3, the amount of ecological compensation and modified weights are measured. In Section 4, the allocation results are obtained and analyzed. Section 5 contains the conclusion of this study.

2. Materials and Methods

2.1. Study Area

The Hun River basin is located in central Liaoning Province, and covers an area of 11,481 km^2. The average annual precipitation in the basin is 718.3 mm, with an annual runoff of 3.05 billion m^3. Qingyuan County lies to the east of Fushun city on the upstream reach of the Hun River, Liaoning Province near Jilin Province, which is located at 124°20′6″~125°28′58″ E and 41°47′52″~42°28′25″ N and has an area of 3921 km^2. Qingyuan County is dominated by mountains and hills, and is covered by approximately 82.7% mountains, 13.8% plains, and 3.5% water surfaces. The elevation of the county ranges from 129 m to 1084 m, and is higher in the southeast and lower in the northwest. Qingyuan County is a temperate continental climate area, and the precipitation is concentrated mainly between June and September with a mean value of 810.8 mm.

In 2014, 14 townships were under the jurisdiction of Qingyuan with a population of 333,709 in 122,023 households. The per capita GDP was 6.79 thousand dollars per year, which is below the national average (7.57 thousand dollars per year). The upper reach of the Hun River basin, which contains nine townships in Qingyuan County and accounts for over three-fifths of the total area (Figure 1), was selected as a study case. Qingyuan County is the source region of the Hun River. As a natural green barrier for Liaoning Province, it is the main water conservation region in the cities of Shenyang and Fushun and its ecological services provide great value. The Dahuofang reservoir, located near Qingyuan County with a storage capacity of 2187 million m^3, is an important source of water supply for Shenyang, Fushun, Anshan, and four other cities. Because of the special location, it is crucial for the sustainable economic development of, and social harmony in, Liaoning Province.

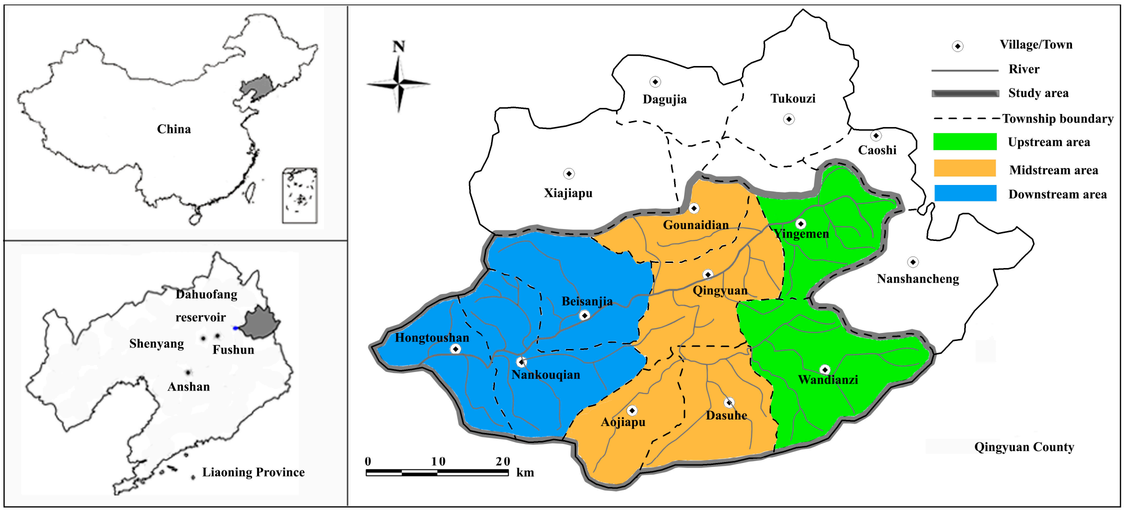

Figure 1. A map showing the study area's key locations. The upstream, midstream, and downstream areas are 583 km^2, 914 km^2, and 807 km^2, respectively.

2.2. Method

2.2.1. DEA

The DEA method was developed by Charnes et al. [16], originates in Farell's seminal work [17], and has been widely used for the measurement of many decision-making units' relative efficiency.

Let there be a set of units DMU_j $(j = 1, \ldots, n)$. Each DMU has m inputs x_{ij} $(i = 1, \ldots, m)$ to obtain s outputs y_{rj} $(r = 1, \ldots, s)$. The relative efficiency of DMU_j can be defined as [18]:

$$E_j = \frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \tag{1}$$

where v_i $(i = 1, \ldots, m)$ and u_r $(r= 1, \ldots, s)$ are input and output multipliers, respectively. According to [16], the relative efficiency of DMU_j can be estimated by solving the following mathematical model:

$$\begin{array}{ll} & Max \quad \frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \\ s.t. & \frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \leq 1 \quad \forall j \\ & u_r, v_i \geq 0 \end{array} \tag{2}$$

Suppose that a cost R is to be distributed among the n $DMUs$. Then, each DMU is to be allocated a cost r_j; that is, $\sum_{j=1}^{n} r_j = R$. If this r_j is treated as a new input, then the model becomes:

$$\begin{array}{ll} & Max \quad \frac{\sum_{r=1}^{s} u_r y_{rj_0}}{\sum_{i=1}^{m} v_i x_{ij_0} + r_0} \\ s.t. & \frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij} + r_j} \leq 1 \quad \forall j \\ & \sum_{j=1}^{n} r_j = R \\ & u_r, v_i \geq 0 \end{array} \tag{3}$$

where j_0 represents one of the $DMUs$, DMU_{j_0}.

2.2.2. Equitable Allocation of Shared Costs

Suppose that decision-makers have to allocate the jth input and the gross total of input allocation is R. Then, the allocation of DMU_j can be expressed as:

$$R_j = \sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \ , \quad j = 1, 2, \ldots, n \tag{4}$$

Let the coalition (S) be a subset of agents $(N = \{1, 2, \ldots, n\})$. Then, the inputs and outputs of S are represented as:

$$x_i(S) = \sum_{j \in S} x_{ij}, \ y_r(S) = \sum_{j \in S} y_{rj}. \tag{5}$$

To minimize the allocation cost given an equitable background, the minimum deviation $R(S)$ of the shared cost can be calculated using the following model:

$$\begin{array}{ll} & R(S) = min[\sum_{r=1}^{s} u_r y_r(S) - \sum_{i=1}^{m} v_i x_i(S)] \\ s.t. & \sum_{j=1}^{n} \left[\sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \right] = R \\ & R_j = \sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \geq 0 \\ & u_r, v_i \geq 0, \forall r, j \end{array} \tag{6}$$

Let $\mu_r = u_r / R$, $\nu_i = v_i / R$, and $w_j = R_j / R$. Then, the model (6) turns into:

$$\begin{array}{ll} & d(S) = min[\sum_{r=1}^{s} \mu_r y_r(S) - \sum_{i=1}^{m} \nu_i x_i(S)] \\ s.t. & \sum_{j=1}^{n} \left[\sum_{r=1}^{s} \mu_r y_{rj} - \sum_{i=1}^{m} \nu_i x_{ij} \right] = 1 \\ & w_j = \sum_{r=1}^{s} \mu_r y_{rj} - \sum_{i=1}^{m} \nu_i x_{ij} \geq 0 \\ & \mu_r, \nu_i \geq 0, \forall r, j \end{array} \tag{7}$$

2.2.3. Modified Results of the Allocation Model

Based on the above model (7), the value of $d(S)$ can be obtained. Then, the Game model is defined as (N, d). The Shapley value is an important solution concept for cooperative games [19–21]. According to Shapley, the allocation coefficient $(\psi_k(d))$ is determined by a classical model as follows:

$$\psi_k(d) = \sum_{k \in S} \frac{(s-1)!(n-s)!}{n!} [d(S) - d(S \backslash \{k\})]. \tag{8}$$

The allocation value (E_k) can be calculated by:

$$E_k = R \times \psi_k / \sum_{k=1}^{n} \psi_k. \quad (9)$$

Considering the above method with equal weight for all of the regions, this study introduces a modified weight (w_k). The D-value (Δw_k) between the modified weight and the equal weight of the kth region is $\Delta w_k = w_k - 1/n$, and the modified value is $\Delta E_k = R \times \Delta w_k$. Next, the modified allocation value ($E_k{}'$) of the kth region can be gained by:

$$E_k{}' = E_k + \Delta E_k. \quad (10)$$

The following flow diagram summarizes the methodology (Figure 2).

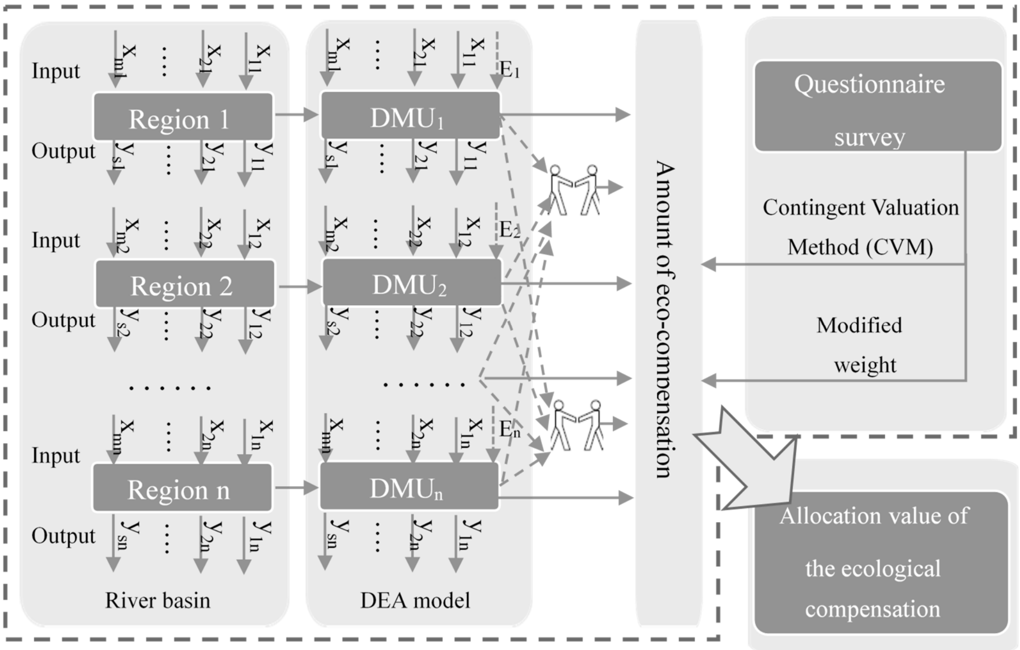

Figure 2. The flow diagram for ecological compensation assessment. DMU, decision-making unit; DEA, data envelopment analysis.

3. Data and Analysis

In China, as natural resources belong to the state, local governments are an interested party, which makes them the main subjects of river eco-compensation [21]. The upper reaches of the Hun River basin cross nine villages and towns of Qingyuan County. Thus, this study takes the villages/towns as decision-making units (DMUs).

3.1. Inputs and Outputs of DEA

This paper selects three inputs and two outputs, taking into account multiple attributes of the compensation system. Three essential indices should be prioritized for the inputs: water consumption, water-regulation ability, and population. Outputs contain socio-economic benefits and the water environment, which can be represented by gross domestic product (GDP) and class of water quality, respectively. With reference to China's National Water Quality Standard [22], water quality is classified into five classes based on the level of water function from high to low: I, II, III, IV, and V. To facilitate computation of the DEA model, five values are accordingly assigned to each class: 5, 4, 3, 2, and 1, as dimensionless metrics. Table 1 summarizes the inputs and outputs chosen for this study.

Table 1. A summary of inputs and outputs.

Category		Index Description/Units
Inputs	Water consumption (X_1)	Consumption of water resource/10^4 m^3
	Water-regulation ability (X_2)	Divide the service discharge of reservoirs and dams by the annual mean runoff/%
	Population (X_3)	Number of people
Outputs	Economic benefit (Y_1)	Gross domestic product/10^4 \$
	Water quality (Y_2)	Class of water quality

The data for all of these variables were obtained from two sources in 2014: (1) the Liaoning Statistical Yearbook from the National Bureau of Statistics; and (2) Statistical information on the financial sector and national economy of Qingyuan from the National Bureau of Statistics.

3.2. Amount of Ecological Compensation

The eco-compensation standard that people who reside in the river basin could accept is essential for developing an eco-compensation mechanism. To promote the eco-compensation mechanism as the optimal selection for the protection and management of the river basin, it is important to evaluate a reasonable amount of ecological compensation. This study employs the Contingent Valuation Method (CVM) to assess public awareness of eco-compensation in the upper Hun River basin, and measure the willingness to pay of the residents. Using stated preference data from questionnaires, the CVM is an easy, flexible nonmarket assessment approach that is commonly applied in cost-effectiveness research and environmental impact valuation [23]. The CVM was initially put forward by Ciriacy-Wantrup [24], and was first used in estimating the benefits of goose hunting by Davis [25]. After that, this approach has been used in landscape conservation, recreation, and water ecosystem rehabilitation in various countries.

The questionnaire for people living in the upper Hun River basin has four parts and contains both a multiple-choice test and open questions (Table 2). The first part is a survey of residents' understanding of the main environmental responsibility for the study area. The second part is an investigation of the ecological state and the preference between environment protection and social development. The third part is a survey of the public's willingness to pay for eco-compensation to Qingyuan in the upper Hun River. The last part covers information on the individual respondents, with the purpose of collecting information on, among other things, age range, education level, and income.

To ensure that the questionnaire's collection was efficient, a face-to-face investigation, carried out from May 2015 to August 2015, was put into effect to increase the availability based on the random sampling method. Three hundred (300) questionnaires were randomly distributed to the nine villages/towns, and 291 valid ones were successfully returned (a response rate of 97%). A total of 269 (92.44%) respondents knew about river eco-compensation, and 221 (75.95%) expressed their support for the compensation. The respondents were aged from 16 to 70, with an average of approximately 42 years. From the perspective of educational background, about 167 (57.39%) had a high school education or above. A majority (176 persons, about 60.48%) received a monthly income between 481.66 and 722.50 dollars. In total, 75.6% of the respondents walked to the river, and only 3.09% selected a bus or car as their main transportation means.

Table 2. A summary of the questionnaire.

	No.	Question	Response
Environmental awareness	1	Do you know about river ecological compensation?	A. Yes B. No
	2	Do you support river ecological compensation?	A. Yes B. No
Ecological state and preference	3	What is your opinion about the local environment changes since river ecological protection and construction?	A. Better B. Worse C. No change
	4	Are you satisfied with the current condition of river ecological protection and construction?	A. Very satisfied B. Moderately C. Not satisfied
	5	What impression does the environment around the river give you? (You may choose more than one option)	A. Filling or blocking arbitrarily the streams and depressions B. Serious pollution of water environment C. Water loss and soil erosion D. A good ecological environment
	6	Which type of embankment slope?	A. Natural vegetation B Artificial structure C. A combination of the two
	7	What is the functionality of the river around your location? (You may choose more than one options)	A. Flood control and waterlogging drainage B. Landscape features C. Ecological function D. Production of agriculture or fishery E. Others
	8	What would be most important thing for you about the river? (You may choose more than one options)	A. Leisure and recreation B. Water loving C. Keep healthy D. Ecological environment E. Agricultural irrigation F. Future generations G. Economic value (business, catering, real estate, etc.) H. Historical and cultural value I. Others
	9	Personal opinions on and ideas for river ecological protection and construction.	Open-ended
Ecological compensation	10	As an important ecological compensation measure, how much would you like to pay as a fee every year ($/household)?	A. 0 B.12.04 C. 24.08 D. 36.12 E. 48.17 F. 72.25 G. 96.33 H. 144.5 I. 240.83 J. 481.66
	11	What method of payment would you like?	A. Donation B. Utilities C. Participating in voluntary labor D. Eco-tax E. Environmental lottery
Personal information	12	What is your age range?	A. <16 B. 16–30 C. 30–50 D. >50
	13	What is your educational level?	A. Primary school B. Middle school C. High school D. College degree and above
	14	What is your monthly income level ($)?	A. <240.83 B. 240.83–481.66 C. 481.66–722.5 D. >722.5
	15	How do you get to the river?	A. Walk B. Bicycle C. Bus or car D. Other

According to the investigation, respondents were willing to pay from 0 to $481.66/household per year. The percentage frequency distribution of willingness-to-pay is shown in Figure 3. About 11.34% of the residents thought that there was no need for ecological compensation. The payment amount in a household below $48.17/year (including $48.17) accounted for 77.32% of all households. The number of residents willing to pay $48.17/year accounted for 26.8% of the households and occurred the most frequently, followed by the willingness to pay $36.12/year (19.24% of the sample).

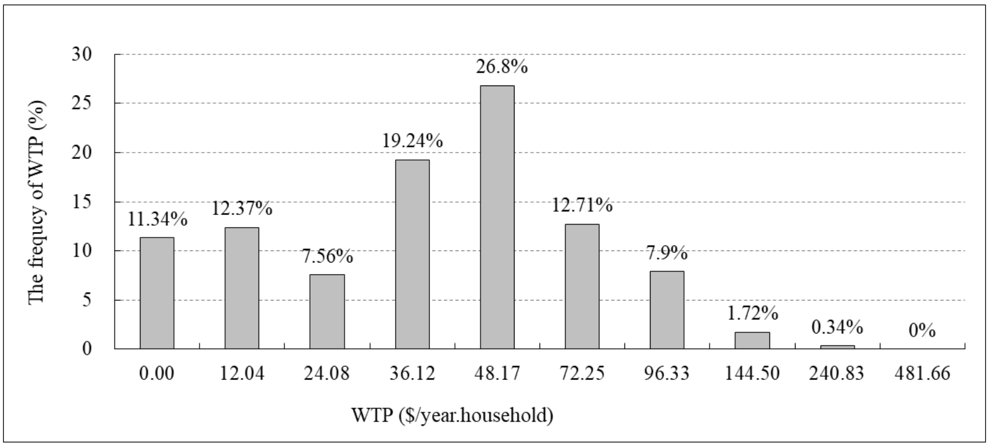

Figure 3. The percentage frequency distribution of the willingness-to-pay (WTP).

Based on the percentage frequency distribution of the willingness-to-pay, an average value can be calculated by referring to the following formula [26]:

$$R(WTP) = \sum_{i}^{n} A_i \times P_i \tag{11}$$

where A_i is the tendered numerical value of WTP, P_i is the probability that a resident will select the value, and n is the number of alternative tenders. In this study, $n = 10$. Then, $R(WTP)$ can be obtained as $43.28/household per year. The amount of willingness-to-pay in the upper Hun River basin is $3.2 $\times$ 10^6 per year. In comparison, Pan et al. [26] showed that the people of Chengdu are willing to pay 63.47 CNY/person a year to repair the Min River's eco-environment. Xiong et al. [9] found that residents in the lower reach of Ganjiang River are willing to pay $47.62/household per year for eco- compensation.

Additionally, on the method of payment, the investigation indicated that the utility and donation types were the main choices, accounting for 31.27% and 26.8%, respectively. Approximately 18.9% of the respondents selected participating in voluntary labor. Only 23.02% of respondents selected the innovative eco-tax and environmental lottery payment methods, which indicates that the public prefer traditional ways of payment.

3.3. Modified Weight

The attitude of the residents towards river ecological protection and construction directly affects the implementation of ecological compensation. Figure 4 shows the statistics of the frequency distribution for the survey.

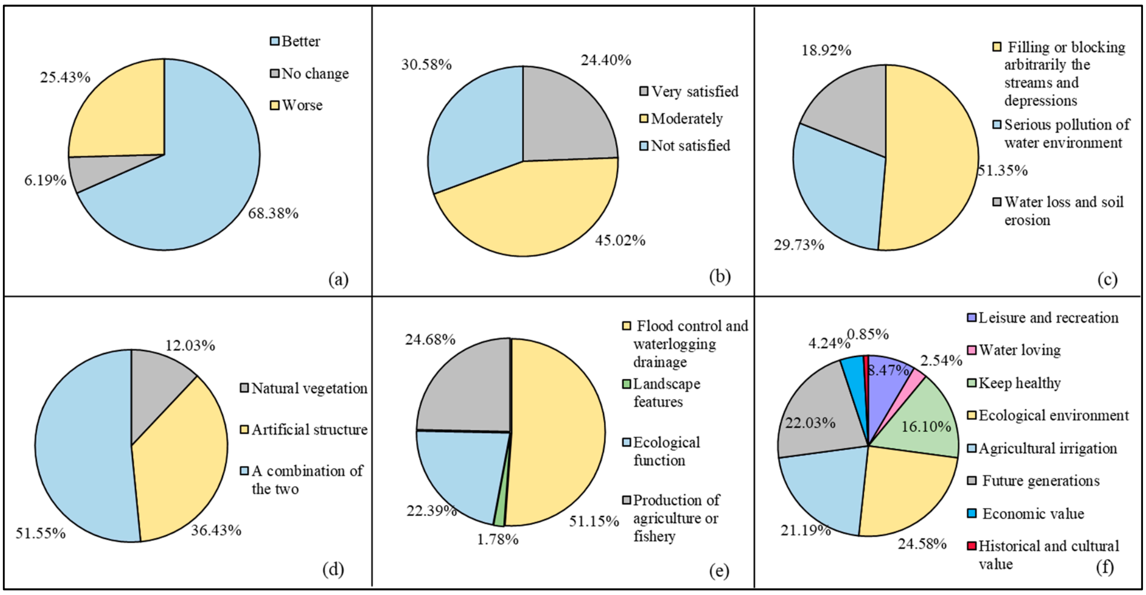

Figure 4. Statistics of the frequency distribution for the survey.

In total, about 68.38% of the respondents agreed that the local ecological environment has changed for the better since the implementation of river ecological protection and construction. A minority (89 persons, about 30.58%) were not satisfied with the current condition of the river's ecological management. The survey indicated that the worst impressions the residents had of the water environment, in descending order of magnitude, were water loss and soil erosion, serious pollution of the water environment, and arbitrary filling or blocking of streams and depressions. Overall, 51.55% of the embankment slope was a combination of natural vegetation and artificial structures. The results showed that the river around the residents played an important role in flood control and waterlogging drainage, agriculture or fishery production, and an ecological function. From the perspective of preferences for the river basin, the order of importance was: ecological environment (24.58%), future generations (22.03%), agricultural irrigation (21.19%), maintaining health (16.1%), leisure and recreation (8.47%), economic value (4.24%), water loving (2.54%), and historical and cultural value (0.85%).

Weights should be introduced to modify the primary result. The Analytic Hierarchy Process (AHP) method can be utilized to ascertain the relative weights of different attributes that decision-makers have [27]. AHP has been commonly applied in recent years to deal with complicated, large, and elusive decision problems [28,29]. This paper uses AHP to calculate the weights of different regions for the upper reach of Hun River basin. Based on the current condition of the river's ecological management, the residents' preferences for eco-conservation and socio-economic development, historical information, the on-the-spot investigation, and expert consulting, the weights were obtained and are shown in Table 3. A total of 15 water experts took part in the assignment. These experts were chosen from the local water expert database.

Table 3. The weights of different regions.

Basin	**The Upper Reach of Hun River Basin**								
Area	Upstream area 0.279			Midstream area 0.422			Downstream area 0.299		
Sub-area	Wandianzi 0.45	Yingemen 0.55	Dasuhe 0.315	Gounaidian 0.118	Qingyuan 0.342	Aojiapu 0.225	Beisanjia 0.391	Nankouqian 0.394	Hongtoushan 0.215
Weight	0.126	0.153	0.133	0.050	0.144	0.095	0.117	0.118	0.064

4. Results and Discussion

4.1. Results

The allocation values of the ecological compensation were calculated using the DEA game model for the upper Hun River basin and are shown in the second column of Table 4. With regard to the different regional characteristics, the modified results were calculated by submitting weights into Equation (10).

Table 4. The allocation result for the upper reach of Hun River basin.

Town/Village	DEA Game (10^4\$)	Modified Allocation Value (10^4\$)	Location
Wandianzi Town	0.00	4.62	Upstream area 18.18
Yingemen Town	0.00	13.56	
Dasuhe Village	11.01	17.99	Midstream area 91.14
Gounaidian Village	46.61	26.98	
Qingyuan Town	10.30	20.94	
Aojiapu Village	30.41	25.23	
Beisanjia Village	43.65	45.50	Downstream area 210.91
Nankouqian Town	51.04	53.18	
Hongtoushan Town	127.23	112.23	
Total (10^4\$)	320.24	320.24	

The amount of ecological compensation is \$3.2 $\times$ 10^6 per year, and the allocation value for the upstream area, midstream area, and downstream area is \$18.18 $\times$ 10^4, \$91.14 $\times$ 10^4, and \$210.91 $\times$ 10^4 per year, respectively. These results are in accordance with the request of the State Council of the People's Republic of China "to accelerate the development of ecological compensation mechanisms" based on the principle of "whoever develops shall protect, whoever damages shall rehabilitate, and whoever benefits shall compensate" [3]. The allocation value for each town or village should be used to protect the natural riverine system and forests, restore the damaged ecosystem, return cultivated land to forests or wetlands, and compensate farmers or residents for their losses from these actions.

The upstream areas are assigned the lowest scores, including Wandianzi Town and Yingemen Town, which are the two head sources of the Hun River. According to the result of the DEA Game, no eco-compensation is allocated to these areas. Because headstreams are far away from the urban area, and own a favorable eco-environment, more ecological input may not bring in more economic and ecological benefits. However, it is essential to decrease the artificial impact to the minimum for these areas. Without enough eco-compensation, the upstream may choose to strengthen economic development rather than protect the ecological environment. Meanwhile, it is more important to maintain the river ecosystem's health and integrity to sustain river flows and water quality. Hence, the modified allocation results increase the allocation value of the upstream areas.

The midstream areas are allocated 28.46% of the total ecological compensation cost. Qingyuan Town is the administrative center of Qingyuan County. The river in the main urban area is highly and frequently affected by human activities. Accordingly, more eco-compensation should be allocated to protect the water quality and ensure that the sewage discharge can meet the requirements of functional water zoning.

From Table 4, the downstream areas gain a value from \$45.5 $\times$ 10^4 (Beisanjia Village) to \$112.23 $\times$ 10^4 (Nankouqian Town), a total of 65.86%. This means that ecological compensation in the downstream areas is a priority. The natural resources and ecological environment in the downstream areas are not substantial, and the major influence of human activity is farming. In order to decrease the effect of farming on the river ecosystem, suitable economic activities should be allowed in the downstream areas, such as afforestation and fishing rather than farming.

4.2. Discussion

The willingness-to-pay of residents for eco-compensation is affected by social and economic conditions. This paper selected five variables, including age range, educational level, income level, environmental awareness, and payment method, to analyze the relationship between the willingness-to-pay and respondents' characteristics using multiple regression. The description and assignment variables are shown in Table 5.

Table 5. Regression results on the explanatory variables influencing willingness-to-pay.

Variable	Description and Assignment	Coefficients	Sig.
Age range	Less than 16 years-old = 1, 16–30 years-old = 2, 30–50 years-old = 3, More than 50 years-old = 4	−6.678	0.000 **
Educational level	Primary school = 1, Middle school = 2, High school = 3, College degree and above = 4	17.644	0.000 **
Income level	Monthly income level: less than $240.83 = 1, $240.83–$481.66 = 2, $481.66–$722.5 = 3, more than $722.5 = 4	7.501	0.000 **
Environmental awareness	Do you support river ecological compensation? Yes = 1, No = 0	0.524	0.000 **
Payment method	Donation = 1, Utilities = 2, Participating in voluntary labor = 3, Eco-tax = 4, Environmental lottery = 5	−1.366	0.098
Constant		−13.278	0.024 **

Note: ** represents significance at the 5% level.

Using the SPSS software, version 16.0, the relationship was obtained by a stepwise regression analysis. At the 5% significance level: (1) there is a significant negative correlation between age and willingness to pay, which means that the older the age, the lower the willingness to compensate; and (2) residents that support river ecological compensation and have a higher education and income are willing to make a greater payment because they have good social resources and economic conditions.

Standards of, and the approach to, eco-compensation, which relate to compensation effects and feasibility, are foundational to ecological compensation [7]. In our case study of ecological compensation assessment for the upper Hun River basin, the result was found to be influenced by several factors, including how well the respondents understood the questionnaire, the personal preferences of the respondents, and the educational and economic level of residents in the study area. Thus, further survey-based research into eco-compensation is needed.

5. Conclusions

Human interference in river ecosystems has received lot of attention in the last few years. The research shows that the rational exploitation and protection of resources and the environment are the basis for the sustainable development of river ecosystems. Ecological compensation is an important part of the theoretical and practical approach to basin management. The purpose of this study was to allocate eco-compensation for river restoration. To make ecological compensation for upstream and downstream regions more scientific and reasonable, an allocation framework was developed based on the CVM and DEA.

The amount of willingness-to-pay in the upper Hun River basin was found to be $\$3.2 \times 10^6$ per year. The downstream area has a higher allocation value of ecological compensation than the midstream and upstream areas, and the ratio is 6.59:2.85:0.57. According to the DEA, assigning more compensation to the downstream area could bring about more economic and ecological benefits. Moreover, the modified value was found to be more reasonable with respect to the importance of different areas. The survey indicates that residents prefer traditional methods to pay for the expense. Due to inadequate publicity, new payment methods, such as eco-tax and environmental lottery, are accepted by only a few people. Therefore, there should be more concern about the public participation in environmental protection and ecological compensation. This framework for ecological compensation assessment can be used to identify both the real preferences of local residents and the actual background of different upstream/downstream regions. It can provide technological support to improving the balance between socio-economic development and protection of a river basin's environment.

Author Contributions: This research was designed by X.J. and Y.L. X.J. contributed to the data collection and analysis. Y.L. developed the original manuscript. R.Z. revised the article and proposed some helpful advice. All the authors read and approved the final version.

Funding: This research was funded by the National Natural Science Foundation of China (No. 51327004).

Acknowledgments: This study was supported by the Jilin Province Science Foundation for Youths (No. 20160520024JH), the Ph. D. Programs Foundation of the University of Jinan (No. XBS1812), and the Science and Technology Planning Foundation of the University of Jinan (No. XKY1809).

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Del Saz-Salazar, S.; Hernández-Sancho, F.; Sala-Garrido, R. The social benefits of restoring water quality in the context of the Water Framework Directive: A comparison of willingness to pay and willingness to accept. *Sci. Total Environ.* **2009**, *407*, 4574–4583. [CrossRef] [PubMed]
2. Benjankar, R.; Koenig, F.; Tonina, D. Comparison of hydromorphological assessment methods: Application to the Boise River, USA. *J. Hydrol.* **2013**, *492*, 128–138. [CrossRef]
3. Sun, L.; Lu, W.; Yang, Q.; Martín, J.D.; Li, D. Ecological compensation estimation of soil and water conservation based on cost-benefit analysis. *Water Resour. Manag.* **2013**, *27*, 2709–2727. [CrossRef]
4. Xie, R.; Pang, Y.; Li, Z.; Zhang, N.; Hu, F. Eco-compensation in multi-district river networks in North Jiangsu, China. *Environ. Manag.* **2013**, *51*, 874–881. [CrossRef] [PubMed]
5. Dong, G.J. Based on the Literature Statistical Ecological Compensation Academic Research Characteristics and Development Analysis. *Adv. Mater. Res.* **2013**, *663*, 795–800. [CrossRef]
6. Pagiola, S.; Ramirez, E.; Gobbi, J.; de Haan, C.; Ibrahim, M.; Murgueitio, E.; Ruiz, J.P. Paying for the environmental services of silvopastoral practices in Nicaragua. *Ecol. Econ.* **2007**, *64*, 374–385. [CrossRef]
7. Pang, A.P.; Sun, T.; Yang, Z.F. Economic compensation standard for irrigation processes to safeguard environmental flows in the Yellow River Estuary, China. *J. Hydrol.* **2013**, *482*, 129–138. [CrossRef]
8. Owubah, C.E.; Le Master, D.C.; Bowker, J.M.; Lee, J.G. Forest tenure systems and sustainable forest management: The case of Ghana. *For. Ecol. Manag.* **2001**, *149*, 253–264. [CrossRef]
9. Xiong, K.; Kong, F.; Zhang, N.; Lei, N.; Sun, C. Analysis of the factors influencing willingness to pay and payout level for ecological environment improvement of the Ganjiang River basin. *Sustainability* **2018**, *10*, 2149. [CrossRef]
10. Moran, D.; McVittie, A.; Allcroft, D.J.; Elston, D.A. Quantifying public preferences for agri-environmental policy in Scotland: A comparison of methods. *Ecol. Econ.* **2007**, *63*, 42–53. [CrossRef]
11. Wünscher, T.; Engel, S.; Wunder, S. Spatial targeting of payments for environmental services: A tool for boosting conservation benefits. *Ecol. Econ.* **2008**, *65*, 822–833. [CrossRef]
12. Pietrucha-Urbanik, K.; Zelazko, A. Approaches to assess water distribution failure. *Period. Polytech. Civ. Eng.* **2017**, *61*, 632–639. [CrossRef]
13. Xu, L.; Yu, B.; Li, Y. Ecological compensation based on willingness to accept for conservation of drinking water sources. *Front. Environ. Sci. Eng.* **2015**, *9*, 58–65. [CrossRef]
14. Bian, Y.W.; Yang, F. Resource and environment efficiency analysis of provinces in China: A DEA approach based on Shannon's entropy. *Energy Policy* **2010**, *38*, 1909–1917. [CrossRef]
15. Liu, Y.; Sun, C.; Xu, S. Eco-efficiency assessment of water systems in China. *Water Resour. Manag.* **2013**, *27*, 4927–4939. [CrossRef]
16. Charnes, A.; Cooper, W.W.; Rhodes, E. Measuring the efficiency of decision making units. *Eur. J. Oper. Res.* **1978**, *2*, 429–444. [CrossRef]

17. Farell, M. The measurement of productive efficiency. *J. R. Stat. Soc. A Stat.* **1957**, 253–290. [CrossRef]
18. Amirteimoori, A.; Shafiei, M. Characterizing an equitable omission of shared resources: A dea-based approach. *Appl. Math. Comput.* **2006**, *177*, 18–23. [CrossRef]
19. Shapley, L.S. A Value for n-Person Games. In *The Shapley value: Essays in honor of Lloyd S. Shapley*; Roth, A.E., Ed.; Cambridge University Press: New York, NY, USA, 1988; pp. 31–40.
20. Butnariu, D.; Kroupa, T. Shapley mappings and the cumulative value for n-person games with fuzzy coalitions. *Eur. J. Oper. Res.* **2008**, *186*, 288–299. [CrossRef]
21. Chang, L.; Xu, D.W.; Hou, T.S.; Yang, C.W.; Wu, A.D. A study of supply Chain theory applied in the water resource market allocation. In *International Asia Conference on Industrial Engineering and Management Innovation (IEMI2012) Proceedings*; Springer: Heidelberg, Germany, 2013; pp. 939–947.
22. China EPA. *Environmental Quality Standards for Surface Water (GB3838-2002)*; China Environmental Science Press: Beijing, China, 2002.
23. Venkatachalam, L. The contingent valuation method: A review. *Environ. Impact Assess. Rev.* **2004**, *24*, 89–124. [CrossRef]
24. Ciriacy-Wantrup, S.V. Capital returns from soil conservation practices. *Am. J. Agric. Econ.* **1947**, *29*, 1181–1196. [CrossRef]
25. Davis, R. The Value of Outdoor Recreation: An Economic Study of the Marine Woods. Ph.D. Thesis, Harvard University, Cambridge, MA, USA, 1963.
26. Pan, J.M.; Zeng, W.Z.; Zhang, W.K. The willingness to pay for the ecological compensation of Min River Basin–Based on the survey of Chengdu 282 households. *Environ. Pollut.* **2012**, *1*, 14–20. [CrossRef]
27. Duke, J.; Aull-Hyde, R. Identifying public preferences for land preservation using the analytic hierarchy process. *Ecol. Econ.* **2002**, *42*, 131–145. [CrossRef]
28. Xu, S.; Liu, Y.; Qiang, P. River functional evaluation and regionalization of the Songhua River in Harbin, China. *Environ. Earth Sci.* **2014**, *71*, 3571–3580. [CrossRef]
29. Serbu, R.; Marza, B.; Borza, S. A spatial Analytic Hierarchy Process for identification of water pollution with GIS software in an eco-economy environment. *Sustainability* **2016**, *8*, 1208. [CrossRef]