

Article

Evolution of “Production–Living–Ecological” Spaces Conflicts and Their Impacts on Ecosystem Service Values in the Farming–Pastoral Ecotone in Inner Mongolia During Rapid Urbanization

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Abstract: Rapid urbanization is causing ecological and environmental issues to worsen. The stability of the ecosystem function of the farming–pastoral ecotone (FPE) in Inner Mongolia is essential to ensuring the sustained growth of the nearby cities, acting as a vital ecological safeguard in China’s northern regions. This study used the “production–living–ecological” spaces (PLES) spatial dynamics, the rate of change index, and the standard deviation ellipse to examine the spatial and temporal evolution of the PLES in the FPE in Inner Mongolia. This study constructed a spatial conflict index model based on the theory of landscape ecology, and evaluated the ecosystem service value (ESV) of the region and visualized the results of the analysis using the micro-scale of the grid. Finally, the relationship between the ESV and PLES spatial conflicts was determined using a bivariate spatial autocorrelation model. The findings show that: (1) During the 20 years, the maximum ecological spatial change rate reached 0.43%, with the cumulative spatial dynamics of PLES totaling 2.49%. Notably, industrial production space activities experienced the most significant increase, amounting to 277.09%. (2) Regional spatial conflict intensity shows an upward trend from 2000 to 2020, with the average conflict level increasing from 0.53 to 0.56, and high conflict values being concentrated in the east. (3) The ESV pattern in the FPE in Inner Mongolia is characterized by “high ESV in the east and low ESV in the central and western regions”, with an overall trend of increasing and then decreasing. A notable negative correlation was observed between ESV and PLES spatial conflicts in the region, with Moran’s I indicating values of −0.196, −0.293, and −0.163, respectively. Specifically, low-value–high-conflict zones were predominantly found in other ecological spaces, high-value–low-conflict zones was concentrated in forest ecological spaces, and high-value–high-conflict zones were predominantly concentrated in aquatic ecological spaces. The research findings serve as a crucial scientific foundation for the development of ecological civilization and the sustainable advancement of the FPE in Inner Mongolia.

Keywords: production–living–ecological; spatial conflict; ecosystem service values; urbanization; farming–pastoral ecotone in Inner Mongolia



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1. Introduction

Human production–living–ecological spaces (PLES) are territorial complexes formed by the ongoing interaction between natural ecological processes and socio-economic systems [1]. Spatial conflict is a phenomenon in which multiple requirements contend with

scarce spatial resources in the process of using land resources, driven by various interests, resulting in contradictions [2,3]. Ecosystems are necessary and fundamental for human survival, providing supply, regulation, cultural, and ecological functions for human development [4,5]. Land used for agricultural production and ecological maintenance has gradually been replaced by land for industry, mining, transportation, and construction since China's reform and opening up [6,7]. This exacerbated the conflict between the need for urban development and the need for ecological and environmental protection. Conflicts and contradictions in the PLES are intensifying, with significant impacts on ecosystem services [8,9]. Therefore, scientifically revealing the attributes of the geographic development of the PLES, quantitatively assessing the ecosystem services value (ESV), and investigating the influence of the evolution of the PLES geographic conflict on the ESV in a specific region can help to analyze the correlation between the economic benefits and ecological benefits of different types of land in the region (either positive or negative correlations). Depending on the correlation, this can provide an important scientific basis for the optimization of regional PLES and the construction of ecological civilization, as well as a data reference for the future formulation of policies on the direction of regional spatial development. This can provide an important scientific basis for the optimization of the PLES in the region and the construction of ecological civilization.

PLES are intertwined and synergistic, forming a complex system through the interweaving of different human behavioral activities. PLES include production spaces (PS), living spaces (LS), and ecological spaces (ES). Production space mainly that provides industrial and agricultural products, LS caters to the activities of human beings, such as housing and leisure, and ecological space mainly provides ecological services and ecological products [10]. Scholars have performed extensive research on PLES, primarily focusing on its theoretical meaning [11], examining its classification system [12], conducting a thorough assessment of PLES using a range of models [13], optimizing PLES [14], and examining PLES's spatial-temporal evolution and driving mechanisms [15]. Common methods for identifying PLES include land use dynamics and land use transfer matrices [16–18]. The research on PLES has concentrated predominantly on their spatial and temporal evolution, coupling mechanism, and spatial optimization [19]. The ESV method has been widely used to properly evaluate the quantity of ecosystem services, with the ESV method being the most popular since it is straightforward and simple to use, with the added benefit of high comparability [20].

Scholars have conducted a large amount of research on PLES and ESV, but few have investigated the influence of the emergence of the PLES dispute on ESV. The existing research has mainly focused on the influence of land use on the ESV, such as land use changes, using methods such as ecosystem service correlation analyses [21,22], a regression examination of land use changes and ecosystem service drivers [23,24], and the geoprobe model-based quantitative detection of driver interactions [25,26]. The farming–pastoral ecotone (FPE) in Inner Mongolia confronts major difficulties such as land deforestation, grassland degradation, and a limited land-carrying capacity, and its human–land relationship is complicated and rapidly changing. Previous studies on the FPE in Inner Mongolia have focused on land use structure [27,28] and ecological and environmental effects [29], but research on ESV from the perspective of the evolution of PLES spatial conflicts is lacking. The ESV is impacted by the evolution of PLES, and research on these effects can explore the connection between different land types and ESV, offer evidence in favor of China's sustainable land resource use, and strike an equilibrium between ecological value and economic development. Therefore, it is important to investigate the spatial and temporal evolution characteristics of the PLES in the FPE in Inner Mongolia, to reveal the impact of the conflicting evolution of the PLES on the ESV, and to provide citations regarding the ecological protection and

sustainable growth of the FPE in Inner Mongolia. This could provide ideas for research focusing on other ecological transition zones, such as the farming–pastoral ecotone. It will also help China to adhere to the sustainable advancement concept of “green mountains are golden mountains” while continuing to promote the development of urbanization and modernization, control the conflicts between development and ecological protection within a reasonable range, and establish a win–win situation in the PLES.

2. Materials and Methods

2.1. Study Area

The FPE in Inner Mongolia is a crucial region for the cooperative growth of both plantations and animal husbandry. It is situated between $109^{\circ}36'–120^{\circ}52'$ E and $39^{\circ}35'–45^{\circ}15'$ N, and it has a complex topography and geomorphology, with mountains, plateaus, hills, and plains scattered throughout. These is a temperate continental monsoon climate; the area is situated at the climatic crossroads of a semi-moisture area and a semi-arid area (Figure 1). The FPE in Inner Mongolia consists of 29 counties (banners), including five in Hohhot, two in Baotou, ten in Chifeng, ten in Ulanqab, and two in the Xilingolite League.

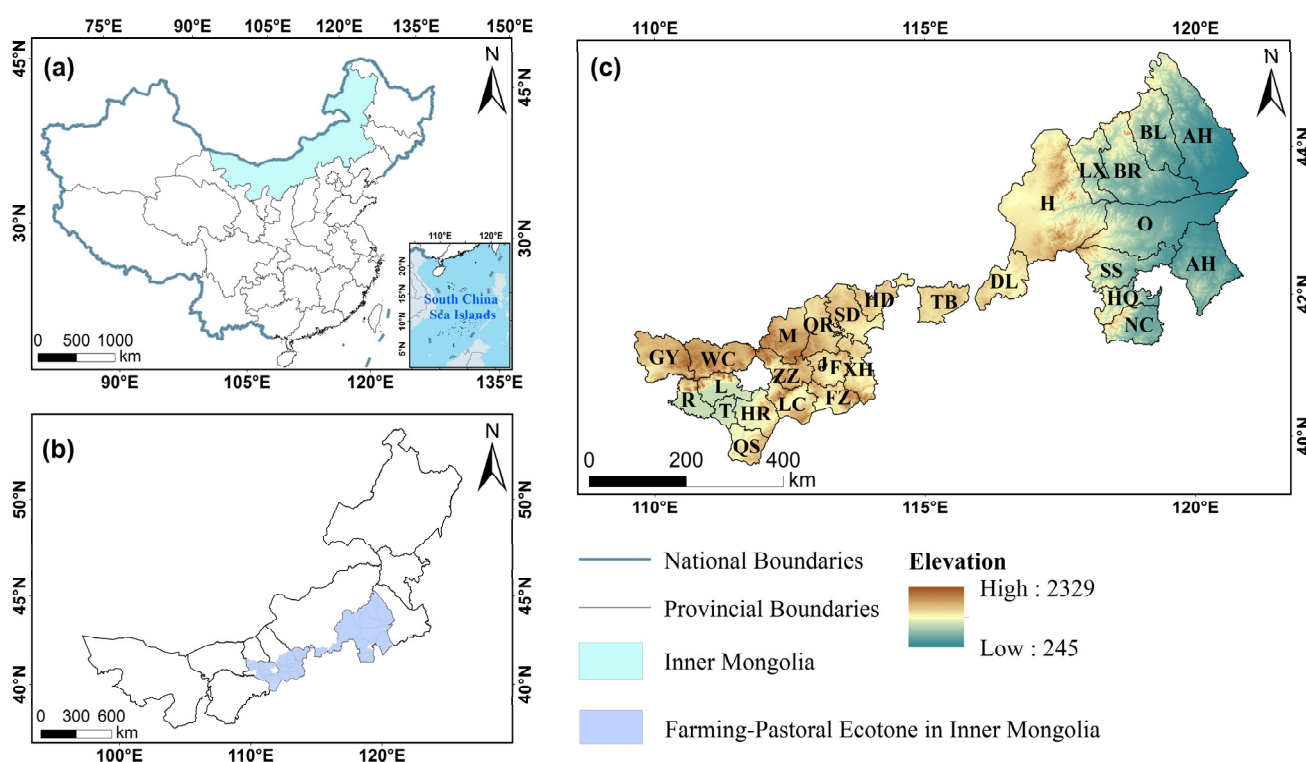


Figure 1. Study area: (a) location of the Inner Mongolia in China; (b) FPE in the Inner Mongolia; (c) The 29 counties (banners) in the FPE in the Inner Mongolia. The abbreviations of county (banners) names are listed in Table S1.

2.2. Data

The Resource and Environmental Science Data Center of the Chinese Academy of Sciences provided the administrative vector boundary data, the land use data at a 30 m spatial resolution, and the DEM data at a 90 m spatial resolution (<https://www.resdc.cn/> accessed on 15 January 2023). The socioeconomic data were obtained from the Inner Mongolia Statistical Yearbook and National Compendium of Cost–Benefit Information on Agricultural Products. The average values of yield per hectare, planted area, and unit price of major grain crops such as wheat, corn, and soybean in Inner Mongolia were used

as the research benchmarks to obtain the ecological service value equivalent scale of the ecosystems in the FPE in Inner Mongolia.

2.3. Methods

To investigate the evolution of spatial conflicts and their impact on the ESV in the FPE in Inner Mongolia from the spatial perspective of the PLES, this study first collected and processed land use and socioeconomic data, and then analyzed the spatial changes in the PLES, using spatial dynamics, the rate of change index, and the standard deviation ellipse to characterize the spatial changes in the PLES characteristics. Secondly, the spatial conflict composite index (SCCI) measurement model was constructed to reveal the spatial conflict intensity in the spatio-temporal dimension, ESVs were assessed based on the modified model, and finally, the impact of the intensities of PLES conflicts on the ESV was quantitatively measured (Figure 2).

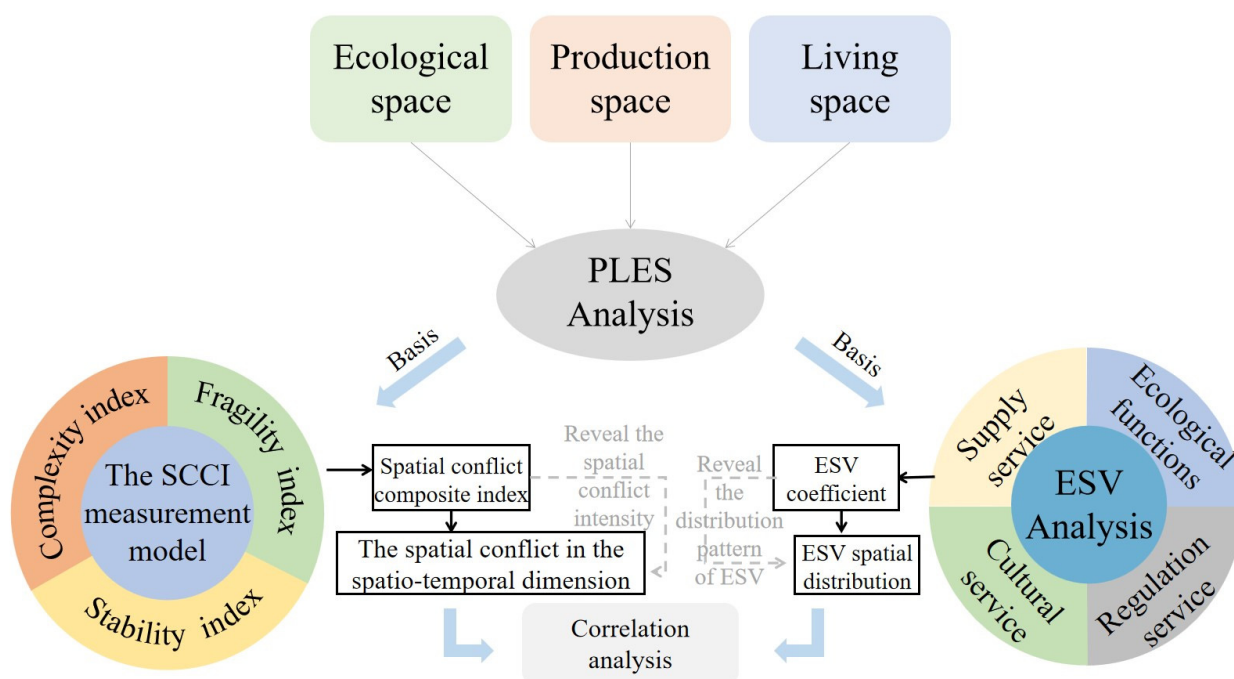


Figure 2. Flowchart revealing the PLES evolution conflicts and their impacts on ESV.

2.3.1. Dynamic Degrees and Rate of Change Index of PLES

(1) PLES dynamic degrees

PLES dynamic degrees refer to the proportional change in the area of each form of PLES over time. This not only reflects the conversion rate of PLES in the research area but also reflects the increase or decrease in a specific category of PLES land use in a specific period of time. It primarily consists of the integrated dynamic degrees of the PLES and the single-dynamic degrees [30,31]. Based on relevant research findings, this study categorized the PLES in the FPE in Inner Mongolia into eight varieties [19] (Table S2). The integrated dynamic degrees of the PLES and the single-dynamic degrees equations are as follows:

$$G = \frac{S_i - S_{ii}}{S_{ii}} \times \frac{1}{T} \times 100\% \quad (1)$$

where G signifies the dynamic degrees index of a certain category of PLES; S_i is the area of the PLES type following the transfer; S_{ii} is the area when no transfer has occurred; T (year) represents the time interval of the study.

$$LC = \left[\frac{\sum_{i=1}^n \Delta LU_{i-j}}{2 \sum_{i=1}^n LU_i} \right] \times \frac{1}{T} \times 100\% \quad (2)$$

where LC (%) is the integrated dynamic degrees of the PLES; LU_i is the region of PLES category i at the study's outset; ΔLU_{i-j} (km^2) is the total worth of the region of PLES type i transformed into non- i PLES type in the given time duration T ; n is the number of regional PLES types.

(2) PLES change rate index

The PLES change rate index is the intensity of the degree of change in the areas of productive, living, and ecological land utilization relative to the study area over time. It enables an effective comparison of the differences in the changes across PLES types. The equations are as follows:

$$F_i = \frac{\Delta V_i}{A} \times \frac{1}{(t_2 - t_1)} \times 100\% \quad (3)$$

$$\Delta V = [LA_{(i,t_2)} - ULA_i] + [LA_{(i,t_1)} - ULA_i] \quad (4)$$

where F_i signifies the rate of change index (%) for PLES type i ; ΔV_i signifies the overall alteration in this type of PLES over the study period; ULA_i signifies the area (km^2) of category i PLES types that did not undergo a transformation during the study period; $LA_{(i,t_1)}$ is the area (km^2) of PLES type i at the start of the study period; $LA_{(i,t_1)} - ULA_i$ represents the sum of the areas (km^2) of i th PLES types that were transformed to other non-type i PLES categories during the study period; $LA_{(i,t_2)} - ULA_i$ indicates the area added during the study period (km^2); t_1 refers to the start time of the study period; and t_2 corresponds to the end time of the study period.

2.3.2. Standard Deviation Ellipse

Originally established by Lefever in 1926, the standard variation ellipse (SDE) is used to characterize the spatial allocation of geographical components and is currently mostly used to examine the patterns of space development in a variety of fields [32]. The method's main parameters are the core point, long axis, short axis, and direction angle, which, as a spatial analysis tool, can accurately represent the geographic distribution of the study object. The formulas are as follows:

Mean center coordinates:

$$\overline{X_w} = \frac{\sum_{i=1}^n w_i x_i}{\sum_{i=1}^n w_i}, \quad \overline{Y_w} = \frac{\sum_{i=1}^n w_i y_i}{\sum_{i=1}^n w_i} \quad (5)$$

Azimuth:

$$\theta = \frac{\arctan \left[\left(\sum_{i=1}^n x_i'^2 - \sum_{i=1}^n y_i'^2 \right) + \sqrt{\left(\sum_{i=1}^n x_i'^2 - \sum_{i=1}^n y_i'^2 \right)^2 + 4 \left(\sum_{i=1}^n x_i' y_i' \right)^2} \right]}{2 \sum_{i=1}^n x_i' y_i'} \quad (6)$$

Axis standard deviation:

$$\delta_x = \sqrt{\frac{\sum_{i=1}^n (x_i' \cos \theta - y_i' \sin \theta)^2}{n}}, \quad \delta_y = \sqrt{\frac{\sum_{i=1}^n (x_i' \sin \theta + y_i' \cos \theta)^2}{n}} \quad (7)$$

where $(\overline{X_w}, \overline{Y_w})$ is the weighted centroid; (x_i, y_i) are the spatial center positions; w_i is the weight; and θ is the ellipse direction; x'_i and y'_i are the center-to-mean center coordinate deviations, respectively. The standard deviations along the x and y axes are indicated by the symbols δ_x and δ_y , respectively.

2.3.3. SCCI Measurement Model

This study constructed a geographic conflict composite index (SCCI) of PLES in the FPE in Inner Mongolia focusing on three aspects: spatial complexity, spatial vulnerability, and spatial stability [33] (Table 1). Spatial intricacy is described by the Area-Weighted Mean Patch Fractal Dimension (AWPFD). This illustrates how different human endeavors impact spatial patterns and the evolution of urban geographic phenomena. Higher AWPFD values indicate less human disturbance. The Spatial Vulnerability Index represents the spatial vulnerability. External forces are the primary cause of a land system's susceptibility, and different land types have differing resistance to disturbances. The Spatial Stability Index measures spatial stability. Stability is strongly influenced by the geographic morphology of land use units. The degree of geographic conflict increases and stability decreases with increasing spatial morphological fragmentation.

Table 1. Calculation methods of PLES conflict indices.

Index	Formula	Formula Description
Spatial Complexity Index	$SCI = \sum_{i=1}^m \sum_{j=1}^n \left[\frac{2 \ln(0.25P_{ij})}{\ln(a_{ij})} \right] \left(\frac{a_{ij}}{A} \right) \quad (8)$	a_{ij} is the patch area; P_{ij} denotes the perimeter of a discrete landscape patch; A represents the aggregate area of specific landscape categories; subscript notation ij corresponds to the j th land cover class within the i th spatial unit cell; m quantifies the total number of assessment grids in the study area; n enumerates the total number of spatial types.
Spatial Fragility Index	$SFI = \sum_{i=1}^n F_i \cdot \frac{a_i}{S} \quad (9)$	F_i is the fragility index of spatial type i ; n represents the overall count of spatial categories; a_i refers to the extent of each landscape category within the unit; S refers to the overall size of the spatial unit.
Spatial Stability Index	$SSI = 1 - \frac{PD - PD_{\min}}{PD_{\max} - PD_{\min}}, \quad (10)$ $PD = \frac{n_i}{A}$	n_i is the number of patches of spatial type i within the spatial unit; A is the area of the spatial unit; PD is the plaque density.
Spatial Conflict Composite Index	$SCCI = SCI + SFI - SSI \quad (11)$	$SCCI$ is the Spatial Conflict Composite Index; SCI , SFI , and SSI are the Spatial Complexity, Fragility, and Stability Indices, respectively.

After comparing grid scales of 1 km × 1 km, 5 km × 5 km, 7 km × 7 km, and 10 km × 10 km, and considering the amount of data and the size of the study area, the final decision was made to analyze the characteristics of the evolution of the PLES conflict based on the 7 km × 7 km grid scale. The results were classified into very low (0.41–0.49], low (0.49–0.53], medium (0.53–0.57], high (0.57–0.63], and very high (0.63–0.72] spatial conflicts.

2.3.4. Ecosystem Services Valuation

The value per unit area conversion factor approach was employed to assess the ESV in FPE in Inner Mongolia [34].

(1) Ecosystem service evaluation indicator construction

Four primary indicators and eleven supplementary indicators of supply, regulation, support, and cultural services were chosen as indicators for the ecosystem services valuation. Referring to the table of ESV coefficients of Xie et al. [35–37], and according to the specific conditions of the study area, the average value of the ESV coefficients of paddy fields and drylands was used for the APS. The FES was calculated as the average of the ESV coefficients of coniferous forests, mixed coniferous forests, broad-leaved forests, and shrubs. GES is calculated as the average of the ESV coefficients of grassland; AES is calculated as the average of the ESV coefficients of aquatic areas; OES is calculated as the average of the ESV coefficients of desert and bare land. Since the IPS, ULS, and RLS have a negative effect on the overall ecosystem of the research region, the ESVs of all three categories of space are recognized as 0 to exclude their effects (Table S3).

(2) Equivalent based on food price correction

The ESV coefficient equivalent factor was updated based on the yield, planted area, per-unit cost, and ecological landscape type of the main agricultural produce in the FPE in Inner Mongolia. The economic value of food crops per unit area of farmland ecosystems in the FPE in Inner Mongolia was determined to be RMB 1256.53 hm² based on the planting acreage, production, and the mean cost of agricultural produce for the four main crops, rice, wheat, maize, and soybeans, in Inner Mongolia in the years 2000, 2010, and 2020. This was carried out in order to remove the effect of crop price variations in different years on the total value (Table S4). The equations are as follows:

$$E_a = \frac{1}{7} = \sum_{i=1}^n \frac{m_i p_i q_i}{M} \quad (12)$$

where E_a is the financial worth of food production services supplied by the cultivated land ecosystem per unit area (CNY/hm²); n is the main agricultural produce species in the study region; p_i is the average price of the i th crop (CNY/t); q_i is the yield per unit region of the i th agricultural produce (t); m_i is the planted area of the i th crop (hm²); M is the planted region of all agricultural produce (hm²).

(3) ESV Calculation

ESVs were calculated in accordance with the equivalent ecosystem service value per unit of space factors table (Table S4). The equation is as follows:

$$ESV = \sum_{i=1}^n \sum_{j=1}^m e_{ij} \times E_a \times A_j \quad (13)$$

where ESV is the regional ecosystem service value (10⁴ CNY/year), e is the i ecosystem service value equivalent factor for the j th ecosystem; and A is the region of the j th ecosystem (hm²).

2.3.5. Bivariate Spatial Autocorrelations

Moran's I index was applied for this study to perform a geographical autocorrelation analysis of ESV and SCCI [38]. A bivariate geographical self-correlation analysis of the effect of PLES evolution on ESV can provide an academic foundation for homeland space refinement by revealing the mechanism of PLES evolution on ESV from the perspective of spatial correlation, identifying the spatial clustering features of the ESV and spatial conflict level and visually expressing them. The equations are as follows:

Bivariate global Moran's index:

$$I = \frac{n \sum_i^n \sum_j^n W_{ij} Q_k^i Q_l^j}{(n-1) \sum_i^n \sum_j^n W_{ij}} \quad (14)$$

Bivariate local Moran's index:

$$I_s = Q_k^i \sum_{j=1}^n W_{ij} Q_l^j \quad (15)$$

$$Q_k^i = \frac{X_k^i - \bar{X}_k}{\partial_K}, Q_l^j = \frac{X_l^j - \bar{X}_l}{\partial_l} \quad (16)$$

where I is the bivariate global Moran index; I_s is the bivariate local Moran index; n is the number of research units; X_k^i is the attribute worth k of research unit i ; X_l^j is the worth of attribute l of research unit j ; $\bar{X}_k$, $\bar{X}_l$ are the mean worths of properties k and l ; ∂_K , ∂_l are the variance in properties k and l ; and W is a weight grid that measures the proximity of the study units and can indicate the geographic relationship between research units i and j . The range of values for Moran I is $[-1,1]$. A favorable worth for Moran I signifies a favorable spatial relationship, meaning that the properties of adjacent research units are similar. Conversely, a negative value for Moran I signifies an adverse spatial relationship and a value of 0 signifies that spatial correlation is irrelevant and that spatial randomness is displayed. The intensity of the spatial interdependence increases with the Moran I value's proximity to 1 or -1 .

3. Results

3.1. PLES Spatio-Temporal Characterization

The ES is the primary distribution among the PLES of the FPE in Inner Mongolia. The distribution of ES is the most extensive and presented as a sheet. The LS is scattered in the form of points and the PS is distributed in line or band in the PLES of Inner Mongolia (Figure 3). The LS area increased from 4234.14 km² in 2000 to 4603.26 km² in 2020, accounting for 0.25%. The PS area increased from 43,624.26 km² in 2000 to 43,796.36 km² in 2020, accounting for an increase of 0.12%. The ES area decreased from 97,937.65 km² in 2000 to 97,392.1275 km² in 2020, accounting for a decrease of 0.37%.

The proportion of LS increased by 0.25%, the percentage of productive space increased by 0.12%, and the percentage of ES decreased by 0.37%. IPS and ULS had the lowest rate of change index (0.01%), while GES had the highest rate of change index (1.72%) between 2000 and 2010. The category shift is more pronounced between 2010 and 2020, with ES showing the highest rate of change index (3.22%) and LS showing the lowest (0.15%). The transition between categories is very smooth between 2000 and 2020, with ES changing at the highest rate (0.43%) and LS changing at the slowest rate (0.04%). Overall, there were clear regional disparities and more significant spatial changes in the FPE in Inner Mongolia between 2000 and 2020 (Table 2). In 2000–2010 and 2010–2020, the study period was more intense and significant, and there were obvious differences between regions. Throughout the entire research cycle, the degree of ecological space change was more significant. In Inner Mongolia, the changes in land use in the FPE are mainly the mutual transformation of land types, so the intensity of the regional area changes was not high from the initial stage to the end of the study.

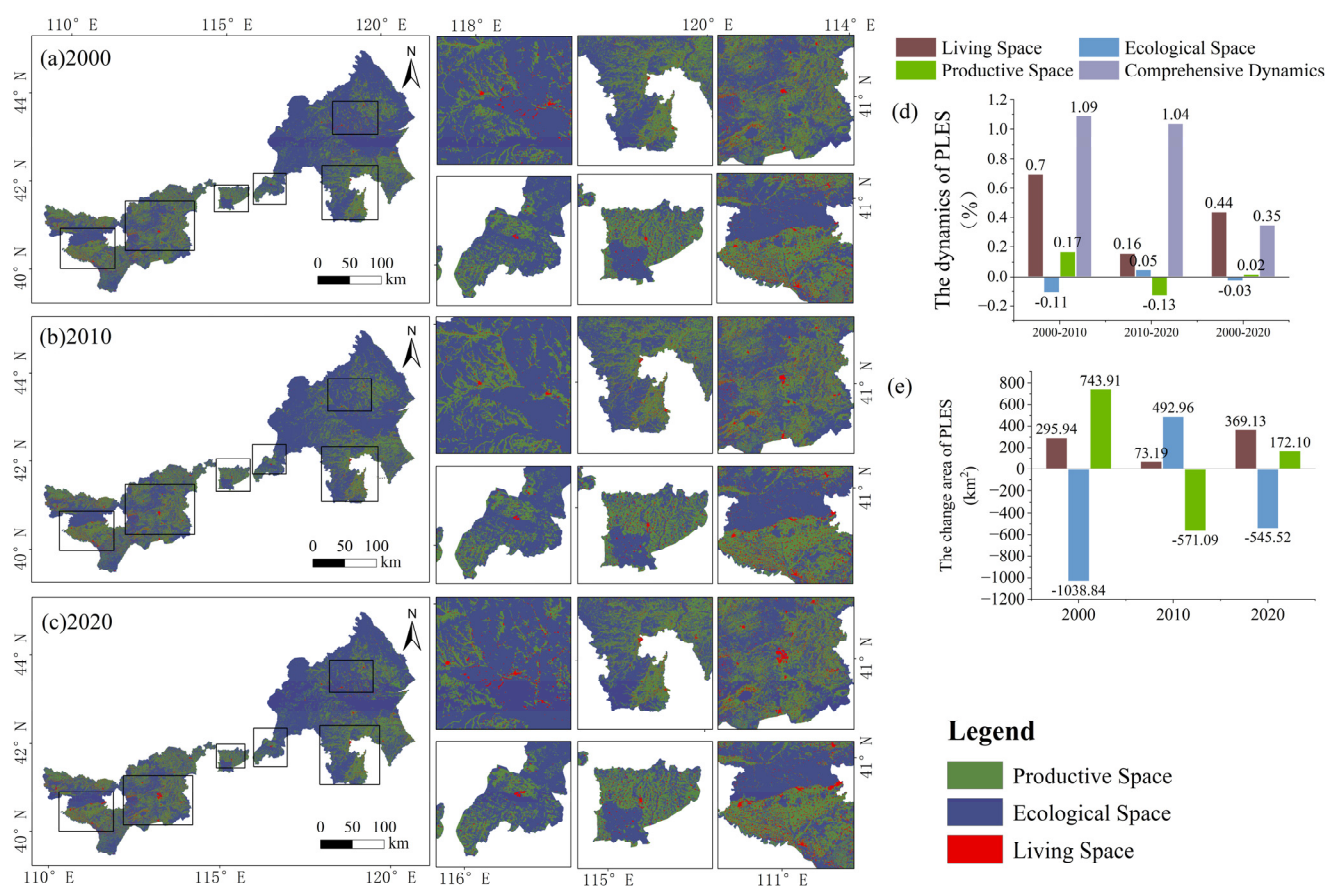


Figure 3. Spatial distribution of PLES in FPE in Inner Mongolia: (a) Spatial distribution of PLES in 2000; (b) Spatial distribution of PLES in 2010; (c) Spatial distribution of PLES in 2020; (d) The dynamic of PLES; (e) The change area of PLES.

Table 2. Index of the change rate of land use type in PLES.

Primary Classification	Secondary Classification	2000–2010 (%)	2010–2020 (%)	2000–2020 (%)
PS	APS	0.89	0.97	0.22
	IPS	0.01	0.03	0.01
	FES	0.87	0.87	0.09
ES	GES	1.72	1.77	0.27
	AES	0.08	0.08	0.01
	OES	0.52	0.50	0.06
LS	ULS	0.01	0.02	0.01
	RLS	0.10	0.13	0.03

The dynamics of PLES within the FPE in Inner Mongolia became increasingly apparent between 2000 and 2020. From the perspective of single-dynamic degrees, the LS had the highest dynamic degrees and the largest increase from 2000 to 2010 (a single-dynamic degree of 0.70% and an increase of 295.94 km²), followed by the PS (a single-dynamic degree of 0.17% and an increase of 743.19 km²) and the ES (a single-dynamic degree of −0.11% and a decrease of 1038.48 km²). LS had the highest single-dynamic degrees (0.16%), with an increase of 73.19 km², ES had the second-highest single-dynamic degrees (0.05%), with an increase of 492.96 km², and productive space had the lowest single-dynamic degrees (−0.13%), with a reduction of 571.09 km² from 2010 to 2020. LS single-dynamic degrees increased by 369.13 km² (0.44%) and PS single-dynamic degrees increased by

172.10 km² (0.02%) between 2000 and 2020, whereas ES single-dynamic degrees decreased by 545.52 km² (−0.03%).

From the perspective of integrated dynamic degrees, the region's integrated dynamic degrees changed more dramatically between 2010 and 2020, with the integrated dynamic degrees during the study period being 0.35%. The integrated dynamic degree was 1.04% in 2000–2010 and the highest integrated dynamic degree was 1.09% in 2010–2020. With the highest single-dynamic degrees among the different land use types during the study period (48.93% for 2000–2010, 38.71% for 2010–2020, and 277.09% for 2000–2020), the IPS has grown significantly over the 20 years. While the single-dynamic degrees for GES were the lowest in the periods 2000 to 2010 and 2000 to 2020, at −1.25% and −0.13%, respectively, the lowest single-dynamic degree between 2010 and 2020 was obtained for FES, at −2.84%, suggesting that the area of GES and FES was reduced more over the 20 years (Figure 3 and Table S5).

The APS and ULS form a southwest-northeast spatial distribution pattern with negligible changes in the spatial standard deviation ellipse change in the FPE at various times (Figure 4). The overall migration trend of APS, FES, GES, and OES is insignificant, and the centers of gravity are roughly overlapping. With reduced directionality and a more dispersed geographical distribution pattern, the standard deviation ellipse's overall oblateness for IPS keeps declining. The IPS experienced a significant increase in its overall size between 2000 and 2010, showing a more visible shift in the spatial pattern of its land use, and then decreased significantly from 2010 to 2020, with more concentrated development and a large horizontal expansion tendency. The total area of GES experienced a decline from 2000 to 2010, but increased dramatically from 2010 to 2020, indicating that the policy of windbreak and sand control, as well as reverting cropland to grassland, plays a significant role. The area of AES rose from 2000 to 2010, and water conservation was successful. However, there was a considerable decline in the area from 2010 to 2020, indicating that the loss of water resources was more severe owing to a variety of circumstances. The overall change in RLS was weakly significant, with an increase in area and a more dispersed distribution from 2000 to 2010, followed by a drop in area from 2010 to 2020, indicating a higher agglomeration of rural living land as urbanization expands.

Overall, APS, FES, GES, and OES migrated southwest to northeast, while IPS, AES, ULS, and RLS migrated northeast to southwest. This is due to the phenomenon of urban development and the uneven distribution of water resources in the FPE of Inner Mongolia. In the study area, Jining District, Tumend Left Banner, and Horinger County, which are located in the southwest, have a higher gross domestic product and higher development level than other areas, so there is a tendency for IPS, AES, ULS, and RLS to migrate to the southwest, whereas the northeast region is less developed, with more unused land being used for agricultural and forestry production, meaning that APS, FES, GES, and OES show a tendency to migrate to the northeast.

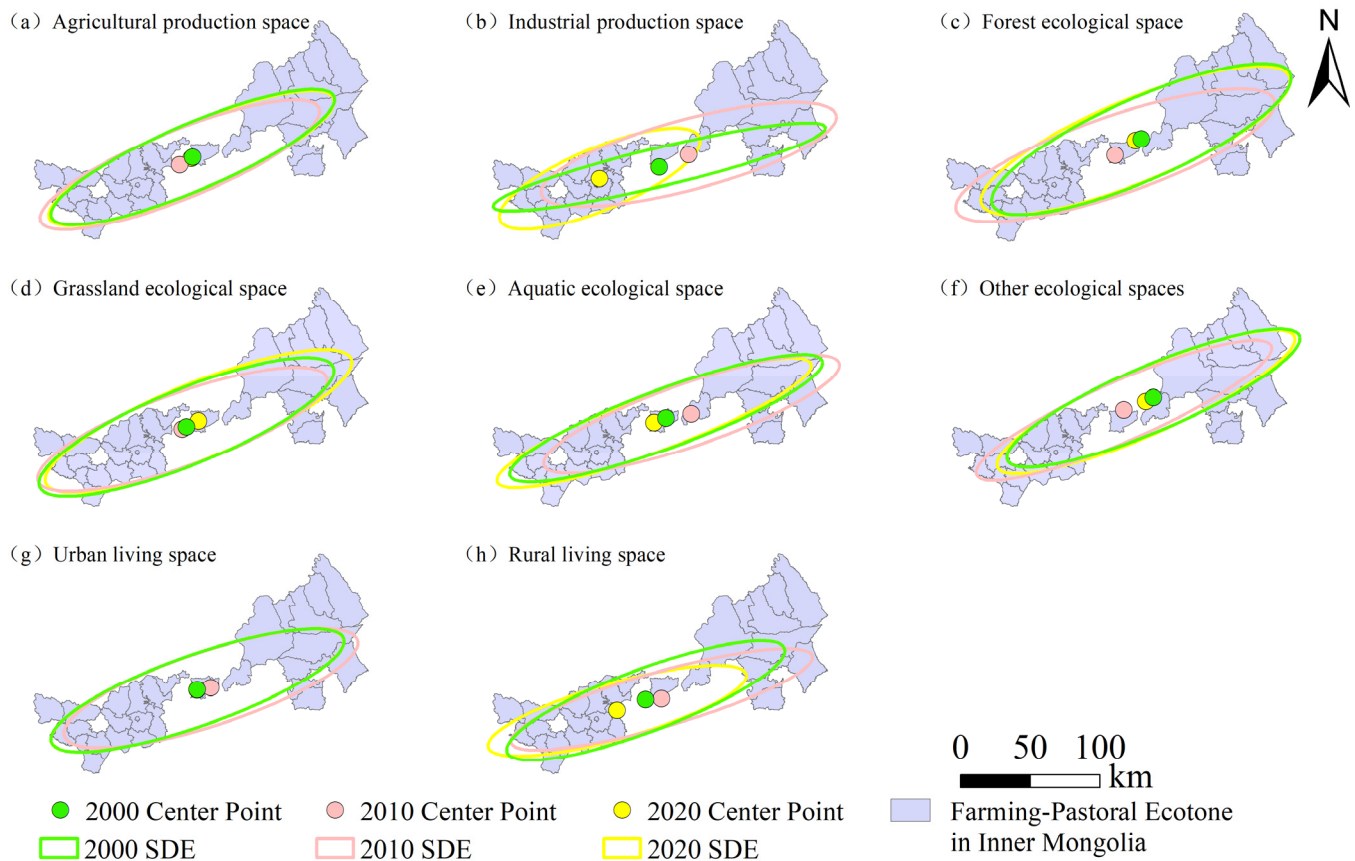


Figure 4. Elliptic variation in the spatial standard deviation of PLES in FPE in Inner Mongolia from 2000 to 2020.

3.2. PLES Spatial Conflict Characterization

There was an upward trend in the average level of spatial conflicts in the FPE in Inner Mongolia. The mean intensity of disputes rose from 0.53 to 0.56, with low and medium spatial conflicts making up over 70% of the total from 2000 to 2020. High- and very high-spatial-conflict areas are concentrated in the eastern region of the FPE located in Inner Mongolia, and the primary land type of high-spatial-conflict areas is other ecological land. Medium-spatial-conflict areas accounted for the greatest proportion of total land, while high-spatial-conflict areas accounted for the smallest proportion, from 2000 to 2020. The percentage of all three types of space conflict increased, except for very low and low spatial conflict, which declined between 2000 and 2010. The proportion of low, high, and high spatial conflicts increased while the proportion of very low and medium spatial conflicts decreased between 2010 and 2020.

In 2000, the east-central region of Ongniud Banner (O) in Chifeng City was the primary location for areas of high spatial conflict, while the central regions of Dolun County (DL) in Xilingol and the southeast region of Ar Horqin Banner (AH) in Chifeng City were the primary locations for stronger spatial conflicts. The southeastern, central, and western regions of the FPE in Inner Mongolia were the primary locations for areas of medium spatial conflicts, with the primary land types of APS and GES. Areas with very low rates of spatial conflicts were primarily found in the FES. In 2010, the east-central area of Ongniud Banner (O) in Chifeng City experienced the most intense spatial conflicts. Many spatial disputes emerged, primarily concentrated in the western half of Hexigten Banner (H) in Chifeng City, with the primary land types being AES and OES. Medium spatial conflicts were primarily found in the western, central, and southeastern regions, with APS and GES being the most common land categories. Very low and low rates of spatial conflicts

were primarily concentrated in the eastern region. The high levels of spatial conflicts are expected to increase in 2020, particularly in the east–central region of Ongniud Banner (O) in Chifeng City. The spatial conflict level decreased in the western part of Hexigten Banner (H) in Chifeng City, and high spatial conflicts increased in the western part of the FPE in Inner Mongolia, primarily concentrated in the Tumed Left Banner (L), and Tumed Right Banner (R) in Hohhot (Figure 5).

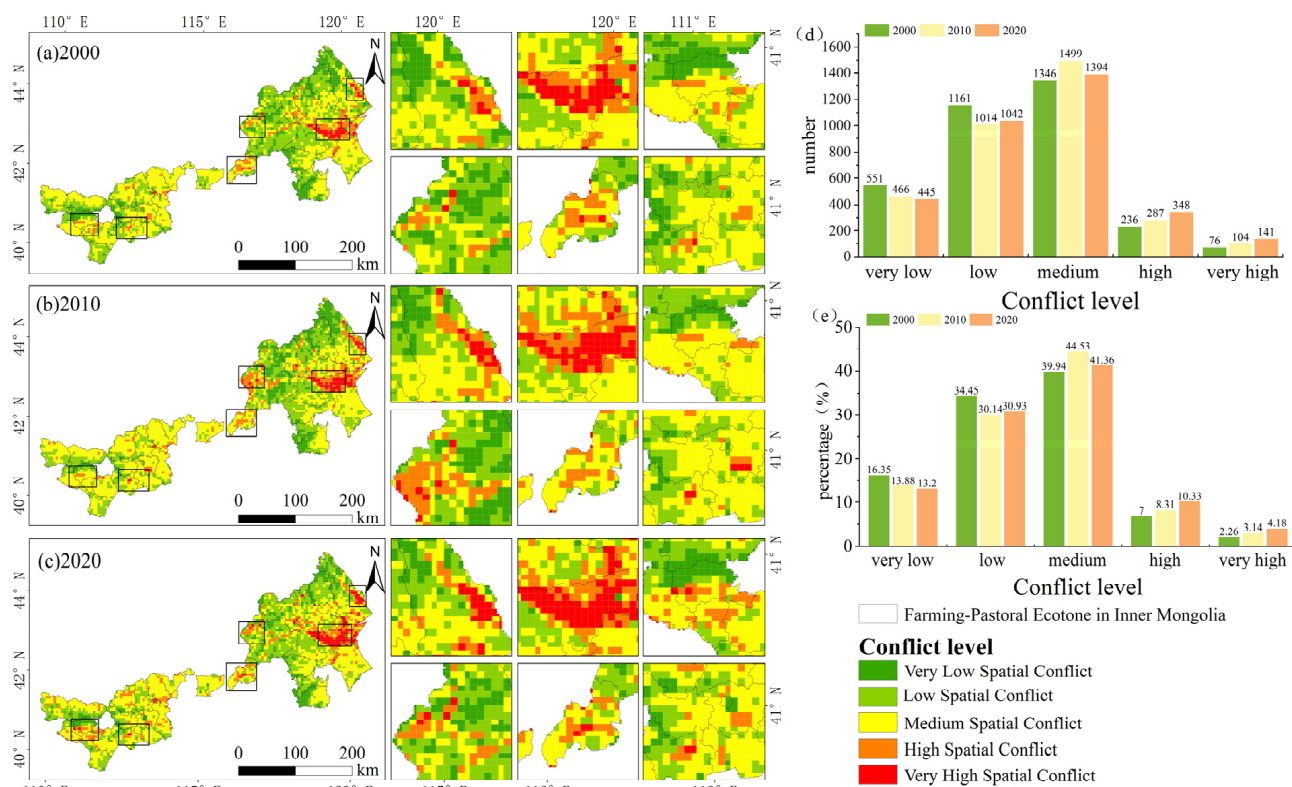


Figure 5. Characteristics of spatial conflicts of PLES in FPE in Inner Mongolia between 2000 and 2020: (a) Spatial distribution of conflict levels in 2000; (b) Spatial distribution of conflict levels in 2010; (c) Spatial distribution of conflict levels in 2020; (d) The number of spaces conflicts; (e) The proportion of spaces conflicts.

3.3. ESV's Spatio-Temporal Patterns

The ESV (104 CNY/hm²) in the FPE in Inner Mongolia was divided into five distinct segments based on the natural breaks approach: very low (0–2418.81], low (2418.81–4878.55], medium (4878.55–6921.03], high (6921.03–9530.87], and very high (9530.87–40,658.90] (Figure 6). The ESV exhibited a spatial distribution characterized by lower values in the central and western regions and higher values in the eastern regions. Ar Horqin Banner (AH), Bahrain Left Banner (BL), Hexigten Banner (H), and Ningcheng County (NC) in eastern Chifeng City are the primary locations for the ESV high-value regions situated within the FES and AES regions. Forests and aquifers have good ecological functions, such as water conservation and climate supervisors, which provide high ecosystem service value functions to the FPE in Inner Mongolia.

Very low- and low-value ESV regions were predominantly found in the central, western, and southern regions of APS and OES. The water supply in the APS's ecological supply service is negative, which is detrimental to water conservation efforts. OES consists primarily of land types such as sandy land, saline land, marshy land, and bare rocky gravel land, which have poor ecological functions and hence provide a lower ecosystem service value function for the FPE in Inner Mongolia.

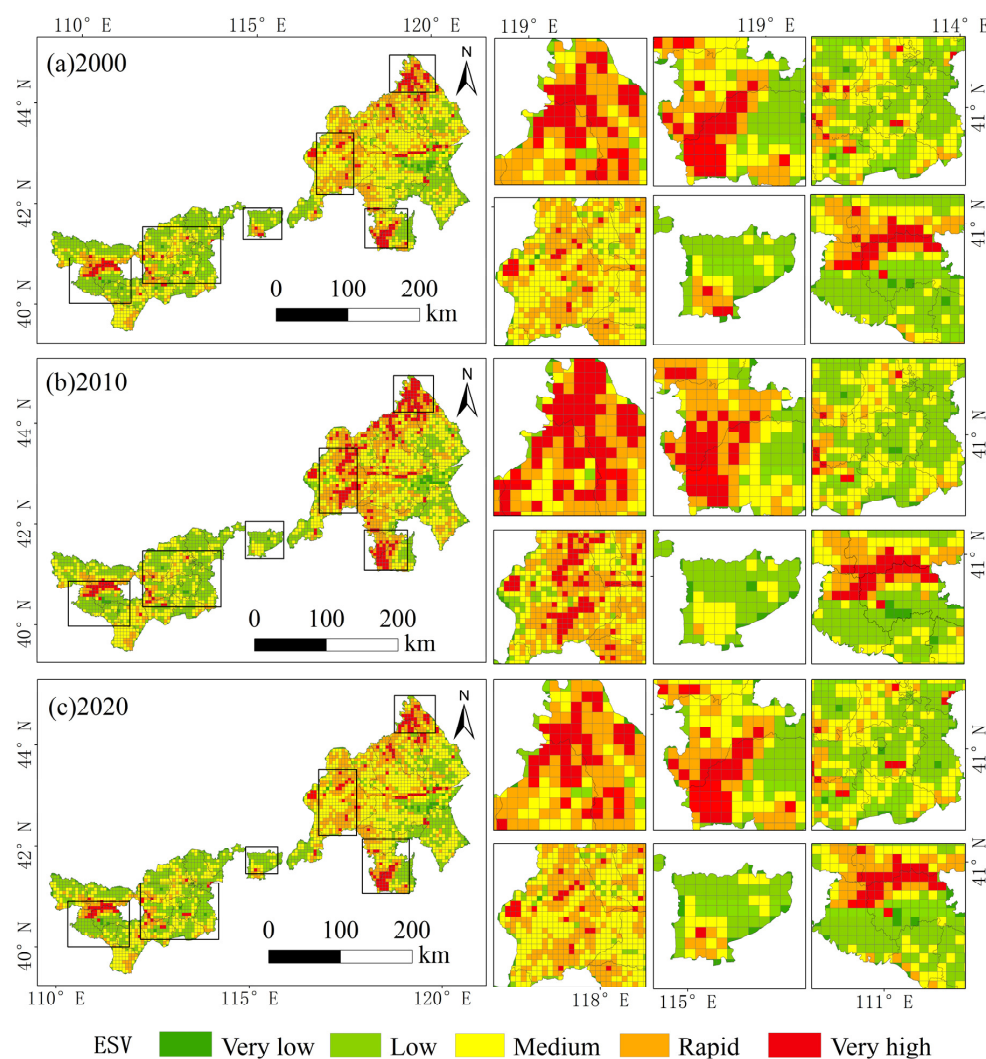


Figure 6. Spatial distribution of ESV levels of the FPE in Inner Mongolia from 2000 to 2020: (a) Spatial distribution of ESV levels in 2000; (b) Spatial distribution of ESV levels in 2010; (c) Spatial distribution of ESV levels in 2020.

Overall, the ESV in the FPE in Inner Mongolia decreased by CNY 0.45 billion over the 20 years. From 2000 to 2010, the implementation of forest land protection policies in the FPE in Inner Mongolia improved, with an increase in the area of forested space in the western, northeastern, and other mountainous areas at higher elevations, increasing the ESV of the FES. Between 2000 and 2020, regulation services accounted for the largest share of the ESV, whereas cultural services represented the smallest proportion. Hydrological regulation had the highest share of the value of secondary individual ecosystem services, while water provisioning had the lowest proportion, with the combined proportion of regulation and ecological functions accounting for 90% of the ESV.

The proportion of climate regulation of the FPE in Inner Mongolia increased from 23% to 24%, with a value increase of CNY 1.775 billion from 2000 to 2010. However, the proportion decreased from 24% to 23%, with a value decrease of CNY 1.832 billion, which represents a decrease of CNY 0.057 billion from 2010 to 2020. Grassland ecological land was the largest contributor to the region's ESV. Its proportion of the ESV dropped from 57.82% in 2000 to 49.05% in 2010 but increased to 57.09% in 2020, reflecting a 0.73% decrease from 2000. The transition from GES to FES resulted in a decline in ESV for GES in 2010. The FPE in Inner Mongolia had the highest proportion of GES in their land use categories, at 48%, 42%, and 47%, respectively, throughout this period (Figure 7).

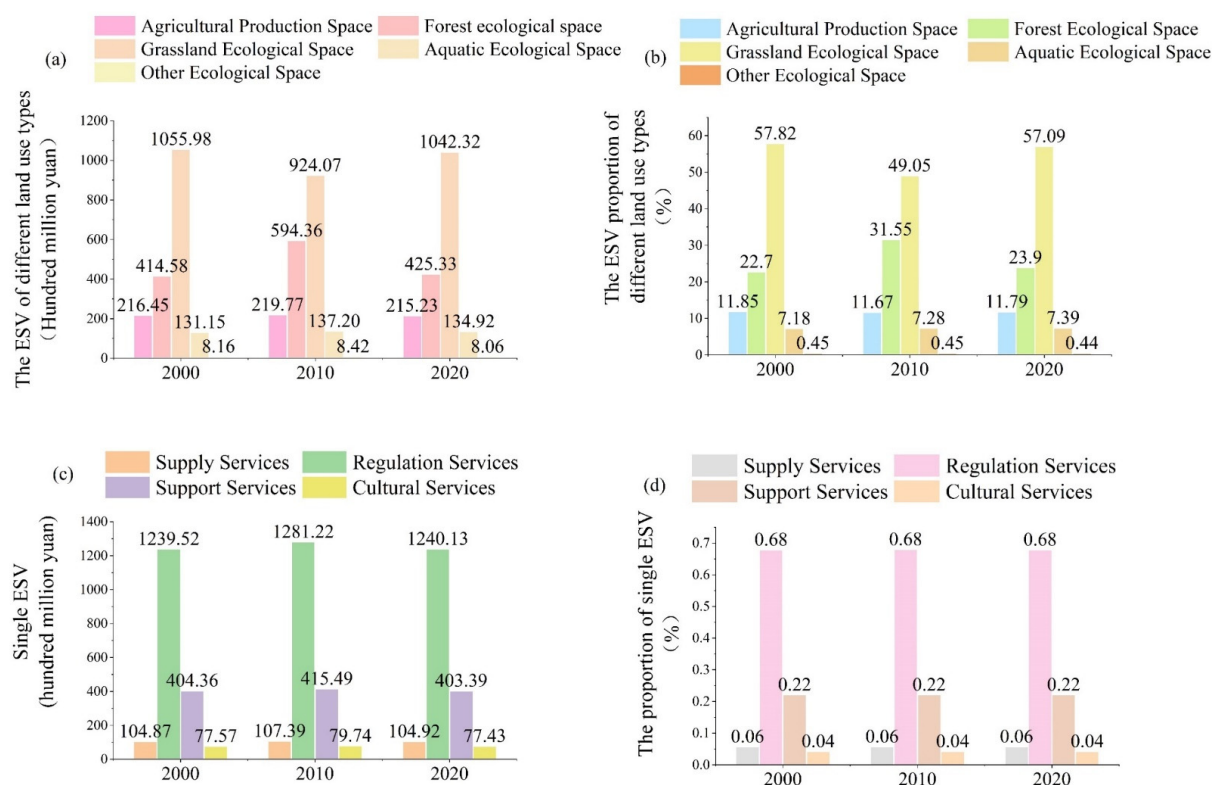


Figure 7. ESV analysis in the FPE in Inner Mongolia from 2000 to 2020: (a) The ESV of different land use types; (b) The ESV proportion of different land use types; (c) Single ESV; (d) The proportion of single ESV.

3.4. Effects of PLES Spatial Conflicts on ESV

The bivariate global Moran's I values of the FPE in Inner Mongolia in 2000, 2010, and 2020 were -0.196 , -0.293 , and -0.163 , respectively. An inverse relationship was observed between ESV and PLES spatial conflicts, suggesting that higher levels of PLES spatial conflicts in the study area resulted in a lower ESV, with the strength of this correlation demonstrating an upward trend.

High-value–high-conflict zones exhibited core aggregation and a linear distribution; these were primarily found along the eastern edges of the Ongniud Banner (O), Bahrain Right Banner (BR), and Hexigten Banner (H), as well as the watershed ecological land in Duolun County (DL) in the center and Liangcheng County (LC) and Qahar Right Rear Banner (QR) in the west. This suggests that the aquatic ecological land in the area has a high level of ESV but also a high ecological risk. The distribution of high-value–high-conflict clusters increased in central Duolun County (DL) from 2010 to 2020, while their distribution along the eastern Hexigten Banner (H) and western Qahar Right Front Banner (F) and Shangdu County (SD) showed a decreasing trend. From 2000 to 2010, there was a notable increase in high value–high-conflict clusters, primarily in the eastern Bairin Right Banner (BR) and Hexigten Banner (H).

Low-value–low-conflict zones were primarily found along the boundaries of the FPE in Inner Mongolia, which consists primarily of OES and APS with a low ESV. Because these areas are on the outskirts of urban development, the intensity of land use is low, resulting in a low spatial conflict intensity and creating a low-value–low-conflict zone. During 2000 and 2010, the spread of low-value–low-conflict zones grew dramatically in the eastern Bairin Left Banner (BL) and Linxi County (LX), while between 2010 and 2020, it climbed greatly in western Guyang County (GY).

The low-value–high-conflict zones were primarily concentrated in Ongniud Banner (O) in the east and Duolun County (DL) in the center, with a scattered distribution in the west, where the land use type is primarily OES, which has a low ESV and high ecological risk due to its fragile ecological environment. The distribution of low-value–high-conflict zones in the eastern Hexigten Banner (H) rose dramatically between 2000 and 2010, indicating a decade-long imbalance in ecological and environmental protection in the region.

High-value–low-conflict zones are mainly clustered in a piecemeal manner, distributed in the northeastern Ar Horqin Banner (AH), Bairin Left Banner (BR), Hexigten Banner (H), the southeastern Harqin Banner (HQ), and Ningcheng County (NC), and in the western Wuchuan County (WC), Guyang County (GY), and the borders of Tumend Left Banner (L), and Tumend Right Banner (R). Its ecological environment is in a relatively balanced state, exhibiting the spatial characteristics of a high-value–low-conflict region. The region is primarily an FES, with high vegetation cover, rich ecological resources, better environmental quality, and little influence from human activities (Figure 8).

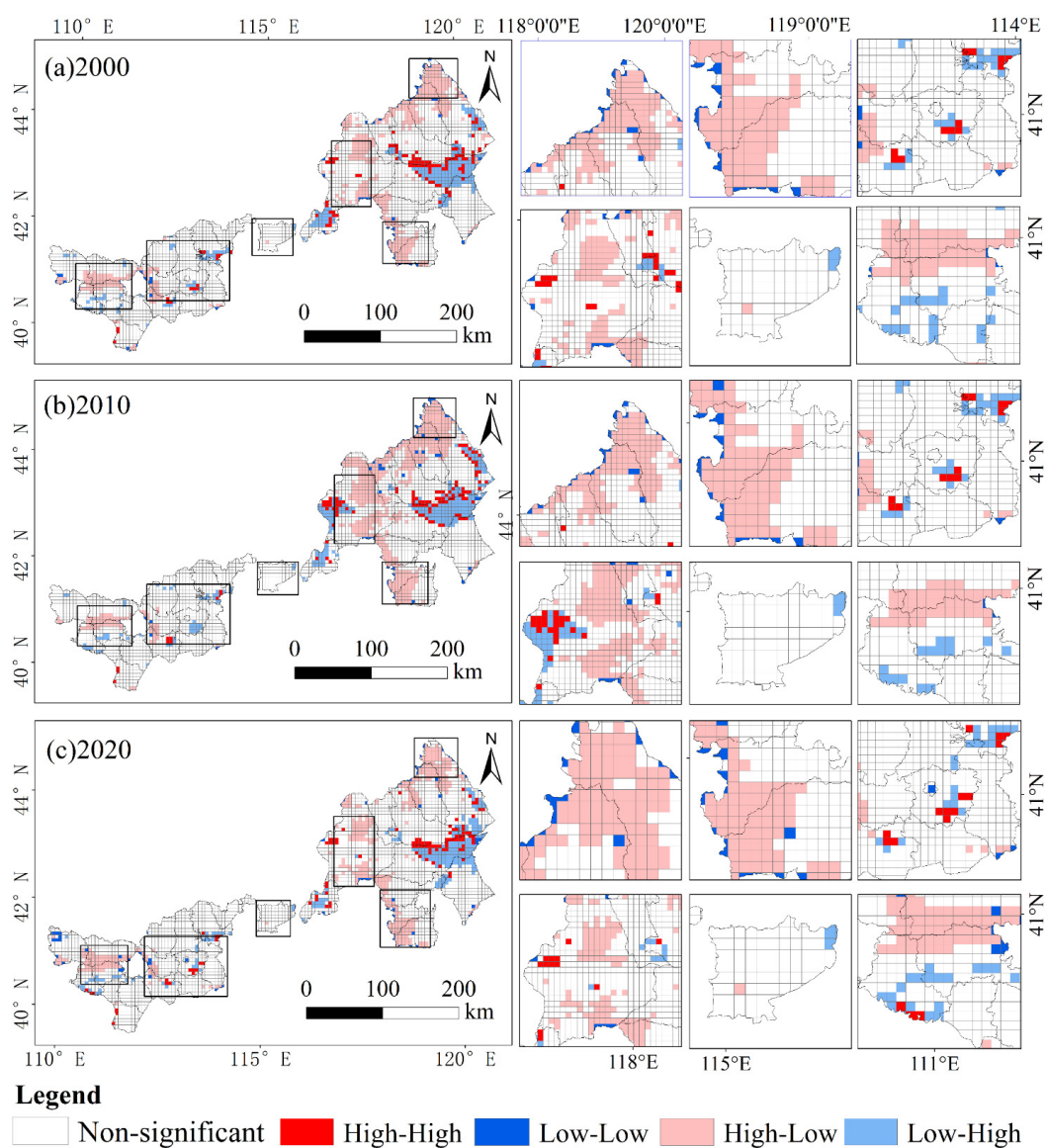


Figure 8. Lisa map of the local autocorrelation of FPE in Inner Mongolia from 2000 to 2020: (a) Lisa map of the local autocorrelation in 2000; (b) Lisa map of the local autocorrelation in 2010; (c) Lisa map of the local autocorrelation in 2020.

4. Discussion

4.1. PLES Conflict Evolution Characterization

OES and AES are the most prevalent space classes, with high and very high spatial conflicts. OES includes sand, gobi, saline, and alkaline land, and the aquatic ecological land includes rivers, lakes, and mudflats.

Numerous factors influenced the changes in the aquatic area of the FPE in Inner Mongolia. The climate of the FPE in Inner Mongolia has been dry and evaporative in recent years; this, along with the standard deviation ellipse, caused the AES area to decrease. Migration to the west increased the degree of conflict in the east. Climate change increased the use of irrigation water and coal mining, among other things, resulting in fewer lakes in Inner Mongolia; some areas of land were desertified and the sand problem has grown worse [39,40]. These regions exhibit significant spatial vulnerability and limited stability, so the composite index of spatial conflict shows high and very high levels of spatial conflict. The majority of medium spatial conflicts were found in APS, including drylands and paddy fields.

In the early period, stability was low and the composite index of spatial conflict showed a medium level because of the growth of agricultural reclamation areas impacted by human activities, extensive planting, and rough cultivation, which cause soil fertility declines, severe wind erosion, and sands in arable land [41]. Therefore, the spatial conflict index for these space classes obtained a medium level in the results. FES and GES are the two most common types of area with very low and low spatial conflicts. China's strategy of converting farmland back to forest and grassland [42,43] and the Ministry of Agriculture's recent round of reforms to grassland rights [44] are responsible for the expansion of grassland and forest areas, as well as the improvement in grassland's ecological conditions. Because of the area's comparatively flat topography and uniform vegetation, the soil is shielded from wind and water erosion and serves a crucial water conservation function [45]. Partially located in a nature reserve with little human interference, it has a high degree of stability and low complexity, with a low level of conflict.

4.2. PLES Spatial Conflicts and ESV Correlation Analysis

A distinct negative spatial relationship was observed between ESV and PLES spatial conflicts, suggesting that the region's ecological conditions were suboptimal throughout the study period. The ESV in the FPE in Inner Mongolia showed an overall decreasing trend from 2000 to 2020, while the intensity of spatial conflicts showed an increasing trend. The FPE in Inner Mongolia is a complex ecosystem in which production, living, and ES interact with each other and have an impact on the regional ecosystem. Existing studies indicate that the main factor influencing changes in ESV is land use changes [46–48]. Between 2000 and 2010, the FPE in Inner Mongolia experienced a notable enhancement in regional ecological quality, driven by the continuous implementation of ecological initiatives like the "Three North" shelterbelt program and farmland-to-forest/grassland conversion projects [49]. This period also contributed to a significant increase in ESV and a decrease in the intensity of spatial conflicts, with the high-value–low-conflict areas in the eastern part of the FPE growing significantly. FES and APS exhibited a declining tendency between 2010 and 2020, while GES and IPS showed an increasing trend due to growing urbanization and economic development [29]. This resulted in a decrease in ESV during this period, from CNY 188.383 billion in 2010 to CNY 182.587 billion in 2020, a decrease of CNY 0.45 million from the beginning of the study. Forest land, cropland, and other ecological land make up the majority of the eastern portion of the FPE in Inner Mongolia. The area of mixed cropland and forest land is larger, and the support and regulation services offered are more significant. However, because of the proximity of urban construction land, this area is

more impacted by human activity, resulting in a higher pattern of spatial conflicts and greater ecological risks. The ESV of the FPE in Inner Mongolia generally shows a decreasing trend while the increase in human activities also increases the intensity of regional spatial conflicts. The PS and LS of the FPE in Inner Mongolia have been expanding, crowding out the ES due to regional economic development and increasing urbanization.

4.3. Innovations and Limitations

The FPE is a dynamic area that evolved throughout time in response to a particular historical and humanistic context, located between farming and pastoral areas and characterized by a distinct landscape ecology. However, environmental issues are substantial as a result of climate change and human activity.

The ecosystem equilibrium of FPE in Inner Mongolia served as the foundation for the stabilization of China's northern ecological security barrier. Using land use data from 2000 to 2020, we analyzed the land use changes in the FPE in Inner Mongolia from the standpoint of PLES. We studied the spatio-temporal evolution and correlation of ESV and spatial conflicts in the region using a $7\text{ km} \times 7\text{ km}$ grid. Furthermore, this provided a scientific basis for balancing development and ecological conservation within the Inner Mongolia FPE. Urbanization is causing living and producing spaces to encroach on ES in the Inner Mongolia FPE. The intensity of spatial conflicts in the region increased over the research period, with OES in the east experiencing more intense spatial conflicts. High values were generally found in the FES and AES, while regional ESV was low in the center and west and high in the east. The area of high ESV increased significantly in 2010 as a result of the expansion of forest land, and the high-value-low-conflict areas were primarily found in the FES when looking at the association between ESV and spatial conflict. The ecosystem will unavoidably be impacted by rapid urban expansion; however, the preservation of the natural environment should be fully taken into account while developing land. The future development of the FPE in Inner Mongolia should follow the ecological priority plan and attempt to prevent PS and LS from encroaching on ES. Meanwhile, we should maintain the policy of converting cropland back to forests and grasslands, regulate the expansion speed of construction land, and customize urbanization development patterns to local contexts, alleviating spatial land use tensions. For example, in terms of farming in the FPE, irrigated agriculture and conservation agriculture should be vigorously promoted, and advanced production technology should be introduced while strengthening the construction of windbreak and sand-fixing forests, in order to improve agricultural production efficiency and farmland windbreak and soil-fixing capacity. To improve the ecological barrier function of the cross-border agricultural and animal husbandry zone, when constructing artificial protection forests, the region's native vegetation should be used as a guide and a mix of trees and shrubs should be planted, while ecological industries should be developed in accordance with local conditions. The conflict intensity of the PLES was only examined in this study from the perspectives of complexity, vulnerability, and stability. In the future, social and economic factors can be fully taken into account when building the spatial conflict measurement model, and further research on grid-scale refinement may be performed. The ESV methodology used in the study evaluates the economic value of ecosystem services. Four primary indicators and eleven supplementary indicators of supply, regulation, ecological functions, and cultural services were chosen as the indicators for the ecosystem services valuation. The existing approaches evaluate supply, regulation, ecological functions, and cultural services independently, neglecting their synergistic or conflicting linkages, which resulted in less comprehensive valuation conclusions. Meanwhile, the spatial heterogeneity of socioeconomic factors, as well as other natural elements (e.g., biodiversity and climate change), has an impact on ESV, and

such spatial heterogeneity should be fully considered in the future through implementing dynamic economic value coefficients and enriching the quantification of ESV. Future studies might explore the factors that influence spatial variations in PLES.

5. Conclusions

This study established a spatial conflict index model of PLES, quantitatively assessed the ESV in the FPE in Inner Mongolia, and revealed the impact of the evolution of the PLES spatial conflict on the ESV based on the grid scale. The main results and recommendations are as follows:

- The extent of ES declined, whereas LS experienced a significant expansion. The IPS purposes throughout all periods had the highest single-dynamic degrees attitude, while the GES and FES had the lowest single-dynamic degrees attitude. The highest single-dynamic degrees attitude of LS was 0.44%, with the largest increase in the area being 369.13 km², while the lowest single-dynamic degrees attitude of ES was −0.03%, with a decrease in the area of 545.52 km². Over the past 20 years, there were significant decreases in the grassland and FES.
- APS, FES, GES, and OES migrated southwest to northeast, while IPS, AES, ULS, and RLS migrated northeast to southwest. With the development of urbanization, spatial conflicts have become more serious, and the uncoordinated spatial development among PS, ES, and LS has become more obvious, with other ecological land types predominantly occupying high-value conflict zones and being concentrated in the eastern region.
- The spatial distribution of ESV exhibits a pattern characterized by lower values in the central and western regions, while higher values are observed in the eastern regions. Regulation services had the highest proportion of the ESV, while cultural services had the lowest proportion. Climate regulation in the regulating service is based on the trend of transferring the ecological land in forest and water areas, which showed an initial rise followed by a subsequent decline. ESV is negatively correlated with spatial conflict, and the level of spatial correlation exhibits an initial upward trend followed by a downward shift.

This study provides statistical support and policy recommendations for developing a regional spatial development plan and balancing economic development and environmental conservation in Inner Mongolia in the future. It also offers research concepts and strategies for other similar ecological transition zones.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/land14030447/s1>, Table S1: Full names and abbreviations of 29 counties (banners) in the FPE in Inner Mongolia; Table S2: Classification system of PLES in the FPE in Inner Mongolia; Table S3: Equivalent factors of ecosystem service value per unit area; Table S4: Equivalent factors of ecosystem service value per unit area of FPE in Inner Mongolia; Table S5: The single dynamic degree of different land use type.

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Abbreviations

PLES	Production–living–ecological space
FPE	Farming–pastoral ecotone
ESV	Ecosystem service value
PS	Production space
LS	Living space
ES	Ecological space
APS	Agricultural production space
IPS	Industrial production space
FES	Forest ecological space
GES	Grassland ecological space
AES	Aquatic ecological space
OES	Other ecological space
ULS	Urban living space
RLS	Rural living space

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