Study on Ecosystem Service Value and Intra-regional Ecological Compensation in Inner Mongolia Based on the Improved Value Equivalent Method

Zhang Qing, A Rong, Tong Baoquan, Li Xiaolu, Bao Wenjie, Gerileqimuge, Xie Zhouzhi

2026-08-24

ChinaRxiv

Abstract

Based on the value equivalent method modified by the three coefficients of "spatial heterogeneity, socioeconomic conditions, and resource scarcity," this study evaluated the ecosystem service value (ESV) of Inner Mongolia Autonomous Region from 2000 to 2022. Taking 2022 as an example, it also identified ecological compensation spaces by incorporating the gross regional product of each league and city, calculated the priorities of compensation payers and compensation recipients, and proposed horizontal ecological compensation strategies suited to local conditions. The results show that: (1) The land use types in Inner Mongolia Autonomous Region are dominated by grassland and desert, and their changes are mainly characterized by mutual conversion between grassland and farmland and between grassland and desert. (2) From 2000 to 2022, the ESV of Inner Mongolia Autonomous Region showed an increasing trend, rising from 6346.03×108 yuan in 2000 to 10582.23×108 yuan in 2022, an increase of 66.75%. Grassland consistently made the greatest contribution to total ESV, accounting for more than 57.00%. Regulating services contributed the most to ESV in the study area (66.79%–67.16%). Climate regulation and hydrological regulation were the most important ecological functions in the study area. Spatially, the ESV of Inner Mongolia Autonomous Region exhibited a distribution pattern of being high in the east and low in the west. (3) Among the 12 leagues and cities, the priority order for receiving compensation is: Hulunbuir City > Xilin Gol League > Hinggan League > Alxa League > Ulanqab City; the priority order for providing compensation is: Hohhot City > Baotou City > Ordos City > Tongliao City. Bayannur City, Wuhai City, and Chifeng City are coordinating entities. The research results provide an important theoretical basis and practical reference for improving the scientific basis of ecological compensation decision-making in Inner Mongolia Autonomous Region and promoting the coordinated development of regional ecological protection and the economy.

Full Text

Study on Ecosystem Service Value and Intra-regional Ecological Compensation in Inner Mongolia Based on the Improved Value Equivalent Method

Zhang Qing[1], A Rong[1,2,3], Tong Baoquan[1,2,3], Li Xiaolu[1], Bao Wenjie[1], Gerileqimuge[1], Xie Zhouzhi[1]

(1. School of Geographical Sciences, Inner Mongolia Normal University, Hohhot 010022, Inner Mongolia; 2. Key Laboratory of Climate Change and Regional Response in the Mongolian Plateau, Hohhot 010022, Inner Mongolia; 3. Mongolian Plateau Research Center, Hohhot 010022, Inner Mongolia)

Abstract: Based on the value equivalent method corrected by three coefficients– "spatial heterogeneity, socioeconomic conditions, and resource scarcity" –this study evaluates the ecosystem service value (ESV) of Inner Mongolia Autonomous Region from 2000 to 2022. Taking 2022 as an example, it combines the gross domestic product of each league and city to identify ecological compensation spaces, calculates the priority levels of compensation subjects and compensated subjects, and proposes horizontal ecological compensation strategies suitable for local conditions. The results show that: (1) The land-use types in Inner Mongolia Autonomous Region are dominated by grassland and desert, and the main feature of their changes is the mutual conversion between grassland and farmland, and between grassland and desert. (2) From 2000 to 2022, the ESV of Inner Mongolia Autonomous Region showed an increasing trend, rising from 6346.03×10^8 yuan in 2000 to 10582.23×10^8 yuan in 2022, an increase of 66.75%. Grassland consistently made the highest contribution to total ESV, accounting for more than 57.00%. Regulating services contributed the most to the ESV of the study area (66.79%–67.16%). Climate regulation and hydrological regulation are the most important ecological functions in the study area. Spatially, the ESV of Inner Mongolia Autonomous Region exhibits a distribution pattern of "higher in the east and lower in the west." (3) Among the 12 leagues and cities, the priority ranking of compensated areas is: Hulunbuir City > Xilingol League > Xing' an League > Alxa League > Ulanqab City; the priority ranking of compensation-paying areas is: Hohhot City > Baotou City > Ordos City > Tongliao City. Bayannur City, Wuhai City, and Chifeng City are coordinating entities. The research results provide an important theoretical basis and practical reference for improving the scientific soundness of ecological compensation decision-making in Inner Mongolia Autonomous Region and promoting coordinated development between regional ecological protection and the economy.

Keywords: ecosystem service value; improved value equivalent method; ecological compensation; Inner Mongolia Autonomous Region

Article number: 1000-6060(2026)08-1640-13(1640~1652)

Ecosystem services broadly refer to all the benefits and services provided by ecosystems to human society, including directly obtained resources and indirectly obtained environmental benefits; they are an important link connecting human society and natural ecosystems[1]. As the natural foundation of regional development, ecosystems, because of their spatial heterogeneity, lead to disparities in development among regions. Moreover, once extensive economic development methods that sacrifice the ecological environment are adopted, problems such as ecosystem degradation and environmental pollution arise, intensifying the contradiction between regional economic development and ecological security. Ecological compensation is an important measure for promoting balanced development between regional ecology and the economy[2] and for advancing the construction of ecological civilization institutions; internationally, it is referred to as "payment for ecosystem services" [3]. It can be seen that ecosystem service value (ESV) is an important basis for ecological compensation. Therefore, accurately accounting for ESV and adopting appropriate ecological compensation measures are of great significance for improving public awareness of ecological protection, narrowing development gaps among regions, and promoting coordinated high-quality development of the ecological environment and economy within a region.

Evaluating ecosystem service value can reveal the benefits of ecosystem services and their changes, enabling the public to recognize that "natural resources have value" [4]. Among various evaluation methods, ESV assessment methods based on ecological value equivalents can effectively quantify the ecological functions of different land-use types and establish ecological compensation standards for different regions, thereby ensuring the scientific validity and rationality of ecological compensation mechanisms[5-6]. Xie Gaodi et al.[7], on the basis of Costanza et al.[8], established a value-equivalent table of ecosystem services per unit area for China, which has been recognized by most scholars. However, because this method is a static assessment method based on the national average level, if it is directly applied to Inner Mongolia Autonomous Region (hereinafter referred to as Inner Mongolia), it will not only affect the accuracy of the assessment but also make it difficult to fully and accurately

Received: 2025-09-18; **Revised:** 2025-10-10

Funding: National Natural Science Foundation of China projects (42001127; 4226010196); Inner Mongolia Normal University Basic Research Operating Expenses Special Fund Project (2022JBBJ015); Inner Mongolia Autonomous Region Natural Science Foundation Project (2024LHMS04005); First-class Discipline Research Special Project (YLXKZX-NSD-030).

Author biography: Zhang Qing (2001-), female, master' s student, mainly engaged in research on multiple functions of ecosystem services and ecological compensation. E-mail: 20234016030@mails.imnu.edu.cn

Corresponding author: A Rong (1988-), female, PhD, associate professor, mainly engaged in research on economic geography and regional sustainable development. E-mail: 20180016@imnu.edu.cn

reflect the dynamic changes of ESV at the temporal scale. Therefore, this method needs to be revised. For example, Wei Zhishou et al.

9

improved the equivalent-factor method by applying a remote-sensing ecological index; Ma Tingting et al.

10

adjusted it using coefficients for stages of social development; Zhou Yu et al.

11

revised the value-equivalent table by using biomass, vegetation coverage, and the ratio of grain yield per unit area of farmland, among other factors. In the revision process, however, relatively few studies have simultaneously considered both natural and socioeconomic correction factors; they have not yet fully taken into account the spatial heterogeneity of ecosystem services, the scarcity of ecological resources, the imbalance in regional economic development levels, and the dynamic changes of ESV over time. With regard to ecological compensation, China' s *Regulations on Ecological Protection Compensation*, issued in 2024, propose improving diversified compensation mechanisms. Among them, implementing horizontal ecological compensation and clarifying the rights-and-responsibilities relationships between compensating entities and recipients across regions can promote balanced development among regions as well as high-quality, coordinated ecological and economic development within regions.

Inner Mongolia has a vast territory and pronounced east–west differences in ecological patterns. As an important ecological security barrier in northern China, it occupies a highly important position in maintaining national ecological security

[12]

. For a long time, development disparities among regions in Inner Mongolia have been obvious, and there have also been ecological–economic development incongruities and ecosystem degradation within the region. Existing studies on ecological compensation in Inner Mongolia, in terms of compensation entities, have mostly involved a single ecological compensation entity, with compensation funds largely allocated uniformly by the central government. In terms of compensation objects, studies have mostly focused on compensation for a single ecological resource, such as grassland ecological compensation

[13–14]

, or on compensation for a particular ecosystem-service function of a single ecological resource, such as determining ecological compensation standards for forests based on forest carbon-sink accounting

[15–16]

. There remains a lack of value studies at the administrative-region scale for composite ecosystems, and there are few studies on horizontal ecological compensation mechanisms within the region.

In summary, this paper comprehensively considers natural and socioeconomic factors and revises the ecosystem service value coefficient (VC), thereby constructing an ESV assessment model more suitable for the study area. On this basis, taking 2022 as an example and incorporating regional gross domestic product (GDP), it identifies ecological compensation spaces and grades the priority of compensation and compensation-receiving, with the aim of providing a theoretical reference for establishing a horizontal ecological compensation mechanism within Inner Mongolia, promoting healthy ecosystem development, and coordinating socioeconomic development.

Fig. 1 Schematic diagram of the study area

Figure 1: Fig. 1 Schematic diagram of the study area

1 Data and Methods

1.1 Overview of the Study Area

Inner Mongolia is located between 97°10′ ∼ 126°29′E and 37°24′ ∼ 53°20′N. It is about 2,400 km long from east to west and has a maximum north–south span of about 1,700 km, with an elevation of 86–3,500 m and an area of 118.3×10^4 km^2, accounting for 12.3% of China' s total area. Due to its great latitudinal extent, there are marked natural-environment differences within the study area: it contains both ecologically fragile deserts and abundant forest and grassland resources. In addition, there are significant differences in the functional positioning and development stages of different regions within the study area. Therefore, carrying out research on horizontal ecological compensation is of great significance for improving ecosystem functions and promoting coordinated regional development (Figure 1).

Note: Prepared based on the standard map with review number GS(2024)0650 from the Standard Map Service website of the Ministry of Natural Resources; the base-map boundaries were not modified. The same applies below.

Fig. 1 Schematic diagram of the study area

1.2 Data Sources

Data on grain-crop sown area, yield per unit area, GDP, and resident population of each league/city were obtained from the *Inner Mongolia Statistical Yearbook* for 2000–2023; grain prices were obtained from the Ministry of Agriculture and Rural Affairs of the People' s Republic of China (https://www.moa.gov.cn/); land-use data were obtained from the *China Land Cover Dataset* released by the School of Remote Sensing and Information Engineering, Wuhan University (https://zenodo.org/record/12779975), with a resolution of 30 m; meteorological data were obtained from the China Meteorological Administration, the *China Environment Statistical Yearbook*, and the Inner Mongolia Climate Bulletin; digital elevation data were obtained from the Resource and Environmental Science Data Center of the Chinese Academy of Sciences (https://www.resdc.cn), with a resolution of 250 m.

1.3 Research Ideas and Framework

First, based on land-use data, the changes in land use in Inner Mongolia from 2000 to 2022 were analyzed. Second, based on the ecosystem service value assessment method, a value-equivalent method corrected by the three coefficients of "spatial heterogeneity, socioeconomic conditions, and resource scarcity" was proposed to calculate the ESV for the same period and analyze its spatiotemporal evolution. Then, the scope of ecological compensation was defined. Among these, food production, raw-material production, water-resource supply, and provision of aesthetic landscape services are non-market service values

5

, that is, they can be converted through market transactions

···into economic benefits; the value of gas regulation and maintaining biodiversity is difficult for beneficiaries to define. Therefore, the above services are not included in the scope of compensation. Ultimately, five types of services—soil conservation, climate regulation, environmental purification, hydrological regulation, and maintenance of nutrient cycling—are included, and their value is incorporated into the ecosystem service value within the compensation scope (NESV). On this basis, the ecological compensation space is identified in combination with the GDP of each league/city. When a region' s ecological score is significantly higher than its economic development level score, it means that the region has invested additional costs in maintaining or improving ecological services, and may have borne the opportunity cost of development because of protecting ecological services; its ecological benefits extend to the entire region and generate significant "positive externalities." Therefore, it should be defined as a compensation recipient, which conforms to the principle of "who protects, who benefits" [^17].

Conversely, economic growth may, to a certain extent, come at the cost of the ecological environment within the region. According to the theory of environmental externalities, its development may generate "negative externalities" for ecological-environmental resources shared within the region; therefore, it is defined as the compensation payer, which conforms to the principles of "who benefits, who compensates" and "the polluter pays." When the two scores are equal, it indicates that the region has basically achieved an internal balance between economic growth and ecological protection at its development stage, with a relatively small net externality impact on the regional ecosystem, and it is defined as a coordinating entity. Finally, the ratio of NESV to GDP is used to calculate the ecological compensation priority (ECPS). For recipient entities, areas with higher ECPS values should receive ecological compensation first[^5]; for compensation entities, the lower the value, the earlier compensation should be paid (Fig. 2).

Fig. 2 Research framework

ESV correction calculation → social-economic factor correction / spatial heterogeneity correction / resource scarcity correction / equivalent-factor method → land-use data → calculate ESV → NESV.

Ecological compensation spatial identification → NESV score and GDP score → difference between the two scores (G value) →
$G < 0$, compensation entity;

$G > 0$, recipient entity;
$G = 0$, coordinating entity.

Priority calculation → ECPS = NESV/GDP →
higher ECPS: priority for receiving compensation;
lower ECPS: pay compensation first.

Note: ESV is ecosystem service value; NESV is ecosystem service value within the scope of compensation; GDP is gross regional product; ECPS is ecological compensation priority; G is the difference between the two scores. The same below.

1.4 Research Methods

1.4.1 Land-use transfer matrix

The land-use transfer matrix can intuitively show the direction and quantity of conversion among land-use types[^18]. The calculation formula is:

$$A_{ab} = \begin{bmatrix} A_{11} & \cdots & A_{1m} \\ \vdots & \ddots & \vdots \\ A_{n1} & \cdots & A_{nm} \end{bmatrix} \qquad (1)$$

where: A_{ab} is the area of land use converted from type a to type b from the beginning to the end of the study period (km^2); a ($a = 1, 2, \ldots, n$) and b ($b = 1, 2, \ldots, m$) are the land-use types at the initial and final stages of the study, respectively; n and m are the numbers of land types ($n = m = 7$).

1.4.2 Ecosystem service value calculation method

The ESV calculation formula is revised using the spatial heterogeneity coefficient, resource scarcity coefficient, and socioeconomic adjustment coefficient, as follows:

$$\mathrm{ESV} = \sum (A \times VC \times N \times D \times F) \qquad (2)$$

where: ESV is ecosystem service value (yuan); A is the area of each land-use type (hm^2); VC is the ecosystem service value coefficient (yuan$\cdot$hm^{-2}); N is the spatial heterogeneity coefficient; D is the socioeconomic adjustment coefficient; and F is the resource scarcity coefficient.

1.4.3 Ecosystem service value coefficient calculation method

The ecosystem service value coefficient, namely the ecosystem service value per unit area, was determined with reference to relevant studies[^19-20]:

$$VC = E \times X_{fj} \qquad (3)$$

$$E = \frac{1}{7}\sum_{i}^{t}\frac{m_i p_i q_i}{M} \qquad (4)$$

where: E is the value of one equivalent factor (yuan·hm^{-2}); X_{fj} is the equivalent factor for service category j of ecosystem type f, taken from the ecosystem service value equivalent table of Xie Gaodi et al.[21]; m_i is the sown area of grain crop i (hm^2); M is the total sown area of grain crops (hm^2); p_i is the price of grain crop i (yuan · t^{-1}); q_i is the unit yield of grain crop i (t · hm^{-2}); and t is the number of grain types. According to the actual local planting conditions in Inner Mongolia, five typical grain crops—wheat, soybean, rice, maize, and tubers—were selected. Finally, E was calculated to be 1923.457 yuan · hm^{-2}, and the ecosystem service value per unit area was obtained (Table 1).

1.4.4 Correction of ecosystem service value coefficients

(1) Correction for spatial heterogeneity

The magnitude of ESV is related to the strength of its service functions. In general, biomass can reflect the strength of ecosystem service functions[22]. Therefore, this study uses net primary productivity (NPP) to reflect biomass and corrects it as the spatial heterogeneity coefficient[23]. Referring to relevant studies, the Thornthwaite Memorial model was selected to calculate NPP[24]:

$$N = \frac{\mathrm{NPP}'}{\mathrm{NPP}''} \qquad (5)$$

$$\mathrm{NPP} = 3000 \times \left[1 - \mathrm{e}^{-0.0009695-(V-20)}\right] \qquad (6)$$

$$V = \frac{1.05r}{\sqrt{1 + \left(\frac{1.05r}{L}\right)^2}} \qquad (7)$$

$$L = 300 + 25 \times T + 0.05 \times T^3 \qquad (8)$$

where: N is the spatial heterogeneity coefficient; NPP$'$ and NPP$''$ are the net primary productivity of vegetation in the study area and in China, respectively; V is the actual evapotranspiration (mm); r is annual precipitation (mm); L is the mean evapotranspiration (mm); and T is the annual mean temperature (℃).

(2) Correction for socioeconomic factors

The public’ s willingness to pay and ability to pay also affect ESV[25]. Among them, willingness to pay shows a certain development trend with changes in the level of socioeconomic development and can be characterized by a Pearl growth curve model[26]; ability to pay is related to residents’ economic income level, and

GDP is usually used as the measurement indicator. Therefore, willingness to pay and ability to pay are taken as socioeconomic factors to correct the value coefficient:

$$D = R \times W \qquad (9)$$

$$R = \frac{Z'}{Z''} \qquad (10)$$

$$W = \frac{\mathrm{GDP}'}{\mathrm{GDP}''} \qquad (11)$$

$$Z = \frac{1}{1 + \mathrm{e}^{3 - \frac{1}{E'}}} \times \frac{h}{H} \qquad (12)$$

$$E' = E_c \times P_c + E_r \times P_r \qquad (13)$$

where: D is the socioeconomic adjustment coefficient; R and W are residents' willingness to pay and ability to pay, respectively; Z is the level of social development; Z' and Z'' are the social development levels of the study area and the whole country, respectively; GDP' and GDP'' are the per capita GDP of the study area and the whole country, respectively; E' is the Engel coefficient; h and H are the urbanization levels of the study area and the whole country, respectively; E_c and E_r are the Engel coefficients for urban and rural areas, respectively; and P_c and P_r are the proportions of the urban and rural populations, respectively.

(3) Correction for resource scarcity

According to the supply-demand relationship in economics, ESV is directly related to the supply of ecological resources[27]. The larger the regional population size, the higher the demand for resources; therefore, population density can to a—

Table 1 Ecosystem service value per unit area in Inner Mongolia

Tab. 1 Ecosystem service value per unit area in Inner Mongolia
Unit: yuan $\cdot$ hm^{-2}

Primary category	Secondary category	Farmland	Forest	Grassland	Wetland	Desert	Water area
Provisioning services	Food production	2125.420	485.673	448.807	980.963	9.617	769.383
Provisioning services	Raw material production	471.247	1115.605	660.387	961.728	28.852	221.198
Provisioning services	Water resource supply	-2510.111	577.037	365.457	4981.753	19.235	10050.062
Regulating services	Gas regulation	1711.877	3668.994	2320.971	3654.568	125.025	913.642
Regulating services	Climate regulation	894.407	10978.130	6135.827	6924.444	96.173	2721.691
Regulating services	Environmental purification	259.667	3216.981	2026.041	6924.444	394.309	5491.469
Regulating services	Hydrological regulation	2875.568	7184.111	4494.477	46605.358	230.815	105184.235
Supporting services	Soil conservation	1000.198	4467.228	2827.481	4443.185	144.259	894.407
Supporting services	Maintenance of nutrient cycling	298.136	341.414	217.992	346.222	9.617	67.321
Supporting services	Biodiversity	326.988	4068.111	2571.021	15137.605	134.642	2462.025

Primary category	Secondary category	Farmland	Forest	Grassland	Wetland	Desert	Water area
Cultural services	Aesthetic landscape	144.259	1784.006	1134.840	9097.951	57.704	1904.222

…to characterize the degree of resource scarcity at a certain scale[^28]. The calculation formula for the resource scarcity coefficient is:

$$F = \frac{\ln q}{\ln Q} \qquad (14)$$

where: F is the resource scarcity coefficient; q is the population density of Inner Mongolia Autonomous Region; Q is the national population density.

In summary, the correction coefficients for the ecosystem service value of Inner Mongolia are as follows (Table 2).

Table 2 Correction factor for the value of ecosystem services

Correction coefficient	2000	2005	2010	2015	2020	2022
Socioeconomic coefficient	0.96	1.11	1.15	1.18	1.08	1.28
Resource scarcity coefficient	0.61	0.61	0.62	0.61	0.60	0.60
Spatial heterogeneity coefficient	0.49	0.48	0.54	0.63	0.66	0.62

1.4.5 Sensitivity analysis

Sensitivity analysis can verify the scientific validity of the corrected VC[^29]. The VC of each land category is adjusted by 50% to examine changes in ESV. If $CS < 1$, it indicates that ESV lacks elasticity with respect to VC, that is, the corrected VC conforms to local actual conditions. The calculation formula is:

$$\mathrm{CS} = \left| \frac{(\mathrm{ESV}_s - \mathrm{ESV}_t)/\mathrm{ESV}_t}{(\mathrm{VC}_s - \mathrm{VC}_t)/\mathrm{VC}_t} \right| \qquad (15)$$

where: CS is the sensitivity index; ESV_t and ESV_s are the ESV before and after adjustment, respectively; VC_t and VC_s are the VC before and after adjustment, respectively.

1.4.6 Spatial identification of ecological compensation and priority calculation

In ArcGIS software, the natural breaks classification method was used to divide NESV and GDP into five levels—high-value group, medium-high-value group, medium-value group, medium-low-value group, and low-value group—and scores of 5, 4, 3, 2, and 1 were assigned in sequence. Then, according to the following formulas, the compensation or compensated subject was determined, and the priority level of compensation or being compensated was calculated:

$$G = G_{\mathrm{NESV}} - G_{\mathrm{GDP}} \qquad (16)$$

$$\mathrm{ECPS} = \frac{\mathrm{NESV}}{\mathrm{GDP}} \qquad (17)$$

where: NESV is the ecosystem service value included in the scope of compensation; GDP is the regional gross domestic product; G_{NESV} is the NESV classification score; G_{GDP} is the GDP classification score; ECPS is the ecological compensation priority; G is the difference between the two scores. If $G > 0$, the region is a compensated subject; if $G < 0$, the region is a compensation subject; if $G = 0$, the region is a coordinating subject.

2 Results and analysis

2.1 Analysis of land-use change

The land-use types in the study area are mainly grassland and desert. In the eastern part, the land-use type is mainly forest; in the central part, grassland covers a relatively large area; and in the western part, desert predominates (Fig. 3). From 2000 to 2022, forest area increased the most, by 66.21×10^2 km^2, followed by

(a) 2000
Legend: national boundary; provincial boundary; league/city boundary. Land-use types: cropland; construction land; forest; water area; wetland; grassland; desert. Scale: 0–500 km.

(b) 2005
Legend: national boundary; provincial boundary; league/city boundary. Land-use types: cropland; construction land; forest; water area; wetland; grassland; desert. Scale: 0–500 km.

(c) 2010
Legend: national boundary; provincial boundary; league/city boundary. Land-use types: cropland; construction land; forest; water area; wetland; grassland; desert. Scale: 0–500 km.

(d) 2015
Legend: national boundary; provincial boundary; league/city boundary. Land-use types: cropland; construction land; forest; water area; wetland; grassland; desert. Scale: 0–500 km.

(e) 2020
Legend: national boundary; provincial boundary; league/city boundary. Land-use types: cropland; construction land; forest; water area; wetland; grassland; desert. Scale: 0–500 km.

(f) 2022
Legend: national boundary; provincial boundary; league/city boundary. Land-use types: cropland; construction land; forest; water area; wetland; grassland; desert. Scale: 0–500 km.

Fig. 3 Land use types in Inner Mongolia from 2000 to 2022

construction land increased by 57.92×10^2 km^2, while the desert area decreased the most, by 59.90×10^2 km^2 (Table 3).

From the land-use transition Sankey diagram, it can be seen that changes in land use in Inner Mongolia were most significant in the conversions between cropland and grassland, and between desert and grassland. Grassland was the land type with the largest amount transferred out. Taking 2010–2015 as an example, its transferred-out area was 282.72×10^2 km^2, mainly converted into cropland and desert, which together accounted for 90.32% of the total grassland transferred out. Next was cropland. Taking 2000–2005 as an example, its transferred-out area was 220.20×10^2 km^2, of which 94.42% was converted into grassland (Fig. 4).

2.2 Spatiotemporal Variation Analysis of ESV

2.2.1 Analysis of temporal changes in ESV

The total ESV of Inner Mongolia showed an increasing trend, rising from 6346.03×10^8 yuan in 2000 to 10582.23×10^8 yuan in 2022 (Fig. 5). From 2000 to 2010, the areas of cropland and desert decreased, while the areas of forest and grassland increased, causing the ESV of forest and grassland to increase by 848.92×10^8 yuan and 1273.33×10^8 yuan, respectively. From 2010 to 2015, ESV increased by 1535.34×10^8 yuan, which was related to the ecological

Fig. 4 Land use transition matrix of Inner Mongolia from 2000 to 2022

Figure 2: Fig. 4 Land use transition matrix of Inner Mongolia from 2000 to 2022

Fig. 5 Ecosystem service value in Inner Mongolia from 2000 to 2022

Figure 3: Fig. 5 Ecosystem service value in Inner Mongolia from 2000 to 2022

positive effects brought by the increases in the areas of forest, water bodies, and wetlands. In addition, the spatial heterogeneity coefficient increased from 0.538 to 0.627, reflecting that climatic conditions had an ecological positive effect on vegetation production potential, thereby further increasing ESV. From 2015 to 2020, people' s willingness and ability to pay declined, and the decrease in the areas of grassland, wetlands, and water bodies, as well as the ecological negative effects brought by the increases in construction land and desert areas, caused ESV to decline by 448.60×10^8 yuan. From 2020 to 2022, increases in wetland and water-body areas, together with rapid economic development and improved willingness to pay, caused ESV to increase by 1027.21×10^8 yuan.

Among the ESV of each land type, forest and grassland contributed the most, and the two

Table 3 Changes in land use area in Inner Mongolia from 2000 to 2022
Tab. 3 Changes in land use area in Inner Mongolia from 2000 to 2022
Unit: /10^2 km^2

Year	Cropland	Forest	Grassland	Water bodies	Desert	Construction land	Wetland
2000	1398.32	1739.71	5457.19	60.57	2748.72	53.18	0.98
2005	1323.92	1770.89	5545.94	50.61	2704.43	62.23	0.64
2010	1316.06	1783.10	5556.96	47.28	2676.60	78.20	0.46
2015	1379.30	1793.48	5483.45	52.10	2657.61	92.20	0.51
2020	1340.68	1809.92	5475.98	51.69	2674.69	105.37	0.34
2022	1372.54	1805.92	5427.39	51.84	2688.82	111.09	1.06
2000–2022	−25.78	66.21	−29.80	−8.73	−59.90	57.92	0.08

Fig. 4 Land use transition matrix of Inner Mongolia from 2000 to 2022

Fig. 5 Ecosystem service value in Inner Mongolia from 2000 to 2022

The proportion of total value accounted for by the former ranged from 86.99% to 88.79%. The order of the contribution of other land types to ESV was:

water area > cropland > desert > wetland. Although the areas of desert and cropland were much larger than that of water area, the ESV per unit area of water area was higher and played a greater role in hydrological regulation and water-resource supply; therefore, the ESV of water area was higher than that of desert and cropland. Because the area of wetland was much smaller than those of other land types, its contribution to the overall service value was the smallest.

Among all services, regulating services were the most important function of the Inner Mongolia ecosystem. Taking 2022 as an example, their value reached 7084.329×10^8 yuan, accounting for 66.95% of the total. They were followed by supporting services, accounting for 22.60%; cultural services had the lowest value, accounting for only 4.50% (Table 4). Among individual ESV items, the value of climate regulation accounted for 24.84% of total ESV, and hydrological regulation was second only to climate regulation; the values of both were far higher than those of other services. Water-resource supply contributed the least to the total value, because Inner Mongolia has extensive cropland, and irrigation needs consume relatively large amounts of water resources.

Overall, except for water-resource supply, the other individual ESV items all showed increasing trends in 2000–2015 and 2020–2022 (Table 5).

Table 4 Value of individual ecosystem services in Inner Mongolia from 2000 to 2022

Tab. 4 Value of individual ecosystem services in Inner Mongolia from 2000 to 2022 /10^8 yuan

Primary category	Secondary category	2000	2005	2010	2015	2020	2022
Provisioning services	Food production	183.123	203.582	239.395	287.523	271.187	303.740
Provisioning services	Raw-material production	180.942	206.685	244.051	287.630	274.454	304.238
Provisioning services	Water-resource supply	14.675	19.079	21.556	20.807	24.035	22.230
Regulating services	Gas regulation	627.340	716.271	845.642	996.634	950.717	1053.999

Primary category	Secondary category	2000	2005	2010	2015	2020	2022
Regulating services	Climate regulation	1558.962	1791.120	2116.787	2485.157	2377.306	2629.058
Regulating services	Environmental purification	537.703	613.518	723.205	850.625	813.499	900.318
Regulating services	Hydrological regulation	1537.905	1690.930	1970.601	2364.187	2252.774	2500.954
Supporting services	Soil conservation	719.950	825.039	974.513	1145.362	1094.326	1211.327
Supporting services	Maintenance of nutrient cycling	64.094	72.803	85.899	101.634	96.727	107.470
Supporting services	Biodiversity	637.875	731.426	863.675	1014.082	969.746	1072.815
Cultural services	Aesthetic landscape	283.457	324.490	382.948	449.971	430.241	476.077

Table 5 Changes in the value of individual ecosystem services in Inner Mongolia from 2000 to 2022

Tab. 5 Changes in the value of individual ecosystem services in Inner Mongolia from 2000 to 2022 /10^8 yuan

Primary category	Secondary category	2000—2005	2005—2010	2010—2015	2015—2020	2020—2022
Provisioning services	Food production	20.459	35.813	48.128	−16.336	32.553

Primary category	Secondary category	2000–2005	2005–2010	2010–2015	2015–2020	2020–2022
Provisioning services	Raw-material production	25.743	37.367	43.578	−13.175	29.784
Provisioning services	Water-resource supply	4.403	2.478	−0.749	3.227	−1.804
Regulating services	Gas regulation	88.931	129.372	150.991	−45.917	103.282
Regulating services	Climate regulation	232.158	325.666	368.370	−107.851	251.752
Regulating services	Environmental purification	75.816	109.686	127.420	−37.126	86.819
Regulating services	Hydrological regulation	153.024	279.671	393.587	−111.413	248.180
Supporting services	Soil conservation	105.089	149.474	170.850	−51.036	117.001
Supporting services	Maintenance of nutrient cycling	8.709	13.095	15.736	−4.907	10.743
Supporting services	Biodiversity	93.551	132.249	150.406	−44.336	103.069
Cultural services	Aesthetic landscape	41.033	58.458	67.023	−19.730	45.836

From 2015 to 2020, because residents' willingness and ability to pay declined, most individual ESV items decreased to varying degrees. During the study period, the most obvious changes occurred in climate regulation and hydrological regulation among regulating services. Both were particularly important to the overall ESV of Inner Mongolia, accounting for 24.57%–25.00% and 23.27%–24.23% of the total value, respectively. Grasslands and forests have relatively strong capacities for climate regulation and hydrological regulation; therefore, protecting forest and grassland ecosystems can effectively support and stably maintain the overall climate-regulation and hydrological-regulation capacities of Inner Mongolia.

2.2.2 Spatial distribution of ESV and analysis of its changes

Combined with land-use data, using a 15 km × 15 km grid as the basic unit, the ESV of each grid in Inner Mongolia from 2000 to 2022 was calculated. According to the following classes: $<0.7 \times 10\hat{}8$ yuan, $0.7 \times 10^{8\text{-}1.4 \times 10}8$ yuan, $1.4 \times 10^{8\text{-}2.1 \times 10}8$ yuan, $2.1 \times 10^{8\text{-}2.8 \times 10}8$ yuan, and $>2.8 \times 10\hat{}8$ yuan, ESV levels were divided into low-value areas, relatively low-value areas, medium-value areas, relatively high-value areas, and high-value areas. Spatially, the overall ESV of Inner Mongolia showed a distribution pattern of "high in the east and low in the west" (Fig. 6).

(a) 2000
Legend
National boundary; provincial boundary; league/city boundary
ESV/10ˆ8 yuan: <0.7; 0.7-1.4; 1.4-2.1; 2.1-2.8; >2.8
N; 0 500 km

(b) 2005
Legend
National boundary; provincial boundary; league/city boundary
ESV/10ˆ8 yuan: <0.7; 0.7-1.4; 1.4-2.1; 2.1-2.8; >2.8
N; 0 500 km

(c) 2010
Legend
National boundary; provincial boundary; league/city boundary
ESV/10ˆ8 yuan: <0.7; 0.7-1.4; 1.4-2.1; 2.1-2.8; >2.8
N; 0 500 km

(d) 2015
Legend
National boundary; provincial boundary; league/city boundary
ESV/10ˆ8 yuan: <0.7; 0.7-1.4; 1.4-2.1; 2.1-2.8; >2.8
N; 0 500 km

(e) 2020
Legend
National boundary; provincial boundary; league/city boundary
ESV/10ˆ8 yuan: <0.7; 0.7-1.4; 1.4-2.1; 2.1-2.8; >2.8
N; 0 500 km

(f) 2022
Legend
National boundary; provincial boundary; league/city boundary

ESV/10^8 yuan: <0.7; 0.7–1.4; 1.4–2.1; 2.1–2.8; >2.8
N; 0 500 km

Fig. 6 Spatial distributions of ESV in Inner Mongolia from 2000 to 2022

The eastern region (Hulunbuir City, Hinggan League, Tongliao City, and Chifeng City) had the highest ESV. Some water bodies in northern Hulunbuir City and the Greater Khingan forest area belonged to high-value and relatively high-value areas; the forest and wetland ecosystems in this region provided stable water conservation and biodiversity-protection services. After 2010, the ESV of the original relatively high-value areas in Hinggan League and northern Chifeng City increased substantially and gradually evolved into high-value areas. The grassland areas of Tongliao City and Chifeng City belonged to medium-value areas, with some grassland areas showing a transition toward relatively high-value areas. The extent of relatively low-value areas was largely consistent with the extent of farmland and showed a gradually shrinking trend.

The central region (Xilingol League, Ulanqab City, Baotou City, and Hohhot City) has a large grassland area and important functions such as climate regulation, hydrological regulation, and maintaining soil fertility. From 2000 to 2010, the central region was mainly a medium-value area. After 2010, some medium-value areas gradually increased to relatively high-value areas, while the original relatively low-value areas in parts of Ulanqab City and Baotou City gradually rose to medium-value areas with grassland ecological improvement and wetland restoration.

The western region (Alxa League, Bayannur City, Wuhai City, and Ordos City) is dominated by deserts, and natural conditions limit ecosystem service functions. Overall, most of it is a low-value area. In particular, in Alxa League, natural conditions such as high temperature and little rainfall caused ESV improvement to be relatively slow, and its distribution range changed little over the years. The Hetao Irrigation District belonged to a relatively low-value area; as a typical irrigated agricultural area, the stable farmland ecosystem formed over a long period kept ESV relatively stable over many years.

2.3 Sensitivity-index analysis

The value coefficients of each ecosystem type were adjusted, and the calculation was carried out.

Its sensitivity index shows that the grassland sensitivity index is the highest (0.5704–0.5827), that is, when VC increases by 10%, grassland ESV increases by 5.704%–5.826%; the wetland sensitivity index is the lowest. In summary, the sensitivity indices for all land types in all periods are less than 1, indicating that the calculation results of ESV for Inner Mongolia in this study have relatively high applicability (Table 6).

Table 6 Sensitivity indices for each land type

Tab. 6 Sensitivity indices for each land type

Year	Farmland	Forest	Grassland	Wetland	Desert	Water area
2000	0.0480	0.2978	0.5721	0.0004	0.0155	0.0661
2005	0.0454	0.3029	0.5810	0.0003	0.0153	0.0552
2010	0.0452	0.3053	0.5827	0.0002	0.0151	0.0516
2015	0.0473	0.3066	0.5741	0.0002	0.0150	0.0568
2020	0.0459	0.3093	0.5732	0.0002	0.0151	0.0563
2022	0.0472	0.3099	0.5704	0.0005	0.0152	0.0567

2.4 Spatial identification and priority analysis of ecological compensation

The spatial identification of ecological compensation comprehensively considered two factors: the natural ecological background and the level of economic development. Taking 2022 as an example, there are five compensation recipients, namely Hulunbuir City, Xilin Gol League, Hinggan League, Alxa League, and Ulanqab City; there are four compensation subjects, namely Hohhot City, Baotou City, Ordos City, and Tongliao City. In addition, Chifeng City, Bayannur City, and Wuhai City are coordinating subjects (Table 7).

For the compensation recipients, Hulunbuir City has the highest compensation priority. The local forest area is large and the ecological background is excellent; while providing relatively high service values such as climate regulation and hydrological regulation for the locality, it also benefits surrounding regions through the spillover of services, and therefore priority compensation should be given. The NESV of Ulanqab City is at a medium level within the region, and its GDP ranks third among the compensation recipients, indicating that the degree of imbalance between ecological protection and economic development is relatively slight, and therefore its compensation sequence is later.

Table 7 Ecological compensation priority index for each league city

Tab. 7 Priority index for ecological compensation in each league city

League/city	GDP/10^8 yuan	Rank	NESV/10^8 yuan	Rank	G	Spatial identification	ECPS	Rank
Hulunbuir City	1536.00	6	2789.17	1	$G > 0$	Compensation recipient	1.82	1

League/city	GDP/10^8 yuan	Rank	NESV/10^8 yuan	Rank	G	Spatial identification	ECPS	Rank
Xilin Gol League	1148.70	7	1499.00	2	$G > 0$	Compensation recipient	1.31	2
Hinggan League	681.50	11	417.72	5	$G > 0$	Compensation recipient	0.61	3
Alxa League	407.30	12	205.81	9	$G > 0$	Compensation recipient	0.51	4
Ulanqab City	1017.90	9	369.24	6	$G > 0$	Compensation recipient	0.36	5
Chifeng City	2148.40	4	594.28	3	$G = 0$	Coordinating subject	0.28	–
Bayannur City	1084.60	8	283.99	8	$G = 0$	Coordinating subject	0.26	–
Wuhai City	803.30	10	12.62	12	$G = 0$	Coordinating subject	0.02	–
Hohhot City	3329.10	3	102.39	11	$G < 0$	Compensation subject	0.03	1
Baotou City	3749.90	2	192.58	10	$G < 0$	Compensation subject	0.05	2
Ordos City	5613.40	1	560.52	4	$G < 0$	Compensation subject	0.10	3
Tongliao City	1561.80	5	316.59	7	$G < 0$	Compensation subject	0.20	4

Note: GDP is the regional gross domestic product; NESV is the ecosystem service value included in the compensation scope; G is the difference between the two scores; ECPS is the priority level of ecological compensation.

For the compensation subjects, Hohhot City has the highest compensation priority. Its GDP is at a relatively high level within the region, while its NESV ranks low within the region, indicating that it relies on the input of a large amount of resources to maintain a high level of economic development; therefore compensation should be paid first. Tongliao City ranks last in GDP among the compensation subjects, but its NESV ranks relatively high among the compensation subjects, indicating that under conditions of relatively limited economic development, it has ensured the relatively healthy development of the ecology; therefore compensation may be paid last.

For the coordinating subjects, the GDP and NESV of Chifeng City are both at an upper-middle level within the region, indicating that while rapidly developing its economy, it has also taken ecological environmental protection into account; Wuhai City, as a resource-based city, has in recent years implemented measures such as ecological restoration and industrial transformation, placing ecological protection and economic development in a state of dynamic equilibrium; Bayannur City, as an agricultural city, has protected the ecological environment and achieved high-quality economic development through its advanced agricultural technologies and development model.

3 Discussion

Against the background of comprehensively promoting the construction of ecological civilization and green development, the report to the 20th National Congress of the Communist Party of China emphasized the need to "establish and improve the mechanism for realizing the value of ecological products and improve the ecological protection compensation system." Therefore, accurately accounting for ecosystem service value and exploring multiple ecological compensation methods are of great practical significance for promoting high-quality economic development and coordinated development of the ecological environment. In terms of the ESV calculation method, this study comprehensively considered the interannual changes in regional residents' willingness to pay, economic level, payment capacity, natural conditions, and other factors, and constructed a more suitable framework for the study area.

ESV calculation model, and verified its reliability through sensitivity analysis. This method effectively avoids the problems that the equivalent table may be detached from regional realities and that ESV fluctuates only with changes in land area, thereby improving the scientific validity and explanatory power of the results.

Temporally, from 2000 to 2022, the total ESV in the study area increased by 66.75%, showing obvious stage-by-stage fluctuations. Its changes were affected not only by adjustments in the land-use structure, but also by regulation from socioeconomic development. Spatially, ESV exhibited a distribution pattern of "high in the east and low in the west," which is determined by the natural background differences among the forest wetlands in the east, the grasslands in the central region, and the deserts in the west. During the study period, the value of some areas in the east and central region continued to rise, whereas changes in the west were slow due to natural-condition constraints; this is the result of the combined effects of ecological protection policies and natural endowments.

The spatial identification of ecological compensation comprehensively considered two factors: natural ecology and the level of economic development. When a place is a compensated subject, this mainly indicates that, in order to protect the ecology, it has slowed its own economic growth, and its favorable ecological environment can benefit surrounding areas. Therefore, from the perspectives of fairness and coordinated regional development, it should receive ecological compensation, such as Hulunbuir City and Ulanqab City. When a place is a compensating subject, this mainly indicates that its emphasis on economic growth exceeds that on ecological protection, as in Hohhot City and other places; as economically leading regions within Inner Mongolia, they should assume the responsibility of compensating subjects. As for coordinating subjects, Wuhai City, as a resource-based city, has in recent years achieved a dynamic balance between ecological protection and economic development through measures such as ecological restoration and industrial transformation. Among compensated subjects, Alxa League lags behind in economic development and should in principle be given priority for compensation; however, when compensation funds are limited, "ecological contribution capacity"must also be considered. The local NESV is relatively low, indicating that the supply capacity of ecosystem services is limited, and therefore its compensation priority ranks in the middle. Among compensating subjects, Ordos City ranks first in GDP within the region and also has a relatively high NESV. Compared with Hohhot City and Baotou City, its local ecological contribution and economic development are relatively balanced, and therefore its compensation priority is lower. For coordinating subjects, Chifeng City' s economic development, which depends on ecological functions, has vulnerability; its level of economic development is relatively high, and its NESV ranking is also high, indicating that its economic development may depend to a large extent on the continuous supply of ecological resources. If the ecosystem cannot be effectively protected, its economic sustainability may be threatened.

This study of horizontal ecological compensation within Inner Mongolia clarifies the compensated, compensating, and coordinating subjects, and can provide a basis for formulating horizontal ecological compensation implementation within the region. The results of this study also accord with the basic logic of ecological compensation mechanism design, namely that regions with a high level of economic development feed back to regions with a low level of economic development[^5]. For priority compensated regions such as Hulunbuir City and Xilin Gol League, compensation funds may be focused on the restoration of grassland and forest ecosystems or the development of alternative industries. For areas such as Alxa League, where ecosystem-service capacity is currently relatively weak but ecological status is important, compensation may emphasize "developmental compensation," such as promoting water-saving technologies and implementing sand-prevention and sand-control projects. The autonomous-region government or relevant departments may encourage Hohhot City and Baotou City to take the lead in participating in compensation through various means such as technology output and industrial cooperation, rather than limiting compensation to financial transfers. For coordinating subjects, it is recommended that their experience in ecological protection or industrial transformation be promoted, while potential risks in their ecologically dependent economies should also be highlighted.

At the same time, this study still has shortcomings. In defining compensation and compensated subjects, subsequent research may identify compensating and compensated subjects by combining ecosystem-service flows at a larger regional scale, thereby making the responsibilities for horizontal ecological compensation more scientifically explicit.

4 Conclusion

(1) The main land-use types in Inner Mongolia are grassland and desert. During the study period, the areas of desert and grassland decreased to some extent, while forest land and construction land showed a continuing expansion trend. The most significant feature of land-use transfer was the mutual conversion between farmland and grassland, and between desert and grassland.

(2) From 2000 to 2022, the total ESV in Inner Mongolia showed an increasing trend, rising from 6346.03×10^8 yuan in 2000 to 10582.23×10^8 yuan in 2022, an increase of 66.75%. Among different land types, grassland had the highest ESV, accounting for more than 57% of the total value. Among all types of ecosystem services, regulating services contributed the most to local ESV (66.79%-67.16%). Among individual ecosystem services, the two services of climate regulation (24.57%-25.00%) and hydrological regulation (23.27%-24.23%) were the most important ecological functions of Inner Mongolia' s ecosystem. The spatial distribution of ESV showed the characteristic of "high in the east and low in the west." During the study period, ESV was high and increased significantly in the eastern region; changes in ESV in the central region were relatively stable; and the overall increase in ESV in the western region was limited.

(3) Taking 2022 as an example, among the 12 leagues and cities in Inner Mongolia, the compensated subjects ranked by compensation priority as follows: Hulunbuir City (1.82) > Xilin Gol League (1.31) > Hinggan League (0.61) > Alxa League (0.51) > Ulanqab City (0.36). The compensating subjects ranked by priority for taking the lead in compensation as follows: Hohhot City (0.03) > Baotou City (0.05) > Ordos City (0.10) > Tongliao City (0.20). Chifeng City, Bayannur City, and Wuhai City were coordinating subjects.

References

[1] Ouyang Z Y, Song C S, Zheng H, et al. Using gross ecosystem product (GEP) to value nature in decision making[J]. *Proceedings of the National Academy of Sciences*, 2020, 117(25): 14593-14601.

[2] Börner J, Baylis K, Corbera E, et al. The effectiveness of payments for environmental services[J]. World Development, 2017, 96: 359-374.

[3] Norgaard R B, Jin L. Trade and the governance of ecosystem services[J]. Ecological Economics, 2008, 66(4): 638-652.

[4] Xie G D, Zhen L, Lu C X, et al. Applying value transfer method for eco-service valuation in China[J]. Journal of Resources and Ecology, 2010, 1(1): 51-59.

[5] Zhao Zhigang, Yu De, Wang Kairong, et al. Ecosystem services value evaluation and strategies of payment for ecosystem service in western Jiangxi Province[J]. Acta Ecologica Sinica, 2020, 40(20): 7507-7518. [Zhao Zhigang, Yu De, Wang Kairong, et al. Ecosystem services value evaluation and strategies of payment for ecosystem service in western Jiangxi Province[J]. Acta Ecologica Sinica, 2020, 40(20): 7507-7518.]

[6] Wang Nüjie, Liu Jian, Wu Daqian, et al. Regional eco-compensation based on ecosystem service assessment: A case study of Shandong Province[J]. Acta Ecologica Sinica, 2010, 30(23): 6646-6653. [Wang Nüjie, Liu Jian, Wu Daqian, et al. Regional eco-compensation based on ecosystem service assessment: A case study of Shandong Province[J]. Acta Ecologica Sinica, 2010, 30(23): 6646-6653.]

[7] Xie Gaodi, Zhen Lin, Lu Chunxia, et al. Expert knowledge based valuation method of ecosystem services in China[J]. Journal of Natural Resources, 2008, 23(5): 911-919. [Xie Gaodi, Zhen Lin, Lu Chunxia, et al. Expert knowledge based valuation method of ecosystem services in China[J]. Journal of Natural Resources, 2008, 23(5): 911-919.]

[8] Costanza R, d' Arge R, De Groot R, et al. The value of the world' s ecosystem services and natural capital[J]. Nature, 1997, 387(6630): 253-260.

[9] Wei Zhishou, Guan Yanming, Cai Danlu, et al. Assessing ecosystem services value with modified remote sensing ecological index[J]. Journal of Geo-Information Science, 2024, 26(7): 1763-1778. [Wei Zhishou, Guan Yanming, Cai Danlu, et al. Assessing ecosystem services value with modified remote sensing ecological index[J]. Journal of Geo-Information Science, 2024, 26(7): 1763-1778.]

[10] Ma Tingting, Wang Xiyi, Zhang Lei. Evaluation of ecosystem service value in mountainous tourism areas based on value equivalent factor methods: A case study of Mount Tai in Shandong Province[J]. Journal of Taishan University, 2024, 46(2): 14-21. [Ma Tingting, Wang Xiyi, Zhang Lei. Evaluation of

ecosystem service value in mountainous tourism areas based on value equivalent factor methods: A case study of Mount Tai in Shandong Province[J]. Journal of Taishan University, 2024, 46(2): 14-21.]

[11] Zhou Yu, Deng Wei, Liu Ting, et al. Spatio-temporal evolution and driving force of ecosystem service value in Chongqing metropolitan area[J]. Research of Soil and Water Conservation, 2020, 27(1): 249-256. [Zhou Yu, Deng Wei, Liu Ting, et al. Spatio-temporal evolution and driving force of ecosystem service value in Chongqing metropolitan area[J]. Research of Soil and Water Conservation, 2020, 27(1): 249-256.]

[12] Li Hongqing, Zhang Lin, Qin Xin, et al. Assessment of regional ecological carrying capacity of the coal-electricity development area in arid and semi-arid grassland of Inner Mongolia[J]. Chinese Journal of Ecology, 2024, 43(2): 522-532.]

[13] Hu Juanjuan, Zhang Xinling, Liu Yuchen. Urban residents' willingness to pay for grassland ecological compensation in Inner Mongolia: Exploring influencing factors[J]. Chinese Journal of Grassland, 2024, 46(7): 112-122. [Hu Juanjuan, Zhang Xinling, Liu Yuchen. Urban residents' willingness to pay for grassland ecological compensation in Inner Mongolia: Exploring influencing factors[J]. Chinese Journal of Grassland, 2024, 46(7): 112-122.]

[14] Wang Tianyan, Ma Xiaoqing. Ecological protection and pastoralist livelihoods: Investigation on the implementation of grassland ecological protection subsidy and reward policy in pastoral areas[J]. Journal of Qinghai Nationalities University (Social Science Edition), 2022, 48(2): 57-69. [Wang Tianyan, Ma Xiaoqing. Ecological protection and pastoralist livelihoods: Investigation on the implementation of grassland ecological protection subsidy and reward policy in pastoral areas[J]. Journal of Qinghai Nationalities University (Social Science Edition), 2022, 48(2): 57-69.]

[15] Huang Minyun. Analysis of the ecological compensation mechanism based on the forest carbon sink accounting in Inner Mongolia[D]. Hohhot: Inner Mongolia University, 2022. [Huang Minyun. Analysis of the ecological compensation mechanism based on the forest carbon sink accounting in Inner Mongolia[D]. Hohhot: Inner Mongolia University, 2022.]

[16] Ma Wenqi. Research on the ecological compensation mechanism based on the value of forest carbon sink in Inner Mongolia under the background of high quality[D]. Hohhot: Inner Mongolia University of Finance and Economics, 2024. [Ma Wenqi. Research on the ecological compensation mechanism based on the value of forest carbon sink in Inner Mongolia under the background of high quality[D]. Hohhot: Inner Mongolia University of Finance and Economics, 2024.]

[17] Liu Chen, Tian Yangfan, Niu Xianchu. A comparative study between the opportunity cost of ecological compensation and the development of ecological functional areas based on major function oriented zoning: An empirical analy-

sis based on Shanxi Province (2008—2015)[J]. Modern Urban Research, 2022(3): 14-20. [Liu Chen, Tian Yangfan, Niu Xianchu. A comparative study between the opportunity cost of ecological compensation and the development of ecological functional areas based on major function oriented zoning: An empirical analysis based on Shanxi Province (2008—2015)[J]. Modern Urban Research, 2022(3): 14-20.]

[18] An Wenju, Yu Yifan, Hao Shanshan, et al. Evolution and response analysis of habitat quality in more sediments and coarse sediments region of northern Shaanxi based on land use change[J]. Arid Land Geography, 2024, 47(3): 474-484. [An Wenju, Yu Yifan, Hao Shanshan, et al. Evolution and response analysis of habitat quality in more sediments and coarse sediments region of northern Shaanxi based on land use change[J]. Arid Land Geography, 2024, 47(3): 474-484.]

[19] Xie Gaodi, Zhang Caixia, Zhang Changshun, et al. The value of ecosystem services in China[J]. Resources Science, 2015, 37(9): 1740-1746. [Xie Gaodi, Zhang Caixia, Zhang Changshun, et al. The value of ecosystem services in China[J]. Resources Science, 2015, 37(9): 1740-1746.]

[20] Zhang Zhiqiang, Chen Pengfei, Shen Wei. Study on land use/cover change and its impact on ecosystem services in Changwu County[J]. Research of Soil and Water Conservation,

2017, 24(4): 219-226, 233.]

[21] Xie Gaodi, Zhang Caixia, Zhang Leiming, et al. Improvement of the evaluation method for ecosystem service value based on the equivalent value factor per unit area[J]. Journal of Natural Resources, 2015, 30(8): 1243-1254. [Xie Gaodi, Zhang Caixia, Zhang Leiming, et al. Improvement of the evaluation method for ecosystem service value based on per unit area[J]. Journal of Natural Resources, 2015, 30(8): 1243-1254.]

[22] Liu Yong, Li Jinchang, Yang Yonggang. Evaluation of forest ecosystem service functions in Shanxi Province based on biomass factors[J]. Acta Ecologica Sinica, 2012, 32(9): 2699-2706. [Liu Yong, Li Jinchang, Yang Yonggang. Evaluation of forest ecosystem services based on biomass in Shanxi Province[J]. Acta Ecologica Sinica, 2012, 32(9): 2699-2706.]

[23] Liu Qian, Li Ge, Zhang Chao, et al. Study on dynamic changes in ecosystem service values in Qinglong County based on coefficient correction[J]. Chinese Journal of Eco-Agriculture (Chinese and English), 2019, 27(6): 971-980. [Liu Qian, Li Ge, Zhang Chao, et al. Study on dynamic changes in ecosystem service values in Qinglong County based on coefficient correction[J]. Chinese Journal of Eco-Agriculture, 2019, 27(6): 971-980.]

[24] Luo Yongzhong, Cheng Ziyong, Guo Xiaoqin. The spatiotemporal variation characteristics of potential climate productivity in Gansu Province over nearly 40 years[J]. Acta Ecologica Sinica, 2011, 31(1): 221-229. [Luo Yongzhong, Cheng Ziyong, Guo Xiaoqin. The changing characteristics of potential climate

productivity in Gansu Province during nearly 40 years[J]. Acta Ecologica Sinica, 2011, 31(1): 221-229.]

[25] Ou Minghao, Zong Zhenling, Dong Yuanhua, et al. Discussion of economic compensation methods for regional ecological reconstruction—A case study of the upper reaches of the Yangtze River[J]. Journal of Nanjing Agricultural University, 2000(4): 109-112. [Ou Minghao, Zong Zhenling, Dong Yuanhua, et al. Economic compensation for regional eco-reconstruction: A case of the upper basin of Yangtze River[J]. Journal of Nanjing Agricultural University, 2000(4): 109-112.]

[26] Xing L, Xue M G, Wang X Y. Spatial correction of ecosystem service value and the evaluation of eco-efficiency: A case for China' s provincial level[J]. Ecological Indicators, 2018, 95: 841-850.

[27] He Nan. Study on the evaluation of ecosystem service value in Hubei Province based on land-use change[D]. Wuhan: Central China Normal University, 2020. [He Nan. Study on the evaluation of ecosystem service value in Hubei Province based on land use change[D]. Wuhan: Central China Normal University, 2020.]

[28] Hu Xisheng, Hong Wei, Wu Chengzhen. Improvement and application of a dynamic evaluation model for land ecosystem service function values—A case study of Fuzhou City[J]. Resources Science, 2013, 35(1): 30-41. [Hu Xisheng, Hong Wei, Wu Chengzhen. An improved dynamic evaluation model and land ecosystem service values for Fuzhou City[J]. Resources Science, 2013, 35(1): 30-41.]

[29] Kreuter U P, Harris H G, Matlock M D, et al. Change in ecosystem service values in the San Antonio area, Texas[J]. Ecological Economics, 2001, 39(3): 333-346.

Value of ecosystem services and intra-regional ecological compensation in Inner Mongolia based on the improved value equivalence method

ZHANG Qing[1], A Rong[1 2 3], TONG Baoquan[1 2 3], LI Xiaocan[1], BAO Wenjie[1], GE Rileqimuge[1], XIE Yuanzhi[1]

(1. College of Geographical Science, Inner Mongolia Normal University, Hohhot 010022, Inner Mongolia, China; 2. Key Laboratory of Climate Change and Regional Response on the Mongolian Plateau for Regional Institutions of Higher Education, Hohhot 010022, Inner Mongolia, China; 3. Mongolian Plateau Research Center, Hohhot 010022, Inner Mongolia, China)

Abstract: Based on the value equivalent method modified by three coefficients of "spatial heterogeneity, socio-economic factors, and resource scarcity"

, this study assesses the ecosystem service value (ESV) of Inner Mongolia Autonomous Region from 2000 to 2022. Using the 2022 gross domestic product of each city and prefecture, this study identifies the ecological compensation space, calculates the priority of compensation subjects and beneficiaries, and proposes a horizontal ecological compensation strategy suitable for the local area. The study reveals the following: (1) The land use types in Inner Mongolia Autonomous Region are mainly grassland and desert, with the main characteristics of change being the mutual transformation between grassland and farmland, as well as between grassland and desert. (2) From 2000 to 2022, the ESV of Inner Mongolia Autonomous Region has experienced an increasing trend, from 6346.03×10^8 yuan in 2000 to 10582.23×10^8 yuan in 2022, with an increase of 66.75%. The contribution of grassland to the total ESV has always been the highest, accounting for more than 57.00%. Regulating services contribute the most to the ESV of the study area (66.79% to 67.16%). Climate regulation and hydrological regulation are the most important ecological functions in the study area. The spatial distribution of Inner Mongolia's ESV is "higher in the east and lower in the west". (3) Among the 12 cities and prefectures, the priority order of compensation recipients is as follows: Hulunbeir City>Xilin Gol League>Xing'an League>Alxa League>Ulanqab City. Further, the priority order of compensation providers is as follows: Hohhot City>Baotou City>Erdos City>Tongliao City. Bayannur City, Wuhai City, and Chifeng City are the coordinating subjects. This study provides an important theoretical basis and practical reference for improving the scientific decision-making of ecological compensation in Inner Mongolia Autonomous Region and promoting the coordinated development of regional ecological protection and economy.

Keywords: ecosystem service value; improved value equivalence method; ecological compensation; Inner Mongolia Autonomous Region