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Spatial and Temporal Distribution of the Ecosystem Provisioning Service and Its Correlation with Food Production in the Songhua River Basin, Northeastern China

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Abstract: Provisioning services are essential components of ecosystem services. Food production is usually a driver of land use change, which has the effect on altering the provisioning services of ecosystems. As one of the main areas of food production in China, the provisioning services of the Songhua River Basin (SHRB) should be taken seriously. In view of this, it is urgent to carry out a study on the assessment of provisioning services in the SHRB to provide data support and scientific reference for the optimization of the spatial pattern of land use in the basin, the sustainable development of agriculture, and the formulation of differentiated protection policies. In this study, based on the equivalent factor method for the unit area value and spatial autocorrelation with the Moran's I, we assessed the provisioning services values (PSV) of the SHRB every ten years during the period of 2000–2020 under different land use types and analyzed the relationships between different PSV and the production of four different food types, including rice, wheat, corn, and soja. The main conclusions are as follows: (1) From 2000 to 2020, the area of paddy fields in the SHRB increased and then decreased, while the area of dry lands continued to increase. The land use transfer matrix showed a significant expansion of paddy fields (+0.55 $\times$ 10^4 km^2), shrinkage of grassland (-0.72×10^4 km^2), and loss of water body (-0.43×10^4 km^2) in the SHRB from 2000 to 2020; (2) The PSV in the SHRB showed an increasing trend from 2000 to 2020, growing by 16.73×10^{10} RMB, with the growth in 2010–2020 being greater than in 2000–2010. The order of increase in each type of PSV was: water supply > food supply > raw material supply; (3) Spatially, the increase in PSV per unit and total PSV in the SHRB was lesser in the center and greater in the east and west. Meanwhile, the spatial distribution of various PSV showed that the value of unit area food supply was higher in the central and eastern plains, while the raw material supply and water supply were higher in the western and eastern hilly areas. (4) In terms of spatial correlation, the distribution of soja production with the total PSV, food supply, raw materials supply, and water supply services values were positively spatially correlated. However, the production of rice, wheat, and corn with the total PSV, food supply, and raw materials supply services values were negatively spatially correlated. Cluster analysis revealed that changing the crop cultivation structure could protect the ecosystem and increase the value of ecosystem services.

Keywords: ecosystem provisioning services; land use; food production; value equivalent factor; spatial distribution; Moran's I

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1. Introduction

Ecosystem provisioning services, one of the four main categories of ecosystem services, are relevant to human survival and development because they provide ecosystem goods, including the supply of food, raw materials, and water [1–4]. Food and water are the lifeblood of human society [5]. Although the conversions of natural ecosystems into agricultural and developed areas have led to vast increases in the production of food [6], land use change can cause fragmentation of landscapes [7]. These increase the vulnerability of ecosystems to extreme events and put them at a high risk of disasters [8]. Water is widely acknowledged as a fundamental component of food security. With continuous increases in grain production, China has entered a stage of rapid agricultural development. At the same time, it has caused an increase in pressure on agricultural ecology, soil, water, and other natural resources [9,10]. Natural resources play a key role in human wellbeing, and provisioning services values (PSV) can serve as a useful tool for assessing their importance [11,12]. Quantifying the PSV not only helps to improve public recognition of natural capital and understanding of ecosystem quality and change, but also provides a scientific basis for the remunerative use of ecological resources, related policy formulation, and regional ecological planning [13,14].

Only 135 million hm^2 of arable land is available in China, which is a serious shortage of resources. For the economic and social development of China as well as its national security, food security and self-sufficiency are strategic tasks [15]. China's Black Soil Granary is one of the most famous fertile black soil areas in the world [16,17]. It is a major supplier of commercial grains such as corn and rice in China, accounting for about a fifth of the country's annual grain production. The Songhua River Basin (SHRB) is an important agricultural region in Northeast China and is among the areas of China's Black Soil Granary, using only 3.6% of the country's land area and 3.5% of its total water resources to produce about 18% of the country's cereal output. The problems of black soil erosion and future hydrological drought events in the SHRB are frequent and seriously endanger the social environment. With the economic and social development, the population in the SHRB is increasing rapidly and the problem of food production and water supply are becoming increasingly prominent. Due to the overexploitation of water resources by irrigated agriculture, the average water storage is significantly lower than pre-2000 levels, despite some recovery in the last 20 years [18]. According to the Statistical Yearbook and Water Resources Bulletin in the SHRB (www.slwr.gov.cn, (accessed on 1 August 2023)), the area of cereals sown increased by 7.75×10^4 km^2 and the amount of irrigation water for agriculture increased by 7.47×10^9 m^3 over the period 2000–2020. In 2020, the water supply in the SHRB is 44.91×10^9 m^3, of which 37.27×10^9 m^3 is for agriculture, accounting for over 80% of the water supply. The increase in the regional agricultural areas, agricultural water consumption, and food production have an impact on the amount of water resources available in the region. Food production therefore has a significant impact on regional provisioning services, particularly water supply, and there is a lack of research on the impact of food production on provisioning services in the SHRB. Simultaneously, due to the difference in water and land consumption per unit yield of different crops, while ensuring the growth of grain production, the adjustment of the internal grain planting structure is bound to affect the water and soil resource consumption of China's grain production [19]. The value of ecosystem services changes with the changing land use patterns in the SHRB. The study of food security evaluation in the region mainly starts from the perspective of arable land resources. In addition, the valuation of ecosystem services in the region has mostly focused on the comprehensive ecosystem service value of a section of the basin or the whole region [20]. Fewer studies have examined the provisioning services and food production of the entire basin.

Therefore, in this study, with analyzing and calculating the temporal and spatial distribution characteristics of food, raw materials, and water supply services in the SHRB, Northern China, and their correlation with food production, it attempts to evaluate the influencing factors on food production in the SHRB from the perspective of the ecosystem provisioning service. Our targets were to (1) analyze the land use and PSV from 2000 to 2020 in the SHRB; (2) assess the spatio-temporal dynamics of unit PSV change and total PSV change from 2000 to 2020 in the municipalities of the SHRB; and (3) reveal the impact of different crops on urban PSV and propose effective measures to improve the provisioning services values. The results provide a theoretical basis for scientific research on land use management and food security in the SHRB, Northern China.

2. Materials and Methods

2.1. Study Area

The SHRB is located between 119°52′–132°31′ E, 41°42′–51°38′ N with a drainage area of 55.68 × 10^4 km^2, comprising mainly 25 municipalities in Jilin and Heilongjiang provinces, China, a small part in Liaoning and Inner Mongolia Autonomous Regions, China (Figure 1). The basin is in the cold temperate zone, which is hot and rainy in summer and cold and dry in the winter. The average annual temperature is 3–5 °C and the average annual precipitation is about 500 mm [21]. The soil type in the basin is diverse, while chernozem and phaeozem are more widely distributed, accounting for 8% and 35% of the total area, respectively. The land is fertile, producing rice, corn, wheat, and soybeans. With 13% of the country's land area and 8% of the population, it contributes a quarter of the country's food production.

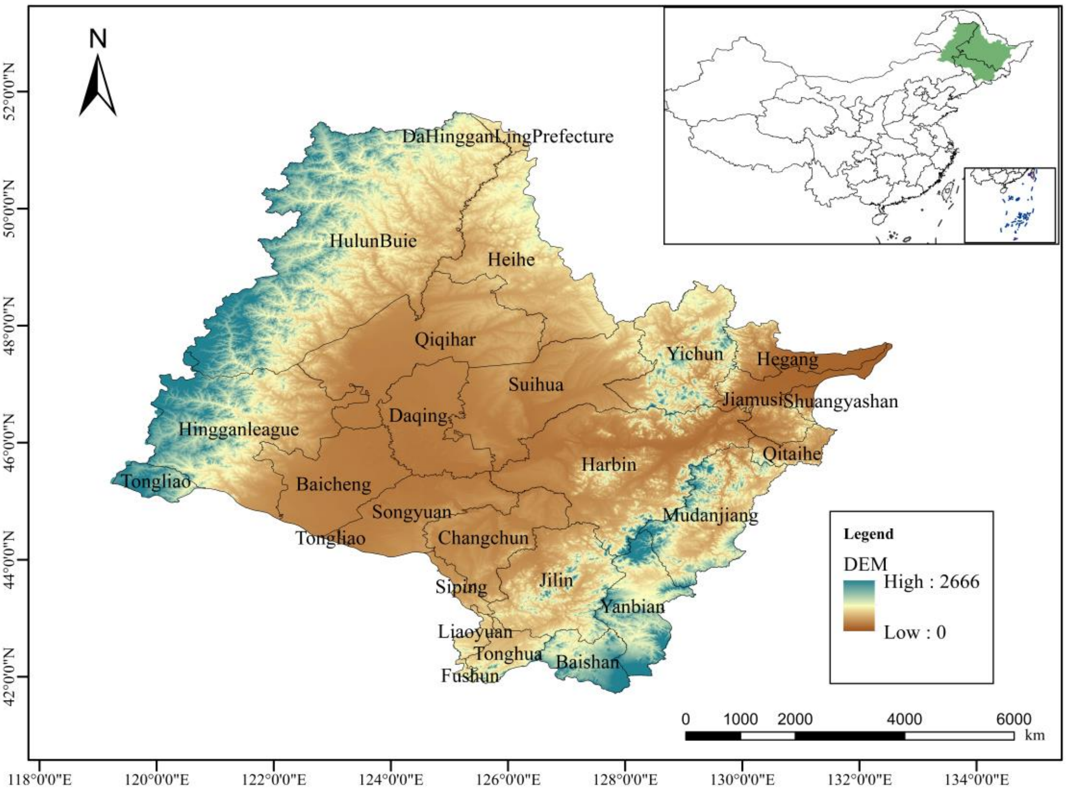

Figure 1. Location of the study area.

2.2. Data Sources

The land use data with a spatial resolution of 1 km are obtained from the Resource and Environment Science Data Centre of the Chinese Academy of Sciences (http://www.resdc.cn, (accessed on 1 December 2022)), including three periods of 2000, 2010, and 2020. The land use types were divided into seven types, namely, forestland, grassland, water body, construction land, bare land, paddy field, and dry land. The crop yield and sown area data for each city in the SHRB are from the 2000, 2010, and 2020 statistical yearbooks of provincial and municipal governments, provided by the local statistical bureaus of Jilin Province, Heilong Province, and Inner Mongolia. The 2020-unit price data of grain comes from the Agricultural Market Information System (AMIS), which is an inter-agency platform.

2.3. Calculation of the PSV

According to the national land use classification standard system, the types of land use in the SHRB are classified into seven primary types. An equivalent factor value (D) is the average annual economic value of grain production for 1 hectare of farmland, which is 1/7 of the national average value of grain in the same year, calculated as [22]:

$$D = \frac{1}{7} \cdot \frac{S}{A} \tag{1}$$

where S is the total economic value of annual crops and A is the annual crop sown area.

The amount of economic value per unit area of the ecosystem service value equivalent factor in the SHRB was calculated to be Chinese Yuan (RMB) 167,624.18/km^2, 42,634.69/km^2, and 933.82/km^2 in 2020, 2010, and 2000, respectively.

The ecological service value (ESV_{ij}, in RMB/km^2/a) of the land corresponding to each raster is accounted for by the formula:

$$ESV_{\text{ij}} = Y_{\text{ij}} \cdot D \tag{2}$$

where Y_{ij} is the ESV equivalence factor for the ijth raster corresponding to the land use type, which was determined based on the table of secondary ecosystem service value equivalence factors in China as modified by Xie et al. [23] and Zhang et al. [20]. The value of PSV per unit area in the SHRB was shown in Table 1.

Table 1. The final value of ecosystem services per unit area in the SHRB.

Land Use Type		Forestland	Grassland	Water Body	Construction Land	Bare Land	Paddy Field	Dry Land
Ecosystem provisioning service	Food supply	0.67	0.22	0.53	0.02	0.00	1.36	0.85
	Raw materials supply	0.35	0.33	0.15	0.03	0.00	0.09	0.40
	Water supply	2.20	0.18	6.25	0.08	0.00	−2.63	0.02

2.4. Moran Index

Spatial autocorrelation is divided into global spatial autocorrelation and local spatial autocorrelation. Global spatial autocorrelation can explore the correlation between variables in the whole study area, while bivariate global spatial autocorrelation analysis can reveal the spatial correlation and significance between different variables in the study area [24]. The bivariate Moran index allows for the assessment of correlation and the degree of difference between the two indicators. The Moran index can be derived from the analysis using GeoDa software 1.20.0 and is therefore used here to assess the spatial correlation between crop acreage and the PSV in the SHRB municipalities. The bivariate Moran index can be calculated between −1.00 and 1.00, with values greater than 0 indicating a good correlation between the two variables. If the calculated Moran index is 0, it indicates that there is no good correlation between the two variables, while values less than 0 indicate a large difference between the two variables.

2.5. Data Analysis

The land use data and municipal boundaries of the SHRB were overlaid using ArcGIS 10.2 to obtain the land use of the municipalities in the SHRB through spatial extraction. GeoDa software 1.20.0 was used for spatial correlation analysis. All data were statistically processed using IBM SPSS Statistics 25, Microsoft Excel 2023, and Origin Lab 2022.

3. Results

3.1. Land Use Change

The land use types in the SHRB are displayed in Table 2, respectively. The highest proportion of forestland is found in the SHRB in 2000, followed by dry land and grassland, while the proportion of water body, construction land, bare land, and paddy field are all below 10%. It is similar in 2020, with the highest proportion of forestland and dry land being at 71.49%. The trend in land use change from 2000 to 2020 is a moderate decrease in grassland and water body and an increase in construction land, bare land, and paddy field, with a decrease in grassland and water body by 1.29% and 0.78%, respectively, from approximately 6.66×10^4 km^2 and 1.50×10^4 km^2 in 2000 to only 5.94×10^4 km^2 and 1.07×10^4 km^2 in 2020. Over the same period, construction land and paddy field increased from nearly 1.37×10^4 km^2 and 2.60×10^4 km^2 in 2000 to 1.66×10^4 km^2 and 3.15×10^4 km^2 in 2020. In addition, forestland and dry land all showed small changes.

Table 2. Land use change in the SHRB (2000–2020).

Year	**2000**		**2010**		**2020**	
Land Use Type	**Area (10^4 km^2)**	**Percent (%)**	**Area (10^4 km^2)**	**Percent (%)**	**Area (10^4 km^2)**	**Percent (%)**
Forestland	21.88	39.44	21.85	39.40	21.54	38.90
Grassland	6.66	12.01	6.66	12.00	5.94	10.72
Water body	1.50	2.71	1.49	2.69	1.07	1.93
Construction land	1.37	2.47	1.40	2.52	1.66	3.00
Bare land	3.62	6.53	3.56	6.42	3.98	7.18
Paddy field	2.60	4.69	2.58	4.65	3.15	5.68
Dry land	17.82	32.13	17.92	32.32	18.05	32.59

For land use transfer (Table 3), throughout the whole study period the area converted from grassland to forestland, dry land, and bare land in 2000 to 2020 is 163.55, 109.84, and 63.22 km^2, respectively. Water body is mainly converted to bare land, with an area of 37.09 km^2. Dry land in 2020 is mainly converted from forestland and grassland in 2000, with an area of 200.93 km^2 and 109.84 km^2, respectively, while the increase in construction land is mainly converted from dry land. This may be driven by population, social, and economic factors. Rural areas have increased the demand for cultivated land, resulting in the reverse ecological process of converting forestland and other ecological land into dry land. With the acceleration of urbanization and the expansion of urban area, the process of converting dry land into construction land has also occurred. The decrease in grassland and the increase in paddy field and dry land may be due to the degradation of grassland caused by overgrazing and anthropogenic mowing, resulting in the conversion of grassland to wetland, which is reclaimed and turned into farmland.

Table 3. Land use transfer of the SHRB from 2000 to 2020 (unit: km^2).

2000	**2020**						
	Forestland	**Grassland**	**Water Body**	**Construction Land**	**Bare Land**	**Paddy Field**	**Dry Land**
Forestland	1737.32	137.64	12.01	11.60	67.52	18.11	200.93
Grassland	163.55	303.25	6.44	8.51	63.22	10.33	109.84
Water body	9.12	7.08	49.32	3.34	37.09	13.99	28.11
Construction land	9.80	6.19	2.36	27.61	3.25	11.27	76.63
Bare land	45.70	38.54	11.79	6.82	151.15	22.83	84.84
Paddy field	18.13	3.50	5.02	15.07	6.70	135.65	75.73
Dry land	170.17	97.53	19.78	93.05	68.51	102.32	1228.33

3.2. Variations in the PSV of the SHRB

The provisioning services and its three secondary categories are listed in Table 4. The total PSV of the SHRB increased significantly, from 0.10×10^{10} RMB in 2000 to 16.83×10^{10} RMB in 2020. We can see that the PSV had an increasing trend during

2000–2010 (4.39×10^{10} RMB) and 2010–2020 (12.34×10^{10} RMB). Regarding the three secondary categories, the values of services were all increased for food supply, raw materials supply, and water supply in the period of 2000–2020. Developments in science and technology have increased the productivity of the land and, as a result, crop yields have increased dramatically.

Table 4. PSV change in the SHRB from 2000 to 2020.

Ecosystem Services	PSV (10^{10} RMB)			PSV Change (10^{10} RMB)		
	2000	2010	2020	2000–2010	2010–2020	2000–2020
Provisioning services	0.10	4.49	16.83	4.39	12.34	16.73
Food supply	0.03	1.52	6.02	1.49	4.50	5.99
Raw materials supply	0.02	0.74	2.87	0.72	2.13	2.85
Water supply	0.05	2.23	7.94	2.18	5.71	7.89

Figure 2 displays the spatial distribution of the PSV per unit in 2000, 2010, and 2020, as well as the total PSV changes in 2000–2010, 2010–2020, and 2000–2020 in the SHRB at the city scale. These distribution patterns varied among the 25 cities in the SHRB (there are 28 cities in total, but 3 of them have very little area within the Songhua River Basin, so they will not be analyzed here). In 2000, 2010, and 2020, the distribution patterns of low PSV per unit were the same, and were concentrated in the Songnen Plain, such as Qiqihar, Baicheng, and Changchun. The high PSV per unit were mainly distributed in the eastern and northwestern mountainous areas of the SHRB. During the three periods, the lowest PSV per unit were found in the Baicheng city, with 44,807.99 RMB/Km^2 in 2010 and 167,366.47 RMB/Km^2 in 2020, respectively. The highest PSV per unit were found in the Baishan city, with 2753.71 RMB/Km^2, 125,155.95 RMB/Km^2, and 506,017.25 RMB/Km^2, respectively.

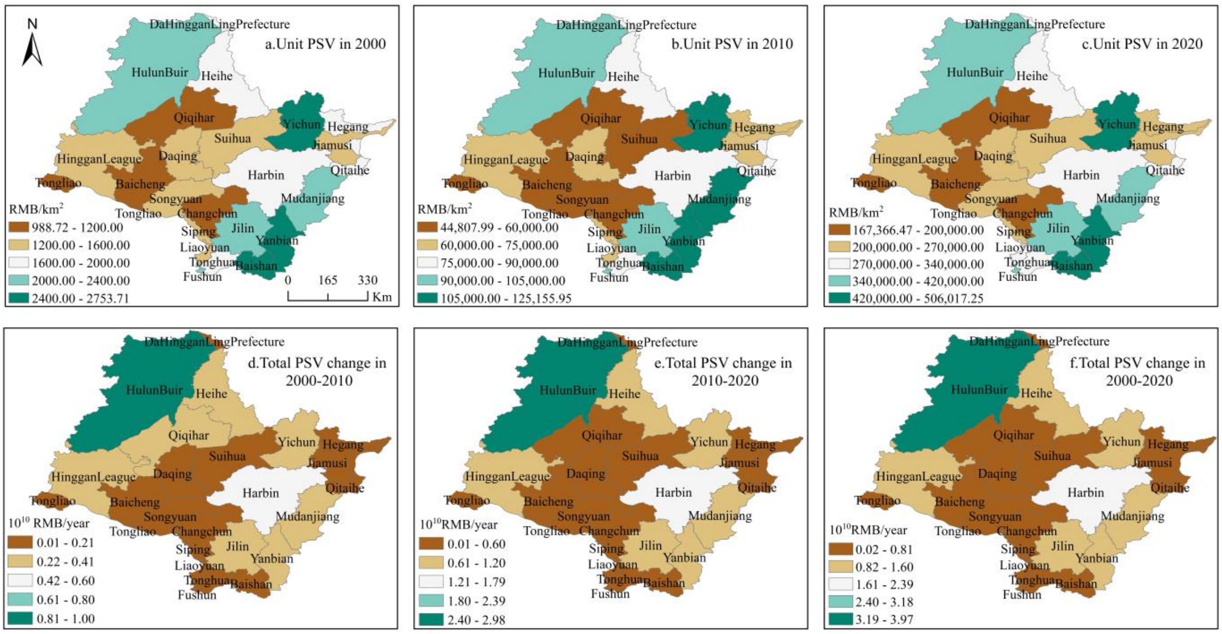

Figure 2. The PSV per unit and total PSV change in the SHRB from 2000 to 2020.

In terms of spatial variations during the entire period (2000–2020), the total PSV in all 25 cities showed an increasing trend. There was a lesser increase in the central plain area of the SHRB and a greater increase in the eastern mountains and western mountain–plain transition zone areas. Changes in the total PSV between 2000 and 2010 were relatively small, and while all cities saw increases in the total PSV, only one city in the eastern region of the SHRB saw an increase of more than 0.80×10^{10} RMB. The total PSV in the SHRB from 2010 to 2020 were generally consistent with the trend of increase from 2000 to 2020, with smaller increases in the total PSV in the central plains of the watershed, and larger increases in the eastern mountainous and western mountain–plain transition zones.

3.3. Spatial Distribution of Secondary Categories of the PSV and Their Change

Changes in the value of secondary categories of provisioning services by unit area of the SHRB are shown in Figure 3. The value of food supply per unit area increased significantly from 2000 to 2020, with the value of food supply in the central and eastern regions higher than that in the west. This is mainly due to the flat terrain and fertile soil in the central region, coupled with scientific and technological progress as well as national policy support in guaranteeing agricultural water security, combating soil erosion problems, and protecting black soil resources. During the period 2000–2010, the Harbin and Changchun cities, as the provincial capitals of the Heilongjiang and Jilin provinces, experienced rapid urbanization, which required a large amount of land, and part of the arable land was converted into construction land, so the value of food supply service has declined to some extent. In contrast, the spatial distribution pattern of the value of raw material supply and water supply services per unit area in the cities in the basin was opposite to the distribution of food supply, which was low in the central region and high in the east and west. It is worth noting that the value of water supply service of Qiqihar city in 2020 was −1014.42 RMB. The negative value of water supply service in 2020 may be since the water body of Qiqihar city has shrunk, and more than half of the transferred area of water body has been reclaimed as paddy field and dry land, and the ESV equivalent coefficient of the paddy field is negative. In addition, the application of fertilizers and pesticides on agricultural land will easily increase the pollution load of water sources.

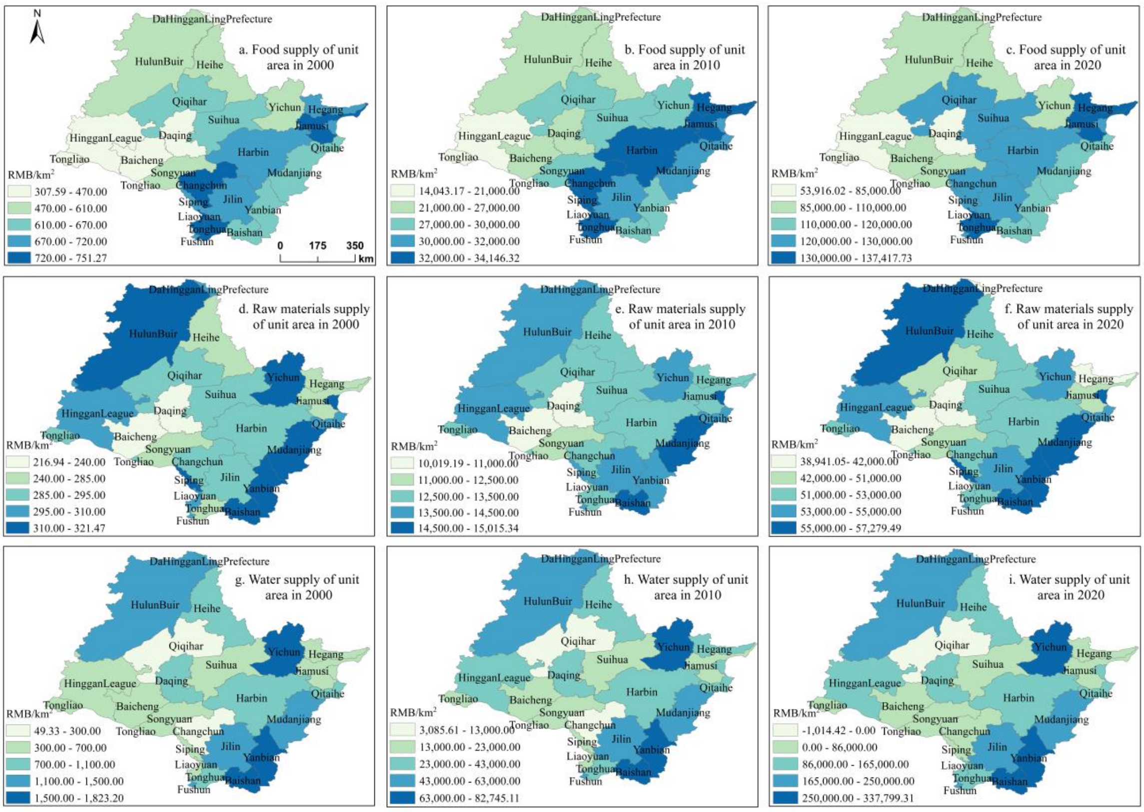

Figure 3. The values of the unit area of food supply (**a**–**c**), raw materials supply (**d**–**f**), and water supply (**g**–**i**) in the SHRB from 2000 to 2020.

3.4. Correlation between the PSV and Food Production

To clarify whether food production has significantly affected the PSV, a bivariate spatial autocorrelation analysis was conducted using the unit area yield of major crops in the SHRB in 2020 with provisioning services and three secondary categories. Table 5 shows the global bivariate Moran index between the PSV and farmland production of unit area in the SHRB in 2020. The results showed that the Moran index was mostly less than 0, indicating a weak negative spatial correlation. The index of soja unit area production with the total PSV, food supply, raw materials supply, and water supply services values were greater than 0, indicating a weak positive spatial correlation.

Table 5. Bivariate Moran index for the SHRB in 2020.

Major Crops	Rice	Wheat	Corn	Soja
Total PSV	−0.016	−0.028	−0.086	0.091
Food supply	−0.093	−0.014	−0.087	0.024
Raw materials supply	−0.032	−0.097	−0.088	0.066
Water supply	0.006	−0.02	−0.064	0.084

However, the global Moran index is unable to estimate the spatial autocorrelation structure. Anselin [25] proposes a local Moran index that can test for local area spatial correlation: bivariate local spatial autocorrelation LISA clustering plot based on a z-test (p = 0.05). Figure 4 shows the cluster analysis of food supply, raw materials supply, and water supply in relation to the unit area production of rice, wheat, corn, and soja for each region of the SHRB. There is no spatial autocorrelation between the production of the four crop types and food supply in the majority of the SHRB. However, in terms of raw material supply, the relationship between production and services for the four crop types in the northwestern part of the basin shows H-L, and the H-L for water supply occurs in the southwestern part of the basin. Therefore, from the point of view of food supply, the production of the four crops does not affect it in most areas of the SHRB. The northwestern part of the basin is not suitable for crop cultivation in terms of raw material supply. And for the southwestern part of the basin, the water supply is not sufficient to support food production. Based on the spatial relationship between the two variables, if the PSV of the ecosystem in some municipalities in the SHRB are to be increased, it can be tentatively concluded that changing the crop cultivation structure can increase the supply service value, e.g., the Hinggan League should reduce the cultivation of all four crops. As an important forest and agricultural area in China, the Hinggan League is rich in forest and grassland resources, and its natural resource assets are mainly ecological assets [26]. Improvements in technology and agricultural practices have led to increased crop yields, while crop selection is also important. Other studies have also shown that food production varied considerably with future land use choices and management, and that maintaining food and water quantities can be difficult. Future changes may lead to significant trade-offs and even lose-lose outcomes across the range of situations studied [27].

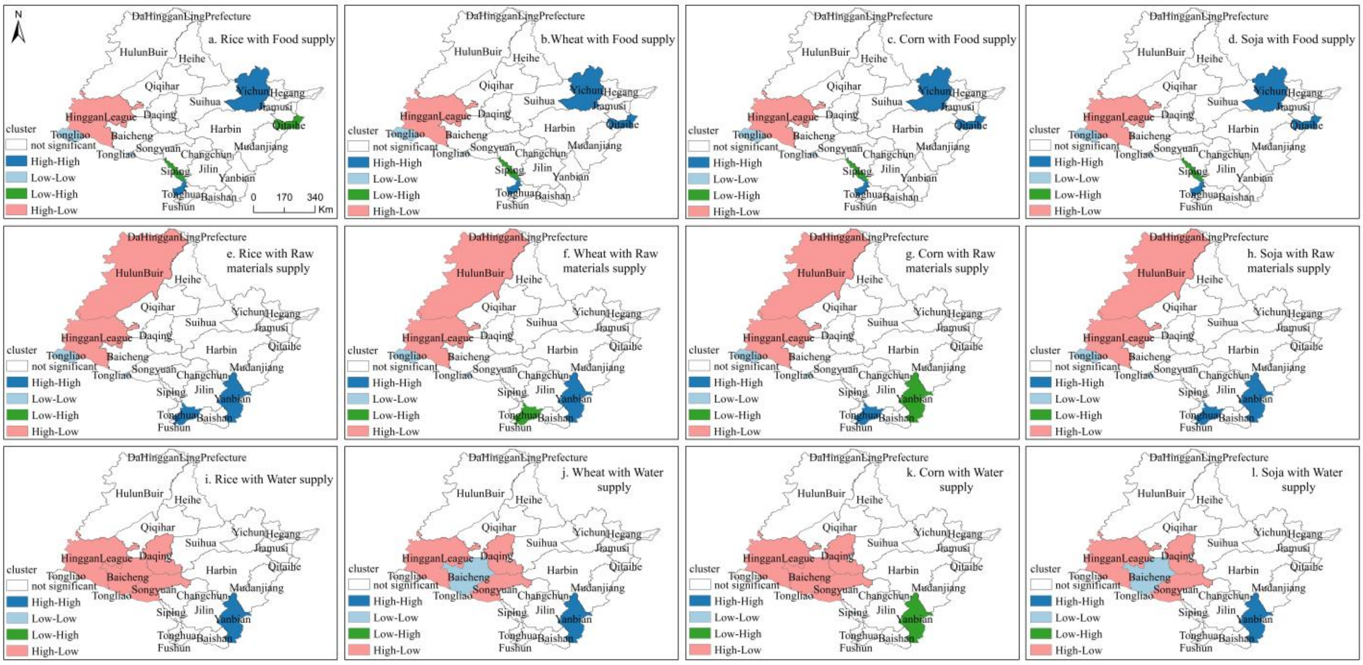

Figure 4. Bivariate LISA distribution map in the SHRB at the city scale.

4. Discussion

4.1. Impacts of Climate Change on the PSV and Food Supply

Climate change affects ecosystem service provisioning mainly through direct or indirect. Climate change directly affects services such as water supply, food supply, carbon sinks, net primary productivity (NPP), and biodiversity distribution [28,29]. Millennium Ecosystem Assessment recognizes that climate change is causing a downward trend in the level of provisioning of most ecosystem services. It has been suggested that climate change affects global food production, and that global warming has made precipitation in the semiarid subtropical regions increasingly scarce, which has led to a decline in food production capacity in the region [30]. Briner [31] et al. found that climate change has a greater impact on the function of food production in high-altitude areas, while the middle- and low-altitude areas are mainly affected by land use changes driven by economic interests. One study analyzed the impact of climate change on crop production and income in Japan and found that climate change reduced rice production and farmers' income in the eastern and northern parts of Japan, but increased rice production and farmers' income in the western part [32].

It has been shown that climate change has a significant impact on ecosystem water conservation and soil retention functions and is a major driver of water yield and soil retention enhancement [33]. However, due to global warming, the frequency and intensity of extreme weather events are increasing globally and regionally, which will profoundly affect the structure and functioning of ecosystems in various places, thus negatively affecting ecosystem services [28]. Studies on the impacts of climate extremes on ecosystem services have mostly focused on the impacts of extreme precipitation, drought, and high temperatures. For example, although extreme precipitation leads to an increase in water supply services [34], it reduces food supply functions due to soil erosion and soil degradation. In 2022, the SHRB also encountered heavy precipitation events, and many farmlands were heavily waterlogged, severely affecting food production. To cope with extreme weather, research and management of soil erosion management can be carried out on a watershed basis, and research on soil erosion management techniques and mechanisms in black soil areas can be strengthened. On a watershed basis, dynamic monitoring of soil erosion and erosion gully management can be systematically carried out, the construction of small watersheds and irrigation areas in black soil areas can be accelerated, small-scale farmland water conservancy infrastructure can be improved, and the configuration of farmland protection forest networks can be optimized.

4.2. Ecological Effects of Different Land Use Types

The ecological effects of land use change in the SHRB are of two kinds: enhancing and reducing ecosystem services, thus showing that different types of land use change have different ecological effects [25,26]. As arable land is converted into forestland and grassland, the main ecological improvements are achieved, while forestland, grassland, and water bodies are negatively affected, mainly in the form of forestland and grassland into arable land and water bodies into bare land. It is worth noting that grassland degradation is severe in the SHRB due to the massive replacement of grassland by dry land and bare land. There is a growing conflict between the supply of agricultural products and the shortage of pasture, both of which result from the mismanagement of overgrazing and reclaimed grasslands [35]. Thus, it is necessary to improve the black soil conservation system integration program for the black soil farming system, soil-type characteristics, and environmental obstacle factors in different regions. For example, the eastern and central parts of the basin should pay full attention to the problem of grassland degradation caused by overgrazing and reclamation. Unplanned reclamation and encroachment of grasslands and water bodies to grow crops, especially rice, will not only reduce vegetation cover, but also negatively affect the value of ecosystem services in the central part of the Songhua River Basin. More action is needed to optimize crop cultivation structures and to protect the degraded grassland and water body. For the SHRB, different types of land use, especially cropland and forestland, need to be spatially optimized for food-friendly land with full consideration of their ecosystem service value. A focus can be put on the healthy evolution process of cropland systems in the SHRB, adopting the strategy of protecting the health of cropland systems through the principles of "fallow", "rotation", "conservation", "retreat", and "comprehensive management", to provide an important guarantee for the sustainable utilization of cropland.

4.3. Impact of Cropping Systems on the PSV and Food Supply

Due to population growth and economic development, urbanization intensified, putting great pressure on land [36,37]. In the 13th Five-Year Plan, as part of its efforts to encourage the development of two urban agglomerations in the northeast, Harbin–Changchun and south-central Liaoning, the state is strongly supporting them [38], resulting in a serious occupation of arable land for construction around large- and medium-sized cities such as Harbin and Changchun. A combination of precipitation variability and vegetation degradation has been causing serious problems in recent years [39]. There is a decrease in grassland quality, a decrease in carrying capacity, and a decrease in soil and water conservation. Artificial grass cutting transforms grassland into wetland, which is then reclaimed as paddy fields or drylands. As marsh wetlands disappear and artificial wetlands increase, it is primarily due to food shortages.

In particular, the results show that the total PSV of the SHRB in the 2000–2020 period increased by 16.73×10^{10} RMB. This is mainly because the direct economic benefits are derived from the physical material goods created by the provisioning services. The centralized distribution of farmland in the central and eastern regions is the main area for food and raw material supply. The value of provisioning services in the mountainous areas in the east and west mainly derives from the raw material supply of forests. The value of food supply of farmland and the raw material supply of forests and grasslands in the western agro-pastoral ecotone are the main sources of the value of provisioning services. At the same time, we found during our fieldwork that human activities in the Songnen Plain strongly affect the degradation of grassland, mainly reclamation, grass cutting, overgrazing, etc. (Figure 5). And farmers' participation in the conservation of biodiversity and its services is crucial for agricultural production. So, farmers can firstly actively participate in publicizing and educating rural grassroots environmental protection laws, regulations, and ecological knowledge, recognize rural ecology, understand the urgency and importance of ecological protection, and enhance their awareness of ecological protection. Secondly, they can protect the farming cultural heritage, by insisting on fewer demolitions and more changes, cautiously cutting down trees, prohibiting digging up mountains and not filling in lakes, respecting the rural texture, and forming a harmonious unity of mountains, water, forests, fields, and lakes. Then, they can use seed banks and traditional farming techniques to promote local crop diversity and guarantee food security. Finally, they can learn traditional techniques that are resource-saving, ecologically conserving, and environmentally friendly, and combine them with modern agronomy, incorporating mechanized, automated, informatized, and intelligent means.

Figure 5. Anthropogenic grass cutting in the SHRB has resulted in grassland converting to bare land, and bare land converting to farmland.

4.4. Limitations

This paper used a land use map with a 1 km resolution remote sensing image. In subsequent studies, higher resolutions can be used to improve the accuracy of the findings. Secondly, in this paper we have chosen three years of data: 2000, 2010, and 2020. In future studies, the conclusions can be made more convincing by lengthening the time scale. Thirdly, while this study has explored the spatial and temporal variation in PSV and the relationship between PSV and food production, the mechanisms have not been studied in detail. Finally, this study only examines the relationship between food production and the PSV in the SHRB from the city scale. In the future, we will consider the relationship between food production and other ecosystem services.

5. Conclusions

This study shows the changes in land use and the PSV during the last 20 years and the correlation between food production and PSV in the SHRB. The results show a significant expansion of paddy fields (+0.55×10^4 km^2), shrinkage of grassland (-0.72×10^4 km^2), and loss of water body (-0.43×10^4 km^2) in the SHRB from 2000 to 2020. At the same time, the total PSV show an increasing trend, increasing by 16.73×10^{10} RMB in 2000–2020. The high values are found in the western and eastern portions of the SHRB for both unit PSV and total PSV. From 2000 to 2020, the value of secondary categories of provisioning services by unit area increases in most cities in the SHRB. A specific analysis of the value of the three provisioning services, in terms of the value of food supply, finds that the value is higher in the central and eastern plains than in the western region. In contrast, the value of raw material supply and water supply are higher in the east and west and lower in the central region. In the spatial autocorrelation relation, from the point of view of food supply, the production of the four crops does not affect it in most areas of the SHRB. The northwestern part of the basin is not suitable for crop cultivation in terms of raw material supply. And for the southwestern part of the basin, the water supply is not sufficient to support food production. Although the method used in this study was relatively limited, it provided a viable reference for scholars studying the ES and the ESV.

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