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Evaluation of Ecosystem Service Change Patterns in a Mining-Based City: A Case Study of Wu'an City

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Abstract: To coordinate the economy and environment in mining cities, it is critical to understand the ecological effects of land use/cover change (LUCC). Therefore, we selected a typical mining city to analyze LUCC-driven ecosystem service changes. In this study, we first used the equivalent factor method to calculate the ecosystem services valuation (ESV) in Wu'an and verified the rationality of the ESV coefficient through the sensitivity index. Secondly, ArcGIS was used to analyze the spatial change of ecosystem service value and explore the reasons for the change. Finally, the spatial autocorrelation index was calculated to analyze the spatial aggregation characteristics of ESV. The results showed that (1) between 2009 and 2018, the total value of ecosystem services decreased by USD 7.41 million, mainly due to the conversion of cropland to construction land. (2) The individual ecosystem services that contributed the most were waste disposal, water conservation, and soil conservation. The pollution caused by the development of mining has reduced the value of the waste disposal function, and the reduction in water body area has been the main factor limiting the water conservation function. (3) The areas with the most significant changes in ecosystem services were concentrated in the east-north direction, where mining resources were widely distributed, and near the central city. Furthermore, there were relatively small losses in the north-west direction, which was related to the protection of ecological resources influenced by topographical factors and less anthropogenic disturbance. (4) The value of ecosystem services and their dynamics exhibited obvious spatial autocorrelation and high-low value (HL) clustering in Wu'an. The high-value and low-value areas dissolved and penetrated each other, and the low-high value (LH) clustering and HL clustering were scattered. The high-value areas were mostly shown in strips, as they were the main locations of water bodies. This study is crucial for mining cities to maintain spatial stability and sustainable development, and the results provide a scientific basis for land use management decision makers to regulate land more precisely.

Keywords: ecosystem services value; spatiotemporal change; spatial autocorrelation analysis; mining city

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1. Introduction

Sustainable development practice is increasingly being valued worldwide because it supports economic development while considering the ecosystem protection necessary for people long-term survival [1]. Environmental Impact Assessment (EIA) is a policy tool for integrated decision making on the environment and development and plays a unique role in building sustainable societies [2]. In areas where mineral resources are developed, changes in land use commonly lead to habitat fragmentation, land pollution, and reduced ecosystem purification capacity. In mineral development zones, land use change/cover

(LUCC) commonly leads to habitat fragmentation, land pollution, and reduced ecosystem purification capacity. This will inevitably lead to changes in the service value of the land ecosystem. The change of ecological service value (ESV) driven by LUCC can be used as a comprehensive indicator to quantify the impact of LUCC on the ecological environment and quantitatively interpret the response of its ecological environment quality to LUCC. Therefore, it is essential to carry out ecological environmental impact assessments on mining areas, and forward-looking measures can be proposed according to the actual situation to effectively control or reduce pollution and damage.

"Ecosystem services" (ES) are the benefits that humans directly or indirectly receive from natural ecosystems, that is, the natural environmental conditions and functions that ecosystems create for humans [3–6]. ES links natural and human social systems, from which humans derive direct or indirect benefits that support survival and development, including provisioning services, regulating services, supporting services and cultural services [6], and they are essential for the sustainable development of human society [7]. Ecosystem services valuation (ESV) is an economic process that assigns economic value to an ecosystem and its ecosystem services. As a comprehensive index to measure regional environmental impact assessment, ESV is difficult to be applied effectively in practice, but it can still provide useful reference for decision makers [8]. The ESV has been assessed with the goal of promoting the sustainable utilization of natural resources. Costanza et al. provided a new research method for ESV, realizing the monetary expression of ESV [4]. Since then, ESV has been extensively studied globally. Based on the evaluation model proposed by Costanza, Xie et al. formulated the ESV equivalent table per unit area of different terrestrial ecosystems in China and has been revising it [4,9,10]. At present, a more subdivided evaluation of ecosystem types and service function types has been realized, and it is widely used in China [8,11]. In recent years, many studies have shown that changes in ESV are often driven by both land use/land cover change (LUCC) and climate change [12,13]. The production, distribution, and quality of ecosystems change under the effects of climate change, with climatic factors directly changing temperature and precipitation levels [14], which will further affect the value we derive from the ecosystem services [15–17]. LUCC factors are vital drivers that alter terrestrial ecosystems [6,18], and many studies have taken LUCC-driven ESV changes as an important quantitative indicator of environmental effects [19–22].

LUCC factors play a decisive role in maintaining the type and intensity of ecosystem services, can cause changes in the types, scales and spatial patterns [23], and can reflect the basic processes of the human–environment system. However, land use types differ greatly in their abilities to provide various ecosystem services [22], with positive and negative influences on ESV. Some scholars have focused on certain regions, watersheds [24–27], plains [28], mountains [29,30], and coastal zones [18], and some have conducted further subdivision and assessed spatiotemporal changes in ecosystem services in different regions [7,31].

These scholars have analyzed the spatial pattern of ESV using many spatial analysis methods. However, there is still a lack of research on the spatial aggregation pattern and spatial distribution changes of ESV in mining cities. Mining city is a specific area formed after the mining industry and its related social economy developed to a certain scale [32]. Mining city has caused serious damage to the regional environment in the process of mining resources exploitation. With the exhaustion of mineral resources, the ecological environment problems, such as ground subsidence of mined-out areas, a large amount of land occupied by garbage, and environmental pollution appear successively, which are important resistance factors of sustainable land use in mining cities [33].

Mining activities interfere with the change in land use types in mining cities, and it is beneficial to understand the direction of regional ecosystem services by quantifying and analyzing ESV. Identifying spatial variation in ESV by "hotspots" is important for ecosystem services [34–37] and can be effective in integrating ecosystem services into planning or current conservation plans [38]. Therefore, it is beneficial and meaningful to systematically explore ESV and analyze the LUCC factors influencing changes in ESV to achieve sustainable development and provide scientific guidance for policymakers. Wu'an city was selected as the study area because it is a typical area in the mining resource-based zone of China. Its rapid development has been accompanied by a heavy drain of mining resources, causing LUCC and affecting ecological quality. The main objectives of this study were to assess the ESV of Wu'an city and analyze the spatial distribution pattern and changes in ESV resulting from the impacts of LUCC. This study provides important support for land use management to promote sustainable development in mining cities.

2. Materials and Methods

2.1. Study Area and Data Sources

Wu'an city is located in the southern part of Hebei Province in China (Figure 1), has a warm temperate continental monsoon climate, and covers 1818.05 km^2. The local topography is high in the west and low in the east, with a hilly area only in the center with less sublime mountains, forming a small local plain. Wu'an city is a typical mining city with mining activities, and the mining resources have obvious regional distribution characteristics. Wu'an urban areas have iron ore resources to the north and south, coal resources to the east and west, and to the west and south, mainly limestone for cement, distributed around the railway. The key industries in the city are mineral mining and processing. The coal reserves in Wu'an are estimated at 2.3 billion metric tons and they produce 36 million metric tons of raw coal annually. The gross domestic product was USD 10.21 billion in 2018, of which the added value of secondary industry accounted for 58.48%; however, these industries also cause ecological destruction, such as ground collapse and fractures.

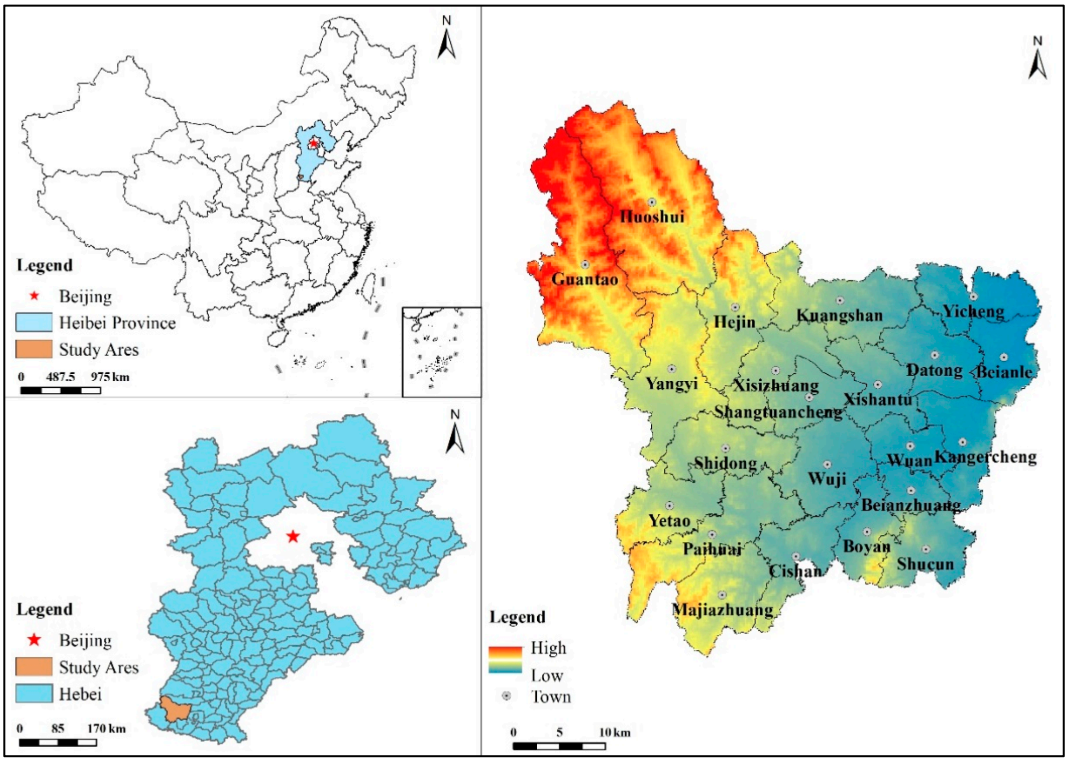

Figure 1. Location of the study area: Wu'an, China.

The LUCC data were obtained from a national land use survey by the Wu'an Land Resources Bureau, and this study used three periods of data from 2009, 2014, and 2018 for ESV assessment and spatial change analysis. According to the "technical regulation of the third nationwide land survey", the land uses were divided into six primary types: cropland, orchard, forestland, grassland, water bodies, built-up land, and unused land. The quantitative relationship in Table 1 and the spatial distribution was shown in Figure 2.

Table 1. Land use change of Wu'an City from 2009 to 2018.

Year	Land Use/Cover (ha)						
	Cropland	Orchard	Forestland	Grassland	Water Bodies	Unused Land	Built Up Land
2009	63,269.13	3568.61	22,926.40	23,348.43	7317.00	39,034.55	22,319.62
2014	63,072.62	3485.04	22,817.37	23,157.39	7138.05	39,199.22	22,914.07
2018	62,613.19	3329.57	22,761.37	23,017.83	6969.32	38,939.32	24,151.95

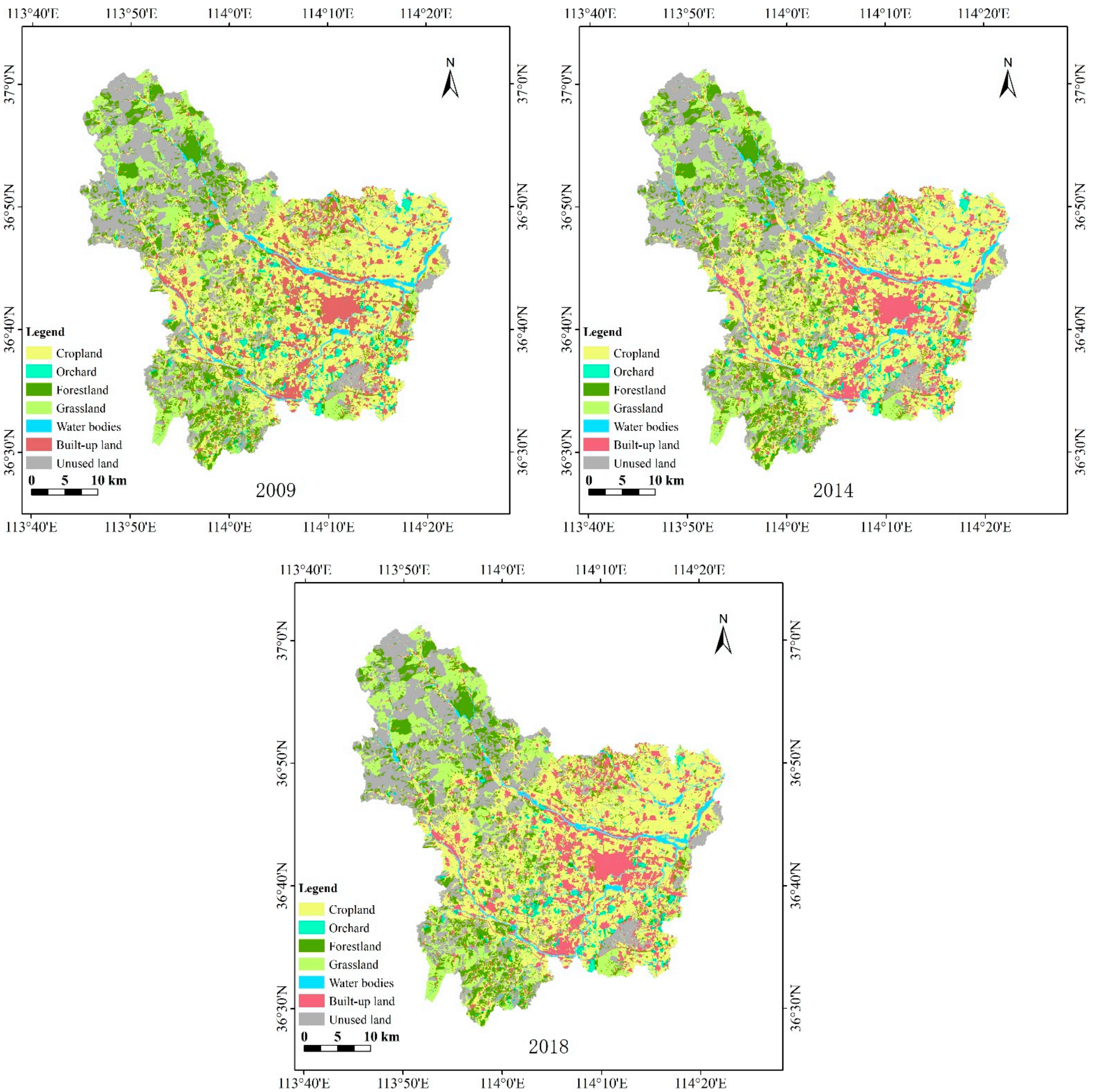

Figure 2. The spatial distribution maps of land-use types during 2009–2018.

A 500 m × 500 m fishing net is used to intersect with the study administrative area to form evaluation units. The digital elevation model (DEM) and slope (generated by the DEM) were downloaded from Geospatial Data Cloud (http://www.gscloud.cn/, accessed on 5 December 2021). Grain yield and price data were derived from the Wu'an City Economic Year Book (2013–2018).

2.2. Assessment of Ecosystem Services

In the ecosystem services estimation process, the equivalent coefficients were used for each land use type according to previous research [4,31,39–41] and modified after considering the local situation in Wu'an.

The standard equivalence factor for ecosystem services was defined as the economic value of the annual natural grain output per unit rea of cropland [10]. Refer to the method of Xiao et al. (2003), in which the economic value provided by the natural ecosystem without human input is 1/7 of the economic value of the food production service provided by the existing unit area of farmland [37]. We mainly use the average net profit per unit area of two major food crops (wheat and corn) from 2014 to 2018 as the standard equivalent economic value, with a value of USD 276.14.

The ESV per unit area of construction land was not estimated by Costanza [4,42]; therefore, we assume a null value of ecosystem services for built up land. The ESV of grassland was quoted from Xie et al. (2001) in the warm temperate zone of North China [43]. The average value of forestland and grassland was taken for the orchard. Finally, the ESV per unit area was obtained for cropland, forestland, orchard, grassland, water bodies, and unused land (Table 2). The ESV was calculated using the following equations (Equations (1) and (2)):

$$\mathrm{VC}_{ij} = D \times \mathrm{VC}_{ij} \tag{1}$$

$$\mathrm{ESV} = \sum(\mathrm{VC}_{ij} \times P_j) \tag{2}$$

Table 2. The equivalent coefficient for the ESV of six land use types in Wu'an.

Ecosystem Services		**Equivalent Coefficient for ESV (USD·ha^{-1}·a^{-1})**					
First Category	**Second Category**	**Cropland**	**Orchard**	**Forest-Land**	**Grassland**	**Water Bodies**	**Unused Land**
Provisioning services	FP	267.14	74.03	26.71	121.34	26.71	2.67
	RM	26.71	347.65	694.56	0.75	2.67	0.00
Regulating services	GR	237.75	474.19	934.98	13.40	0.00	5.34
	CR	133.57	377.23	721.27	33.19	122.88	0.00
	WC	160.28	444.07	854.84	33.31	5444.25	8.01
	WD	438.10	267.83	349.95	185.71	4856.55	82.81
Supporting services	SC	390.02	547.65	1041.83	53.47	2.67	5.34
	BC	189.67	479.32	870.87	87.78	665.17	5.34
Cultural services	RC	2.67	178.04	341.94	14.15	1159.37	2.67
Total		1845.92	3190.02	5836.94	543.11	12,280.28	112.20

Note: FP, RM, GR, CR, WC, WD, SC, BC and RC refer to food production, raw material production, gas regulation, climate regulation, water conservation, waste disposal, soil conservation, biodiversity conservation, and recreation and culture, respectively.

In these expressions, VC_{ij} (USD ha^{-1}) denotes the value coefficient for land use type j and ecosystem service function i. D is the value of ecosystem services with a standard equivalent factor. D was 276.14 USD ha^{-1}. VC_{ij} is the adjusted ecosystem service equivalent value of the ecosystem service function i of land use type j per unit area (according to literature). ESV is the estimated ecosystem service value. P_j is the area (in ha) of land use type j.

2.3. Coefficient of Sensitivity Analysis

Due to the uncertainties about the veracity of Costanza et al.'s value coefficients, this article introduces of sensitivity analysis model to explore the application of ESV coefficients in study. The coefficient of sensitivity (CS) reflects the change of ecosystem service value over time and the degree of dependence on the value coefficient [44].

The traditional CS calculation is to adjust the equivalent factor of each type of land use by 50% to measure the change of the total ecosystem service value [44,45]. If CS is greater than one, the estimated ESV is considered elastic relative to that coefficient; otherwise, it is considered to be inelastic, and the result is reliable even if the value coefficient has relatively low accuracy. The greater the percentage change in the ESV relative to the percentage change in the valuation coefficient is, the more critical it is to have an accurate ecosystem value coefficient [46]. The formula is as follows (Equation (3)):

$$CS = \frac{\left(ESV_j - ESV_i\right)/ESV_i}{\left(VC_{j,k} - VC_{i,k}\right)/VC_{i,k}} \tag{3}$$

where CS refers to the coefficient of sensitivity, ESV_i and ESV_j are the initial and adjusted total value estimated of ecosystem services, respectively, and $VC_{j,k}$ and $VC_{i,k}$ are the initial and adjusted value coefficients for land use type k, respectively.

Afterwards, Aschonitis et al. simplified the result as follows (Equation (4)) and argued that the CS values are used to rank the importance of each land use class, rather than to assess the robustness of our analysis [47,48].

$$CS = \frac{VC_{i,k} \cdot A_k}{ESV_i} \tag{4}$$

2.4. Spatial Changes in Different Directions

To explore the spatial variation in ESV in different directions from of the urban area of Wu'an, we first used ArcGIS to overlay land use data and divided Wu'an area into 8 equal-angle 45° sectors to obtain ESV in eight directions [49]. The division was (in anticlockwise order): east-northeast (ENE) or 0°–45°, north-north-east (NNE) or 45°–90°, north-northwest (NNW) or 90°–135°, west-northwest (WNW) or 135°–180°, west-southwest (WSW) or 180°–225°, south-southwest (SSW) or 225°–270°, south-southeast (SSE) or 270°–315°, east-southeast (ESE) or 315° to 360°, quadrants I, II, III, IV, V, VI, VII, and VIII, respectively and the percentage of area is 34.32%, 14.46%, 8.21%, 5.90%, 2.91%, 5.47%, 9.55%, and 19.18%, respectively. Then, we calculated the ESV and analyzed the causes of changes in the eight directions.

2.5. Spatial Autocorrelation Analysis

Spatial autocorrelation analysis is a measure of whether the distribution of spatial variables is clustered, including global spatial autocorrelation and local spatial autocorrelation. Global spatial autocorrelation is a description of the spatial characteristics of geographic element attribute values across the region [50]. The global Moran's I is considered to be the widely used global autocorrelation statistic [51]. This study reveals the general trend of the spatial correlation of ESVs in Wu'an by calculating the global Moran's I. The formula is as follows:

$$I = \frac{n\sum_{i=1}^{n}\sum_{j\neq i}^{n} w_{ij}\left(x_i - \overline{x}\right)\left(x_j - \overline{x}\right)}{\left(\Sigma_{i=1}^{n}\Sigma_{j\neq 1}^{n} w_{ij}\right)\sum_{i=1}^{n}\left(x_j - \overline{x}\right)^2} \tag{5}$$

where n is the number of space units; x_i is the attribute value of region i; x_j is the attribute value of region j; $\overline{x}$ is the mean of the attribute values; and w_{ij} is the spatial weight matrix, which represents the potential forces of interaction between spatial units, generally determined by spatial proximity and spatial distance [50], and the neighborhood takes the w_{ij} value of 1; otherwise, it is 0 by spatial proximity [52]. At a given significance level, if Moran's $I \in (-1,1)$ is significantly positive, it indicates that regions with similar attributes are spatially significantly clustered; in contrast, if Moran's I is significantly negative, it indicates that regions have significant spatial differences in attribute values from surrounding regions.

Furthermore, the results are generally tested statistically using z-test, and the formula is as follows:

$$Z(I) = \frac{I - E(I)}{S(I)} \quad (6)$$

where $Z(I)$ is used to test for spatial autocorrelation, $E(I)$ is the expectation of the autocorrelation of the observed variable, and $S(I)$ is the standard deviation. When the p-value obtained is greater than 0.05, the basic assumption is accepted, implying that the data values are randomly spread out spatially.

Local indicators of spatial association (LISA) is a measure of the degree of similarity (positive correlation) or difference (negative correlation) between observed unit attribute values and those of surrounding units [51]. It can help us to grasp the heterogeneity of spatial elements more accurately. The LISA distribution was plotted on the basis of a z-test ($p < 0.05$). The formula is as follows:

$$I_i = \frac{(x_i - \overline{x})}{s^2} \sum_j w_{ij}(x_j - \overline{x}) \quad (7)$$

According to the calculation results of ESV based on LUCC, we analyzed the spatial agglomeration and divergence characteristics of ESV distribution.

3. Results

3.1. Spatiotemporal Change of ESV

3.1.1. Changes in Value of Individual Ecosystem Services

The changes in ESV revealed a significant reduction in the total values over the first (2009–2014), second (2014–2018), and entire (2009–2018) study periods (Figure 3 and Table 3). Between 2009 and 2018, the change in total ESV was approximately USD 7.39 million and the change in ESV during the second study period was approximately 52% of the value of the total ESV. Comparing the contributions of individual ecosystem services to the total ESV (Table 3), the regulating services had the highest contribution, accounting for more than 70% of the total value, and they were the main driver of ESV changes in Wu'an. In terms of the secondary category of services, the ESV provided by waste disposal and water conservation was higher, followed by the values for biodiversity conservation, soil conservation, recreation and culture gas regulation, climate regulation, food production, and raw material production, and the order of this contribution did not change in the different study periods. From 2009 to 2014, the value of individual ecosystem services also showed a decreasing trend. The value of the water conservation service decreased the most, at USD 2.26 million, representing 30.52% of the total changes. This was followed by the value of waste treatment services, which accounted for 29.30%, and the values of all other services consistently decreased with varied proportions.

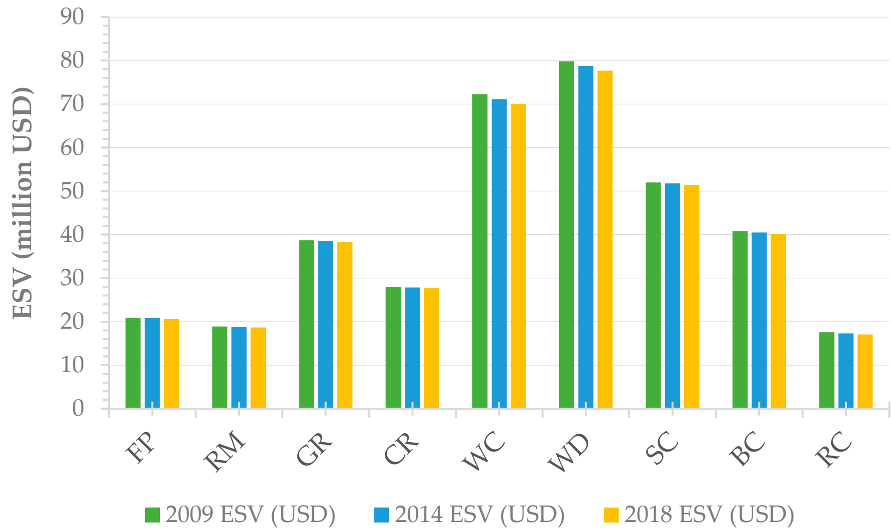

Figure 3. The ESV for different ecosystem service types in Wu'an city from 2009 to 2018.

Table 3. Changes and contribution in the ESV in Wu'an City from 2009 to 2018.

First Category	Second Category	2009 (Million USD)	2013 (Million USD)	2018 (Million USD)	Contribution (%)	Level
Provisioning services	FP	20.91	20.82	20.67	3.34%	8
	RM	18.89	18.78	18.68	2.93%	9
Regulating services	GR	38.70	38.51	38.27	5.79%	6
	CR	28.01	27.85	27.66	4.74%	7
	WC	72.26	71.12	70.00	30.52%	1
	ED	79.81	78.77	77.64	29.30%	2
Supporting services	SC	52.00	51.75	51.42	7.81%	4
	BC	40.81	40.50	40.16	8.70%	3
Cultural services	RC	17.56	17.30	17.06	6.88%	5
Total		368.95	365.40	361.56	100.00%	

3.1.2. ESV Changes in Different Land Use Types

Among the seven land use types in Wu'an during 2009–2018, the increase in construction land exceeded the total new construction land target for the entire planning period 2010–2020, which was larger than the decrease area; in contrast, the other land use areas decreased more area than they gained (Figure 4). The main reason is that Wu'an City is in a period of rapid development of industrial transformation and upgrading, mining resources development, and urban construction. The tourism industry is also facing a new wave of development. The social and economic development has caused the excessive growth of construction land. The area of cropland decreased by 655.39 ha, which was mainly converted to unused land and construction land. With the largest transfer of cropland to construction land of 1555.13 ha, only 16% of this transferred area was used to replenish cropland, whereas the transfer of other land use types to cropland was far from able to compensate for the amount of cropland occupied by construction land. The results of this study showed that ESV had notably different variations under different land use conversion types, and the conversion could reflect the integral direction and the degree of land use change. The increase in ESV in the study area from 2009 to 2018 was mainly contributed by the transfer of cropland to water bodies, construction land to cropland, and grassland to forestland. The forestland and grassland decreased by 165.04 ha and 330.32 ha, respectively. Unused land is driven by agricultural development, urban development, and other factors and mainly flows to cultivated land and construction land, followed by grassland. ESV had notably different variations under different land use conversion types. Overall, all types of ESV decreased, and the large decrease in orchards and water bodies caused the most obvious decrease in ESV, followed by grassland, with a decrease of 1.41%, and cropland and forestland, with values of 1.04% and 0.72%, respectively. Water bodies in the study area had an essential impact on the decline in ESV from 2009 to 2018, and the changes in the area's water bodies were closely associated with human activities. Water bodies were used for agriculture and urban and rural construction of 498.91 ha in the study area, which increased the cropland and urban construction land to some extent and caused the loss of water bodies. As seen from Table 2, the ESV per unit area of cropland was obviously lower than that of forestland and water bodies, but the contribution of cropland was more than water bodies in the total, overall value of ecosystem services in Wu'an.

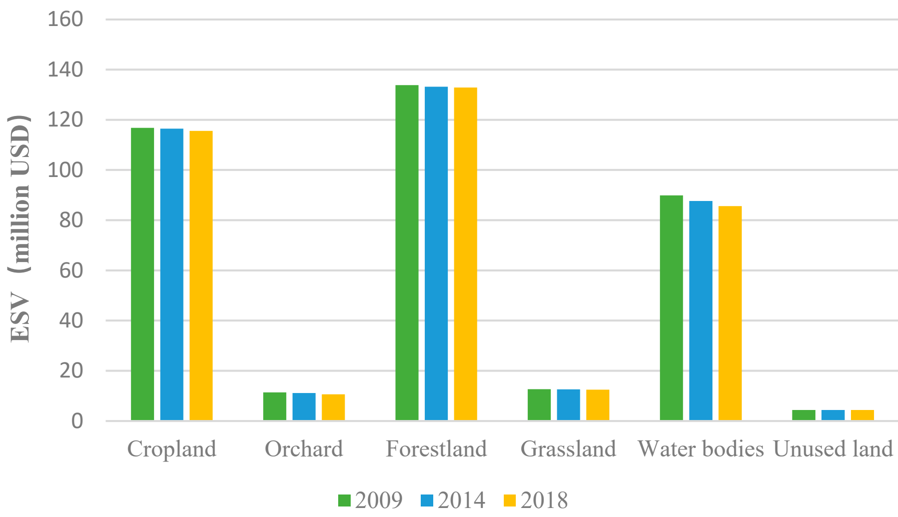

Figure 4. The ESV for different land use types from 2009 to 2018.

3.1.3. Temporal and Spatial Change of ESV

The statistical results were averaged and adjusted on the basis of the natural discontinuity method and divided into five grades according to the ecosystem service value (Figure 5). The results show that there are differences in the spatial distribution of ESV grades in Wu'an City in different years. Ecosystem service high-value areas are mainly distributed in rivers and their areas. Low-value areas are mainly distributed in built-up land and unused land and are large and concentrated.

From the spatial variation of ESV in different directions in Wu'an, ESV change per unit area was mainly in the northwest directions between 2009 and 2018 (Figure 6), where mining resources were widely distributed and mining activities had a greater impact. The total ecological service value decreased to different degrees in eight directions from 2009 to 2018. The areas with more decreasing areas are still ENE, ENN, and WNW. In addition to being mainly distributed near the central urban areas, the government should strengthen the use of stock urban land, strictly control the expansion of new construction land, and reasonably protect cropland. The relatively small losses in the north to west direction were related to the protection of ecological resources. In terms of each individual service, the loss of ESV in each direction was mainly due to the decrease in the value of regulating services, and the value of the water conservation or waste disposal function decreased the most in every direction.

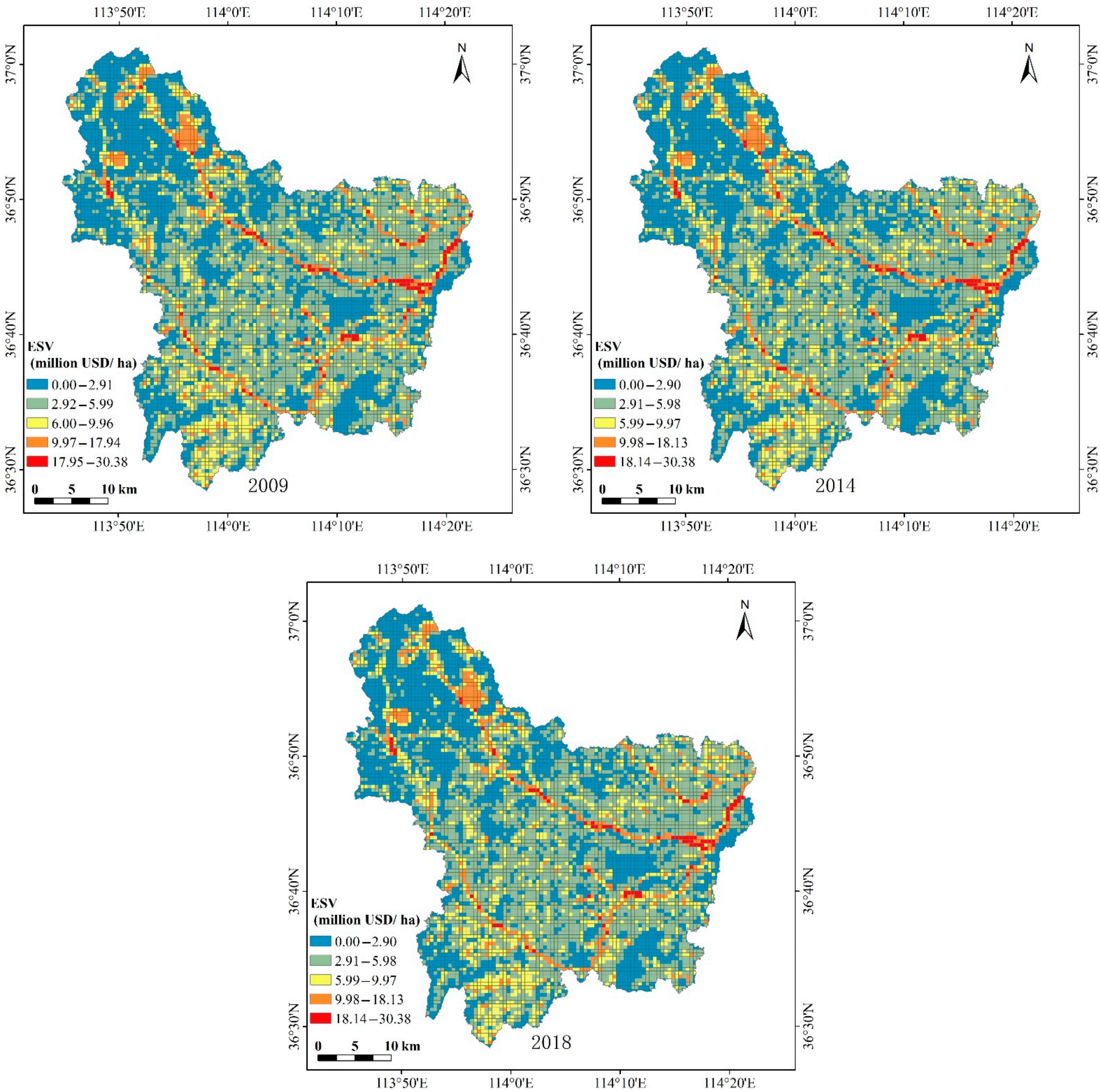

Figure 5. The spatial distribution maps of ESV.

From 2009 to 2018, the farmland ESV increased in the second and fourth quadrants and decreased in other quadrants, of which the ESV increased by 657,609.83 (USD·ha^{-1}·a^{-1}) in the second quadrant. The orchard ESV decreased in all eight quadrants and decreased the most in the second quadrant, which was 545,366.32 (USD·ha^{-1}·a^{-1}). Both forestland and grassland ESV decreased in eight directions, and the decrease was relatively uniform. The water bodies ESV decreased the most, reaching 4,269,624.41 (USD·ha^{-1}·a^{-1}), in the second quadrant and the fourth quadrant decreased the most. Unused land increased and decreased, and the total ESV decreased by 10,684.73 (USD·ha^{-1}·a^{-1}) (Figure 6).

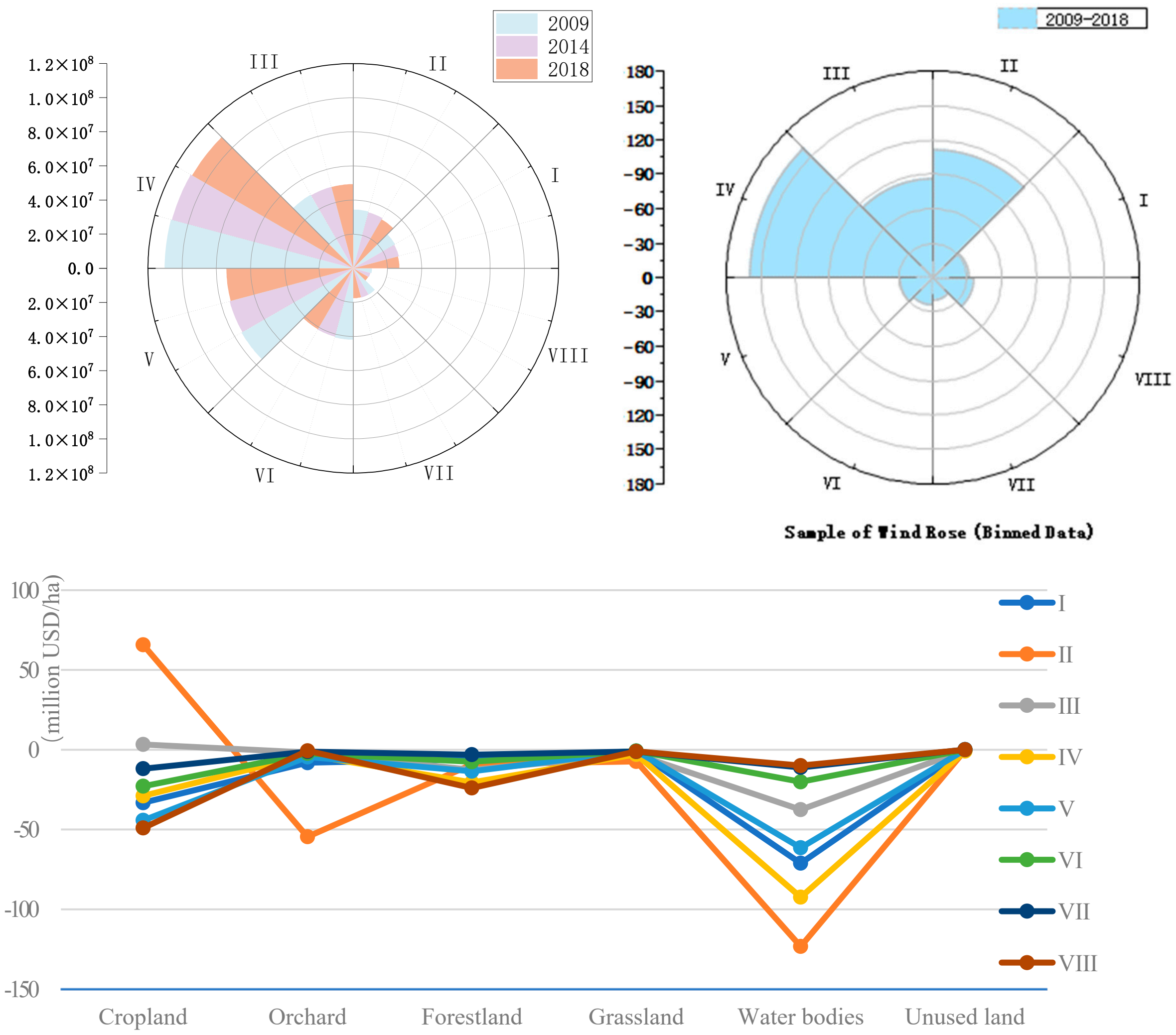

Figure 6. ESV and ESV change per unit area (USD ha^{-1}) in different directions from 2009 to 2018.

3.2. Sensitivity Analysis

According to the CS calculation formula, the sensitivity index of Wu'an city was obtained for three periods (Table 4). The results showed that the sensitivity indices of the ESV coefficients of all land use types in Wu'an city were less than one. The sensitivity index of ecosystem service value to ecosystem service function value index in different types of areas changed greatly, but the difference between different years was small. The sensitivity index of forestland was the highest, with an average of 0.39; additionally, the ESV of forestland increased (decreased) by 1%, and the total ESV increased (decreased) by 0.39%. Cropland and water bodies were ranked second, and changes in ESV coefficients of other land types had little effect on changes in the total ESV. This result indicated that forestland, cropland, and water bodies play crucial roles in ecosystem services. Sensitivity analysis showed that the ESV was inelastic to the value coefficient (VC) in Wu'an. That is, there is uncertainty in VC, but the ESV calculation is stable throughout the study area, and the study results have some reliability.

Table 4. Sensitivity of ESV to its value coefficient in Wu'an city.

Year	Land Use/Cover					
	Cropland	Orchard	Forestland	Grassland	Water Bodies	Unused Land
2009	0.336	0.033	0.385	0.037	0.259	0.013
2014	0.339	0.032	0.388	0.037	0.254	0.013
2018	0.340	0.031	0.391	0.037	0.250	0.013
average	0.338	0.032	0.388	0.037	0.254	0.013

3.3. Spatial Autocorrelation Analysis of ESV

3.3.1. Global Spatial Autocorrelation of ESV

We found that the Moran's I of the ESV in 2009, 2014, and 2018 in Wu'an city was greater than 0, and the p-values were less than 0.001 (Table 5), indicating that the ESV in the study area had a strong positive spatial autocorrelation and that the regions with similar ESVs were spatially clustered.

Table 5. Sensitivity of ESV to its value coefficient in Wu'an city.

Year	2009	2014	2018
Moran's I	0.5421	0.5384	0.5385
$E(I)$	−0.000131	−0.000131	−0.000131
$Z(I)$	65.4979	65.0566	65.0654
p-value	<0.001	<0.001	<0.001

3.3.2. Local Spatial Autocorrelation of ESV

The agglomeration map is a geographical representation of the regional units that pass the significance test; the spatial agglomeration among ESV is mainly expressed as the agglomeration of spatially similar value [20], and ArcGIS was used to generate a LISA agglomeration map of the ESV in three periods (Figure 7). The area of cold spots of ESV loss (low-low (LL) agglomeration) in Wu'an was significantly higher than the area of value-added hot spots (high-high (HH) agglomeration). The ESV value-added hot spots in 2009 were located in the local mountainous areas in northwestern Wu'an and some areas in the east; the services here included natural scenery, history and culture, and rich tourism resources. The cold spot areas were mainly distributed in the northwestern middle mountainous area and the central and southern parts of the area. Most of the northwestern mountainous areas were villages with small populations and poor economic conditions, and many villagers went out to work so that the high labor force outflow led to idle and abandoned cropland. The central part was comprised of iron resources, and the southern part was comprised coal resources. The large amount of mining resource development made the value of ecosystem services low, and the implementation of ecological policies, such as returning farmland to forest and grassland, constructing a water conservancy, and land remediation added several hot spots. The decrease in the aggregation of low-value areas was related to the improvement of Wu'an's ecological environment. Wu'an has changed the phenomenon of slag stacking, reduction in the vegetation, dust pollution, and other phenomena by improving the style of the nature reserve and the mine ecological restoration and treatment project.

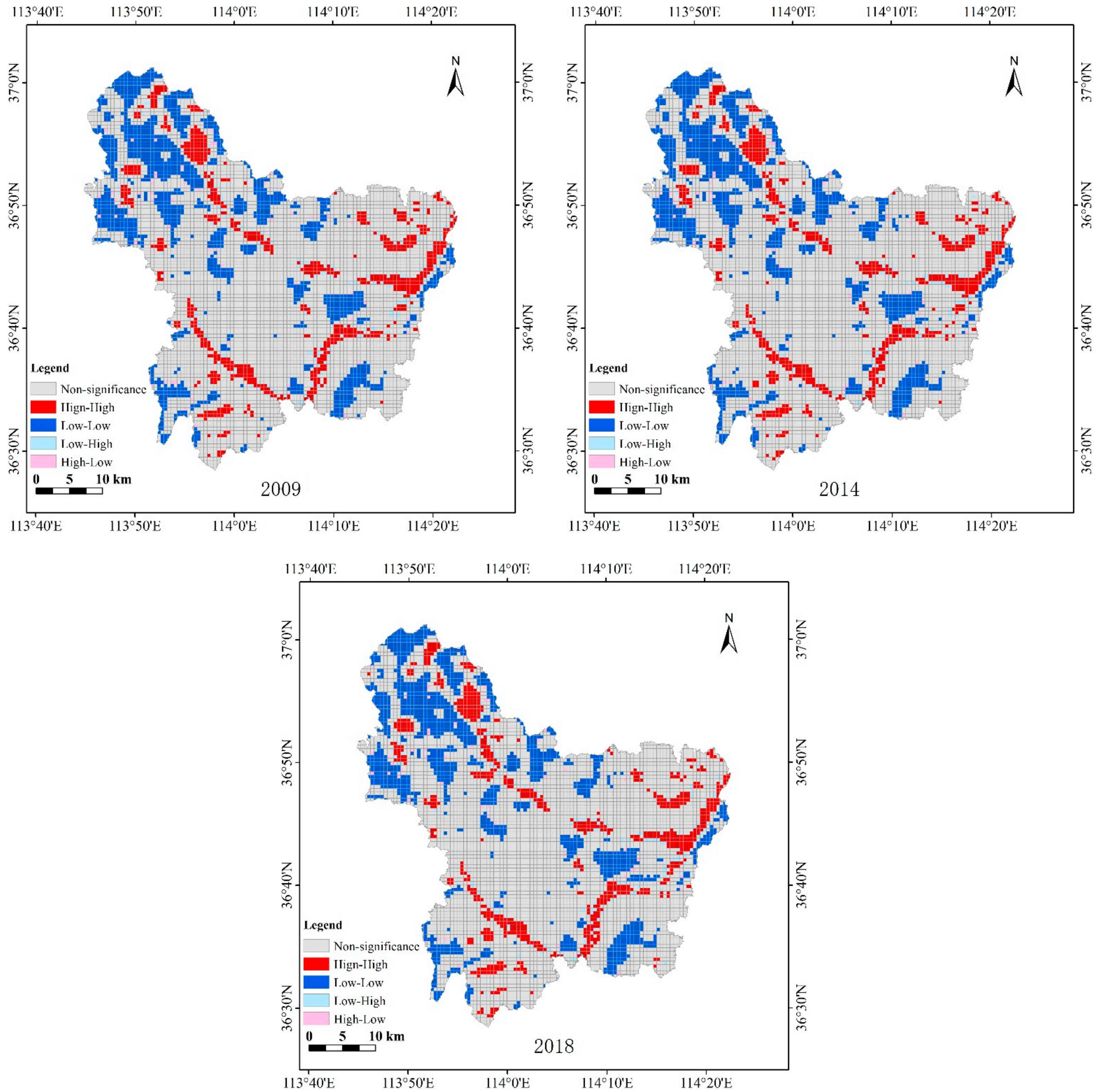

Figure 7. LISA aggregation diagrams.

4. Discussion

4.1. The Relationship between ESV and LUCC

Mining activities interfere with the change in land use types in mining cities. The ESV had notably different variations under different land use types conversion, and the land use conversion affected the directionality and degree of ESV changes. The total value of ecosystem services in Wu'an displayed a downward trend, with a net decrease of USD 7.39 million, and all types of ESVs decreased. The results of ESV assessments are an important basis for ecological management planning and decision making, and their changes can indirectly reflect the effectiveness of current ecological management initiatives [53]. Rapid urbanization, industrialization, land development strategies, and ecological conservation policies are the main factors that have caused ESV changes [36]. LUCC is influenced by the policy of urban and ecological protection, which is the main reason for land use structure adjustment, thus driving the changes in ESV, and it is not feasible to investigate each LUCC type separately to determine a total value [54]. If the aim is to assess the directional changes in ESV over time, rather than to obtain an absolute ESV estimate at one point in time [55], it is more valuable to use the method of value coefficients. Thus, this article used the equivalent coefficient and revised it based on the local situation of Wu'an.

The excavated land and dump was caused by open-pit mining [56,57], destroying surface soil and vegetation [58]. Underground mining is dominated by collapse and gangue crushing [59,60], resulting in subsided land, excessive land occupation, and destruction of the original ecosystem. The study area is one of typical mining cities; mining activities and the construction of iron and steel enterprises also occurs in the land occupation, such as Ji'nan Steel Group, Hebei Xinjin Iron and Steel Group, and Hebei Puyang Iron and Steel Group. Large amounts of pollution, such as waste gas, waste liquid, and solid waste, were discharged but not effectively treated while mining activities continuously developed in Wu'an; these wastes affected the soil, rivers, and buildings, influenced erosion, and threatened biodiversity. Meanwhile, the direction of urban expansion had an impact on the change in the ESV in Wu'an city. The decrease in ecological land would pose a threat to the ecological environment. It is more important to coordinate the relationship between development and ecological protection in the process of land utilization, and the government paid more attention to the "Grain for Green" program [61] to increase the area of ecological land to reverse the declining trend of ESV in China.

4.2. Land Use Management Based on Low and High ESV Areas

Identifying low and high ecosystem services value areas is crucial for land use management, enabling policies that can better target particular sustainability challenges of different areas [62]. The LUCC-driven ecosystem service changes derive primarily from spatial and temporal heterogeneities [63–66]. The ESV showed obvious spatial autocorrelation and HL clustering in Wu'an city. The high-value areas were mainly distributed in the local mountainous area in the northwest, which combines cultural heritage and natural scenery, and some areas were shown in strips as being the main locations of water bodies. The implementation of ecological policies, such as fallowing and land reclamation, added several hot spots. Low-value areas of ESV were in the middle mountainous regions in the northwest, central, and southern regions due to the development of mining land and tourism resources. The decrease in the low-value area mainly contributed to the implementation of projects, such as the establishment of rural revitalization, the promotion of ecological management of rivers, and the comprehensive improvement of the environment in Wu'an city. Nevertheless, there were still some shortcomings in the analysis of spatial autocorrelation. ESV spatial autocorrelation depends on the spatial autocorrelation scale and how to scientifically determine its scale remains to be studied. Second, only univariate spatial autocorrelation analysis was used in this article, and multivariate analysis could be conducted in future research by selecting other factors, such as policies and land use intensity, to make the results more scientific.

4.3. Further Research on Ecosystem Services of Construction Land

As the most influential and concentrated areas of human activities, construction land plays an important role in providing ecosystem services [41,67]. However, this article did not estimate the ecosystem service values of construction land ecosystems, such as settlements and industrial and mining land, transport land, and scenic sites, which are more affected by human activities. Furthermore, land use change also includes changes in land use intensification [8], but these were not quantified here due to a lack of relevant data and a defensible method, so this work needs to be further investigated.

5. Conclusions

Land use in mining cities faces greater pressure on ecological protection than other cities. This article focused on the effects of land use/cover change on ecosystem services. Wu'an City is in the boom stage of mineral resources, urban construction, and tourism development. The rapid development of the social economy has prompted the increase in construction of land areas at the expense of ecological land. From 2009 to 2018, construction land increased, and other types of ecological land decreased to varying degrees. The land use data were used to estimate the valuation of ecosystem services for three periods, which was also based on the equivalent coefficient of Xie et al. [31]. If mining cities are left unchecked, the value of ecological services will continue to decrease. According to the CS calculation formula, the sensitivity index was obtained and the results had some reliability for Wu'an city in the three periods. This shows that Wu'an should focus on cultivated land and forest land to improve the ecosystem service value. The results of spatial variation showed that the total ESV decreased during 2009–2018, mainly concentrated in the north to east direction, which coincided with the distribution of mining resources, and the regulating function was the main driving force causing ESV changes, which were mainly influenced by the decrease in water bodies and the continuous development of mining resources. The results revealed obvious spatial autocorrelation and HL clustering in Wu'an city, and the area of cold spots was significantly higher than the value-added area of hot spots. The high-value area was distributed in the mountainous area in the northwest and some areas in the east, and the cold spot area was distributed in the northwestern middle mountainous area and in the central and southern regions.

It should be noted that in the process of adjustment, it should be combined with the ecological protection red line of Wu'an City and the control of natural ecological space use. When focusing on economic development, according to the spatial pattern of Wu'an City's "five mountains, half water and three fields", the land use should be reasonably arranged by the type of area, and green space should be expanded. Furthermore, building an ecological protection barrier area with contiguous wood Forestland, grassland, and basic farmland as the main body; enhance biodiversity function. Strengthen the protection of ecological land with high ecosystem service value per unit area, such as key rivers, in Wu'an City. Promote the reclamation and ecological reconstruction of unused land to effectively increase the area of ecological land and realize the coordinated development of social economy and ecology.This research is crucial for mining cities to maintain spatial stability and sustainable development. It can provide a reference for the study of ecosystem services in other similar areas. Moreover, it can provide a scientific basis for land use management decision makers to conduct more targeted land regulation.

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