Identifying internal distributions and multi-scenario simulation of ecosystem service value in Liaohe basin based on Geodetector and PLUS model

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Research Article

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Abstract

Ecosystem services value (ESV) can assess the level of basin ecological restoration and provide a basis for ecological management decision-making. This study object selects Liaohe River Basin (LHB), a typical basin in Northeast China. The ecosystem service value variation caused by changes in land use cover and the spatial distribution characteristics was evaluated by employing the benefit transfer method, which is based on data sets for land use over 2000–2020. Meanwhile, geographical detector was employed to investigate the impacts and interactions of various factors driving the ESV, and predicted future changes in land and ESV by PLUS model. The results showed the following: 1) LHB land transformations mainly concentrated in the transformation between grassland, farmland and forestland. ESV in LHB decreased and then increased between 2000 and 2020 (1224 billion-928 billion-1238 billion), 2) Ecosystem service value exhibited a strong positive spatial autocorrelation, high ESV was mainly distributed in the eastern and western regions of LHB, and low ESV in the central region. 3) The variation in ecosystem service value mainly arises from the human activity intensity index of human factors. 4) In the future, the ecological protection priority scenario can improve the ESV in LHB, and the natural development priority and economic development priority scenario is not conducive to the improvement of ESV. The results show that the ecological restoration effect of the LHB is obvious with the ecosystem service value is significantly improved. In the future, attention should be paid to control human activities and strengthen ecological protection in ESV hotspots.

1. Introduction

Ecosystem plays a key role in the maintenance and balance of life and environmental systems, among which the watershed ecosystem is the most important. It is the origin of human society and is rich, including social, economic, cultural, natural and other elements.A watershed is a major natural area where people and nature coexist, analogous to a major artery connecting a region (Blanchard et al., 2015). It also has a close relationship with regional social and economic growth. Watersheds exhibit considerable spatial heterogeneity and great integrity as a whole ecological unit (Zhao et al., 2018; Straton, 2006). Around the world,countries are placing a greater focus on ecological civilization, the concept of watershed ecosystem management and sustainable development has been widely recognized by governments and international scholars (Alcolea et al., 2019).

As a result of rampant development and exploitation of natural resources, the state of the world's ecosystems is deteriorating, which is leading to a number of ecological problems like forest loss and desertification (Hou et al., 2021). Human activities have exacerbated global ecological destruction and ecosystem degradation. In the trend of global environmental change, unreasonable land development caused by human activities poses a serious threat to the development and well-being of human society (Bai et al., 2019). The environmental Kuznets curve states that low-income nations acquire arable land through the early years of nature devastation (Brain and Anderson, 2020). China also experienced this. China entered a phase of rapid economic expansion in 1995 with the introduction of a socialist market economic system and the deepening of reform. According to figures provided by the World Bank, the economic size of China increased from 2.37% of the global economy in 1995 to 18.45% in 2021. People started to show solicitude for the phenomena of ecological damage brought on by earlier economic expansion as a result of the economy's rapid growth.

For improving the management of preservation initiatives, the Chinese government has implemented a range of ecological restoration programs (ERPs). These ERPs include the Program of Returning Farmland to Forest/Grassland (Bennett,2008), the Natural Forest Protection Program (Xu et al.,2006), and the Sloping Land Conversion Program (Yin and Yin,2010). Numerous researches have demonstrated that the implementation of ERPs can successfully enhance damaged ecosystems. Ecological restoration project is an effective way to slow down ecological degradation, solve environmental problems and restore ecosystem function.

The assessment of ecosystem services value (ESv) is an important tool for assessing the level of ecological restoration, which can quantitatively assess the various changes that occur in ecosystems (Ouyang et al., 2020). Ecosystem services (ES) are the benefits peolple receive from the structures, processes, and functions of the natural environment and are essential for human survival and progress (Aschonitis et al., 2016. Costanza et al., 1997). Assessing the value of ecosystem services (ESV) is crucial for safeguarding the ecological environment, understanding the role of ecosystems in specific regions, building sustainable societies, managing environmental economic resources, and making informed decisions on ecological compensation (Daily et al.,2000. Ouyang et al.,1999. Xie et al.,2015). Watershed ecosystems offer us essential products for our survival,as well as important ecosystem services on a large scale like climate regulation,water preservation,carbon dioxide absorption,water and air purification,soil and water conservation,and biodiversity (Daily, 1997; Qin et al., 2020).

The Liaohe River (LHB) is one of the seven major rivers in China with important industrial and agricultural production base. Home to a population of 34.04 million in the LHB. It is also an important base for steel, machinery, building materials, chemical industry, grain production, and animal husbandry in China. The middle and lower reaches of the LHB are one of the most developed industrial and economic regions in China. Since the 1960s, with the acceleration of economic development, industrialization, and urbanization, numerous human activities have caused interference, especially the large discharge of industrial, agricultural, and domestic sewage. A series of problems such as poor water environment quality, river interruption, serious soil erosion, and continuous reduction of biodiversity have made ecological restoration in the LHB urgent. In 2006, the Liaohe River was listed as one of the key rivers for national governance. In 2010, the Liaoning Provincial Party Committee The provincial government has designated the Liaohe River Reserve and established the Liaohe River Reserve Management Bureau to protect and manage the LHB through comprehensive planning, centralized management, and comprehensive protection Between 2000 and 2019, the government invested a total of 18.249 billion yuan in water volume regulation, water quality restoration, and watershed ecological restoration (Fig. 1).

However, due to the lack of reasonable and effective evaluation methods, the effectiveness of ecological restoration is difficult to grasp in a timely manner, resulting in some unreasonable ecological restoration measures being difficult to correct in a timely manner. Not only does this result in a significant waste of human resources and materials,but it also hinders the advancement of ecological restoration and worsens the degradation of the environment. The correct evaluation of the restoration effect of river basin ecosystems has important practical significance in alleviating ecological degradation and promoting sustainable development of regional ecological environment. At the same time, in the context of Global change and human interference, the land use mode of the basin has changed frequently, which has caused noticeable damage to its ecological environment. The urgent problem in achieving sustainable development of the basin ecology is to find solutions to effectively manage the relationship between ecological protection and regional development which includes improving the land distribution and ensuring the continued functionality of the ecosystem service.

To address the above issues, the main objectives of this study are as follows: (1) To test the effectiveness of ecological restoration policies of LHB, we evaluated the changes in ecosystem service value in the LHB from 2000 to 2020 using the equivalent factor method; (2) Based on the method of cold and hot spot analysis, the spatial heterogeneity characteristics of ecosystem service value in river basins were systematically analyzed, revealing the coupling driving mechanism of natural and human factors on the spatial distribution pattern of ecosystem service value; (3) Predicted the ecosystem service value of the LHB under different development scenarios, providing a basis for decision-makers to formulate corresponding land management policies and sustainable development in the LHB.

2. Materials and methods

2.1 Study area

The area of LHB is 219,000 km^2, of which 35.7% are mountainous, 23.5% hilly, 34.5% plain and 6.3% sand dune (Fig. 2). In the west are the Daxing'an Mountains, Qoltu Mountain and Nuruer Tiger Mountain, with an elevation of 500 ~ 1500 meters, and in the east is Jilin Hadaling, Longgang Mountain and Qianshan Mountain, with an elevation of 500 ~ 2000 meters. The basin's topography slopes mainly from north to south and from east to west towards the center, forming Liaohe Plain in the middle and lower reaches, with an elevation of less than 200 meters. Most areas of the LHB belongs to the temperate semi-humid and semi-arid monsoon climate. According to the statistics from 1956 to 1979, the annual average annual runoff of the whole basin is 12.6 billion cubic meters. The upper part of the Taizi River,located east of the main section of the Liaohe River,is in proximity to the Yellow Sea and receives an average annual rainfall of approximately 900 mm. The temperature distribution of LHB, high plain, low mountain, annual average between 4 ~ 9℃, from south to north, each latitude about 0.8℃, the lowest in January, the average between-9 ~ 18℃, the absolute minimum temperature, all below-30℃, July temperature is the highest, the average between 21 ~ 28℃, the absolute highest temperature between 37 ~ 43℃.

2.2. Evaluation of ESV

Costanza et al. (1997) firstly defined the scientific estimation principle and method of ESV, and estimated 17 ESV of 16 ecosystems in the world. Considering the shortcomings and reliable results of previous studies, Xie et al. (2003) used the questionnaire survey based on 200 Chinese ecologists, and made many improvements to methods employed in the study of Costanza et al. (1997). The ecosystem service function was divided into the food production (FP), Raw materials (RM), water resource (WTR), gas regulation (GR), Climate regulation (CR), environmental purification(EP), Water regulation(WR), Soil retention (SR), Nutrient cycling(NC), Biodiversity protection Recreation (BR) and Recreation and culture (RC) (Xie et al., 2005). According to the study of Xie et al. (2015), the ESV equivalent table and the ESV equivalent factor are equal to 1/7 of the average market value of grain production (He et al., 2017) (Table 1). Hence,using this foundation,this research reevaluated the economic worth of the ESV equivalent factor per unit of land area using the mean grain yield and the average market price of unprocessed grain declared by the respective governmental departments. The formula is as follows:

$$E_a = \frac{1}{7}\sum_{j=1}^{n}\frac{m_j p_j q_j}{M}$$

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Ea is the economic value of unit ecosystem in Yuan / (hm^2 a); *j* is food crop type; m_j is the average price of the *j* grain crops in the study area; the unit is Yuan / kg; P_j is the unit in kg/hm^2; q_j is the *j* planting area in hm^2; *M* is the total planting area of grain crops in hm^2. The results show that the economic value of the unit ecosystem service in the LHB is 3933.15 Yuan / (hm^{2}·a) (Table 1).

The ecosystem services value is calculated as follows:

$$ESV = \sum_{i=1}^{n} A_i \times VC_i$$

2

$$VC_i = \sum_{j=1}^{k} EC_j \times E_a$$

3

ESV is ecosystem service value, unit is Yuan / a; *i* is land use type; *j* is ecosystem service type; *Ai* is distribution area of land use type, unit is hm^2; VC_i is ecosystem service value equivalent per unit area of class i in Yuan / (hm^2·a); EC_j is ecosystem service value equivalent of item *j* of land use type; *k* is quantity of ecosystem service type; E_a is economic value of 1 unit ecosystem service, unit is Yuan / (hm^2·a).

Table 1
Value per unit area of ecosystem service

Primary category	Subcategories	Cultivated land	Forestland	Grassland	Water area	Barren land	Urban land
Provision services	Food production	3343.24	1140.63	1494.62	3146.58	0.00	0.00
	Raw materials	1573.29	2595.93	2202.61	904.64	0.00	0.00
	water resource	78.66	1337.30	1219.30	32606.42	0.00	0.00
Regulation services	Gas regulation	2635.26	8535.09	7748.45	3028.58	78.66	0.00
	Climate regulation	1415.96	25565.95	20492.09	9007.08	0.00	0.00
	Environmental purification	393.32	7591.12	6765.14	21829.39	393.32	0.00
	Water regulation	1061.97	18643.48	15024.91	402132.75	118.00	0.00
Supporting services	Soil retention	4051.22	10423.04	9439.74	3657.90	78.66	0.00
	Nutrient cycling	471.99	786.64	707.98	275.33	0.00	0.00
	Biodiversity protection	511.32	9479.07	9479.07	10029.72	78.66	0.00
Cultural services	Recreation and culture	235.99	4169.22	3775.89	7433.79	39.33	0.00

2.3. Identifiation of spatial patterns

(1) Land use transfer matrix

The LHB undergoes a transformation of land use types due to human or natural factors, which is known as land use transfer. The Stochastic matrix of land use refers to the mutual conversion relationship (area or transfer ratio) between land use types in different periods in the same research area, which can directly reflect the source and destination of each land type (Li et ai., 2021). The formula is as follows:

$$P_{ij} = \begin{bmatrix} P_{11} & \cdots & P_{1n} \\ \vdots & \ddots & \vdots \\ P_{n1} & \cdots & P_{nm} \end{bmatrix}$$

4

(2) Spatial autocorrelation analysis

To examine the spatial distribution of LHB in the YRB,the correlation and clustering patterns were analyzed using Moran's I. Moran's I is a widely used statistical measure that determines if there is a significant correlation between attribute values and their neighboring elements. Nonzero values indicate a correlation in the LHB data. According to Liu et al. (2020c), a negative Moran's I value indicates a negative spatial correlation for LHB,whereas a positive value indicates a positive correlation.

(3) Hotspot analysis of the selected ecosystem services

Hotspot analysis is a specialized method of spatial analysis that has been utilized to identify regions where there are concentrated high values for a particular variable of significance. It has been extensively employed to pinpoint prime areas that require attention for the preservation of biodiversity and ecosystem services (Li et al., 2017;Schröter et al., 2017; Fan et al., 2023). To identify areas that can offer substantial ecosystem service provisions,we utilized Gi* statistics,a functionality integrated into ArcGIS 10.3. The process of determining the distribution of hotspots for ecosystem services involved several steps. Initially, zonal statistics were applied to compute the cumulative sum of each chosen ecosystem service type within every county within the LHB region. Subsequently,the Hotspot Analysis (Getis-Ord Gi*) tool was employed to pinpoint the hotspots where ecosystem services are most prominently provided.

2.4. Geographical Detector

Driving forces can ascertain the process of land cover transformation and unveil the mechanism behind regional ecological shifts. In particular,geographical detectors refer to a collection of statistical techniques that can identify spatial variations and uncover the concealed factors that drive such changes. Ever since Wang et al. (2010) introduced the geographic detector, which has been extensively employed in driving force analyses (Wu et al., 2022).

We proposes two types of 8 driving factors from the perspectives of natural environment and socio-economic factors (Zhang et al., 2021a): 1) Natural environment driving factors: DEM (digital Elevation Model), Road distances, River distances, NDVI (normalized vegetation index), Annual precipitation (AP) Annual temperature (AT); 2) GDP, HAI (human active index), Population density (PD). Here, we use the natural discontinuity method to discretization the data.

2.5. PLUS model

The PLUS model is a new land use simulation model proposed by Liang et al.(2021), which can better simulate the patch level change of multiple classes of land use types, It consists of a new land-use expansion analysis strategy (Land Expansion Analysis Strategy, LEAS) and based on multi-type random plaque seeds (CA based on multi-type random patch seeds, Cellular Automata for CARS) (Cellular Automata, CA) model consists of two major parts. PLUS model combining the advantages of transformation analysis strategy (TAS) and pattern analysis strategy (PAS) can better explore the inducement of various kinds of land use changes, simulate the changes of multiple types of land use patch level, and realize the simulation of multiple land use types. We set three development scenario models, including natural development priority (NDP), ecological protection priority(EPP), economic development priority (EDP).

3. Result and discussion

3.1. Spatiotemporal change in land use

Table 2
Changes in the areas of ecosystem types in LHB (2000–2020).

Type	2000	2005	2010	2015	2020
Farmland	124681.40	120573.46	120399.69	122989.28	117951.33
Forestland	37045.84	38352.68	38995.67	39917.47	40400.41
Grassland	77631.03	81163.16	78860.32	74335.21	78441.80
Water area	1736.63	1718.71	1644.13	1622.82	1492.40
Barren land	5787.15	4253.69	4823.65	4366.55	4152.91
Urban land	11463.27	12283.63	13621.88	15114.00	15906.48

The land use change (LUC) dynamics in the LHB area is shown in Fig. 3. From 2000 to 2019, the cultivated land area in the LHB was the largest, accounting for approximately 50% of the total area, mainly concentrated in the southeast. Next are forest and grassland, accounting for approximately 17–20% of the total area, mainly distributed in the northwest region. Construction land accounts for approximately 8–12%, mainly concentrated in urban areas. The proportion of wetlands is the lowest, about 2%, mainly distributed in the eastern region. Between 2000 and 2020, the woodland construction land and grassland in LHB area increased, while the cultivated land and water area were significantly degraded (Table 2).

Figure 4 displays that from 2000 to 2020, the main types of land cover transferred out from the LHB were grassland, farmland, and forestland, corresponding to 4336863 ha, 3119759 ha, and 457400 ha. From 2000 to 2020, the characteristics of land cover transfer remained consistent according to the three primary types of land transfer. Grassland is the land type with the most land change in the LHB region, and the grassland is mainly converted into farmland, with the transition amount increasing first and then decreasing during 2000–2020. The transition of grassland to forestland is increasing during 2000–2020, which is consistent with the trend of farmland transition. The conversion of farmland to forest land is increasing year by year. The increase in construction land mainly comes from the transition of arable land. The degradation of water area is mainly due to the transformation of water area into farmland.

3.2. Characteristics of ESVs in different land use

From 2000 to 2020, the ESV in the LHB region showed a trend of first decreasing and then increasing (Fig. 5 and Table 3). From 2000 to 2010, the ESVJ decreased by 24%, from 1224.4 billion yuan to 928.2 billion yuan. From 2010 to 2020, the ESV increased by 33%, from 928.2 billion yuan to 1238.2 billion yuan. The total ESV increased from 1224.4 billion yuan to 1238.2 billion yuan, with PSV decreasing from 125.4 billion yuan to 123.2 billion yuan. Both regulatory support services and cultural services are showing an increasing trend.

ESV had clear spatial heterogeneity in the LHB, the ESV increases outward from the LHB center, and high ESV areas are mainly distributed in the western and eastern regions. The coverage of forest and grassland in these areas is relatively high. Among the various land covers in LHB, forest can provide the highest regulatory support and cultural services (Fig. 5), while low ESV is mainly distributed in the central region, which is mainly concentrated in construction land and cannot provide ecosystem service value. Other moderate ESV areas are mainly composed of cultivated land, which can provide a large amount of product supply services.

Table 3
Ecosystem services value in the LHB (100 million yuan)

Types of ecosystem services		**2000**		**2005**		**2010**		**2010**		**2020**	
		ESV	**Ratio%**	**ESV**	**Ratio%**	**ESV**	**Ratio%**	**ESV**	**Ratio%**	**ESV**	**Ratio%**
Provision services	**Food production**	580.06	4.74	573.04	4.56	509.99	5.49	572.40	4.71	561.84	4.54
	Raw materials	464.46	3.79	469.15	3.73	377.69	4.07	461.90	3.80	464.15	3.75
	water resource	210.44	1.72	215.58	1.72	162.63	1.75	206.42	1.70	207.42	1.68
Regulation services	**Gas regulation**	1250.84	10.22	1278.34	10.17	956.75	10.31	1244.90	10.24	1267.14	10.23
	Climate regulation	2727.61	22.28	2827.34	22.50	1979.53	21.33	2730.07	22.45	2818.19	22.76
	Environmental purification	894.81	7.31	925.98	7.37	644.38	6.94	890.60	7.32	917.12	7.41
	Water regulation	2686.04	21.94	2751.67	21.90	2100.58	22.63	2642.37	21.73	2655.25	21.44
Supporting services	**Soil retention**	1629.37	13.31	1659.48	13.21	1267.56	13.66	1620.81	13.33	1643.69	13.27
	Nutrient cycling	143.30	1.17	144.88	1.15	115.46	1.24	142.39	1.17	143.27	1.16
	Biodiversity protection	1167.58	9.54	1211.01	9.64	816.97	8.80	1161.45	9.55	1201.02	9.70
Cultural services	**Recreation and culture**	489.69	4.00	507.30	4.04	350.33	3.77	487.92	4.01	503.26	4.06
□□		12244.20	100.00	12563.76	100.00	9281.87	100.00	12161.23	100.00	12382.36	100.00

3.3. Spatial agglomeration of ESVs

This study validated the spatial correlation of ecological risk in the research area, Moran's I scatterplots and global spatial autocorrelation analyses were conducted. The results revealed that the LHB exhibited strong positive spatial correlation across the period of 2000–2020 (Fig. 6), with Moran's I values of 0.8113, 0.8103, 0.8119, 0.8082, 0.8096, and 0.8161 (Table 4), respectively. This significant Moran value indicates a clear clustering pattern in the spatial distribution of LHB,supporting the findings of Liu et al. (2020c).

Table 4
Moran'I index table

Year	**Moran *I***	**Z(I)**	**P(I)**
2000	0.82	117.64	0.00
2005	0.82	117.64	0.00
2010	0.81	117.31	0.00
2015	0.81	117.39	0.00
2020	0.81	117.09	0.00

Figure 7 displayed the hotspots for various ecosystem services in 2000 and 2020, indicating their respective confidence levels. It is widely accepted that a confidence level of $P < 0.05$ (i.e.,95% confidence level) is considered statistically significant (Li et al., 2017). Therefore, our study primarily focused on hotspots with confidence levels exceeding 95%, as these were deemed crucial for the provision of ecosystem services. The spatial distribution pattern of ecosystem services cold hotspots in the LHB region from 2000 to 2020 is similar, with hotspots mainly distributed in the western and eastern regions. This is because the ecological vegetation coverage in the western and eastern regions is high, with higher elevations and rich terrain. Forests and grasslands are mainly concentrated in this area and can provide various ecosystem services (Du et al., 2023). The central and eastern regions are where the majority of the cold spot area is found. These areas are mainly composed of grassland and arable land, and their aggregation is relatively scattered.

3.4. Mechanisms of drive changes in ESVs

The results from differentiating and detecting factors indicated that the spatial differentiation of ESV in the study region was influenced by multiple factors (Table 5).

The Q values were ranked as follows: HAI (0.424) > AP(0.298) > DEM(0.232) > AT(0.211) > other factors (< 0.2). HAI was the main driver of the differences in ecosystem services value (ESV) across the study area. Factors related to human actions and the landscape had a bigger impact on ESV compared to natural factors. The analysis showed that the combined effects of pairs of factors were more significant than the individual effects of any single factor. These interactions mostly contributed to enhancing the effects of both factors involved (Table 5 and Fig. 8). The factors LA and HAI were strongly influenced by AP and NDVI,as indicated by significant factor interactions (0.796, 0.817). Additionally, the q values for the interactions between LA and other factors,as well as HAI and other factors, were several times higher than the values for the independent actions of these factors.

Among the different factors studied,the combined influence of LA and NDVI AP and AD had the most noteworthy impact on ESV. The average q values for these interactions were consistently above 0.5,indicating their significant effects. Meanwhile, out of all the factors,LA and NDVI had the highest q value of 0.817,highlighting their substantial contribution to the spatial variation of ESV across the study area. Both LA and AP had q values greater than 0.2, indicating that the spatial variation of ESV in the LHB was influenced by a combination of human factors,natural factors,and landscape factors. Among these, human factors had the greatest impact.

Table 5
The contributions (Q statistics) of different factors to ESV variation.

Factor	Q statistic	P value
DEM	0.232	0.000
GDP	0.052	0.000
Road distances	0.037	0.000
HAI	0.424	0.000
River distances	0.018	0.000
NDVI	0.153	0.000
Annual precipitation (AP)	0.298	0.000
Population density (PD)	0.043	0.000
Annual temperature (AT)	0.211	0.000

3.5. Multi-scenario simulation of land pattern and ESVs

The land use in the LHB have undergone significant changes under three scenarios (Fig. 9). The area of farmland land has decreased under all three scenarios, with the EPP scenario showing the largest decrease of 8011km^2, while the forest area has increased, the EPP scenario shows the largest increase of 5822km^2. Under the NDP and EDP scenarios, the grassland area significantly decreased, while the grassland increased 1156km^2. The water area slightly increased under the NDP and EPP scenarios, while decreased under the EDP scenario. The area of barren land significantly decreased in all scenarios, with EDP mode having the highest reduction. The urban land shows an increasing trend, with the smallest increase in urban land under the EPP scenario.

The distribution of ESV in LHB projected under different scenarios was shown in Fig. 10. The distribution of ESV in 2026 under various scenarios is similar, with CR being the highest, approaching 300 billion yuan, followed by WR, both exceeding 250 billion yuan. Moreover, the value of WR and CR under the EPP scenario is much higher than that of NDP and EDP. SR, EP, and GR are all between 100 to 200 billion yuan, while other services do not exceed 100 billion yuan, with EPP slightly higher than NDP and EDP, and EDP being the lowest.

The value of ESV in LHB projected under different scenarios was shown in Table 6, The ESV in the LHB region improved under the EPP scenario, with the ESV in 2060-EPP increasing by 50.7 billion yuan compared to 2020. Regulatory services are the main driving factor, with an increase of 38 billion yuan compared to 2020. Support services and culture services increased by 10.3 billion yuan and 2.7 billion yuan respectively. The ESV under the NDP and EDP scenarios decreased by 25 billion yuan and 36.4 billion yuan respectively compared to 2020. The change in ESV in the NDP scenario is attributed to a decrease in product supply and regulatory services, while the change in ESV in EDP is mainly attributed to a decrease in regulatory and support services.

Table 6
The value of ESV in LHB projected under different scenarios

Year	**2020**	**2060-NDP**		**2060-EPP**		**2060-EDP**	
	ESV	ESV	Change	ESV	Change	ESV	Change
Provision services	1234.5	1196.2	-38.3	1231.2	-3.3	1187.3	-47.2
Regulation services	7664.7	7526.4	-138.3	8045.2	380.5	7452.8	-211.9
Supporting services	2990.7	2965.7	-25	3093.7	103	2899.1	-91.6
Cultural services	503.7	495.1	-8.6	530.7	27	490.2	-13.5
Total ESV	12393.7	12143.4	-250.3	12900.8	507.1	12029.4	-364.3

4. Discussion

The findings of the study revealed significant and extensive transformations in the land utilization of the investigated region,highlighting a highly precarious ecological framework in the area (Table 2, Fig. 3). Throughout the study period,intricate and dynamic shifts were observed between various land-use classifications and within each category. The dominant conversions primarily took place in agricultural land,which experienced concentrated human activities. This outcome aligns with one of the key features of resource utilization in Northeast China (Mao et al., 2019; Jia et al., 2022). Changes in land use encompass modifications in the intensification and conversion of land utilization,ultimately leading to alterations in ecosystem services value (Song and Deng,2017). The results of ESV in the LHB region show a trend of first decreasing and then increasing, which is due to the rapid economic development promoting urbanization, the increase in human activity intensity leading to an increase in construction land, as well as the degradation of water and grassland, which leads to a decrease in ESV in the LHB region. After 2010, ESV significantly increased, mainly due to a significant increase in forest area with ecological restoration, from 38995.67 km^2 to 39917.47 km^2. The ESV has increased from 928.187 to 1238.236 billion yuan, which indicates that the governance of the LHB has achieved significant results.

In addition, we also explore the spatial distribution of ESVs in the LHB through Spatial analysis. The results of spatial autocorrelation analysis in LHB region show that the ESV in the LHB have very high spatial autocorrelation, which indicates that the spatial concentration of ESV in LHB region is very high. The results of the cold hot spot analysis also prove this, as the ESV hot spot area is mainly distributed in the western and eastern regions of the LHB. The potential decline in various ecosystem services due to ecological degradation in these regions could pose a major risk to human well-being,as highlighted by Qiu and Turner (2013). As a result,safeguarding the ecological security of these areas should be a top priority for LHB ecological protection efforts. We predicted the changes in land and ESV under three scenarios based on the PLUS model in 2060, and the results showed that ESV only increased under the environmental protection scenario, while natural development and economic development scenarios reduced ESV. This indicates that the ecological restoration work in the LHB area is not yet complete, and it is necessary to increase the protection of the ecosystem. We should continue to protect and restore hotspots of ecosystem services in the future. Additionally, we discovered that the urban region of LHB does not align with the distribution of ecological service hotspots. This discrepancy hinders the potential supply of ecological services to human society. One possible approach to address this is the creation of ecological corridors within the area, which would enhance the flow of ecological service value. This could be done in conjunction with regional economic development efforts. These ecological corridors can also serve as landscape amenities,boosting the economic benefits associated with an improved ecological environment (Luo et al., 2022).

In this study, an analysis was conducted to determine the significance of ESV drivers in the study region using quantitative methods. The study also aimed to identify the interactions between different factors. The results of the analysis revealed that the spatial differentiation in the ESV of the study region is attributed to the interactions between multiple factors. Among these factors,the HAI for human activities was identified as the primary driver. This result is consistent with those of existing studies on drivers of ecosystem services (Pan et al., 2021;; Luo et al., 2020; Msofe et al., 2020), which indicates that ESV in the LHB is most affected by human active index.

The speed at which society is developing has quickened the degree to which humans are exploiting the natural environment for resources. As a result, regional natural landscapes undergo a conversion into semi-natural landscapes, including farmland and artificially created environments (Ma et al., 2018). Simultaneously, the population has been steadily increasing,resulting in an increased demand for both construction lands and food.

Consequently, there has been a continuous reclamation of substantial non-agricultural areas and an intensification of regional land use within this context. Ultimately, this will result in a reduction of ecosystem services value (ESV).

Even though this study has adjusted the value coefficient based on the current conditions of the study area, there is still a level of uncertainty. This research utilized the equivalent coefficient of ESV per unit area to estimate ESV in the middle and lower sections of the LHB. However,the determination of this equivalent ESV coefficient is subjective, which impacts the precision of the ESV assessment findings (Zhang et al., 2020b. Zheng et al., 2020). To address these concerns,it is necessary to develop more accurate evaluation models for the research area that can account for these influences. Furthermore, relying solely on economic value to estimate the value of regional ecosystem services fails to capture the worth of intangible services like aesthetic and cultural contributions. Hence, the evaluation results currently fail to accurately depict the full range of service functions and values provided by the study area ecosystem. Consequently, for future research, it is crucial to develop an assessment model that more comprehensively embodies the ecosystem service functions in the study area and aligns with the actual conditions in the study area, for mitigating the influences (Pan et al., 2021).

5. Conclusions

This study utilized the benefit transfer method to assess the ESV of the midstream and downstream regions of the Liaohe River Basin (LHB), and the spatiotemporal distribution of ESV was analysed accordingly. Afterwards, the Geographical detector model was used to measure the contributions of factors that drive the ecosystem service value. The primary findings demonstrated that the Land Use and Land Cover (LUC) structure in the study area was not stable as a result of both ecological destruction and restoration,which were marked by significant human activities. Over the course of the 20-year study period,there was a continuous increase in the expansion of forested and grassy areas of land. LHB The total ESV in LHB area decreased first and then increased, which indicates that the restoration of LHB basin was effective. Moreover, the spatial clustering of ESV in LHB is high, with ESV hotspots mainly concentrated in the western and eastern regions. The intensity of human activity is the main driver of ESV variation.

Declarations

Funding

No funding was obtained for this study

Competing interests

The authors declare that there is no conflict of interest.

Authors contributions

Changgeng Jia

Contributions The idea construction and writing of the paper

Chaoxiang Wei

Contributions Value accounting of ecosystem services in the paper

Kunyu Luo

Contributions Ecological model construction in the paper

Sihui Li

Contributions Related accounting data support

Yu Fan

Contributions Paper guidance and revision.

Data Availability

The datasets used or analysed during the current study are available from the corresponding author on reasonable request.

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Figures

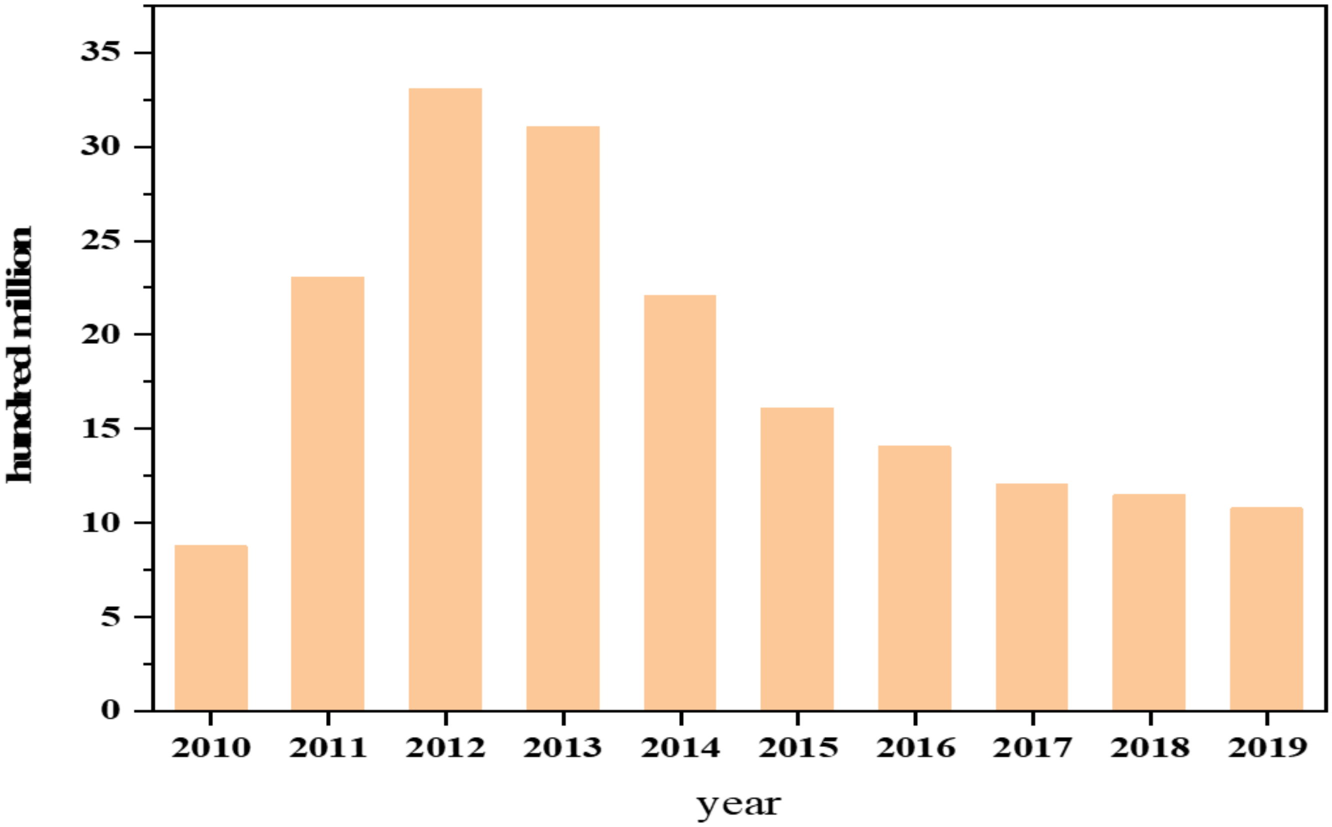


Figure 1

Ecological restoration investment in the Liaohe River Basin

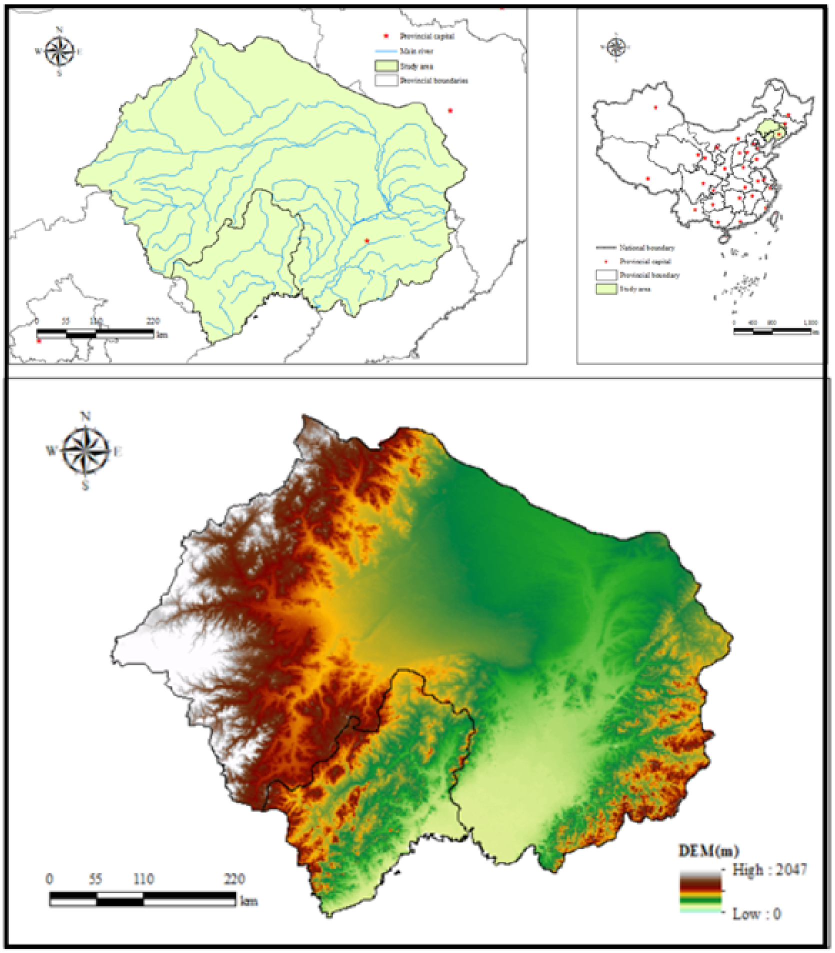


Figure 2

Study area

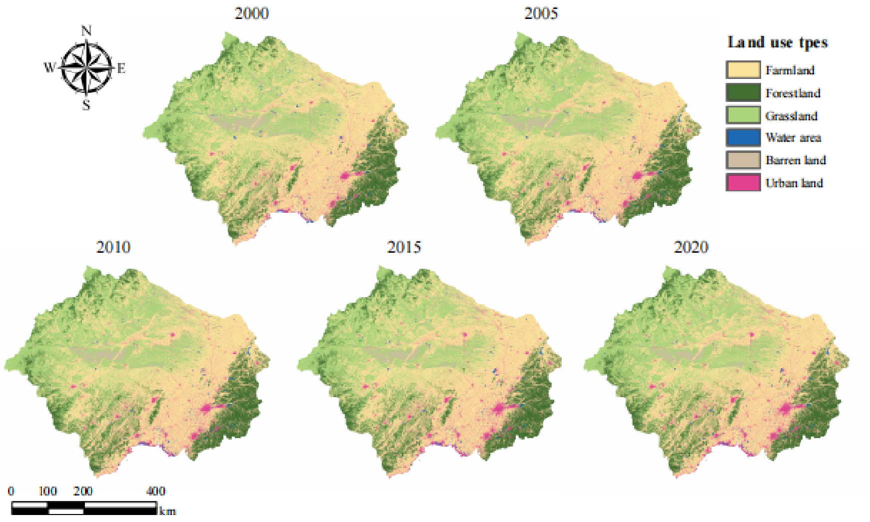


Figure 3

Land use dynamics in the LHB from 2000 to 2020.

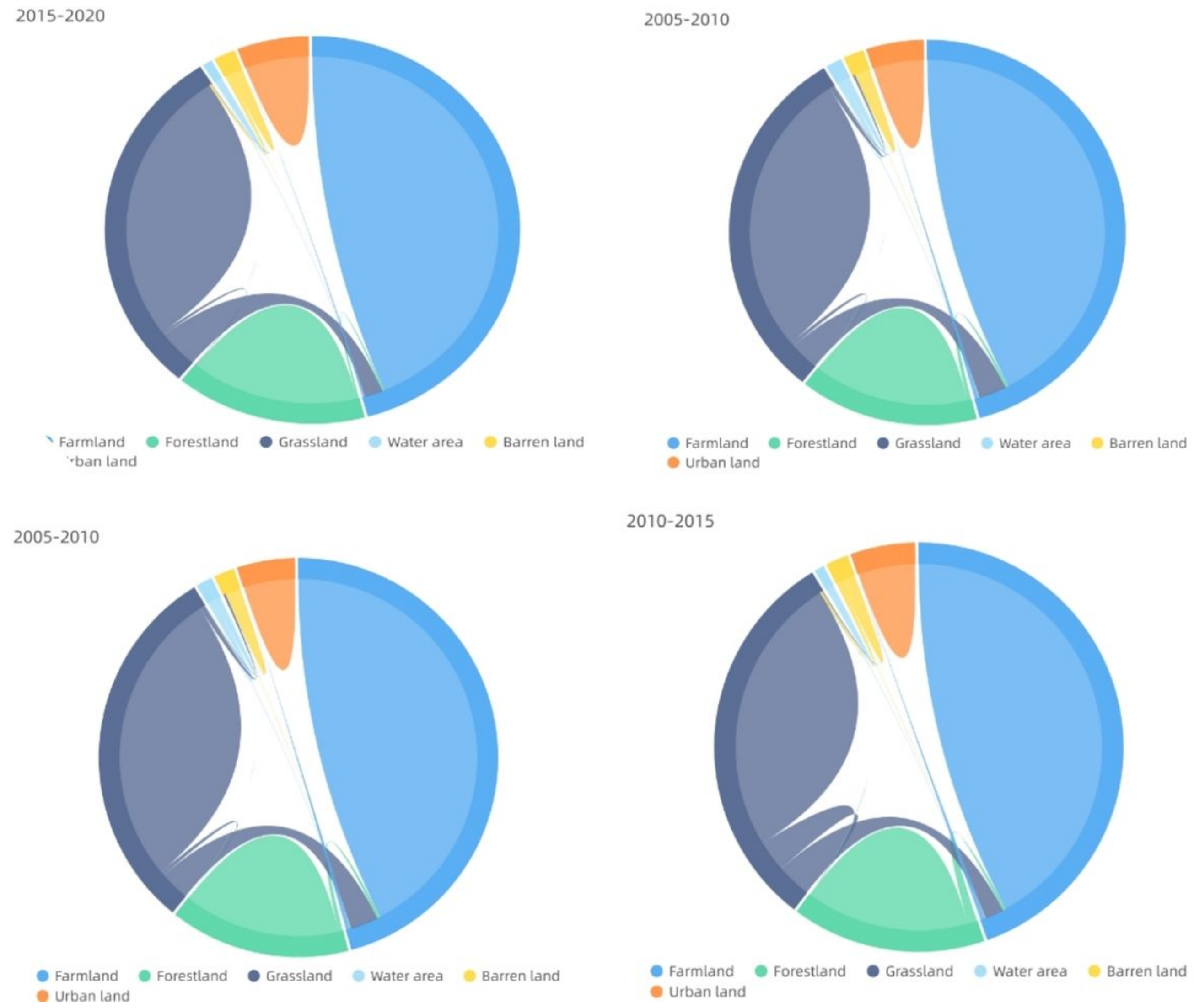


Figure 4

Land use transition of LHB during 2000-2020

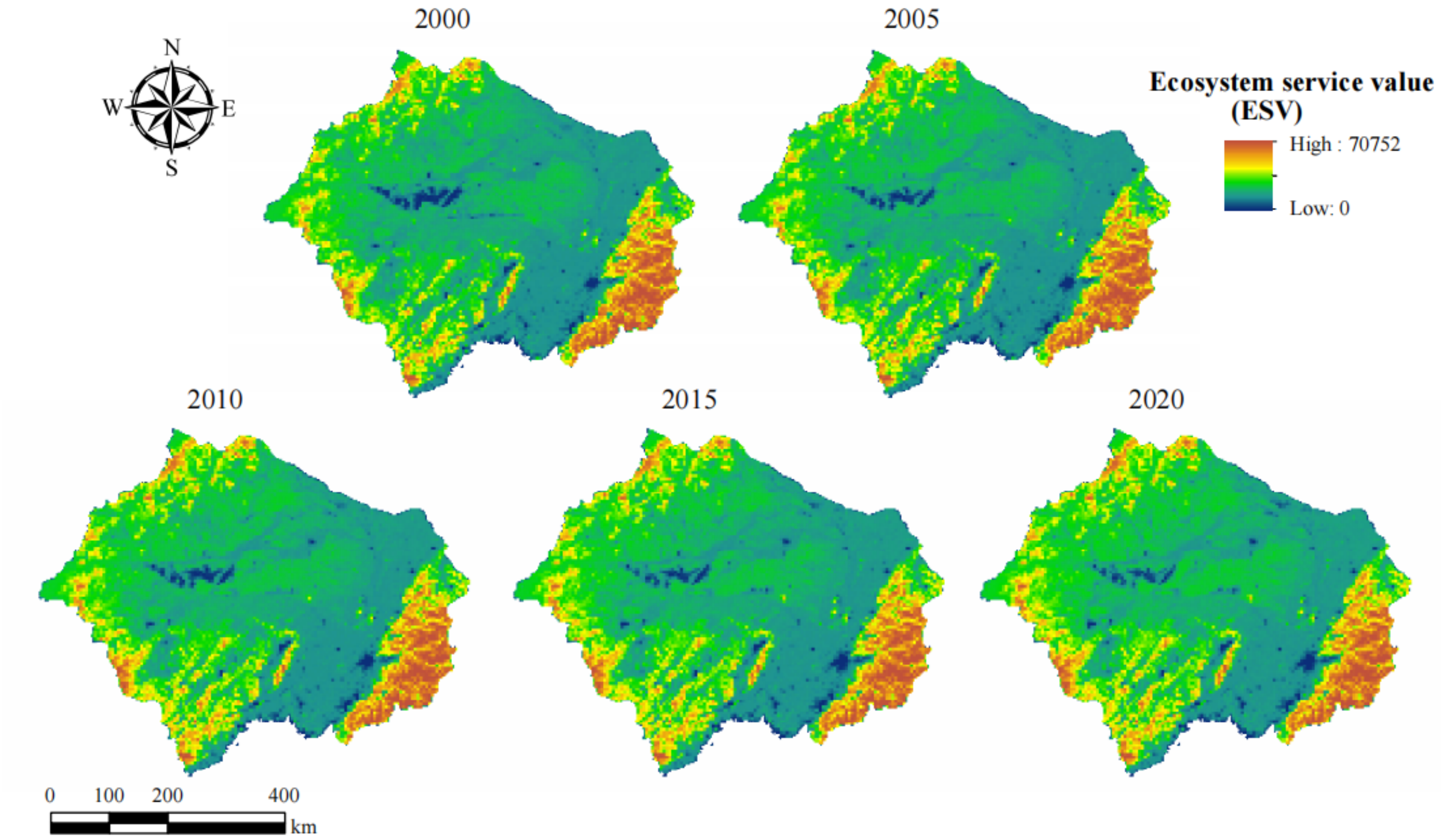


Figure 5

Spatial distribution map of the ecosystem service value

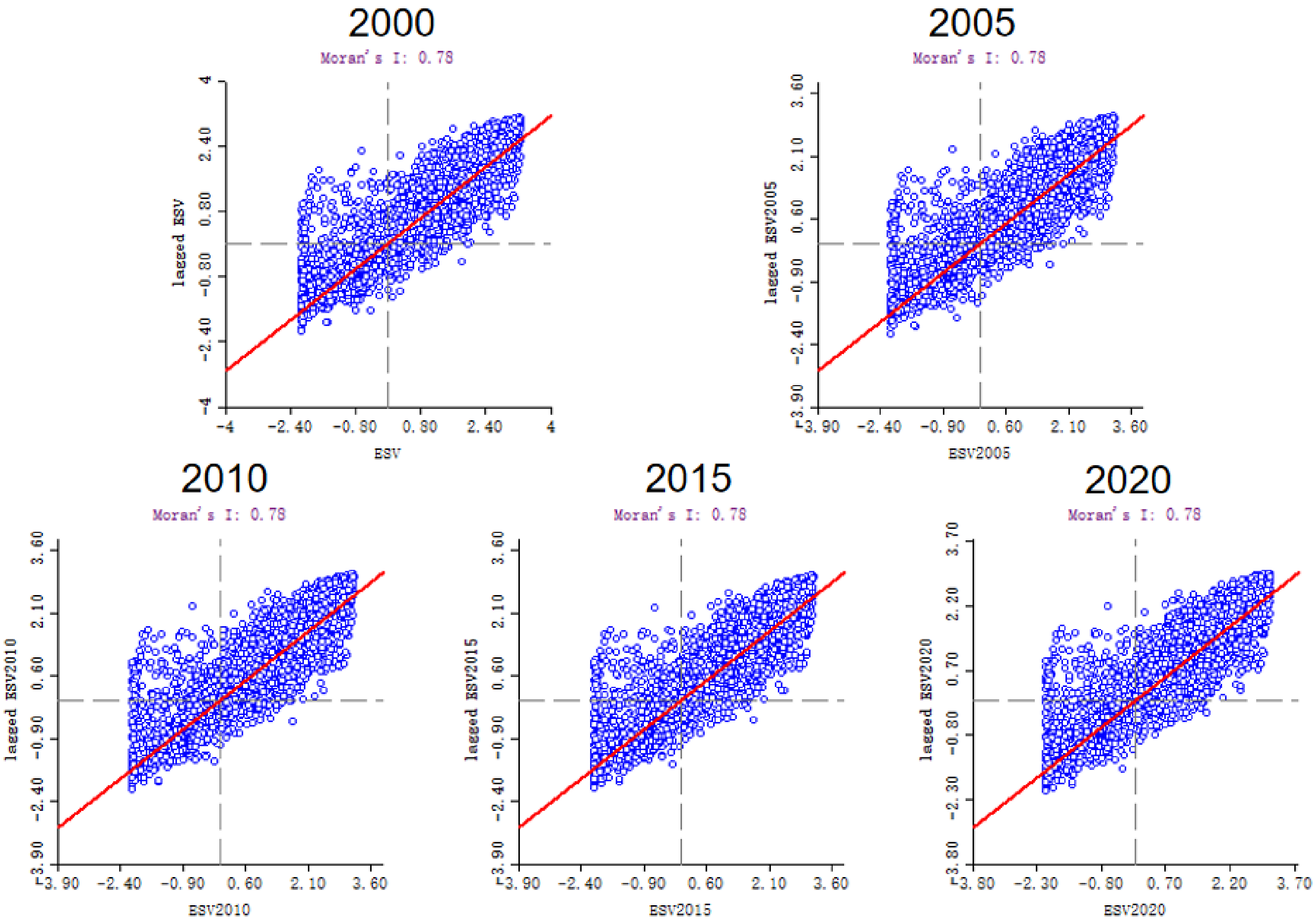


Figure 6

Spatial autocorrelation of ecosystem service in 2000–2020

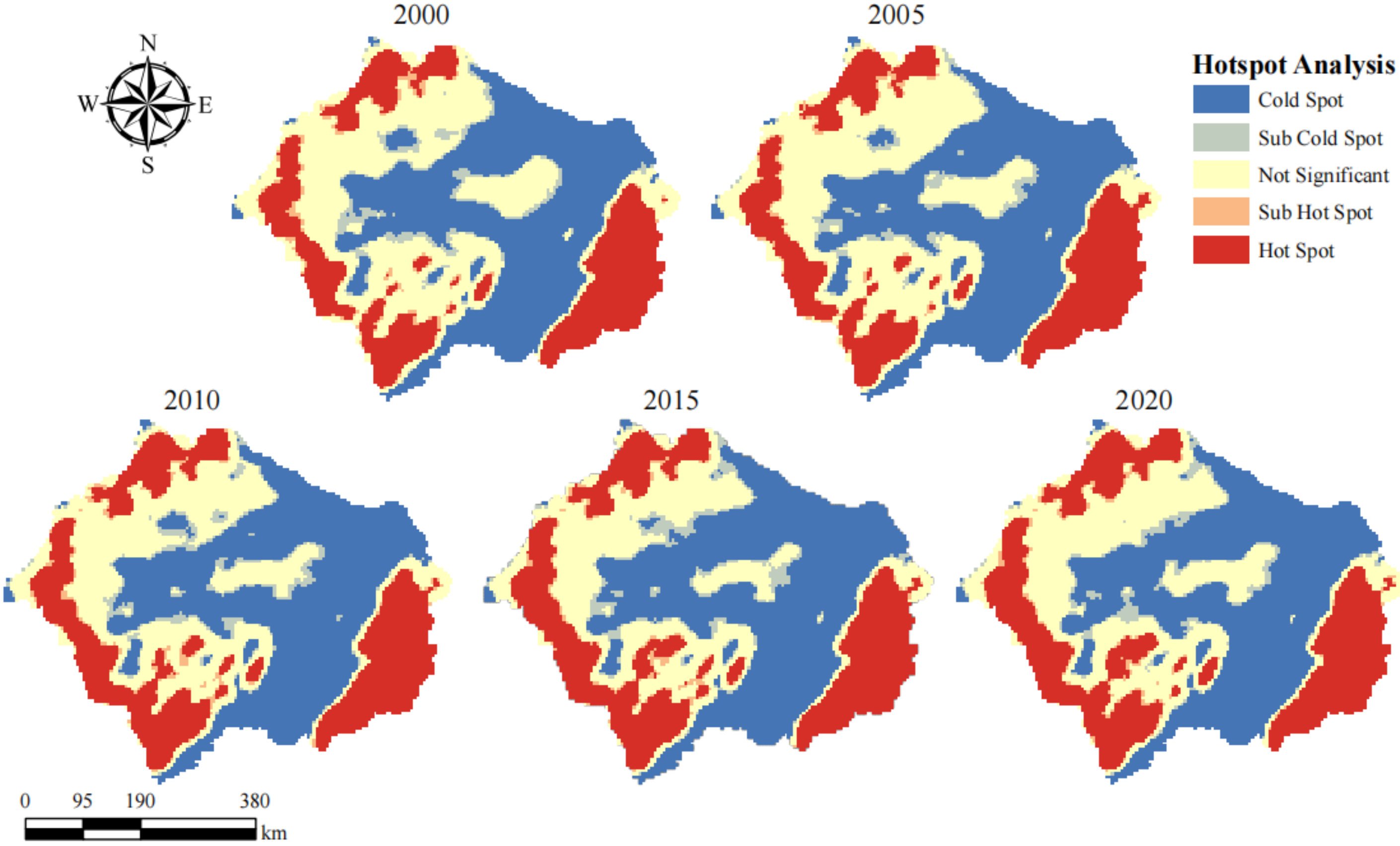
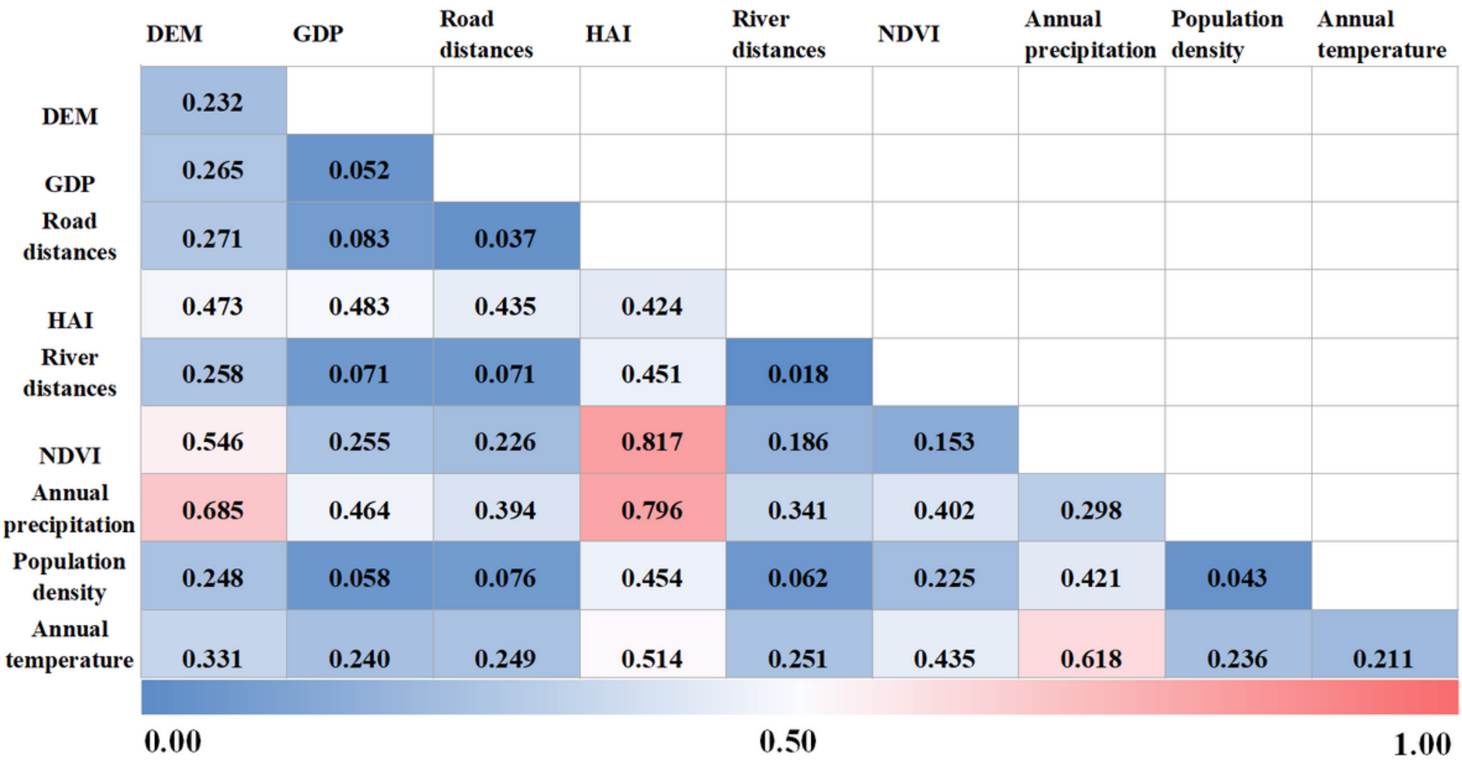


Figure 7

Hotspots of ecosystem services in LHB



	DEM	GDP	Road distances	HAI	River distances	NDVI	Annual precipitation	Population density	Annual temperature
DEM	0.232								
GDP	0.265	0.052							
Road distances	0.271	0.083	0.037						
HAI	0.473	0.483	0.435	0.424					
River distances	0.258	0.071	0.071	0.451	0.018				
NDVI	0.546	0.255	0.226	0.817	0.186	0.153			
Annual precipitation	0.685	0.464	0.394	0.796	0.341	0.402	0.298		
Population density	0.248	0.058	0.076	0.454	0.062	0.225	0.421	0.043	
Annual temperature	0.331	0.240	0.249	0.514	0.251	0.435	0.618	0.236	0.211

Figure 8

Interactive effects between the factors.

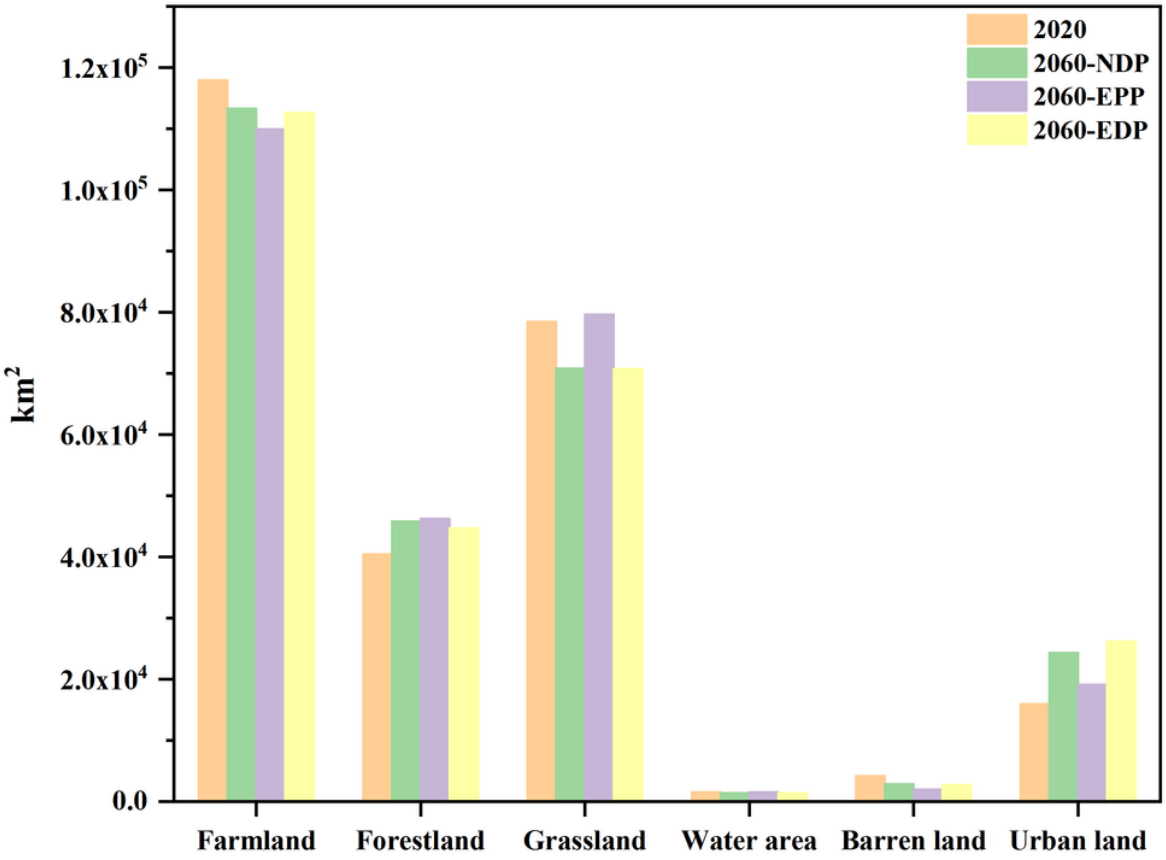


Figure 9

Spatial distribution of land use under three different scenarios in 2060.

Figure 10

The distribution of ESV in LHB projected under different scenarios