# RESEARCH ON THE SPATIOTEMPORAL DIFFERENTIATION PATTERNS OF ECOSYSTEM SERVICE VALUES AND EQUILIBRIUM IN INNER MONGOLIA, CHINA

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**Abstract.** Ecosystem service value accounting is a preliminary exploration and concrete practice of the "Two Mountain Theory." In this study, data on land use/land cover changes (LUCC) in various leagues and cities in Inner Mongolia Autonomous Region, China, from 2001 to 2020 were used to calculate the ecosystem service value (ESV) and ecosystem dynamics (EC) of Inner Mongolia Autonomous Region. The study calculated the equilibrium of ecosystem service values at the league and county levels and conducted spatial autocorrelation analysis on the unit ecosystem service value and equilibrium, revealing the differentiation patterns and characteristics of ecosystem service values in Inner Mongolia. The results indicate that the overall trend of ecosystem service values in Inner Mongolia Autonomous Region is stable with a slight decline. In the past 20 years, the maximum value occurred in 2013, with an ESV of 9765.4 billion yuan, and the minimum value occurred in 2019, reaching 9664.41 billion yuan. The average ESV over 20 years is 9727.96 billion yuan. In the past 20 years, the distribution of city-level ecosystem service values in Inner Mongolia Autonomous Region has generally shown a pattern of higher values in the east and lower values in the west, with significant spatial differentiation characteristics. The overall per capita ecosystem service value in county-level areas of Inner Mongolia Autonomous Region has slightly increased in the northeast, slightly decreased in most of the central and southeast areas and showed overall an upward trend in the western region. The combination of ecosystem service values and equilibrium in Inner Mongolia Autonomous Region exhibits four categories, seven regions, and one belt.
**Keywords:** *Ecosystem Service Value, land use, equilibrium, spatial autocorrelation, Inner Mongolia*

## Introduction

The current guiding principle of ecological civilization construction in China, the "Two Mountain Theory," provides theoretical guidance for how to balance economic and social development with environmental protection. The valuation and monetization of a sound ecological environment, symbolized by the concept of "green waters and lush mountains," have become an inevitable path for China's current sustainable economic and social development. This represents a preliminary exploration and concrete practice of the "Two Mountain Theory." Achieving the goal of "green waters and lush mountains are invaluable assets" requires prioritizing environmental protection in the nation's economic and social development. In the pursuit of modernization today, it is essential to emphasize the importance of the ecological environment, discard development models that neglect environmental concerns for the sake of economic growth, and truly implement environmentally friendly and resource-efficient development concepts throughout the entire process of economic development.

In recent years, the assessment of ecosystem service value and related research has become a focal point in academia regarding the valuation of "green waters and lush mountains." Ecosystem Service Value (ESV) represents the monetization and valuation


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of services provided by ecosystems, measuring the benefits that humans derive from these ecosystems. Against the backdrop of increased emphasis on environmental protection, there is an urgent need to assess the ecosystem service value, clarifying the benefits humanity gains from ecosystems and revealing crucial "missing items" in current economic development assessments.

Costanza pioneered the research on ecosystem services, presenting the scope, functional services, and assessment methods in the journal "Nature." Subsequently, research on ecosystem service values has flourished (Costanza et al., 1997). In China, Xie et al. initiated early research on ecosystem services, proposing an equivalent factor table specifically for China and continuously refining it in recent years. Compared to other domestic scholars, Xie et al. (2008, 2015a,b) research achievements are more comprehensive and have been widely applied in later studies by other scholars. Inner Mongolia Autonomous Region plays a significant role in constructing the beautiful scenery of northern China. Balancing economic development and ecological protection is a major proposition for the region's development. Currently, Inner Mongolia faces prominent issues in ecological and environmental constraints, making the implementation of the "Two Mountain Theory" a crucial historical mission. It is imperative to thoroughly understand the ecological foundation and assess the ecosystem service value.

Existing domestic research on ecosystem service values mainly involves the assessment of values for different regions and ecosystem types, such as forests (Zhao et al., 2012), grasslands (Mu, 2016), wetlands (Wei et al., 2021), farmland (Luo et al., 2017), deserts (Song et al., 2021), etc. However, most studies use land-use data for a specific year or data with several years of intervals, lacking continuous annual land-use data for the assessment of ecosystem service values.

Over the past two decades, rapid economic development in China has led to changes in land use, resulting in the degradation of ecosystem service functions, especially in wetland areas where frequent and unsustainable land conversions occur (Li et al., 2024). In the process of land development, it is crucial to focus on the impact of land use changes on ecosystems, optimize land use structures, restore ecologically vulnerable areas, and promote the sustainable development of ecosystems and the economy. Additionally, there is an increasing emphasis on the concept of ecosystem services, ap-plying it to planning and decision-making, which can lead to more effective climate change adaptation (Longo et al., 2024). In the Yellow River Delta region, land use/cover changes significantly affect the value of wetland ecosystem services, making it essential to explore the past and future trajectories of land use/cover changes for wetland management and habitat stability (Zhang et al., 2024). Furthermore, the Harbin-Changchun urban agglomeration represents the pinnacle of fully developed urban spatial organization. However, cur-rent research overlooks the impact of human activities on ecosystem well-being, as well as the consequences of scale expansion on ecosystem management policies and future urban growth plans (Guo et al., 2024). Studies conducted in the Zhoushan Archipelago analyze carbon social costs and ecosystem service values, providing information for national and governmental decision-making in climate change mitigation and adaptation (Zhou et al., 2024). In Inner Mongolia Autonomous Region, ecosystem services and the urbanization process are closely related to human well-being (Zhang et al., 2023). Similarly, research in the Liangzi Lake Basin highlights the impact of historical land misuse on topography and the influence of changing land use methods during urbanization on the valuation of ecosystem services (Zhou et al., 2023). Additionally, the long-term dynamic assessment of ecosystem services in the southwestern region is crucial for understanding the


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environmental vulnerability of one of the world's largest karst landscapes (Ci et al., 2023). Research in the Qinghai Lake Basin reveals the relationships between different services by analyzing the balance/cooperation of ecosystem services (Wu et al., 2023). In Anxi County, exploring the spatiotemporal evolution patterns of regional ecosystem service functions and their key driving factors provides support for formulating regional ecological conservation policies (Li et al., 2023). For resource-based cities in China, studying the coupling coordination degree of supply and demand and its key influencing factors is essential for ecological security and sustainable socio-economic development (Zhao et al., 2023). Moreover, an analysis of the spatiotemporal changes in land cover from 1992 to 2020 in China reveals the impact of climate change and human activities on global ecosystem services (Bao et al., 2023). The rapid expansion of cities and economic development in the southwestern region leads to eco-system degradation, necessitating the rational delineation of regions and the provision of targeted management strategies for sustainable regional economic development and ecological maintenance (Zhang et al., 2023). Perceptions of ecosystem loss and threats are crucial for adapting to disasters (Komatsubara et al., 2023). A study on Hainan Island evaluates the current ecological environment through the analysis of ecosystem total value, emphasizing the contributions provided by the ecosystem (Zhou et al., 2022). Finally, research in the Hexi region of the north-west emphasizes the significant impact of land use and climate change on the value of ecosystem service (Li et al., 2022). In the Wuhan metropolitan area, the PLUS-GMOP model pro-vides a scientific reference for coordinating the economic development and ecological conservation of large urban regions (Zhu et al., 2022). In urban ecological areas, monitoring and evaluating land use/cover changes and ecosystem service values through multiresolution remote sensing data achieve the dual goals of environmental protection and ecological economic development (Liu et al., 2022). In the Guangxi region, the impact of land use/cover changes on the value of ecosystem services becomes a key indicator for measuring the quality of the ecological environment (Zhao et al., 2022). These studies collectively point out that factors such as land use changes, climate change, and urbanization have significant impacts on the value of ecosystem services. Therefore, it is essential to comprehensively consider these factors and formulate sustainable development management strategies and policies.

This paper takes Inner Mongolia Autonomous Region's ecosystem service value as the research object. Utilizing continuous Land Use/Land Cover Change (LUCC) data from 2001 to 2020 and based on the Inner Mongolia ecosystem's per-unit area service value equivalent table and the value of Inner Mongolia's standard per-unit area ecosystem service value equivalent factors, the ecosystem service values of various leagues and cities in Inner Mongolia Autonomous Region are calculated. Combining spatial correlation analysis of unit ecosystem service value and equilibrium, this study further reveals the distribution patterns of ecosystem service values in different regions of Inner Mongolia Autonomous Region. This research aims to provide scientific references for rational land planning, regional economic development, and ecosystem protection, while also offering a sample case for research on ecosystem service value assessment in China.

## Materials and methods

### *Overview of the research area*

Inner Mongolia Autonomous Region, abbreviated as "Inner Mongolia," has its capital in Hohhot. Located in the northern part of China, it is situated between 37°25′ and 53°23′


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north latitude and 97°12′-126°04′ east longitude. To the northeast, it borders Heilongjiang, Jilin, Liaoning, and Hebei; to the south, it is adjacent to Shanxi, Shaanxi, and Ningxia; to the southwest, it connects with Gansu; and to the north, it shares borders with Russia and Mongolia, spanning the Northeast, North China, and Northwest regions. The terrain of Inner Mongolia Autonomous Region extends diagonally from the northeast to the southwest, forming a narrow and elongated shape. The region is predominantly a high plateau, encompassing various landforms such as plateaus, mountains, hills, plains, deserts, rivers, and lakes. The climate is mainly temperate continental, and it includes four major river systems: the Yellow River, Ergun River, Nen River, and West Liao River. Inner Mongolia covers a total area of 1.183 million square kilometers and administratively consists of 12 prefecture-level divisions, including 9 prefecture-level cities and 3 leagues. These divisions comprise 23 districts, 11 county-level cities, 17 counties, and 49 banners (a type of administrative division), along with 3 autonomous banners.

### *Data source*

This study utilized the annual Land Cover Dataset (CLCD) for China, developed by Wuhan University, to obtain land-use change data for Inner Mongolia Autonomous Region from 2001 to 2020. With China experiencing rapid economic and population growth over the past few decades, significant changes have occurred in land cover, necessitating continuous and detailed monitoring. However, due to a lack of sufficient training samples and computational capabilities, annual land cover datasets for China based on satellite remote sensing observations are relatively scarce. Professor Yang Jie and Professor Huang Xin's team at Wuhan University (Yang and Huang, 2021) created the CLCD using 335,709 Landsat images on Google Earth Engine, providing annual land cover information for China from 1985 to 2020. The research team utilized all available Landsat data on Google Earth Engine to construct spatiotemporal features, combined them with a random forest classifier to obtain classification results, and proposed a post-processing method involving spatiotemporal filtering and logical inference to further enhance the spatiotemporal consistency of CLCD. Finally, based on 5,463 visual interpretation samples, the overall accuracy of CLCD reached 80%. Additionally, CLCD was compared with existing land cover thematic products, showing good consistency with global forest changes, global land surface water and impervious surface time series datasets. Currently, CLCD's land cover dataset from 1985 to 2021 is one of the few publicly available 30-meter resolution long-term annual land cover datasets. Importantly, this study compared CLCD with state-of-the-art 30-meter thematic products, including impervious surface area (ISA), surface water, and forests, to comprehensively assess the quality of CLCD (*Figure 1*).

## Inner Mongolia land use types and overall changes

### *Inner Mongolia land use types and changes*

As a crucial ecological security barrier in northern China, Inner Mongolia Autonomous Region is located in the transitional zone between agriculture and animal husbandry. Taking the data from the year 2020 as an example, grassland, bare land, forest, and farmland are essential components of Inner Mongolia's land use, accounting for 99% of the total area. Over the past 20 years, forest, grassland, ice and snow, and impervious


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surfaces have shown an increase in area (*Table 1*). Forests have experienced a significant expansion, increasing by 7,215.25 square kilometers, while grassland has increased by 3,111.95 square kilometers. The areas covered by ice and snow and impervious surfaces have also seen slight increments, with an increase of 1.72 square kilometers and 12.92 square kilometers, respectively. On the other hand, farmland, shrubs, water bodies, bare land, and wetland have witnessed decreases. Farmland has decreased significantly by 8,515.79 square kilometers, shrub areas decreased by 19.1 square kilometers, bare land has sharply reduced by 6,102.11 square kilometers, water bodies decreased by 738.22 square kilometers, and wetlands decreased by 50.19 square kilometers. This study covers the period from 2001 to 2020, divided into four phases for analysis: 2001-2005, 2005-2010, 2010-2015, and 2015-2020.

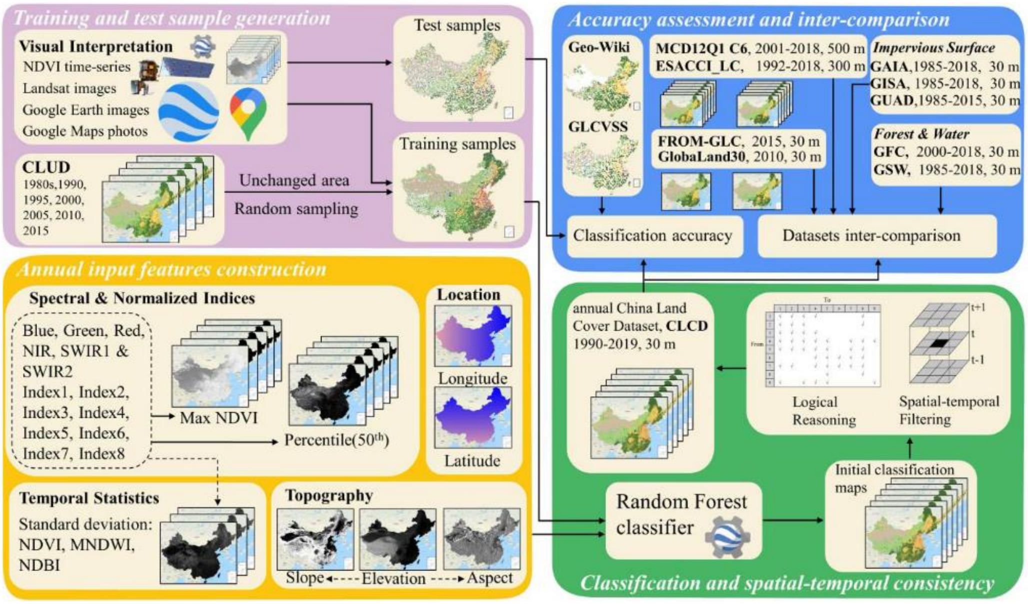


***Figure 1.*** *CLCD Technical flow chart*

During the period from 2001 to 2005, there were significant changes in Inner Mongolia's land use types. The forest and grassland types both experienced substantial increases, with gains of 3,148.28 square kilometers and 7,199.43 square kilometers, respectively. The ice and snow type increased by 2.54 square kilometers, and impervious surfaces increased by 768.41 square kilometers. On the other hand, the remaining five types exhibited a decreasing trend. Farmland decreased by 7,342.86 square kilometers, wetlands decreased by 21.88 square kilometers, water bodies decreased by 787.03 square kilometers, bare land decreased by 2,962.58 square kilometers.

During the "Eleventh Five-Year Plan" period (2005-2010), with the support of the national government, Inner Mongolia implemented key ecological construction projects such as natural forest resource protection, wind and sand source control in the Beijing-Tianjin region, returning farmland to forests, and returning pastures to grasslands. The ecological governance achieved remarkable results, but the reduction in farmland, water bodies, and wetland areas remained a challenging issue for ecological protection efforts.


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***Table 1.** Statistical Table of Land Use Type and Area Change in Inner Mongolia from 2001 to 2020*

| Year | Farmland | Forest | Shrub | Grassland | Water Bodies | Ice and Snow | Bare Land | Impervious Surfaces | Wetland |
|---|---|---|---|---|---|---|---|---|---|
| 2001（km2） | 141132.30 | 176494.95 | 30.08 | 549814.06 | 5857.29 | 0.15 | 276454.23 | 5519.50 | 86.20 |
| 2005（km2） | 133789.43 | 179643.23 | 25.76 | 557013.49 | 5070.26 | 2.69 | 273491.65 | 6287.91 | 64.33 |
| 2010（km2） | 133026.00 | 180883.82 | 16.22 | 558064.36 | 4733.56 | 5.65 | 270713.42 | 7899.66 | 46.07 |
| 2015（km2） | 139451.77 | 181934.47 | 17.02 | 550586.73 | 5223.14 | 1.68 | 268805.51 | 9316.68 | 51.75 |
| 2020（km2） | 132616.50 | 183710.20 | 10.98 | 552926.01 | 5119.06 | 1.86 | 270349.12 | 10619.00 | 36.01 |
| Changes during 2001-2005 | -7342.86 | 3148.28 | -4.32 | 7199.43 | -787.03 | 2.54 | -2962.58 | 768.41 | -21.88 |
| Changes during 2005-2010 | -763.44 | 1240.59 | -9.53 | 1050.87 | -336.70 | 2.96 | -2778.24 | 1611.75 | -18.26 |
| Changes during 2010-2015 | 6425.78 | 1050.65 | 0.79 | -7477.62 | 489.58 | -3.97 | -1907.91 | 1417.02 | 5.68 |
| Changes during 2015-2020 | -6835.27 | 1775.73 | -6.03 | 2339.28 | -104.07 | 0.18 | 1543.61 | 1302.32 | -15.74 |
| Changes during 2001-2020 | -8515.79 | 7215.25 | -19.10 | 3111.95 | -738.22 | 1.72 | -6105.11 | 5099.50 | -50.19 |


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From 2005 to 2010, Inner Mongolia witnessed an upward trend in grassland, forest, ice and snow, and impervious surfaces. Impervious surfaces saw the largest increase, reaching 1,611.75 square kilometers. Grassland and forest types increased significantly, reaching 1,050.87 and 1,240.59 square kilometers, respectively. Bare land saw a substantial decrease, reaching 2,778.24 square kilometers. Additionally, farmland decreased by 763.44 square kilometers. During the "Eleventh Five-Year Plan" period, Inner Mongolia vigorously promoted new industrialization, with the added value of large-scale industries growing at an average annual rate of 27.1% in the first four years, contributing 60% to economic growth. The rapid development of industry inevitably had some impact on the ecological environment.

From 2010 to 2015, six land use types in Inner Mongolia—farmland, forest, shrub, water bodies, impervious surfaces, and wetland—showed an increasing trend. Farmland witnessed the largest growth, reaching 6,425.78 square kilometers, followed by an increase of 1,050.65 square kilometers in forest, and 1,417.02 square kilometers in impervious surfaces. Shrub, water bodies, and wetland increased to a lesser extent. Grassland, ice and snow, and bare land showed a decreasing trend, with grassland decreasing the most at 7,477.62 square kilometers, followed by a decrease of 3.97 square kilometers in ice and snow, and a decrease of 1,907.91 square kilometers in bare land. During the "Twelfth Five-Year Plan" period, Inner Mongolia accelerated the construction of a crucial ecological security barrier in northern China, achieving an overall containment and partial improvement in the ecological environment.

From 2015 to 2020, Inner Mongolia observed an upward trend in five land use types: forest, grassland, ice and snow, bare land, and impervious surfaces. Grassland experienced the largest growth, reaching 2,339.28 square kilometers, followed by an increase of 1,775.73 square kilometers in forest, and a slight increase of 0.18 square kilometers in ice and snow. Bare land and impervious surfaces increased by 1,543.61 and 1,302.32 square kilometers, respectively. Farmland witnessed the largest decrease, reaching 6,835.27 square kilometers, and wetland decreased by 15.74 square kilometers. During the "Thirteenth Five-Year Plan" period, Inner Mongolia's economy transitioned from a high-speed growth stage to a high-quality development stage, emphasizing ecological environment protection, which yielded noticeable results, particularly in the "Grain for Green" project.

### *Analysis of ecological change characteristics in Inner Mongolia's land use*

Ecological Change (EC) is employed to measure the speed of land use changes, reflecting the degree of change in land use types. In this section, both individual land use dynamics and comprehensive land use dynamics are calculated. The individual land use dynamic (K) reflects the quantity changes of a specific land use type within a certain period in the study area. Its calculation formula is as follows:

$$K = \frac{U_b - U_a}{U_a} \times \frac{1}{T} \times 100\% \tag{Eq.1}$$

where $U_a$ and $U_b$ represent the area of a certain land use type at the beginning and end of the period T, respectively. When T is set to a year, K value represents the annual change rate of a specific land use type in the research area, indicating the individual land use dynamic of that type. A negative K value indicates a decreasing trend for that type. The calculation results using *formula 1* are shown in *Table 2*.


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***Table 2.*** *Dynamic degree of single land use in Inner Mongolia from 2001 to 2020*

| Land Types | Individual Land Use Dynamic | | | | |
|---|---|---|---|---|---|
| | **2001-2005** | **2005-2010** | **2010-2015** | **2015-2020** | **2001-2020** |
| Farmland | -1.04% | -0.11% | 0.97% | -0.98% | -0.30% |
| Forest | 0.36% | 0.14% | 0.12% | 0.20% | 0.20% |
| Shrub | -2.87% | -7.40% | 0.98% | -7.09% | -3.17% |
| Grassland | 0.26% | 0.04% | -0.27% | 0.08% | 0.03% |
| Water Bodies | -2.69% | -1.33% | 2.07% | -0.40% | -0.63% |
| Ice and Snow | 348.96% | 22.02% | -14.05% | 2.20% | 58.96% |
| Bare Land | -0.21% | -0.20% | -0.14% | 0.11% | -0.11% |
| Impervious Surfaces | 2.78% | 5.13% | 3.59% | 2.80% | 4.62% |
| Wetland | -5.08% | -5.68% | 2.47% | -6.08% | -2.91% |

From the individual land use dynamics in Inner Mongolia, it can be observed that, over the past 20 years, five types—farmland, shrub, water bodies, bare land, and wetlands—have shown a decreasing trend. Among them, shrub and wetland types have a relatively larger individual dynamics compared to farmland, water bodies, and bare land types. On the other hand, four types—forest, grassland, ice and snow, and impervious surfaces—have shown an increasing trend. The ice and snow type has the largest magnitude of change, with an individual dynamic of 348.96%. The impervious surface type has an individual dynamic of 18.48%. The individual dynamics of forest and grassland are 0.82% and 0.11%, respectively, indicating relatively small overall changes.

Looking at different time periods, the farmland type initially decreased, then continuously increased before finally turning to a decreasing trend. The forest type showed an increasing trend in all periods. The shrub type initially remained relatively stable, increased from 2011 to 2015, and then decreased, with a relatively large dynamic compared to other types. The grassland type initially showed a brief increase, followed by a continuous decrease from 2005 to 2015, and then turned to an increasing trend. The water bodies type had a similar trend to shrub, but with a smaller dynamic. The ice and snow type, influenced significantly by climate, had a dynamic of 348.96% from 2001 to 2005, continued to grow until 2010, and then decreased before rising again. The bare land type continuously decreased from 2001 to 2015, with a slight increase from 2015 to 2020. The wetland type, similar to shrub, had a relatively large dynamic.

The Comprehensive Land Use Dynamic (EC), as reflected by the formula below, illustrates the overall changes in land use quantity within a specific period in the research area:

$$EC = \frac{\sum_{i=1}^{n} L_{i-j}}{\sum_{i=1}^{n} L_i} \times \frac{1}{T} \times 100\% \quad \text{(Eq.2)}$$

where: *Lij* represents the absolute value of the area of land type *i* converted to a non-*i* type ecosystem within a certain period. *Li* represents the area of land type *i*. *T* is the duration of the study. The calculation results using *formula 2* are shown in *Table 3*.

By referring to the above table, it can be observed that, from 2001 to 2020, Inner Mongolia's Comprehensive Land Use Dynamic (EC) is 0.07%. Within this period, the land use dynamics during 2001–2005, 2010–2015, and 2015–2020 exceeded the average land use dynamics over the 20-year span, with the dynamics during 2005–2010 showing relatively minimal changes at 0.05. This suggests a dynamic process in the land use


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changes in Inner Mongolia, transitioning from a high-speed phase (2001–2005) to a low-speed phase (2005–2010), followed by a return to a high-speed phase (2010–2020). Additionally, the speed of the second high-speed phase exhibits a decreasing trend, going from 0.16 to 0.12.

***Table 3.*** *Dynamic degree of comprehensive land use in Inner Mongolia from 2001 to 2020*

| | 2001-2005 | 2005-2010 | 2010-2015 | 2015-2020 | 2001-2020 |
|---|---|---|---|---|---|
| Comprehensive Land Use Dynamic (EC) (%) | 0.24 | 0.05 | 0.16 | 0.12 | 0.07 |

## Inner Mongolia ecosystem service value accounting

In this section, we utilize Xie Gaodi's value equivalent factor method to calculate the ecosystem service value in Inner Mongolia. The three required elements for the value equivalent factor method are the area of each land use type (*Li*), the per unit area ecosystem service value equivalent table, and the value quantity (*A*) of the standard unit ecosystem service value equivalent factor. Here, the elements (*Eij*) of the per unit area ecosystem service value equivalent table represent the equivalent of the *j*-th ecosystem service value for the *i*-th land use type in the region.

The formula for calculating ecosystem service value is as follows:

$$ESV_i = \sum_{j=1}^{m}\sum_{i=1}^{n}\left(A * E_{ij} * L_i\right) \quad (i = 1,2,\cdots,n; j = 1,2,\cdots,m) \qquad \text{(Eq.3)}$$

where:

- *ESV* is the total ecosystem service value,
- *n* is the number of land use types,
- *m* is the number of ecosystem service value items,
- *Eij* represents the equivalent of the *j*-th ecosystem service value for the *i*-th land use type,
- *Li* is the area of the *i*-th land use type,
- *A* is the value quantity of the standard unit ecosystem service value equivalent factor.

### *Determination of the value quantity of the standard unit ecosystem service value equivalent factor*

The value quantity (A) of the standard unit ecosystem service value equivalent factor is a crucial component in the calculation of ecosystem service value. It represents the value associated with each unit of the standard unit ecosystem service value equivalent factor. The determination of this value involves careful consideration of various factors such as ecological characteristics, economic valuation, and regional conditions.

The process of establishing the value quantity (A) is fundamental to ensure the accuracy and relevance of the ecosystem service value calculation. It requires a comprehensive analysis of the specific ecosystem services provided by each land use type, taking into account their ecological functions, contributions to biodiversity, and the economic benefits derived from these services.


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Once the value quantity (A) is determined, it serves as a crucial parameter in the overall formula for calculating the ecosystem service value, ensuring that the economic valuation of ecosystem services accurately reflects their significance and impact on the region's well-being.

According to the inferiority principle, the value quantity (A) of the standard unit ecosystem service value equivalent factor in Inner Mongolia is defined as the average grain output value per hectare of the tenth-grade arable land. This value is equal to the product of the average selling price (P) of grain and the unit area yield (M) of grain crops on the tenth-grade arable land in Inner Mongolia. The average selling price of grain is obtained from the "Summary of National Agricultural Cost and Income Data," specifically the average selling price of three types of grain per 50 kilograms. The calculation formula is as follows:

$$A = P * M \tag{Eq.4}$$

$$M = Y - \sum_{i=1}^{9} [S_i * 1500 * (10 - i)] \tag{Eq.5}$$

In 2019, the Ministry of Agriculture and Rural Affairs, based on the "Methods for the Investigation, Monitoring, and Evaluation of Farmland Quality" (Decree No. 2 of the Ministry of Agriculture in 2016) and the national standard "Farmland Quality Grades" (GB/T 33469-2016), organized and completed the national farmland quality grade survey and evaluation work. The evaluation was based on the total of 2.023 billion mu (about 134.87 million hectares) of farmland nationwide. Using land use maps, soil maps, and administrative maps overlaid to form evaluation units, the assessment considered indicators such as site conditions, profile characteristics, physical and chemical properties of the plow layer, nutrient status, soil health, and soil management to comprehensively evaluate farmland quality and establish national farmland quality grades (*Figure 2*).

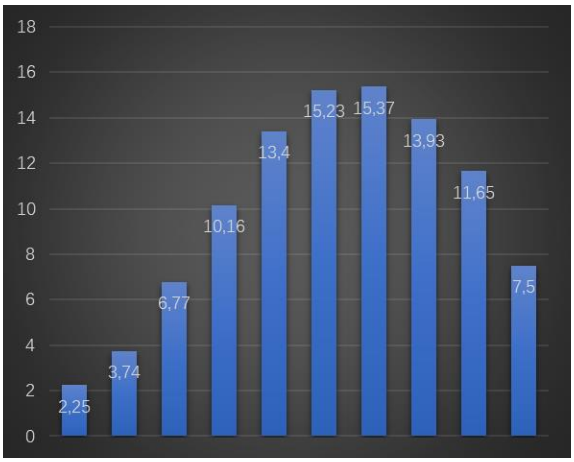


***Figure 2.*** *Statistical Chart of Cultivated Land Quality Grade and Proportion in Inner Mongolia*

According to the different production capacities formed by the basic fertility of farmland, the country's farmland was divided into ten fertility grades. The grain yield per unit area ranged from greater than 13,500 kg/ha (900 kg/mu) to less than 1,500 kg/ha


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(100 kg/mu), with a difference of 1,500 kg/ha (100 kg/mu) between grades. Based on the average grain yield of cereal crops in each province and the proportion of Grade 1–10 farmland in the table, combined with the grading standards and the average selling price of cereal crops, the unit area output value of grain crops on Grade 10 farmland in each province was obtained. This value was then taken as the value quantity of the standard unit ecosystem service value equivalent factor (A). In Inner Mongolia, the value quantity (A) of the standard unit ecosystem service value equivalent factor was determined to be 1692.16 yuan per hectare in 2019.

### *Determination of the equivalent table of ecosystem service value per unit area*

This article refers to Xie Gaodi's approach of correcting the ecosystem service value in different regions. Based on the linear relationship between ecosystem functional intensity and biomass, the biomass coefficient (0.44 in Inner Mongolia) is used to correct the equivalent ecosystem service value per unit area, as shown in the *Tables 4,5* below.

Combine the values from the table above with the standard unit value factor for Inner Mongolia to calculate the service value per unit area for each ecosystem. Based on the results in the table below, multiply each item with the corresponding land use data from the China Land Cover Data Set (CLCD), summing them up to obtain the ecosystem service value for each region.

### *Overall changes in ecosystem service value*

The ecosystem service value of Inner Mongolia Autonomous Region from 2001 to 2020 is calculated according to *formula 3,4,5*, as shown in *Figures 3,4*. As observed from the graph, the overall trend of ecosystem service value in Inner Mongolia Autonomous Region remains stable with a slight decline. Over the past two decades, the maximum value occurred in 2013, with an Ecosystem Service Value (ESV) of 9765.4 billion yuan, while the minimum value was recorded in 2019, reaching 9664.41 billion yuan. The average ESV over the 20-year period is 9727.96 billion yuan. Taking the data for the year 2020 as an example, the ecosystem service value for Inner Mongolia Autonomous Region is 9746.5 billion yuan. The supply services contribute 725.89 billion yuan, including 248.78 billion yuan for food production, 300.53 billion yuan for raw material production, and 176.58 billion yuan for water resource supply. Regulation services have the highest proportion, reaching 6334.45 billion yuan. This includes 940.32 billion yuan for gas regulation, 2441.38 billion yuan for climate regulation, 813.05 billion yuan for environmental purification, and 2169.71 billion yuan for hydrological regulation. Support services account for 2245.41 billion yuan, with 1171.47 billion yuan for soil conservation, 94.83 billion yuan for maintaining nutrient cycling, and 979.11 billion yuan for biodiversity. The aesthetic landscape function of cultural services is valued at 440.74 billion yuan.

The total value of ecosystem services is not only influenced by the types of ecosystems but also significantly impacted by land area. Regions with large land areas and generally ordinary ecological environments might have a total ecosystem service value that is potentially lower than regions with smaller land areas but more favorable ecological conditions. Therefore, to eliminate the influence of land area on the regional ecological level, the per-unit area ecosystem service value is selected to reflect the ecological value. The average per-unit area ecosystem service value for Inner Mongolia Autonomous Region from 2001 to 2020 is 6682.18 yuan per hectare.


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***Table 4.*** *Table of Ecosystem Service Value Equivalents per Uunit Area in Inner Mongolia*

| Ecosystem Service Type | Provisioning Services | | | Regulating Services | | | | Supporting Services | | | Cultural Services |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Food Production | Raw Material Production | Water Resource Provision | Gas Regulation | Climate Regulation | Environmental Purification | Hydrological Regulation | Soil Conservation | Nutrient Cycling Maintenance | Biodiversity | Aesthetic Landscape |
| Farmland | 0.44 | 0.21 | 0.01 | 0.35 | 0.19 | 0.05 | 0.14 | 0.53 | 0.06 | 0.07 | 0.03 |
| Forest | 0.11 | 0.27 | 0.14 | 0.88 | 2.62 | 0.77 | 1.73 | 1.07 | 0.08 | 0.97 | 0.42 |
| Shrub | 0.10 | 0.22 | 0.11 | 0.73 | 2.19 | 0.66 | 1.73 | 0.89 | 0.07 | 0.81 | 0.36 |
| Grassland | 0.12 | 0.18 | 0.10 | 0.62 | 1.65 | 0.55 | 1.21 | 0.76 | 0.06 | 0.69 | 0.31 |
| Water Bodies | 0.41 | 0.12 | 4.29 | 0.40 | 1.19 | 2.87 | 52.92 | 0.48 | 0.04 | 1.32 | 0.98 |
| Ice and Snow | 0.00 | 0.00 | 1.12 | 0.09 | 0.28 | 0.08 | 3.69 | 0.00 | 0.00 | 0.01 | 0.05 |
| Bare Land | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.05 | 0.02 | 0.01 | 0.00 | 0.01 | 0.01 |
| Impervious Surfaces | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 |
| Wetland | 0.26 | 0.26 | 1.34 | 0.98 | 1.86 | 1.86 | 12.54 | 1.20 | 0.09 | 4.07 | 2.45 |


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***Table 5.*** *Statistical Table of Service Value per Unit Area of Ecosystems in Inner Mongolia*

| Ecosystem Service Type | Provisioning Services | | | Regulating Services | | | | Supporting Services | | | Cultural Services |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Food Production | Raw Material Production | Water Resource Provision | Gas Regulation | Climate Regulation | Environmental Purification | Hydrological Regulation | Soil Conservation | Nutrient Cycling Maintenance | Biodiversity | Aesthetic Landscape |
| Farmland | 744.55 | 355.35 | 16.92 | 592.26 | 321.51 | 84.61 | 236.90 | 896.84 | 101.53 | 118.45 | 50.76 |
| Forest | 186.14 | 456.88 | 236.90 | 1489.10 | 4433.46 | 1302.96 | 2927.44 | 1810.61 | 135.37 | 1641.40 | 710.71 |
| Shrub | 169.22 | 372.28 | 186.14 | 1235.28 | 3705.83 | 1116.83 | 2927.44 | 1506.02 | 118.45 | 1370.65 | 609.18 |
| Grassland | 203.06 | 304.59 | 169.22 | 1049.14 | 2792.06 | 930.69 | 2047.51 | 1286.04 | 101.53 | 1167.59 | 524.57 |
| Water Bodies | 693.79 | 203.06 | 7259.37 | 676.86 | 2013.67 | 4856.50 | 89549.11 | 812.24 | 67.69 | 2233.65 | 1658.32 |
| Ice and Snow | 0.00 | 0.00 | 1895.22 | 152.29 | 473.80 | 135.37 | 6244.07 | 0.00 | 0.00 | 16.92 | 84.61 |
| Bare Land | 0.00 | 0.00 | 0.00 | 16.92 | 0.00 | 84.61 | 33.84 | 16.92 | 0.00 | 16.92 | 16.92 |
| Impervious Surfaces | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 16.92 |
| Wetland | 0.26 | 0.26 | 1.34 | 0.98 | 1.86 | 1.86 | 12.54 | 1.20 | 0.09 | 4.07 | 2.45 |


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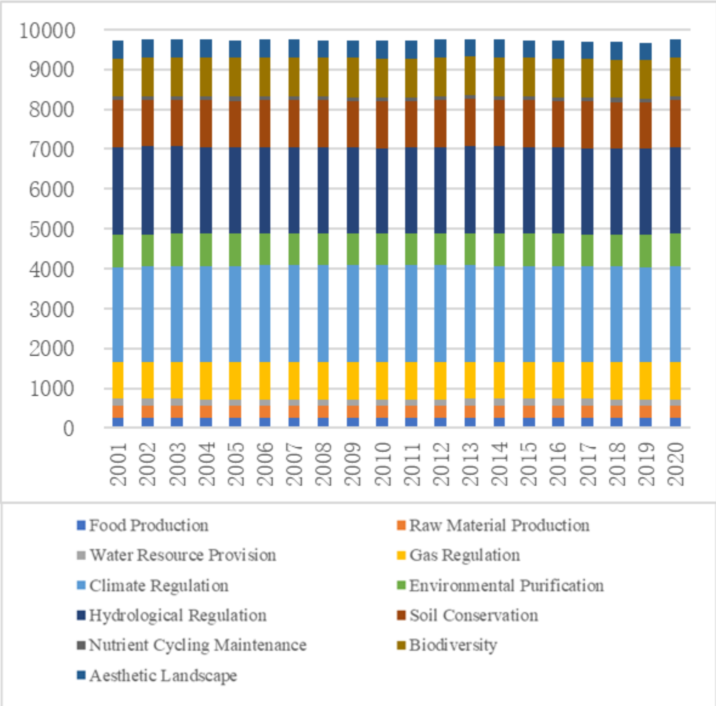


***Figure 3.*** *Statistical Chart of Ecosystem Service Value in Inner Mongolia Autonomous Region from 2001 to 2020 (Unit: RMB100mn)*

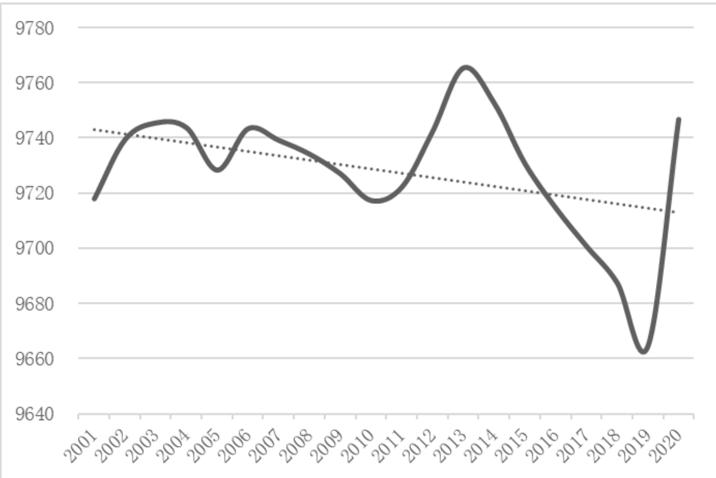


***Figure 4.*** *Classification and Statistics of Ecosystem Service Value in Inner Mongolia Autonomous Region from 2001 to 2020*

## Characteristics of spatiotemporal differentiation of ecosystem service value in Inner Mongolia

### *Spatial and temporal differentiation characteristics of ecosystem service value in Inner Mongolia League cities*

The total value of ecosystem services is not only influenced by the types of ecosystems but also significantly impacted by land area. Regions with large land areas and generally


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ordinary ecological environments might have a total ecosystem service value that is potentially lower than regions with smaller land areas but more favorable ecological conditions. Therefore, to eliminate the influence of land area on the regional ecological level, the per-unit area ecosystem service value is selected to reflect its level.

*(1) Distribution patterns in each year*

Using the natural breaks method (Jenks), the per-unit area ecosystem service value levels for the league-level cities in Inner Mongolia Autonomous Region in the years 2000, 2005, 2010, 2015, and 2020 are divided into 5 categories: low, relatively low, medium, relatively high, and high.

As shown in the *Figure 5*, the relative levels of per capita ecosystem service values in the 12 Leagues and Cities of Inner Mongolia Autonomous Region in the years 2001, 2005, 2010, 2015, and 2020 are summarized in the *Table 6* below.

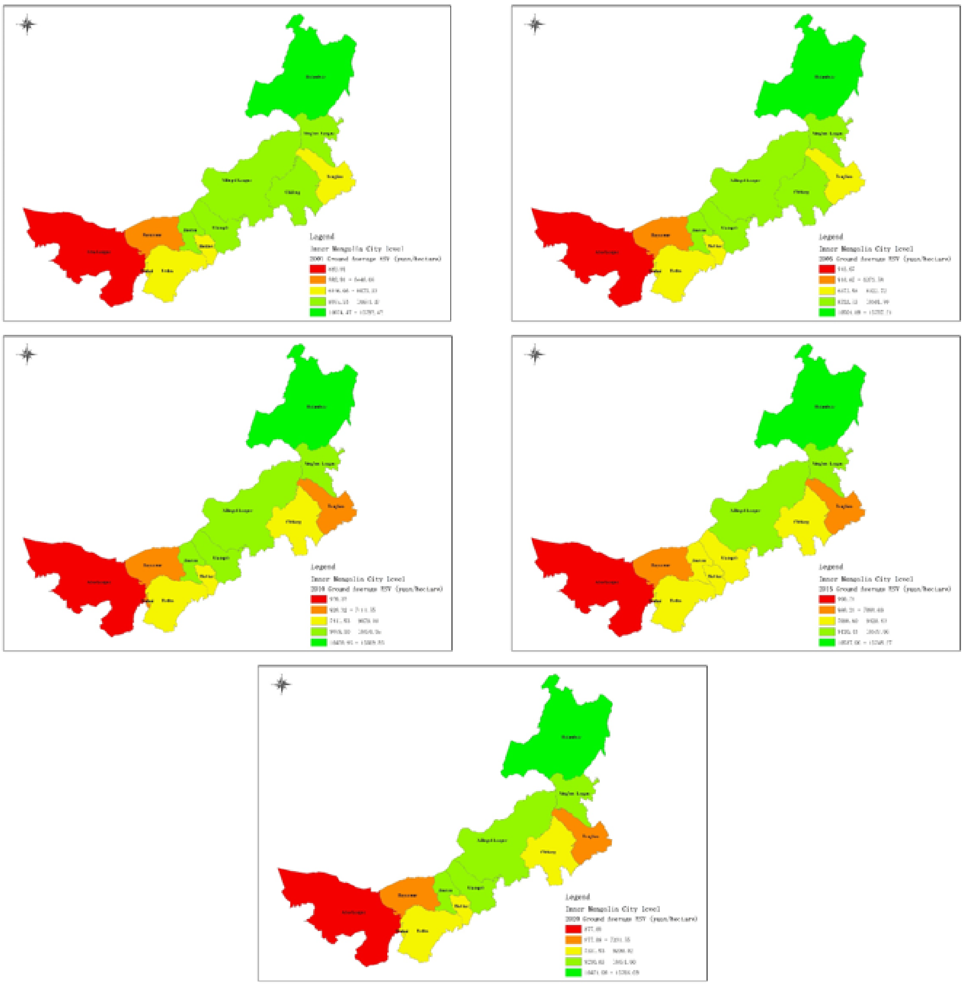

***Figure 5.*** *Distribution Map of Ecosystem Service Value at City Level in Inner Mongolia Autonomous Region from 2001 to 2020. Note: The map is created based on the standard map with the approval number of Mongolian S (2017) 026 downloaded from the Inner Mongolia Autonomous Region Standard Map Service Website, and the base map has not been modified*


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***Table 6.*** *Grouping Statistics of Ecosystem Service Value at the City Level in Inner Mongolia Autonomous Region from 2001 to 2020*

| Year | 2001 | 2005 | 2010 | 2015 | 2020 |
|---|---|---|---|---|---|
| Low | Alxa League | Alxa League | Alxa League | Alxa League | Alxa League |
| Relatively Low | Bayannur City | Bayannur City | Bayannur City<br>Wuhai City<br>Tongliao City | Bayannur City<br>Tongliao City | Bayannur City<br>Tongliao City |
| Medium | Hohhot City<br>Ordos City<br>Wuhai City<br>Tongliao City | Hohhot City<br>Ordos City<br>Wuhai City<br>Tongliao City | Hohhot City<br>Ordos City<br>Chifeng City | Hohhot City<br>Ordos City<br>Wuhai City<br>Ulanqab City<br>Chifeng City<br>Baotou City | Hohhot City<br>Ordos City<br>Wuhai City<br>Chifeng City |
| Relatively High | Baotou City<br>Ulanqab City<br>Chifeng City<br>Xilin Gol League<br>Hinggan League | Baotou City<br>Ulanqab City<br>Chifeng City<br>Xilin Gol League<br>Hinggan League | Baotou City<br>Ulanqab City<br>Xilin Gol League<br>Hinggan League | Xilin Gol League<br>Hinggan League | Baotou City<br>Ulanqab City<br>Xilin Gol League<br>Hinggan League |
| High | Hulunbuir City | Hulunbuir City | Hulunbuir City | Hulunbuir City | Hulunbuir City |

From the above chart, it can be observed that the distribution of ecosystem service values at the municipal level in Inner Mongolia Autonomous Region mainly shows an east-high and west-low, north-high and south-low pattern, exhibiting significant spatial differentiation characteristics. Hulunbuir City, Hinggan League, and Xilin Gol League ranked in the top three during the period from 2001 to 2020. The extensive ecosystems of forests and grasslands supported the per capita ecosystem service values of these three leagues, with Hulunbuir City having the highest per capita ecosystem service value. Alxa League and Bayannur City ranked at the bottom two, with Alxa League consistently having the lowest per capita ecosystem service value. The large area of bare land ecosystems, deserts, and other factors led to a lack of effective provision of ecosystem services. Tongliao City and Wuhai City had per capita ecosystem service values fluctuating between the low and medium groups, with significant fluctuations. They need to maintain determination in ecological environment protection and steadily promote the practice of the "Two Mountains Theory." In addition, Chifeng City was in the high group in 2000 and 2005 but could not re-enter this group afterward. By 2020, it was in the medium group, indicating a declining trend in the provision of ecosystem services, which requires attention and reflection. Hohhot City and Ordos City remained in the medium group throughout the study period, while Baotou City and Ulanqab City were in the medium group in 2015, and in the remaining years, they were in the high group.

*(2) Average distribution pattern*

The sentence describes the distribution of the average ecological system service values for the league-level cities in Inner Mongolia Autonomous Region in the years 2000, 2005, 2010, 2015, and 2020. The distribution shows a trend of higher values in the northeast and lower values in the southwest. The eastern and central regions, with the exception of cities like Tongliao and Hohhot, generally exhibit high to moderately high levels of ecological system service values, while the western region tends to have lower levels. In summary, there is an overall imbalance in the distribution of ecological system service


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values in Inner Mongolia, with significant regional disparities. The text emphasizes the need for concerted efforts to develop the scenic beauty of northern Inner Mongolia (*Figure 6, Table 7*).

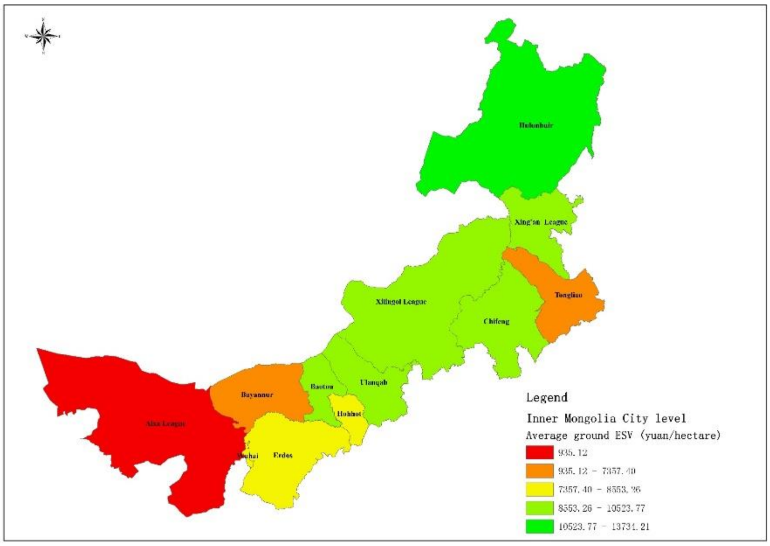


***Figure 6.*** *Distribution Map of Average Terrestrial Ecosystem Service Value at the City Level in Inner Mongolia Autonomous Region from 2001 to 2020. Note: The map is created based on the standard map with the approval number of Mongolian S (2017) 026 downloaded from the Inner Mongolia Autonomous Region Standard Map Service Website, and the base map has not been modified*

***Table 7.*** *Statistical Table for Distribution of Average Territorial Ecosystem Service Value at the City Level in Inner Mongolia Autonomous Region*

| Group | Low | Relatively Low | Medium | Relatively High | High |
|---|---|---|---|---|---|
| Leagues and Cities | Alxa League | Bayannur City<br>Tongliao City | Hohhot City<br>Ordos City<br>Wuhai City | Baotou City<br>Ulanqab City<br>Xilin Gol League<br>Hinggan League<br>Chifeng City | Hulunbuir City |

## *Spatial and temporal differentiation characteristics of ecosystem service value in Inner Mongolia Qixian region*

The previous section mainly analyzed the spatiotemporal differentiation characteristics of the average ecosystem service value from the perspective of Inner Mongolia Autonomous Region. In order to better analyze the actual distribution of ecosystem service value in Inner Mongolia Autonomous Region and understand the family background, this section adopts the perspective of the banner county region to analyze the spatiotemporal differentiation characteristics of the average ecosystem service value.


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***Spatial and temporal differentiation characteristics of ecosystem service value in banner and county regions***

*(1) Distribution pattern by year*

The text describes the distribution of the average ecological system service values at the county and league levels in Inner Mongolia Autonomous Region. While the overall county-level distribution is similar to that at the league level, there are notable differences within the leagues. According to the average data shown in the *Figure 7,8*, the top five counties or banners in Inner Mongolia are Ewenki Autonomous Banner, New Barag Right Banner, Zhalantun City Ewenki Autonomous Banner, and Arxan City.

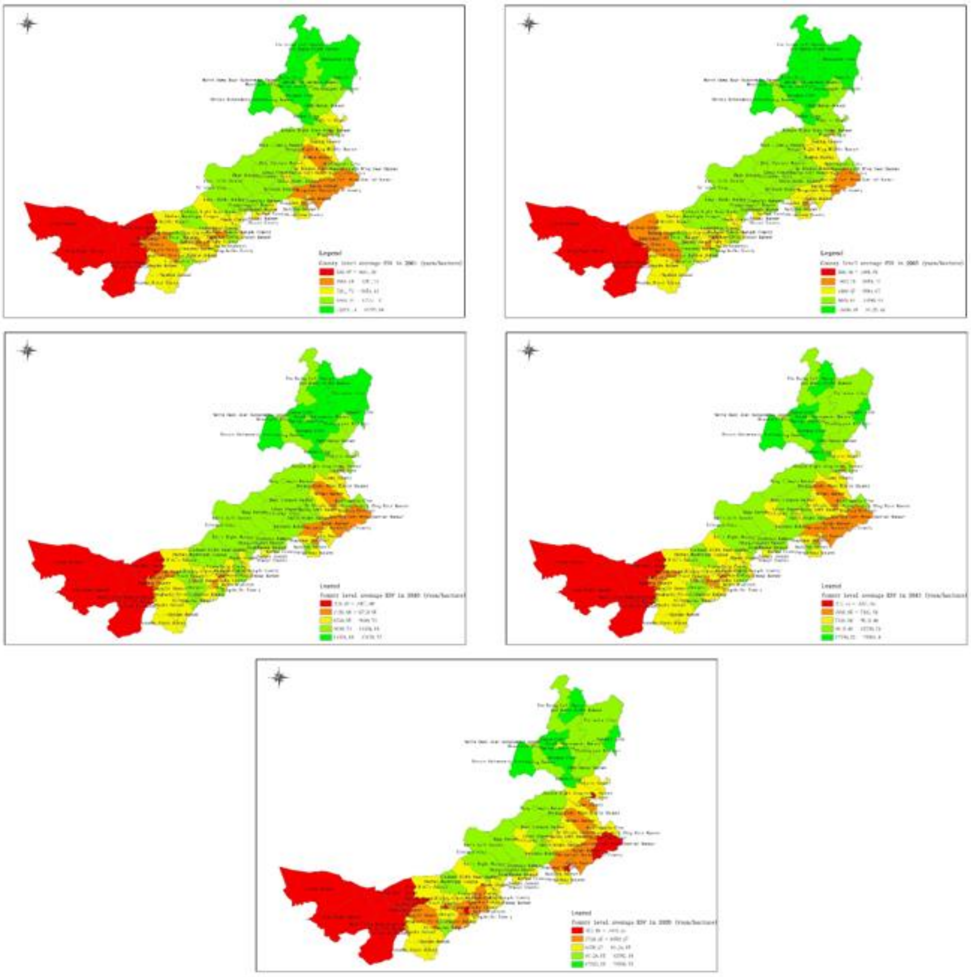

***Figure 7.*** *Distribution Map of Ecosystem Service Value at County Level in Inner Mongolia Autonomous Region from 2001 to 2020*

Additionally, Arong Banner, Eerguna City, Urad Qian Banner, Chen Barag Banner, and New Barag Left Banner also belong to the high-scoring group. The bottom five are in the low-scoring group and consist of Ejina Banner, Alxa Right Banner, Alxa Left Banner, Urad Qian Banner, and Yuquan District. The five low-scoring entities are mainly located in the western region of Alxa League, the 21 moderate-scoring entities are mainly in the western part of Bayannur City and the southern part of Chifeng City and Tongliao


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City in the eastern region, the 30 moderate-high-scoring entities are primarily in Hohhot City, Ordos City, Ulanqab City, and Hinggan League, the 37 high-scoring entities are mainly in Xilin Gol League, and the 10 highest-scoring entities are mainly in Hulunbuir City (*Table 8*).

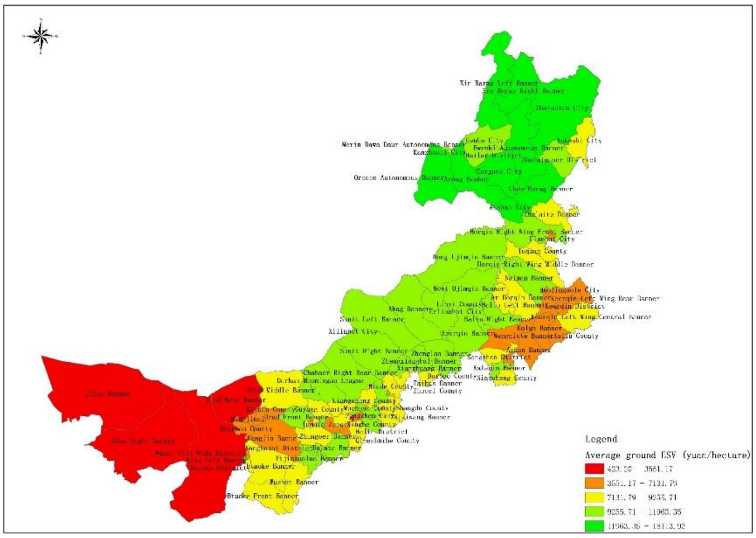


***Figure 8.*** *Distribution Map of Average Terrestrial Ecosystem Service Value at County Level in Inner Mongolia Autonomous Region from 2001 to 2020*

***Table 8.*** *Statistical Table of Average Territorial Ecosystem Service Value Grouping at County Level in Inner Mongolia Autonomous Region*

| Group | Quantity | Banners and Counties |
|---|---|---|
| Low | 5 | Alxa League Ejina Banner<br>Alxa League Alxa Right Banner<br>Alxa League Alxa Left Banner<br>Bayannur City Urad Qian Banner<br>Hohhot City Yuquan District |
| Relatively Low | 21 | Tongliao City Keerqin District<br>Bayannur City Hanggin Rear Banner<br>Bayannur City Dengkou County<br>Chifeng City Hongshan District<br>Ulanqab City Jining District , etc |
| Medium | 30 | Tongliao City Keerqin Zuoqi Zhong Banner<br>Baotou City Qingshan District<br>Ulanqab City Shangdu County<br>Ulanqab City Siziwang Banner<br>Hohhot City Tumot Zuoqi , etc |
| Relatively High | 37 | Ulanqab City Chaha'er Youyi Zhong Banner<br>Baotou City Donghe District<br>Chifeng City Linxi County<br>Xilin Gol League Xilinhot City<br>Hohhot City Xincheng District , etc |
| High | 10 | Hulunbuir City A'roun Qi<br>Hulunbuir City Eerguna City<br>Wuhai City Wuda District<br>Hulunbuir City Chen Barag Banner<br>Hulunbuir City Xin Barag Zuo Qi , etc |


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*(2) Changing characteristics*

The time change rate of ecosystem service value in each county from 2001 to 2020 represents the rate of change in ecological value in each county, as shown in the following *Figure 9, Table 9*. The overall ecosystem service value per county in Inner Mongolia Autonomous Region shows a slight increase in the northeast region, a slight decrease in the central and southeastern regions, and an overall upward trend in the western region. Divide 103 counties into six categories: significant decrease, decrease, slight decrease, slight increase, increase, and significant increase. Among them, the change rate of Alxa Right Banner in the descending part is the highest, reaching -25.84%, while the change rate in Uda District in the ascending part is the highest, reaching 239.63%. The four significantly declining counties and districts are mainly distributed in Alxa League, Tongliao City, Baotou City, and Bayannur City; The 19 declining counties and districts are mainly distributed in Xilingol League, Ulanqab City, Hohhot City, and Xing'an League; The 25 slightly declining groups are mainly concentrated in Xilingol League, Bayannur City, and Xing'an League; In addition, 48 counties and districts are located in a slightly rising group; Five counties and districts are located in the ascending group.

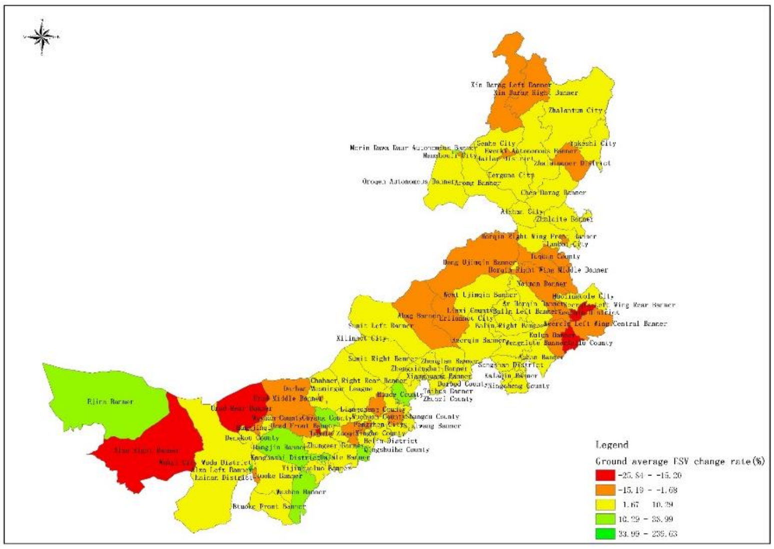


***Figure 9.*** *Changes in the value of ecosystem services in counties of Inner Mongolia Autonomous Region from 2001 to 2020*

## *County-level spatial autocorrelation of ecosystem service values*

Geoda software was employed for spatial correlation analysis (An et al., 2021). The specific steps involved calculating the spatial weight matrix using the Queen method, followed by univariate local Moran’s I analysis to obtain both the global Moran’s I index and local Moran’s I index. Monte Carlo simulation was utilized to test for significance levels.

*(1) Spatial autocorrelation analysis for each year*

A global correlation analysis was conducted on the per capita ecosystem service values for counties in Inner Mongolia from 2001 to 2020. It was observed that the per capita ecosystem service values exhibited a significant positive correlation in different years.


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The global Moran’s I index ranged from 0.421 to 0.624. Additionally, Monte Carlo test results indicated that the P-values were all less than 0.01, and Z-values exceeded the test threshold (1.96). This suggests that the spatial differences in per capita ecosystem service values among counties in Inner Mongolia are highly significant (*Table 10, Figure 10*).

***Table 9.*** *Statistical Table of Changes in Ecosystem Service Value at County Level in Inner Mongolia Autonomous Region from 2001 to 2020*

| Group | The change rate intervals (%) | Quantity | Banners and Counties |
|---|---|---|---|
| Significant Decrease | -25.84—-15.20 | 4 | Alxa League, Alxa Right Banner<br>Tongliao City, Ke'erqin District<br>Baotou City, Kundulun District<br>Bayannur City, Urad Rear Banner |
| Decrease | -15.20—-4.34 | 19 | Tongliao City, Kailu County<br>Ulanqab City, Chahar Right Front Banner<br>Ulanqab City, Jining District<br>Hohhot City, Yuquan District<br>Bayannur City, Hanggin Rear Banner, etc |
| Slight Decrease | -4.34—0 | 25 | Tongliao City, Horqin Left Rear Banner<br>Bayannur City, Urad Middle Banner<br>Hohhot City, Tumed Left Banner<br>Hohhot City, Huimin District<br>Tongliao City, Kulun Banner, etc |
| Slight Increase | 0—14.20 | 48 | Chifeng City, Bairin Right Banner<br>Chifeng City, Hexigten Banner<br>Chifeng City, Yuanbaoshan District<br>Bayannur City, Linhe District<br>Hulunbuir City, Genhe City, etc |
| Increase | 14.20—33.99 | 5 | Baotou City, Guyang County<br>Ordos City, Kangbashi District<br>Ordos City, Uxin Banner<br>Ulanqab City, Huade County<br>Ordos City, Hangjin Banner |
| Significant Increase | 33.99-239.63 | 2 | Alxa League, Ejina Banner<br>Wuhai City, Wuda District |

***Table 10.*** *Global Moran's I Index of Territorial Ecosystem Service Value in Inner Mongolia Autonomous Region from 2001 to 2020*

| Year | 2001 | 2005 | 2010 | 2015 | 2020 |
|---|---|---|---|---|---|
| Global Moran's I index | 0.624 | 0.618 | 0.613 | 0.426 | 0.421 |
| Inspection valueZ | 9.58 | 9.51 | 9.44 | 6.19 | 6.16 |

Building upon the global spatial autocorrelation analysis, a Local Indicators of Spatial Association (LISA) map was generated to visually illustrate the spatial clustering characteristics of ecological values in the counties of Inner Mongolia Autonomous Region. Overall, during the period from 2001 to 2020, most counties exhibited significant spatial clustering of ecological values, and there was a general trend of decline. "High-High" clustering was concentrated in Hulunbuir City, while "Low-Low" clustering was mainly concentrated in Alxa League. There were fewer instances of "High-Low" and "Low-High" clustering.


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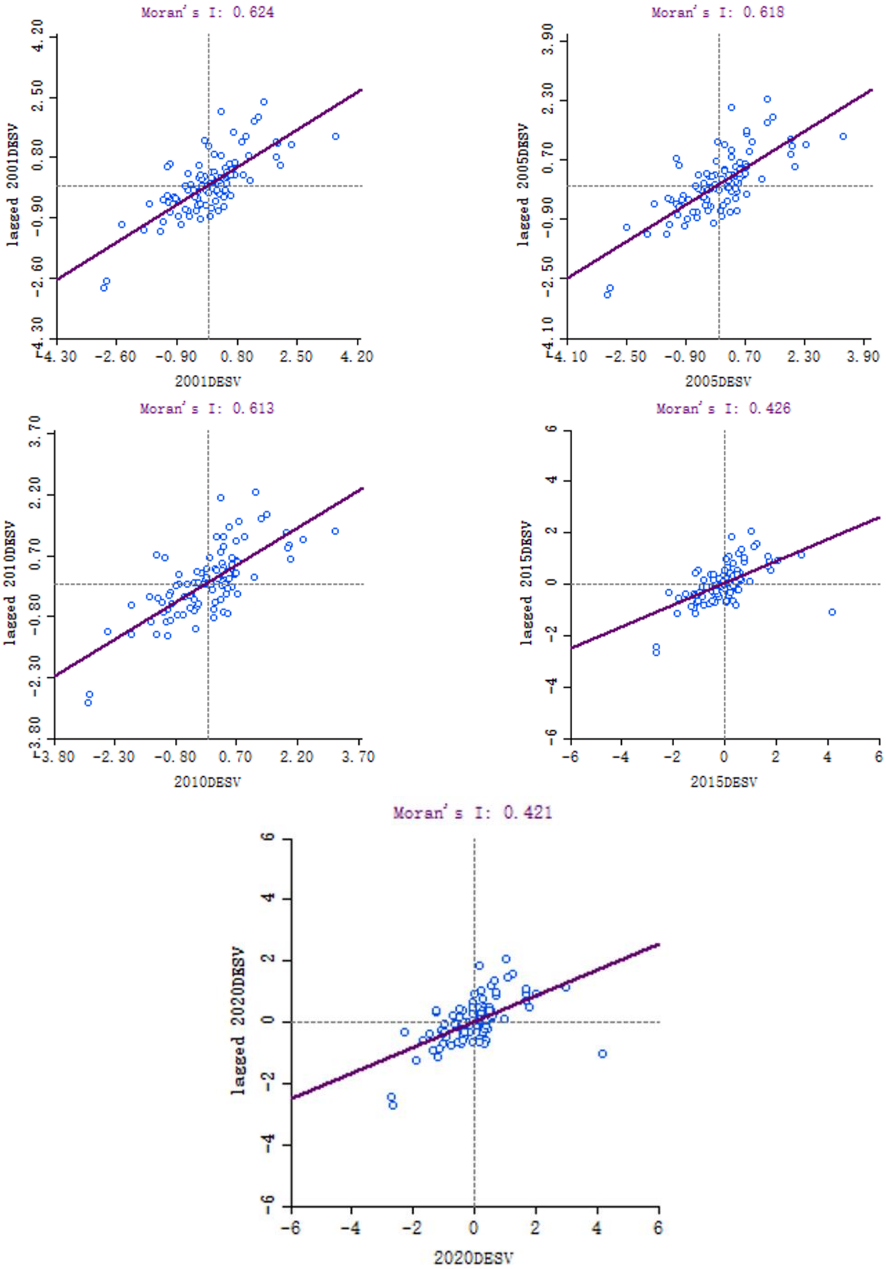


***Figure 10.*** *Moran's I Diagram of Ecosystem Service Value at County Level. in Inner Mongolia Autonomous Region from 2001 to 2020*

The number of areas exhibiting "High-High" clustering decreased from 14 counties in 2001 to 10 counties in 2020, including most counties in Xilinhot and Hulunbuir, especially in Hulunbuir. This region consistently maintained an average high ecological value from 2000 to 2020, indicating high-quality ecological conditions. However, the decline in the number of "High-High" clustering areas is noteworthy, emphasizing the urgent need for efforts to improve ecological quality and enhance ecosystem service values.

The number of areas with "Low-Low" clustering remained around 10 and was mainly concentrated in Alxa League, the western part of Urad Rear Banner in Bayannur City,


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adjacent to Alxa Left Banner in Alxa League, and Tumote Left Banner in Hohhot City. Naiman Banner entered this group in 2005, followed by Kailu County (2010) and Horqin Left Rear Banner (2015) showing similar "Low-Low" clustering. These counties consistently exhibit low or relatively low ecological system service values, and most are spatially adjacent, indicating a small clustering status with potential spillover risks. The urgent implementation of the "Two Mountains" theory is essential in these areas.

The number of areas with "Low-High" and "High-Low" clustering relatively decreased. Zaolinuo Banner showed "Low-High" clustering in 2001 and 2005 but shifted to "High-High" clustering later, indicating an optimization in the provision of ecosystem services. In 2020, Zaolingol Banner presented "High-High" clustering, suggesting emerging negative impacts on the ecological environment. Areas exhibiting "High-Low" clustering from 2001 to 2010 included Urad Middle Banner and Etuoke Banner. In 2015, Uda District and Horqin Left Central Banner entered this group. By 2020, Urad Middle Banner moved to the "Low-Low" clustering region, revealing the spatial clustering of environmental degradation (*Table 11*).

***Table 11.*** *Statistical Table of Spatial Autocorrelation Analysis Results of Ecosystem Service Value per County in Inner Mongolia Autonomous Region from 2001 to 2020*

| Year High- | High-High Quantity | Low-Low Quantity | Low-High Quantity | High-Low Quantity | Not Significant Quantity | Total |
|---|---|---|---|---|---|---|
| 2001 | 14 | 10 | 1 | 2 | 76 | 103 |
| 2005 | 13 | 11 | 1 | 2 | 76 | 103 |
| 2010 | 15 | 12 | 0 | 2 | 74 | 103 |
| 2015 | 11 | 9 | 0 | 4 | 79 | 103 |
| 2020 | 10 | 10 | 1 | 3 | 79 | 103 |

*(2) Spatial correlation analysis of average distribution pattern*

The spatial autocorrelation analysis was conducted on the average level of county-level per capita ecosystem service value in Inner Mongolia Autonomous Region from 2001 to 2020. As shown in the *Figure 11*, it can be observed that the average level of ecosystem service value in Inner Mongolia Autonomous Region exhibits a significant positive correlation, with a global Moran’s I index reaching 0.617. The Monte Carlo test indicates that the P-value is less than 0.01, and the Z-value is higher than the test threshold (1.96).

The results of local spatial autocorrelation analysis for the average level of per capita ecosystem service value in county-level units in Inner Mongolia Autonomous Region are summarized as follows. The clustering characteristics of the average level of per capita ecosystem service value at the county level are similar to the overall distribution characteristics for each year, showing a "Low-Low" cluster in the western and southern parts of the eastern region. This includes 10 county-level units: Tumote Left Banner, Dengkou County, Alxa Left Banner, Kailu County, Urad Rear Banner, Alxa Right Banner, Keerqin Left Back Banner, Hanggin Rear Banner, Ejina Banner, and Naiman Banner. The "High-High" cluster is distributed in Hulunbuir City and Xilin Gol League, and Uda District, Etuoke Banner, and Urad Middle Banner are in the "High-Low" cluster, with no "Low-High" cluster (*Table 12*).


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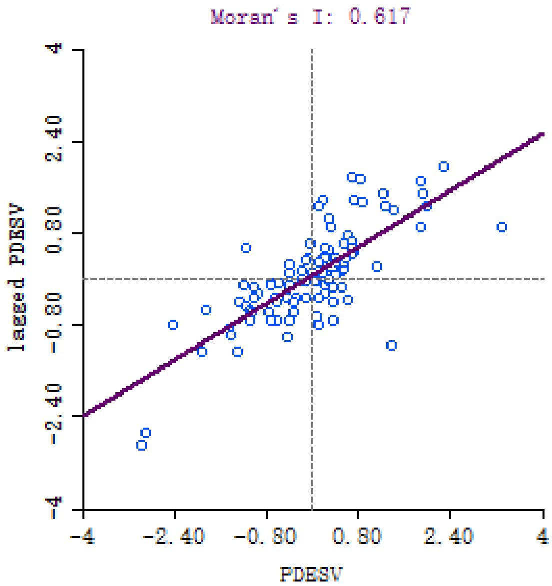


***Figure 11.*** *Moran's I Diagram of Average Territorial Ecosystem Service Value at County Level in Inner Mongolia Autonomous Region from 2001 to 2020*

***Table 12.*** *Cluster Statistical Table of Average Terrestrial Average Ecosystem Service Value in Inner Mongolia Autonomous Region*

| Group | Banners and Counties | | |
|---|---|---|---|
| H-H | Manzhouli City | Ar Horqin Banner | New Barag Right Banner |
| | Zhalainuo'er District | Ewenki Autonomous Banner | Arxan City |
| | Yakeshi City | Morin Dawa Daur Autonomous Banner | Zalantun City |
| | Zhalantun City | Evenk Autonomous Banner | Erlianhot City |
| | Eerguna City | Chen Barag Banner | |
| | Genhe City | New Barag Left Banner | |
| L-L | Tumote Left Banner | Dengkou County | Alxa Left Banner |
| | Kailu County | Urad Rear Banner | Alxa Right Banner |
| | Keerqin Left Back Banner | Hanggin Rear Banner | Ejina Banner |
| | Naiman Banner | | |
| L-H | | —— | |
| H-L | Wuda District | Etuoke Banner | Urad Middle Banner |

## Spatial patterns of ecosystem service value balance in Inner Mongolia

In this section, the study uses data from the year 2020 to explore the spatial differentiation characteristics of ecosystem service value balance in the counties of Inner Mongolia Autonomous Region. Combining the spatial differentiation features of ecosystem service value, the aim is to better understand the basic characteristics and patterns of ecosystem service value distribution in Inner Mongolia, classify regional areas at the county level, and lay the groundwork for subsequent research.


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### *Differentiation characteristics of ecosystem service value balance*

*(1) Ecosystem service value balance*

The ecosystem service value balance measures the balance of different types of ecosystem services within a certain land area (Tong, 2014). A lower balance indicates a more singular ecosystem in the region, while a higher balance suggests a richer variety of ecosystems, providing more comprehensive ecosystem services. This, in turn, contributes to the well-being that humans derive from ecosystems. The calculation formula is as follows:

$$D_{ESV} = 1 - \frac{S_1}{S_1 + S_2} = \frac{S_2}{S_1 + S_2} \qquad \text{(Eq.6)}$$

Due to the fact that the land use type providing ecosystem services is 9, which is a positive integer, the formula is simplified as:

$$D_{ESV} = \frac{2\sum_{i=1}^{9} y_i}{9} \qquad (i = 1,2,\cdots,9) \qquad \text{(Eq.7)}$$

Among them, $y_i$ represents the progressive percentage of ecosystem service value from type 1 to type i to the total ecosystem service value.

*(2) Result analysis*

After calculation, the ecological system service value balance index for Inner Mongolia Autonomous Region in 2020 is 0.308. At the municipal level, 7 leagues and cities surpass the regional average. The highest ecological system service value balance index at the municipal level is 0.394 in Xing'an League, while the lowest is 0.233 in Xilingol League. The lower balance index in Xilingol League is closely related to its relatively singular types of ecosystems. At the county level, among the 103 counties and districts, 42 exceed the regional average, accounting for 40.8% of the total. The remaining 61 counties and districts fall below the regional average. This indicates that, from the perspective of Inner Mongolia's counties, most counties have a relatively single ecosystem, making them more susceptible to destruction. Therefore, greater resource investment is needed for ecological protection (*Table 13*).

### *Spatial differentiation features of the combined ecological system service value and balance index*

Using Bivariate Moran's I, one can explore the spatial correlation characteristics between the per capita ecological system service value and the ecological system service value balance index. The results indicate the overall spatial distribution correlation between the independent variable in region i and the dependent variable in region j. The results of Bivariate Local Moran's I represent the local correlations between the independent variable in region i and the dependent variable in region j, categorizing into four aggregation types: H-H (High per capita value - High balance index), L-L (Low per capita value - Low balance index), H-L (High per capita value - Low balance index), and L-H (Low per capita value - High balance index) (*Figure 12*).


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***Table 13.*** *Statistical Table of Ecosystem Service Value Equilibrium at the City Level in Inner Mongolia Autonomous Region in 2020*

| City Code | League/City | Ecosystem Service Value Balance Degree | Inner Mongolia Ecosystem Service Value Balance Degree |
|---|---|---|---|
| 1501 | Hohhot | 0.328↑ | 0.308 |
| 1502 | Baotou | 0.259 | |
| 1503 | Wuhai | 0.344↑ | |
| 1504 | Chifeng | 0.332↑ | |
| 1505 | Tongliao | 0.332↑ | |
| 1506 | Erdos | 0.255 | |
| 1507 | Hulunbuir | 0.327↑ | |
| 1508 | Bayannur | 0.299 | |
| 1509 | Ulanqab | 0.265 | |
| 1522 | Xing'an League | 0.394↑ | |
| 1525 | Xilingol League | 0.233 | |
| 1529 | Alxa League | 0.335↑ | |

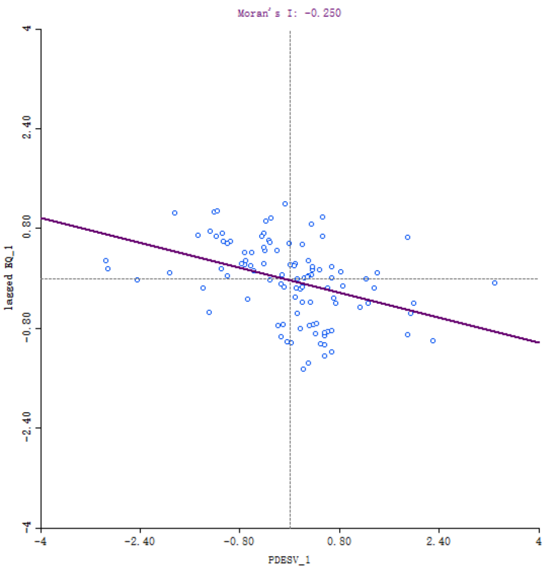


***Figure 12.*** *Bivariate Moran's I Diagram of Value and Equilibrium of Ecosystem Services per County in 2020*

H-H aggregation type indicates that both the per capita ecological system service value in region i and the ecological system service value balance index in region j are high. L-L aggregation type indicates that both the per capita ecological system service value in region i and the ecological system service value balance index in region j are low. H-L aggregation type indicates that the per capita ecological system service value in region i is high, while the neighboring region j has a low ecological system service value balance index. L-H aggregation type indicates that the per capita ecological system service value in region i is low, while the neighboring region j has a high ecological system service value balance index.

H-H and L-L aggregation types suggest a positive correlation between the per capita ecological system service value in region i and the ecological system service value balance index in region j. H-L and L-H aggregation types suggest a negative correlation


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between the per capita ecological system service value in region i and the ecological system service value balance index in region j.

From the *Figure 13*, it can be observed that the combination of ecological system service value and balance index in Inner Mongolia Autonomous Region exhibits "four types," "seven regions," and "one belt."

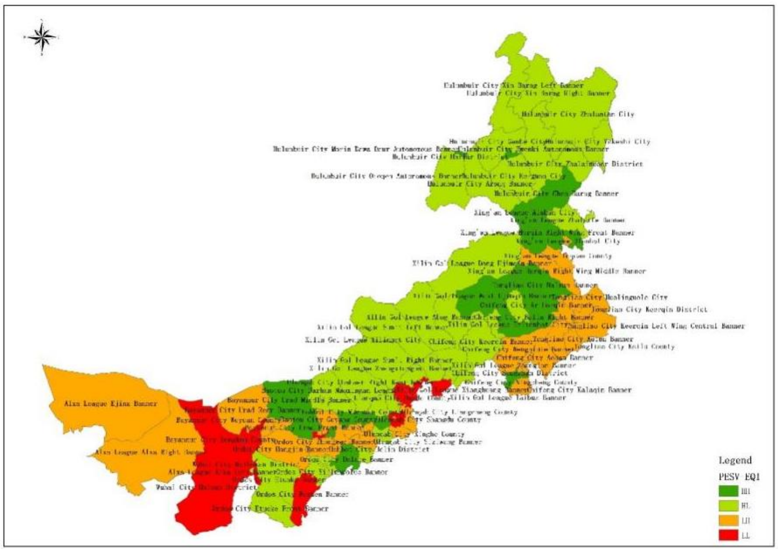


***Figure 13.*** *Cluster Distribution Diagram of Value and Equilibrium of Ecosystem Services per County in 2020*

In the "four types," Type I (High per capita - High balance) includes 20 counties and districts, mainly located in Xing'an League, Chifeng City, and Baotou. Type II (High per capita - Low balance) includes 37 counties and districts, mainly situated in Hulunbuir City and Xilingol League. Type III (Low per capita - High balance) consists of 35 counties and districts, primarily located in Tongliao City, Chifeng City, as well as some areas in the western regions such as Alxa League, Baotou, and parts of Ordos City. Type IV (Low per capita - Low balance) encompasses 11 counties and districts, mainly found in areas around Ulanqab City and other league-level cities.

In the "seven regions," Type I (High per capita - High balance) is mainly distributed in the western regions of Xing'an League, the border areas of Xilingol League and Chifeng City, as well as both regions. Type II (High per capita - Low balance) is predominantly found in Hulunbuir City and most areas of Xilingol League. Type III (Low per capita - High balance) is mainly located in the southern regions of Tongliao City and Chifeng City, as well as the western regions of Alxa League. Type IV (Low per capita - Low balance) is primarily concentrated in the southern regions of Ulanqab City.

The term "one belt" refers to areas with relatively high balance indexes in Hohhot City and Baotou City. However, the distribution of per capita ecological system service values in these areas is complex, with high urbanization rates, dense populations, and belonging to major human settlement areas, designated as complex zones.


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## Discussion

During the "Tenth Five-Year Plan" period, Inner Mongolia addressed ecological environmental issues effectively by implementing key ecological construction projects such as natural forest resource protection, control of sand sources affecting Beijing and Tianjin, conversion of cropland to forest, and grazing land to grassland. Notably, there was a significant increase in the forest and grassland types. However, the decline in farmland, wetland, and water body types indicated that ecological protection projects still faced significant challenges. Despite the evident positive effects of ecological construction projects on local ecosystems during this period, a balance between economic development and environmental protection is crucial in land use planning.

In the "Eleventh Five-Year Plan" period, Inner Mongolia, under national support, promoted new industrialization, resulting in an upward trend in grassland, forest, ice and snow, and impervious surface types. However, a substantial decrease in bare land and a reduction in farmland types reflected the impact of rapid industrialization on the ecological environment. The trend of prioritizing economic development over environmental protection during this period needs careful consideration in future development to balance the relationship between the economy and the environment.

In the "Twelfth Five-Year Plan" period, Inner Mongolia accelerated the construction of an ecological security barrier, with an upward trend in farmland, forest, and impervious surface types, effectively restraining the overall decline in the ecological environment. However, the significant decrease in grassland types indicated an urgent need for national policies supporting grassland ecological rewards. The adverse effects of industrial development on grassland require attention to achieve coordinated development between the economy and the environment.

During the "Thirteenth Five-Year Plan" period, Inner Mongolia achieved high-quality economic development while emphasizing ecological environmental protection. Grassland, forest, ice and snow, bare land, and impervious surface types showed an upward trend, with the most significant growth in grassland, demonstrating significant achievements in ecological protection. However, the decrease in farmland types suggests a need for further strengthening ecological protection to balance land use and the provision of ecosystem services.

In summary, Inner Mongolia has achieved significant results in ecological construction over various periods. However, the challenge of balancing economic development and environmental protection persists. Future efforts should focus on the sustainability of ecosystems in land planning and management, deepen grassland ecological reward policies, and strengthen the synergy between industrial development and ecological environment to achieve both economic prosperity and continuous improvement in Inner Mongolia's ecological environment.

The dynamic changes in various land use types reflect the process of ecological environment evolution in Inner Mongolia. Some specific types, such as ice and snow, shrubs, and wetlands, are particularly sensitive and may be influenced by factors like climate and human activities. In-depth analysis of these changes helps to better understand the dynamic evolution of ecosystems, providing a scientific basis for future ecological protection and sustainable development.

The farmland type initially decreased, then steadily increased, and finally showed a decreasing trend. The initial decrease may be related to urbanization and the modernization of agriculture, leading to the conversion of land to other types. The subsequent increase may be driven by national ecological construction policies, guiding


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the protection and regeneration of farmland. However, the ultimate decrease may reflect the challenge of balancing agricultural land pressure and ecological protection, necessitating more effective coordination between agricultural development and environmental conservation.

Forest and grassland types showed an overall upward trend with relatively small dynamic changes throughout the study period. This may reflect Inner Mongolia's effective protection and restoration of forest and grassland ecosystems. However, despite the overall small changes, long-term monitoring and protection of forests and grasslands remain crucial to maintain ecosystem stability and biodiversity. Shrub and wetland types exhibited significant dynamic changes, especially a rapid decline after an increase from 2011 to 2015. This may be influenced by both human activities and natural factors. Shrubs may be affected by urban expansion and agricultural cultivation, while wetlands could be damaged by climate change or human activities. In-depth research into the mechanisms behind these changes is needed to formulate targeted protection strategies. The grassland type showed a continuous decline from 2005 to 2015, followed by a subsequent increase. This suggests that the ecosystem is sensitive to changes in grassland, possibly related to climate, grazing management, and agricultural expansion. In-depth research into the reasons behind this cyclical fluctuation is necessary to provide a scientific basis for future grassland ecological protection. Other types, such as water bodies, ice and snow, and bare land, exhibited diverse dynamic features at different periods, with the ice and snow type showing the largest amplitude of changes. This may be significantly influenced by climate factors, warranting continued attention to the impact of climate change on these special types and providing warnings and references for future ecological regulation.

The overall trend changes in comprehensive land use dynamic indicate the long-term evolution of land use patterns in Inner Mongolia. A more in-depth analysis of this evolution helps us understand the underlying reasons and potential impacts. Firstly, the high-speed dynamic stage (2001-2005) may be related to the rapid economic development and large-scale land use activities in Inner Mongolia at that time. The region may have faced pressures from various aspects, including agriculture, industry, and urbanization, leading to rapid changes in land use. This change may have been influenced by government policies, market demands, and factors such as population growth. Secondly, the relatively stable period (2005-2010) may reflect more cautious land use management, possibly due to considerations for resource protection and sustainable development. During this period, Inner Mongolia may have implemented measures to control the irrational use of land, slowing down the growth rate of land use dynamic. The subsequent high-speed dynamic stage (2010-2020) indicates an adjustment in land use patterns and acceleration once again. This may be related to the implementation of policies promoting the development of large-scale industries, advancing new urbanization, and strengthening ecological protection in Inner Mongolia in recent years. This period of high-speed dynamics may accompany large-scale development and utilization of land, with potential impacts on the stability of ecosystems and the sustainability of land resources. Finally, the slowing speed in the second high-speed dynamic stage (2010-2020) may suggest that Inner Mongolia is gradually reaching a balance in land use. This balance may be a trade-off among economic development, ecological protection, and social sustainability, requiring more in-depth research to understand the specific mechanisms. In conclusion, the changes in comprehensive land use dynamic reflect the complex adjustment process in land use in Inner Mongolia over the long term. This trend is likely influenced by a combination of policy, economic, and


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social factors. In-depth analysis of these changes is crucial for guiding future land management, resource utilization, and sustainable development decisions.

During the 20-year research period, the ecosystem services value in Inner Mongolia Autonomous Region showed a certain fluctuating trend. From the highest value in 2013 to the lowest in 2019, there was a slight decline in ecosystem services value, likely influenced by various factors. Interestingly, during this time, the ecosystem services value maintained relative stability amid fluctuations, indicating a certain resilience of Inner Mongolia's ecosystems to external pressures. Looking at the data from 2020, the ecosystem services value in Inner Mongolia Autonomous Region exhibited distinctive characteristics in various service functions. Regulating services dominated the ecosystem services value, with significant contributions from gas regulation and climate regulation functions. This suggests the crucial role Inner Mongolia's ecosystems play in maintaining climate balance and environmental cleanliness. Additionally, the soil retention function in supporting services also held significant importance, positively contributing to maintaining soil quality and water resource health. These results emphasize the indispensability of ecosystem services in sustaining regional ecological balance and promoting sustainable development. However, the declining trend in ecosystem services value warrants attention. Despite an overall stable trend, the reasons for fluctuations may include natural factors (such as climate change), human activities (such as excessive development and resource utilization), and changes in land use. The interaction of these factors may weaken ecosystem services, negatively impacting ecological balance and socioeconomic conditions. Examining the contributions of various ecosystem service functions, regulating services, particularly gas and climate regulation functions, dominated the ecosystem services value. This highlights the key role of Inner Mongolia's ecosystems in maintaining climate balance and environmental cleanliness. In future sustainable development planning, focusing on the protection and promotion of these regulating functions will positively impact Inner Mongolia's ecological health and climate resilience. The value of soil retention function in supporting services also underscores its importance in maintaining soil health and water resource management. In arid regions like Inner Mongolia, soil retention is a critical factor for ensuring sustainable agricultural development and is closely related to the sustainable supply of water resources. Therefore, rational planning of land use policies and agricultural practices will play a crucial role in enhancing soil retention function. In summary, a thorough analysis of the fluctuation in ecosystem services value in Inner Mongolia Autonomous Region not only helps understand the trends over the past 20 years but also provides a foundation for formulating targeted ecological protection strategies and sustainable development plans. In future research, further consideration of the relationship between ecosystem services value and socioeconomic indicators will contribute to a more comprehensive assessment of the contribution of ecosystems to human society. In the analysis of the ecosystem services value at the municipal level in Inner Mongolia Autonomous Region, noticeable spatial differentiation features were observed. Over the 20-year period from 2001 to 2020, the per capita ecosystem services value exhibited an east-high, west-low, north-high, and south-low pattern among these municipal administrative units. Hulunbuir, Xing'an League, and Xilin Gol League consistently ranked in the top three during this period, mainly due to their extensive ecosystems, such as forests and grasslands, providing relatively high ecosystem services value. Hulunbuir, in particular, stood out with a significantly higher per capita ecosystem services value. In contrast, Alxa League and Bayannur City consistently remained at lower levels over the 20 years, with Alxa League


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having the lowest per capita ecosystem services value. This is mainly attributed to the large areas of ecosystems such as bare land and issues like desertification, leading to a relatively inadequate supply of ecosystem services. Tongliao City and Wuhai City experienced considerable fluctuations in the ecosystem services value between low and medium levels, requiring steady efforts in ecological environmental protection and the gradual implementation of the "Two Mountains Theory." Interestingly, Chifeng City was in a higher group in 2001 and 2005 but failed to re-enter this group in subsequent years, ultimately dropping to the medium group in 2020. This suggests a declining trend in the ecosystem services value of Chifeng City, deserving attention and reflection. Hohhot City and Ordos City consistently maintained a medium-level per capita ecosystem services value throughout the entire study period, while Baotou City and Ulanqab City were in the medium group in 2015 and the higher group in other years. This spatial differentiation phenomenon indicates differences among the municipal administrative units in Inner Mongolia Autonomous Region in terms of ecosystem services. This variation may result from the interaction of various factors such as geography, climate, and human activities. Therefore, in future ecological environmental planning and policy-making, greater attention should be paid to the characteristics of different regions, promoting targeted enhancement of ecosystem services and sustainable development.

Further analyzing the spatial variation of ecosystem service values at the municipal level, we can explore influencing factors and future development directions from various perspectives. Firstly, Hulunbuir, Xing'an League, and Xilin Gol League stand out as areas with the highest per capita ecosystem service values, primarily due to the abundance of ecosystems such as forests and grasslands, forming the foundation for providing high-level ecological services. This emphasizes the need for focusing on the protection and restoration of these ecosystems in ecological environmental management to ensure the sustainability of their ecological service values. Secondly, Alxa League and Bayannur City consistently remained at lower levels over the 20 years, mainly constrained by issues like bare land and desertification. In these areas, enhancing ecological restoration and land governance, increasing land and vegetation coverage, is crucial to strengthen their ecosystem service functions. While Chifeng performed well initially, it later declined to a moderate level, possibly indicating the impact of unsustainable land use and declining ecological environmental quality. This suggests the necessity to find a balance between economic development and ecological environment protection to avoid sacrificing ecosystem service values. For Tongliao and Wuhai, where ecosystem service values fluctuated between low and moderate levels, careful consideration in balancing ecological environmental protection and land use planning is needed to ensure stable provision of ecosystem services.

In summary, the ecosystem service values of different municipal administrative units are influenced by factors such as ecosystem types, land use changes, and climatic conditions. In future research and management, a deeper exploration of the relationships between these factors is essential for scientifically formulating ecological protection policies and sustainable development strategies. Additionally, cooperation across regions and industries needs to be strengthened to collectively address environmental issues and maximize the utilization of ecosystem services.

Environmental Impact: Inner Mongolia Autonomous Region has diverse geographical environments, including grasslands, deserts, forests, lakes, and various ecosystem types. The ecosystem service values manifest different characteristics in different geographical environments. For example, grassland areas may provide higher values in terms of food


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production functionality, while wetland areas may contribute higher values in water supply and regulation functionality.

Human Activities Impact: Human activities are one of the crucial factors influencing the spatial distribution of ecosystem service values. Urbanization, agricultural expansion, and industrial development may lead to changes in land cover and ecosystem degradation, thereby reducing the ecosystem service values. In Inner Mongolia Autonomous Region, some areas experience significant disturbances due to human activities such as development, resource exploitation, which may result in lower ecosystem service values.

Ecosystem Type Impact: Different types of ecosystems have distinct characteristics and advantages in providing ecosystem services. For instance, grassland ecosystems may excel in soil conservation and food production, while forest ecosystems play a vital role in water conservation and climate regulation. Therefore, the distribution and characteristics of ecosystem types have a significant impact on the spatial distribution of ecosystem service values.

Ecological Protection and Management Measures: The implementation of ecological protection and management measures can significantly improve the health of ecosystems and enhance their service values. Establishing natural reserves, promoting sustainable land-use planning, and implementing soil and water conservation measures contribute to the stability and resilience of ecosystems, thus increasing their service values.

Taking into account the impacts of these factors, we can comprehensively understand the spatial distribution patterns of ecosystem service values in Inner Mongolia Autonomous Region. This understanding provides a basis for proposing targeted policy recommendations for future ecological protection and sustainable development. For example, reinforcing the protection of vulnerable ecosystems, optimizing land-use structures, and promoting the coordinated development of ecological protection and economic growth to achieve sustainable development goals in Inner Mongolia Autonomous Region.

A comprehensive analysis of ecosystem service values and equilibrium performance in Inner Mongolia Autonomous Region suggests adopting a differentiated management strategy. For regions with high per capita values and high equilibrium, efforts should be directed towards enhancing service quality and strengthening ecological supervision. In regions with high per capita values but low equilibrium, measures should be taken to address over-exploitation, focus on environmental vulnerability, and promote sustainable development. Regions with low per capita values but high equilibrium can learn from successful policy practices to further increase per capita values. Lastly, regions with low per capita values and low equilibrium need to intensify ecological restoration efforts, promoting sustainable land use. At the policy level, recommendations include promoting ecological economic development, formulating sustainable urban planning, enhancing technological support to achieve the goal of coordinated development between ecological protection and socio-economic progress.

The determination method of the unit area value equivalent factor, referred to in this paper as the method for determining the value of the required service value per unit area, has problems as it overlooks the differences in the quality of ecological and environmental resources. The key to solving this problem is to use the marginal consumption of the worst ecological and environmental resources as the standard for the equivalent factor of the ecosystem service value per unit area, rather than using the economic value of the natural grain output of farmland per year as a standard equivalent factor. Further research on the extension of the inferiority rule. This paper uses the inferiority rule to calculate the


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standard unit ecosystem service value equivalent factor value of farmland ecosystems. However, for other types such as forests, shrubs, grasslands, water bodies, wetlands, the standard unit ecosystem service value equivalent factor values have not been calculated. According to the inferiority rule, the economic output of the worst ecological and environmental resources of these types of ecosystems needs to be calculated and weighted to obtain the standard unit ecosystem service value equivalent factor values for a general ecological system.

## Conclusion

The overall trend of ecosystem service value (ESV) in Inner Mongolia Autonomous Region shows stability with a slight decline. Over the past two decades, the highest ESV occurred in 2013, reaching 976.54 billion yuan, while the lowest was observed in 2019 at 966.41 billion yuan. The 20-year average ESV stands at 9,727.96 billion yuan. The distribution of ESV at the municipal level exhibits an east-high-west-low and north-high-south-low pattern, displaying significant spatial variations. The county-level per capita ecosystem service value in Inner Mongolia shows a slight increase in the northeastern region, a slight decrease in the central and southeastern regions, and an overall upward trend in the western region.

Initially, an analysis was conducted on the overall changes in land use types in Inner Mongolia Autonomous Region, utilizing descriptive statistics. A specific analysis was then carried out on both individual and comprehensive land use dynamic degrees, providing an initial understanding of the current state and changes in land use in Inner Mongolia over the past 20 years. Subsequently, based on the law of inferiority, the proportion of different grades of arable land in Inner Mongolia was considered. Combining this with the existing equivalent factor method for calculating ecosystem service values, adjustments were made. This led to the computation of the standard unit ecosystem service value equivalent factor value for Inner Mongolia and the construction of the per unit area ecosystem service value equivalent table. Using the land use data employed in this study, ecosystem service values were calculated for Inner Mongolia at the provincial, municipal, and county levels.

In the third step, an analysis of the spatiotemporal differentiation features of the calculated ecosystem service values was conducted. The aim was to gain a comprehensive understanding from provincial, municipal, and county perspectives and to perform spatial autocorrelation analysis on the per capita ecosystem service values at the county level. Scatter plots and LISA maps were created to visually reflect the distribution of ecosystem service values in Inner Mongolia Autonomous Region.

Finally, in conjunction with ecosystem service value balance, the ecosystem service value balance at the provincial, municipal, and county levels in Inner Mongolia was calculated. This aimed to further refine the analysis of the distribution of ecosystem service values in Inner Mongolia Autonomous Region. The results clarified that the combination of ecosystem service values and balance in Inner Mongolia exhibited a "four-type," "seven-region," and "one-belt" distribution pattern.

## REFERENCES

[1] An, G., Han, Y., Gao, N., Ji, L., Gao, H., Tan, X. (2021): The spatial differentiation law of the value and balance of ecosystem services in Shandong Province China Population, Resources and Environment. – China Population, Resources and Environment 31(10): 9-18.
[2] Bao, J., Wang, W., Zhao, T. (2023): Spatiotemporal Changes of Ecosystem Service Values in Response to Land Cover Dynamics in China from 1992 to 2020. – Sustainability 15(9): 7210.
[3] Cao, Y., Zhao, S., Yang, Y., Guo, P. (2020): Research on the Spatiotemporal Dynamic Relationship between Ecosystem Service Value and Regional Economic Growth in Chongqing. – Resources and Environment in the Yangtze Basin 29(11): 2354-2365.
[4] Ci, M., Ye, L., Liao, C., Yao, L., Tu, Z., Xing, Q., Tang, X., Ding, Z. (2023): Long-Term Dynamics of Ecosystem Services and Their Influencing Factors in Ecologically Fragile Southwest China. – Sustainability 15(16): 12331.
[5] Costanza, R., D’Arge, R., Groot, R. D., Farber, S., Grasso, M., Hannon, B. (1997): The value of the world's ecosystem services and natural capital. – Nature 1(1): 253-260.
[6] Guo, Y., Xu, D., Xu, J., Yang, Z. (2024): Multi-Scale Analysis of Spatial and Temporal Evolution of Ecosystem Health in the Harbin–Changchun Urban Agglomeration, China. – Sustainability 16(2): 837.
[7] Komatsubara, K., Keeley, A. R., Managi, S. (2023): Revisiting the Value of Various Ecosystems: Considering Spatiality and Disaster Concern. – Sustainability 15(4): 3154.
[8] Li, Y., Liu, W., Feng, Q., Zhu, M., Zhang, J., Yang, L., Yin, X. (2022): Spatiotemporal Dynamics and Driving Factors of Ecosystem Services Value in the Hexi Regions, Northwest China. – Sustainability 14(21): 14164.
[9] Li, W., Geng, J., Bao, J., Lin, W., Wu, Z., Fan, S. (2023): Analysis of Spatial and Temporal Variations in Ecosystem Service Functions and Drivers in Anxi County Based on the InVEST Model. – Sustainability 15(13): 10153.
[10] Li, T., Shi, D., Jiang, S., Li, Y., Yu, H. (2024): Analysis of Spatial-Temporal Variation in Ecosystem Service Value in Shandong Province over the Last Two Decades. – Sustainability 16(2): 515.
[11] Liu, S., Huang, G., Wei, Y., Qu, Z. (2022): Monitoring and Assessing Land Use/Cover Change and Ecosystem Service Value Using Multi-Resolution Remote Sensing Data at Urban Ecological Zone. – Sustainability 14(18): 11187.
[12] Longo, A., Zardo, L., Maragno, D., Musco, F., Burkhard, B. (2024): Let’s Do It for Real: Making the Ecosystem Service Concept Operational in Regional Planning for Climate Change. – Sustainability 16(2): 483.
[13] Luo, H., Song, Y., Peng, J. (2017): Research on Ecological Service Value Assessment of Major Grain Producing Areas in China Based on Costanza Model. – Resources and Environment in the Yangtze River Basin 26(4): 6.
[14] Mu, S. L. (2016): The ecosystem service value and spatial distribution of temperate grasslands in Inner Mongolia Autonomous Region from 1982 to 2014. – Resources and Environment in Arid Regions 10: 6.
[15] Shi, L., Wang, S., Yao, X., Niu, J., Yu, L. (2012): Spatiotemporal characteristics and driving forces of land use change in Shanghai from 1994 to 2006. – Resources and Environment in the Yangtze Basin 21(12): 1468-1479.
[16] Song, J., Wen, L., Wang, F., Li, K., Wu, C., Zhang, H. (2021): The spatiotemporal dynamics of ecosystem service value in Ulan Buh Desert. – Journal of Ecology 41(6): 2201-2211.
[17] Tong, Y. (2014): Research on the Spatial Differentiation of Traditional Chinese Villages Based on GIS. – Human Geography 29(04): 44-51.

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http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2205_40654099

[18] Wei, Q., Xi, Z., Su, H., Miao, Y., Cao, Y. (2021): Research on the Spatial Differentiation of Support Service Value of Caofeidian Coastal Wetland Ecosystem. – Geographic Science 41(5): 10.
[19] Wu, X., Zhang, L., Gao, L., Li, Y., Liu, X. (2023): Change and Tradeoff/Synergy Analysis of Watershed Ecosystem Services: A Case Study of Qinghai Lake Basin. – Sustainability 15(15): 11711.
[20] Xie, G., Zhen, L., Lu, C., Xiao, Y., Chen, C. (2008): A method for valuing ecosystem services based on expert knowledge. – Journal of Natural Resources 23(5): 9.
[21] Xie, G., Zhang, C., Zhang, L., Chen, W., Li, S. (2015): Improvement of ecosystem service valuation method based on unit area value equivalent factor. – Journal of Natural Resources 8: 12.
[22] Xie, G., Zhang, C., Zhang, C., Xiao, Y., Lu, C. (2015): The value of ecosystem services in China. – Resource Science 37(9): 7.
[23] Yang, J., Huang, X. (2021): The 30 m annual land cover dataset and its dynamics in China from 1990 to 2019. – Earth System Science Data 13(8): 3907-3925.
[24] Zhang, R., Wang, Y., Chang, J., Li, Y. (2019): Response of land use change to human activities in the Yellow River Basin based on water resource zones. – Journal of Natural Resources 34(2): 274-287.
[25] Zhang, S., Wang, H., Fu, X., Tang, M., Wu, D., Li, S., Wu, G. (2023): Analysis of the Effect of Ecosystem Services and Urbanization on Human Well-Being in Inner Mongolia Province. – Sustainability 15(22): 16021.
[26] Zhang, Y., Yang, R., Li, X., Sun, M., Zhang, L., Lu, Y., Meng, L., Liu, Y., Wang, C. (2023): Designing a Sustainable Development Path Based on Landscape Ecological Risk and Ecosystem Service Value in Southwest China. – Sustainability 15(4): 3648.
[27] Zhang, Z., Han, L., Feng, Z., Zhou, J., Wang, S., Wang, X., Fan, J. (2024): Estimating the Past and Future Trajectory of LUCC on Wetland Ecosystem Service Values in the Yellow River Delta Region of China. – Sustainability 16(2): 619.
[28] Zhao, Z., Li, K., Zeng, G., Li, D. (2012): Evaluation of Forest Ecosystem Services in Qinhuangdao City. – Resources and Environment in Arid Regions 26(2): 6.
[29] Zhao, Y., Han, Z., Xu, Y. (2022): Impact of Land Use/Cover Change on Ecosystem Service Value in Guangxi. – Sustainability 14(17): 10867.
[30] Zhao, H., Li, C., Gao, M. (2023): Investigation of the Relationship between Supply and Demand of Ecosystem Services and the Influencing Factors in Resource-Based Cities in China. – Sustainability 15(9): 7397.
[31] Zhou, Y., Chen, T., Wang, J., Xu, X. (2023): Analyzing the Factors Driving the Changes of Ecosystem Service Value in the Liangzi Lake Basin-A GeoDetector-Based Application. – Sustainability 15(22): 15763.
[32] Zhou, Q., Gui, F., Zhao, B., Liu, J., Cai, H., Xu, K., Zhao, S. (2024): Examining the Social Costs of Carbon Emissions and the Ecosystem Service Value in Island Ecosystems: An Analysis of the Zhoushan Archipelago. – Sustainability 16(2): 932.
[33] Zhou, X., Wang, Q., Zhang, R., Ren, B., Wu, X., Wu, Y., Tang, J. (2022): A Spatiotemporal Analysis of Hainan Island's 2010–2020 Gross Ecosystem Product Accounting. – Sustainability 14(23): 15624.
[34] Zhu, L., Huang, Y. (2022): Multi-Scenario Simulation of Ecosystem Service Value in Wuhan Metropolitan Area Based on PLUS-GMOP Model. – Sustainability 14(20): 13604.


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