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Article

Ecological Compensation Based on the Ecosystem Service Value: A Case Study of the Xin'an River Basin in China

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Abstract: To establish a sound ecological compensation (EC) mechanism in the Xin'an River Basin, this study suggested utilizing ecosystem service valuation to determine the compensation amount. In this study, the first step was to establish a reasonable watershed EC model using the ecological compensation supply coefficient (ECSC) based on the value spillover theory (VST) of the ecosystem services and the ecological compensation demand coefficient (ECDC). The second step was to classify the ecosystem services of the Xin'an River Basin into three categories, including supply service, regulating service, and cultural service, with 14 specific functions to determine the ecological compensation standard accounting scope in these services. Then, a case study on the Xin'an River Basin for EC standards was presented. The total ecosystem service value (ESV) in the Xin'an River Basin was estimated to be CNY 70.271 billion, with supply service accounting for 22.7%, regulating service accounting for 24.6%, and cultural service accounting for 52.7%. Based on the compensation scope, the ecosystem service values for the upper and lower limits of the EC were calculated as CNY 57.779 billion and CNY 17.292 billion. Combined with the results of the ECSC and ECDC, the upper and lower limits of the EC standard in the Xin'an River Basin were computed to be CNY 4.085 billion and CNY 1.438 billion, respectively. Therefore, the ESV-based EC model for the Xin'an River Basin can effectively address the challenge of inadequate EC in the watershed. It also facilitates balanced regional development and serves as a theoretical foundation and empirical evidence for the government to establish a unified national policy on cross-border river basin ecological compensation.

Keywords: ecological compensation; ecosystem services value; value spillover theory; river basin; Xin'an River Basin

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1. Introduction

Watersheds are essential components of natural ecosystems that provide habitats for humans and various organisms. However, due to the rapid development of the social economy, water pollution in watersheds has become inevitable. Additionally, disputes over water resources between the upstream and downstream regions of watersheds continue to arise, threatening the sustainability of watersheds [1]. Since the 1980s, China has implemented an ecological compensation (EC) mechanism to protect the ecological environment by regulating the relationship between stakeholders and casualties of the ecological environment [2]. The basic principle of the Chinese government's policy on EC is to balance the interests of ecosystem service providers and demanders by requiring that beneficiaries and polluters pay for the compensation fund [3,4]. By using EC, ecosystem service providers can protect or restore ecosystems, thereby promoting ecological sustainability [5]. For water resource and eco-environment protection, establishing an EC mechanism in the river basin has become inevitable. However, despite the potential of EC to achieve both ecological protection and economic development [6,7], practical issues remain in defining the subject and object of EC, standardizing compensation criteria, and allocating compensation funds [8].

Taking China's first trans-provincial watershed ecological compensation pilot project as an example, the Xin'an River Basin has obtained significant achievements in watershed protection and development, which has strengthened the Chinese government's confidence in replicating its successful experience via the subsequent implementations of other large watersheds, such as the Yangtze and Huang Rivers. During the 1990s, the water quality of Qiandao Lake downstream of the Xin'an River Basin showed an increasing trend toward eutrophication. This situation intensified the conflict between ecological conservation and economic expansion in the upstream and downstream regions of the basin, which hindered the sustainable development of the socio-economy within the Xin'an River Basin [9–11]. In 2012, the governments of the Anhui and Zhejiang provinces signed the Agreement on Water Environmental Compensation for Xin'an River Basin, which officially implemented the first trans-provincial EC mechanism in China. Under the collaborative efforts of the Anhui and Zhejiang provinces, three rounds of pilot programs were launched from 2012 to 2014, 2015 to 2017, and 2018 to 2020, respectively, with the goal of establishing an operating mechanism based on the principle of "beneficiaries pay and protectors receive compensation" [12]. Since the establishment of the ecological compensation pilot program in the Xin'an River Basin, there has been a significant improvement in water quality in the basin compared to the past. At present, cross-provincial upstream and downstream horizontal EC pilot projects have been expanded to other rivers, such as the Jiuzhou River, Tingjiang-Hanjiang River, Dongjiang River, Huaihe River, Yangtze River Economic Belt, and the Yellow River Basin [13–16]. However, Huangshan City in Anhui Province received a total of CNY 2.2 billion in ecological compensation funds based on the three-round ecological compensation agreement in the Xin'an River Basin, as shown in Figure 1, with an average of CNY 0.244 billion per year, which is significantly different from the actual investment in ecological protection in Huangshan City [9,17]. In addition, according to existing research, the opportunity cost of Huangshan City's loss due to the implementation of basin compensation during 2013–2017 was between CNY 2.456 billion and CNY 5.327 billion, which led to a significant gap in economic development between the upstream and downstream of the basin. In addition, the compensation efforts were clearly insufficient, making it difficult to enhance the enthusiasm for strengthening the protection in Huangshan City.

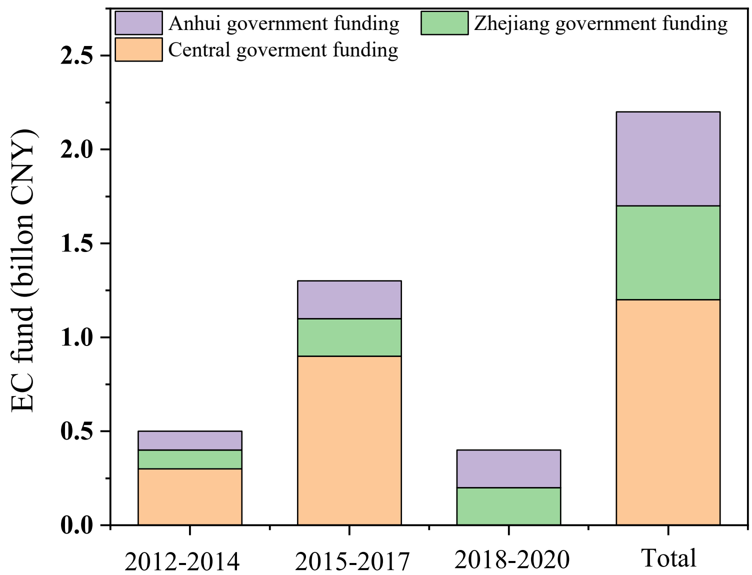

Figure 1. Three rounds of watershed EC agreement between Huangshan and Hangzhou.

Therefore, the Chinese government encourages the implementation of market EC in upstream and downstream watersheds, but a unified and feasible mechanism for watershed

EC has yet to be established [18,19]. In this instance, establishing compensation standards that are mutually recognized by both upstream and downstream areas has become the top priority of watershed EC work. To solve this problem, several studies on calculating the watershed EC standards have been conducted in recent years, mainly based on the theory of ecosystem service [20].

According to the Millennium Ecosystem Assessment, there are four main types of ecosystem services, as follows: support services, regulation services, provision services, and cultural services [21,22]. Watershed ecosystems provide vital functions such as flood control, drought resistance, climate regulation, water conservation, flood regulation, land reclamation, biodiversity protection, and tourism, which generate significant ecological, economic, and social benefits for humans. The ecological compensation mechanism based on the ESV is a novel approach that integrates the economic value of ecosystem services into compensation standards to promote a win–win situation for ecological protection and economic development [23].

Based on previous research, a reasonable calculation of the ecosystem service value is a prerequisite for determining the upper limit of EC standards, and it would be unreasonable to directly use the ESV as a standard for EC due to its excessively high value [24]. Dai et al. (2021) indicated that the total value of ecosystem services in the Xin'an River Basin from 2013 to 2017 was between CNY 8.828 billion and CNY 9.088 billion [25]. Yang, N (2019) showed that the total value of water ecosystem services in the Xin'an River Basin in 2020 was CNY 41.409 billion [26]. In these studies, there was an excessive focus on upstream enthusiasm to protect the ecological environment while ignoring downstream willingness to pay (WTP). Once the profit balance of EC is broken, it will cause the EC rules and regulations to lose their effectiveness. Therefore, extensive research and revision of the value of ecosystem services and compensation standards are necessary to ensure their rationality and feasibility [27].

Consequently, this study aims to establish a new EC scheme by exploring a reasonable revision of the ESV or the amount of EC to increase the applicability of Xin'an River Basin EC and achieve a better compensation effect. The formulation of compensation standards will consider multiple factors, such as the actual value of ecosystem services, the rights and interests of compensation subjects and objects, and the source of compensation funds. In this paper, we will propose an EC standard model by employing the ecological compensation supply coefficient (ECSC) based on the value spillover theory and the ecological compensation demand coefficient (ECDC) to adjust the ESV after identifying the types and functions of the main watershed ecosystem services in Huangshan City. Finally, a case study will be conducted to verify the reasonable range of the Xin'an River Basin EC standard based on the established model.

2. Data and Methods

2.1. Studied Area

The Xin'an River originates from Xiuning County, Huangshan City, and flows through the Anhui and Zhejiang provinces (Figure 2). It is the third-largest water system in Anhui Province, after the Yangtze and Huaihe Rivers, and is also the largest river that flows into Qiandao Lake in Zhejiang Province [28].

The Xin'an River Basin covers approximately 11,452.5 square kilometers, of which 5569.75 square kilometers are located in Huangshan City, accounting for 56.79% of the city's total area. In Anhui Province, the Xin'an River's annual average outflow exceeds 6 billion cubic meters, which represents over 60% of the yearly inflow of Qiandao Lake, making it an essential strategic water source in the downstream region of Zhejiang Province [12].

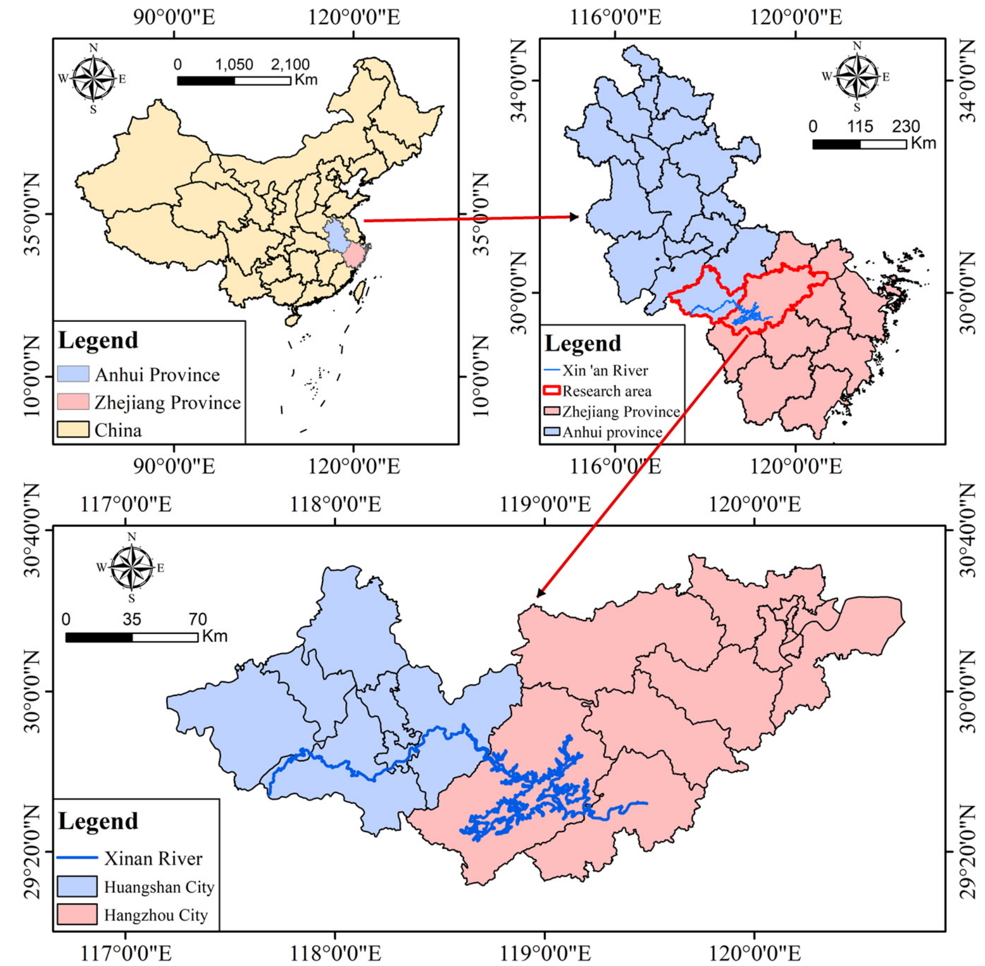

Figure 2. Map of Xin'an River Basin.

2.2. Data Sources

Empirical calculations were carried out to determine the EC standards for the Xin'an River Basin. To obtain the necessary data, remote sensing data were utilized to gather administrative boundary data, first-level ecological system classification data for 2020, the net primary productivity, the vegetation normalized index, soil physical properties, vegetation evaporation, and the digital elevation grid. Other data sources included the "Anhui Statistical Yearbook", "Huangshan Statistical Yearbook", "Hangzhou Statistical Yearbook", "Huangshan Environmental Quality Bulletin", "Hangzhou Environmental Quality Bulletin", "Anhui Water Resources Bulletin", "Anhui Environmental Statistical Yearbook", "Zhejiang Water Resources Bulletin", "Compilation of China's Urban Sewage Treatment Plants", and official websites of the Huangshan Ecological Environment Bureau and Huangshan Water Conservancy Bureau. The data collected encompassed the ecological environment, economic development, population, and other relevant information.

2.3. Methodology

The main idea of this study is illustrated in Figure 3. The first step was to classify the ecosystem services in Huangshan City's upstream area of the Xin'an River. Second, the value of different ecosystem services was calculated using various methods, including shadow engineering, market comparison, and alternative cost. Third, the value of ecosystem services was adjusted using a value correction coefficient. Finally, based on the ecological compensation coefficient and the ecological service spillover theory, this study estimated the EC that Huangshan City should receive in the river basin.

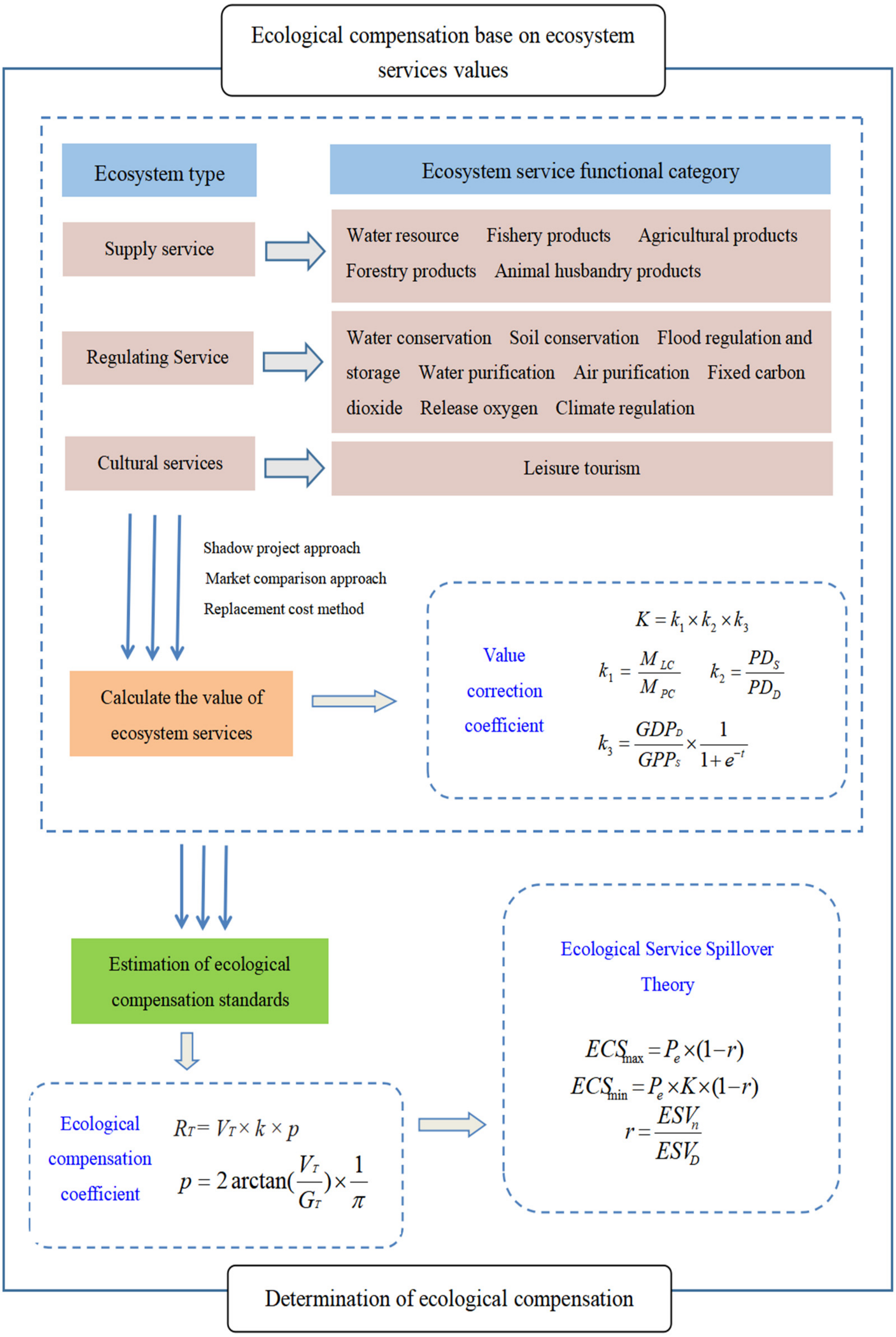

Figure 3. Flow graph of the basin eco-compensation framework based on ecosystem service values.

2.3.1. Value Measurement of Main Ecosystem Services

This study classifies the basin ecosystem services into the following three main categories: supply services, regulating services, and cultural services, including 14 subcategories presented in Table 1. The calculation method for gross ecosystem services value is as follows:

$$V_{total} = \sum_{i=1}^{14} V_i \quad (1)$$

In the formula, V_{total} is the total value of ecosystem service; V_i is the ecosystem service value of the *i*th ecosystem type; and *i* is the ecosystem type, including the water resource products (V_1), fishery products (V_2), agricultural products (V_3), forestry products (V_4), animal husbandry products (V_5), water conservation (V_6), soil conservation (V_7), flood regulation and storage (V_8), water purification (V_9), air purification (V_{10}), fixed carbon dioxide (V_{11}), release (V_{12}), climate regulation (V_{13}), and leisure tourism values (V_{14}), which are calculated and presented in Table 2.

Table 1. Classification and function of ecosystem services in Huangshan City.

Eco-Services Category	Eco-Service Project	Explain
Supply service	Water resource products	Mainly including local water supply and watershed water supply.
	Fishery products	The total amount of various fish products in the watershed.
	Agricultural products	Mainly including grains, oilseeds, cotton, cocoons, tobacco, and tea.
	Forestry products	Mainly including various garden fruits.
	Animal husbandry products	Mainly including meat products, dairy products, and poultry egg products.
Regulating Service	Water conservation	Storage and retention of water in forests and wetlands.
	Soil conservation	Mainly including reducing non-point source pollution and reducing sediment deposition.
	Flood regulation and storage	Mainly including the construction and operation of the reservoir.
	Water purification	Industrial treatment cost of atmospheric pollutants.
	Air purification	The value of purified air is evaluated using the cost of industrial treatment of water pollutants.
	Fixed carbon dioxide	The cost of fixed carbon dioxide in the market.
	Release oxygen	The cost of producing oxygen in the market.
	Climate regulation	The electricity cost required for manually adjusting temperature and humidity.
Cultural service	Leisure tourism	Total tourism revenue of the city.

Table 2. Calculation of ecosystem service values for various ecosystem service types.

Eco-Service Project	Formula	Illustrate
Water resource products	$V_1 = V_L + V_W$ $V_L = P_L \times W_L$ $V_W = P_W \times W_W$	V_1 is the water resource products value (CNY); P_L is the local water consumption of Huangshan City (m^3); W_L is the current water price in Huangshan City (CNY/m^3); P_W is the cost of water pollution control (CNY); and W_W is the net water supply of the watershed (m^3).
Fishery products	$V_2 = P_2 \times W_2$	V_2 is the fishery products value (CNY); P_2 is the price of fishery products (CNY/kg); and W_2 is the total production of fishery products in Huangshan City (kg).
Agricultural products	$V_3 = \sum_{i=1}^{6} P_i \times W_i$	V_3 is the fishery products value (CNY); P_i is the *i*-th price of agricultural products (CNY/kg); W_i is the *i*-th production of agricultural products in Huangshan City (kg); and *i* is the agricultural products type (*i* = 1 to 6).
Forestry products	$V_4 - P_4 \times W_4$	V_4 is the forestry products value (CNY); P_4 is the average price of fruit products (CNY/kg); and W_4 is the total production of fruit products in Huangshan City (kg).

Table 2. *Cont.*

Eco-Service Project	Formula	Illustrate
Animal husbandry products	$V_5 = \sum_{i=1}^{3} P_j \times W_j$	V_5 is the animal husbandry products value (CNY); P_j is the j-th price of animal husbandry products (CNY/kg); W_j is the j-th production of animal husbandry products in Huangshan City (kg); and j is the animal husbandry products type (j = 1 to 3).
Water conservation	$V_6 \times Q_6 \times P_6$	V_6 represents the value of water conservation (CNY); Q_6 is the amount of water conservation (m^3); and P_6 is the market price of water resources (CNY/m^3).
Soil conservation	$V_7 = V_s + V_D$ $V_s = \lambda \times \left(\frac{Q_D}{\rho}\right) \times c$ $V_D = \sum_{i=1}^{2} Q_D \times r_i \times P_i$	V_7 represents the soil conservation value (CNY); Vs represents the value of reducing siltation (CNY); V_D represents the value of reducing non-point source pollution (CNY); λ represents the sedimentation coefficient; Q_D represents the soil conservation quantity (t); ρ represents the soil bulk density (t/m^3); c represents per unit cost of reservoir desilting project(CNY/m^3); r_i represents the purity of the ith pollutant (such as nitrogen or phosphorus) in the soil (%), where i represents the number of nutrient substances in the soil; and P_i represents the cost of treating the i-th pollutant (i =1 to 2).
Flood regulation and storage	$V_8 = Q_8 \times C_w$	V_8 represents the flood storage value (CNY); Q_8 represents the amount of flood storage (m^3); and Cw represents the engineering cost and maintenance cost per unit capacity of the reservoir (CNY).
Water purification	$V_9 = \sum_{i=1}^{n} Q_{9,i} \times C_i$	V_9 represents the total value of water purification (CNY); $Q_{9,i}$ represents the purification amount of the i-th water pollutant (t); Ci represents the treatment cost of the i-th water pollutant (CNY); and i is the water pollutant (i = 1 to n).
Air purification	$V_{10} = \sum_{i=1}^{n} Q_{10,i} \times C_i$	V_{10} represents the total value of air purification (CNY); $Q_{10,i}$ represents the purification amount of the i-th air pollutant (t); Ci represents the treatment cost of the i-th air pollutant (CNY); and i is the air pollutant (i =1 to n).
Fixed carbon dioxide	$V_{11} = Q_{11} \times C_C$	V_{11} is the value of fixed carbon dioxide (CNY); Q_{11} is the total amount of fixed carbon dioxide (t); and C_C is the price of industrial carbon capture (CNY/t).
Release oxygen	$V_{12} = Q_{12} \times C_O$	V_{12} is the value of release oxygen (CNY); Q_{12} is the total amount of release oxygen (t); and C_0 is the price for industrial oxygen production (CNY/t).
Climate regulation	$V_{13} = E_{13} \times P_E$	V_{13} is the value of climate regulation (CNY); E_{13} is the total energy consumed by ecosystem transpiration and evaporation (kW·h); and P_E is the electricity price (CNY/kW·h).
Leisure tourism	$V_{14} = C_t \times N$	V_{14} is the value of leisure tourism; C_T is the average travel cost for tourists (sampling survey); and N represents the total number of tourists.

2.3.2. Ecological Compensation Supply Coefficient

The value spillover theory is an extension of the energy value analysis and the water ecological footprint theory in the field of ecological economics. The theory posits that after the primary service providers in an ecological economic system eliminate their own consumption value, they can provide surplus value to other areas. Consequently, only the region that has a spillover value can be worthy of corresponding compensation [29]. Therefore, the reference value for calculating the EC standard in a watershed should not be determined based on all ecosystem service values generated in the upstream areas. Instead, it should be determined by considering the reasonable scope, which encompasses the supply or consumption value of eco-products after deducting the portion required to meet the comfortable living standards of the residents. This is known as the ecological service VST, thereby avoiding overestimating the EC standard based on the value of ecosystem services. In this study, it is assumed that (1) the national per capita value of ecosystem services is the basis for judging the spillover effect of ecological services in a region, defined as the VST coefficient (VSTC) and (2) the region's willingness to accept compensation is substituted by the local level of economic development.

The formula is as follows:

$$ECSC = VSTC_{target} \times WTA \quad (2)$$

$$VSTC_{target} = \frac{ESVnation/P_{nation}}{ESV_{target}/P_{target}} \quad (3)$$

$$WTA = 2\arctan(\frac{ESV_{target}}{GDP_{target}}) \times \frac{1}{\pi} \quad (4)$$

In the formula, $VSTC_{target}$ represents the level of per capita ecosystem service value spillover in the target area compared with the national per capita ecosystem service value (ESV_{nation}/P_{nation}); if $VSTC_{target} < 1$, it indicates that the region is a supplier of ecological products, if $VSTC_{target} > 1$, it indicates that the region is a demander of ecological products, and if $VSTC_{target} = 1$, it indicates that the region is in a self-sufficient state and cannot provide supply ecological products. WTA represents the region's willingness to accept compensation; GDP_{target} represents the total GDP within the region.

2.3.3. Ecological Compensation Demand Coefficient

In order to establish a long-term operating EC mechanism, the perspectives of the compensators must be considered, such as willingness to pay, ability to pay, and scarcity of ecosystem services. In this study, we constructed an ecological compensation demand coefficient, denoted as $ECDC$. The formula for $ECDC$ is as follows:

$$ECDC = k_1 \times k_2 \times k_3 \quad (5)$$

$$k_1 = \frac{M_{LC}}{M_{PC}} \quad (6)$$

$$k_2 = \frac{PD_S}{PD_D} \quad (7)$$

$$k_3 = \frac{GDP_D}{GDP_S} \times \frac{1}{1+e^{-t}},\ t = \frac{1}{En} - 3 \quad (8)$$

In the formula, k_1 represents the adjustment coefficient of payment willingness, which is represented by the ratio of the compensation amount to the actual pollution control investment, reflecting the consumption willingness and preference of the consumption area for ecological products; M_{LC} represents the compensation amount of the previous year; and M_{PC} represents the pollution control investment amount of the previous year. k_2 is the inverse of the ecological product scarcity, which is related to the scarcity of resources. PD_S is the population density of the supply area, and PD_D is the population density of the consumption area. The adjustment coefficient k_3 is related to the consumer's socio-economic development level, and the ratio of the demand area GDP_D to the supply area GDP_S is selected as the indicator of regional economic strength. e is the natural constant; t is the social and economic development level; and En is the Engel coefficient.

2.3.4. Ecological Compensation Standard Model

In this study, the purpose of the EC standard model is to enhance the result practicability and acceptability expected to be adopted in the EC pilot to change the current fixed compensation standards. To establish the new model, it is assumed that (1) the EC standard is calculated on the basis of the region's ecosystem services value; (2) the EC standard is determined through the comprehensive consideration of the supply side and demand side; (3) the ecosystem service value within the scope of ecological compensation is the basis of EC standard calculation; and (4) the executive EC standard is a matter for negotiation between the supplier and demander, the output from this model is an interval range including the upper and lower limits of the compensation standard, and the difference is between including the supply service value and the cultural service value.

The EC standard model is established as follows:

$$ECS_{max} = ESVC_{target} \times ECSC \times ECDC \tag{9}$$

$$ECS_{min} = (ESVC_{target} - ESSVC_{target} - ECSVC_{target}) \times ECSC \times ECDC \tag{10}$$

In the formula, ECS_{max} represents the upper limit of the compensation standard; ECS_{min} represents the lower limit of the compensation standard; $ESVC_{target}$ represents the ecosystem service value within the compensation scope in the target era; $ESSVC_{target}$ represents the supply service value within the compensation scope in the target area; and $ECSVC_{target}$ represents the cultural service value within the compensation scope in the target area.

3. Results

3.1. Value of Main Ecosystem Services

According to formulas in Table 2, the ecosystem service values of the Xin'an River Basin are calculated as shown in Table 3. According to Formula (1), the total value of the ecological system in the Xin'an River Basin is calculated as CNY 70.271 billion, of which the supply services account for 22.7%, the regulatory services account for 24.6%, and the cultural services account for 52.7%.

Table 3. Total value of ecosystem services in Huangshan City.

Eco-Services Category	Eco-Service Project	Method of Calculation	Value (Billion)
Supply service	Local water use	Shadow project approach	1.19
	Basin water supply	Shadow project approach	3.468
	Fishery products	Market comparison approach	0.281
	Agricultural products	Market comparison approach	6.019
	Forestry products	Market comparison approach	2.254
	Animal husbandry products	Market comparison approach	2.748
Regulating Service	Water conservation	Shadow project approach	0.655
	Soil conservation	Replacement cost method	0.561
	Flood regulation and storage	Shadow project approach	7.84
	Water purification	Replacement cost method	0.363
	Air purification	Replacement cost method	0.011
	Fixed carbon dioxide	Replacement cost method	4.914
	Release oxygen	Replacement cost method	1.323
	Climate regulation	Replacement cost method	1.625
Cultural services	Leisure tourism	Market comparison approach	37.019
Total			70.271

3.2. Scope of Basin Ecological Compensation

There is a significant difference in economic development between the upstream and downstream areas of the Xin'an River Basin, and regional EC will involve disputes and contradictions among various stakeholders. By analyzing the service functions of the Xin'an River ecosystem, the compensation accounting scope of downstream to upstream is determined, as shown in Table 4. Considering that the value of supply services in ecosystem services is transformed into monetary value in the market, it is impossible to allocate compensation responsibility for them, so they cannot be included in the final value compensation. As a result, the primary focus of EC in the Xin'an River Basin is on 10 service functions, including watershed water supply, water conservation, soil conservation, flood control, water purification, air purification, carbon fixation, oxygen release, climate regulation, and recreation and tourism. After calculation, the total value of the ecosystem services within the scope of EC ($ESVC_{target}$) is CNY 57.779 billion, the $ESSVC_{target}$ is CNY 3.468 billion, and the $ECSVC_{target}$ is CNY 37.019 billion.

Table 4. Scope of basin ecological compensation in Huangshan City.

Eco-Services Category	Eco-Service Project	Beneficiaries of Water Ecosystem Services				In the Compensation Range
		Global	Nationwide	This City	Downstream City	
Supply service	Local water use			√		No
	Basin water supply			√	√	Yes
	Fishery products			√		No
	Agricultural products			√		No
	Forestry products			√		No
	Animal husbandry products			√		No
Regulating service	Water conservation		√	√	√	Yes
	Soil conservation		√	√	√	Yes
	Flood regulation and storage		√	√	√	Yes
	Water purification	√	√	√	√	Yes
	Air purification	√	√	√	√	Yes
	Fixed carbon dioxide		√	√	√	Yes
	Release oxygen	√	√	√	√	Yes
	Climate regulation	√	√	√	√	Yes
Cultural services	Leisure tourism		√	√	√	Yes

Note: √ means the area can benefit from this water ecosystem service.

3.3. Correction of Ecological Compensation

First, calculate the ecological compensation supply coefficient. According to the "Biodiversity and Ecosystem Service Economics" research results in China and the "2020 Statistical Bulletin of National Economic and Social Development of Huangshan City", the total value of ecosystem services in China is CNY 7.8 trillion, and the population of China is 1.383 billion, so the per capita value of ecosystem services in China is CNY 5639.913. The GDP of Huangshan City was CNY 8.504 billion, with a registered population of 1.331 million in a 9807-square kilometer area, so the per capita value of the ecosystem services in Huangshan is CNY 52,795.642. According to Formulas (2)–(4), the $VSTC_{target}$ is calculated as 0.107 and the WTA is 0.923, so the $ECSC$ is 0.099.

Then, calculate the ecological compensation demand coefficient. According to the "2020 Statistical Bulletin of National Economic and Social Development of Zhejiang Province", the GDP of Hangzhou City was CNY 1610.6 billion, with a resident population of 11.965 million at the end of 2020 in a 16,596-square kilometer area, and the Engel coefficient of urban residents was 32.3%. According to Formulas (5)–(8), k_1 = 0.143, k_2 = 5.312, and k_3 = 0.524; thus, $ECDC = k_1 \times k_2 \times k_3 = 0.840$.

3.4. Theoretical Total Amount of Ecological Compensation

According to the EC standard model, the $ECS_{max} = 57.779 \times 0.099 \times 0.840 = 4.805$, and the $ECS_{min} = (57.779 - 3.468 - 37.019) \times 0.099 \times 0.840 = 1.438$. Therefore, the upper limit of the EC standard for the Xin'an River Basin is calculated as CNY 4.805 billion, and the lower limit of the EC standard is calculated as CNY 1.438 billion.

4. Discussion

Firstly, we categorized watershed ecosystem services into the following three categories in this study: provisioning services, regulating services, and cultural services. The calculated total value of the ecosystem in the Xin'an River Basin is CNY 70.271 billion. The result shows that the value of cultural services (recreation and tourism) was 37.019, accounting for 52.7% of the total value of ecosystem services. As we all know, Huangshan City is famous for its spectacular Huangshan Scenic Area and is one of China's well-known tourist destinations. The tourism industry in Huangshan City is highly developed, attracting a large number of domestic and foreign tourists for sightseeing and travel every year [30]. Therefore, cultural and tourism services play an important role in the ecosystem services of the Xin'an River Basin. Secondly, the computed ecosystem service value is higher than that reported by Dai et al. (2021) and Yang, N (2019), obviously indicating that the upstream city of Huangshan has made great efforts to protect the watershed ecological environment so the downstream cities can enjoy greater benefits from the watershed ecosystem [25,26]. Consequently, the downstream cities have a greater responsibility for watershed ecological compensation, and the ecosystem service value offered by the watershed ecosystem to downstream cities can serve as a basis for determining the compensation fund. However, using this value directly for the ecological compensation fund clearly exceeds the capacity of the downstream city of Hangzhou. Therefore, this study established the EC standard model using the ECSC and ECDC to adjust the ecosystem service values within the compensation scope.

Finally, this new framework used the ESV overflow from the upstream cities of the Xin'an River as the standard for ecological compensation in the downstream cities, removing the ecosystem services not affecting the downstream cities, such as local water use, fishery products, agricultural products, forestry products, and animal husbandry products, which should not be included in the compensation scope. The EC standard value based on ECSC and ECDC revision in the Xin'an River Basin was calculated, as shown in Figure 4. The results show that the upper limit of the compensation amount in Huangshan City according to the supply–demand relationship is CNY 4.805 billion, and the lower limit of the EC amount after correction according to the compensation scope is CNY 1.438 billion, forming a compensation standard interval, which can be used as a reference for cooperation and decision-making between the compensation subject and object.

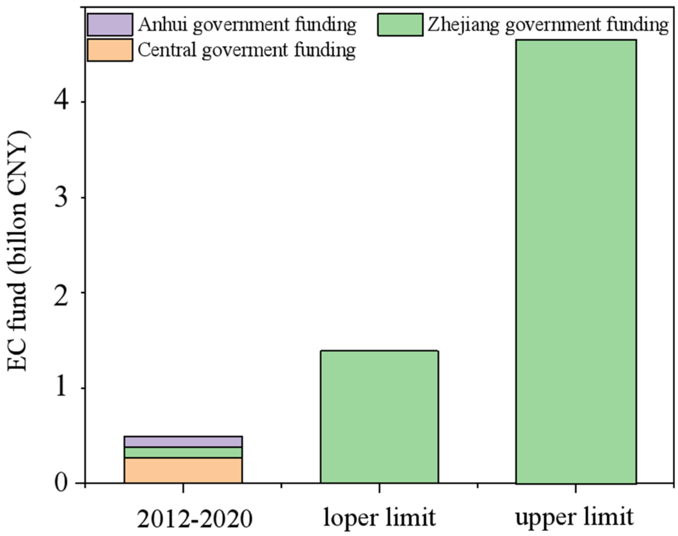

Figure 4. The upper and lower limits of actual annual and theoretical calculation of EC in Xin'an River Basin.

It should be noted that (1) the watershed ecological compensation standard model established in this article relies on the accounting results of the ecosystem service value in the watershed. However, due to the lack of uniformity in the conceptual connotation, scope definition, and value accounting methods of ecosystem services, there are significant differences in the results of different accounting studies in the same region, which to some extent, affects the accuracy and recognition of the model's calculation results in practical applications. Therefore, in the future, we should optimize the algorithm for calculating the ecosystem value in the model, reduce the model's dependence on the value of ecosystem services, and gradually improve the guidance of the watershed ecological compensation model. (2) The model established in this article is primarily used for calculating ecological compensation standards at the macro level. As China's emphasis on ecological protection in river basins increases, there will be more and more compensation between cities and counties in the future. Therefore, in subsequent research, the model established in this article should be further improved by enriching calculation indicators, optimizing calculation methods, and refining application scenarios to continuously enhance the model's applicability.

5. Conclusions

This study shows that Huangshan City can receive compensation of no less than CNY 1.438 billion in market value, and the upper limit of compensation of CNY 4.805 billion based on the compensation model is established, accounting for only 2.29% of Hangzhou's fiscal revenue in 2020 (CNY 209.34 billion), which will not cause significant financial pressure and partially compensate for the problem of insufficient funds in the compensation process, effectively improving the existing deficiencies in compensation and providing a good reference for future basin compensation, and even cross-regional EC. Therefore, the proposed method can be used to provide reasonable suggestions for solving the water resource disputes between upstream and downstream cities, the contradiction between economic development and protection, and promoting the ecological protection of the river basin, thereby offering valuable insights for potential future watershed compensation and cross-regional ecological compensation efforts.

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