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RESEARCH ARTICLE

Land use transformation and eco-environmental effects based on production-living-ecological spatial synergy: evidence from Shaanxi Province, China

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Abstract

The research on land use transformation has attracted more and more attention, and there are few research results on the eco-environmental effects of regional land use change from the perspective of land use function transformation. From the perspective of production-living-ecological land use function classification, this paper obtained land use change data of Shaanxi Province in 2000, 2010, and 2020, calculated the land use transfer matrix, ecological environment quality index, and ecological contribution rate of land use transformation, and quantitatively analyzed the temporal and spatial evolution of production-living-ecological spaces and the eco-environmental effects of land use structure transformation in Shaanxi Province. The results showed that the land use change in Shaanxi Province is mainly manifested in the continuous increase of ecological and living land area and the continuous decrease of production land area from 2000 to 2020. In the transformation of land use structure in Shaanxi Province, the biggest change in area is the mutual transformation between productive cultivated land and ecological grassland land. The occupation of ecological grassland land by other land types is an important factor leading to the decline of ecological environment quality. Overall, the ecological environment of Shaanxi Province has shown a trend of improvement in the past two decades. Quantitative research on the transformation characteristics of land use structure and its ecological environment effects in the past two decades is conducive to providing data support for the promotion of ecological civilization construction in Shaanxi Province.

Keywords Production-living-ecological spaces · Land use transformation · Eco-environmental effect · Shaanxi Province

Introduction

In recent years, the research on land use transformation has attracted more and more attention (Asabere, et al. 2020; Yao and Tian, 2020; Das and Angadi, 2020). It mainly involves the theoretical basis and research framework of land use transformation and the relationship between rural land use transformation and urban–rural development, resources, and environment effects (Zhao, et al. 2020; Wynn,et al. 2020). Among them, due to a series of environmental problems in the process of land use leading function transformation, the impact of land use transformation on ecological environment has become one of the important research directions (Zhao et al. 2018; Yang and Li, 2020; Basheer, et al. 2020). The existing research mainly focuses on the macro scale, mostly in river basins, provinces, and cities (Lorenzen, et al. 2020; Dong, et al. 2020; Huang, et al. 2020). Transfer matrix, ecosystem service value evaluation, spatial econometric regression analysis, and landscape pattern index are used to study the environmental effects caused by land use transformation (Mumtaz, et al. 2020; Yang and Li, 2020; Abramowicz, et al. 2021). There are few research results on the eco-environmental effects of regional land use change from the perspective of land use function transformation.

The research on eco-environmental problems originated from the rapid spread of cities, the decline of environmental quality, and the harm to human health caused by the industrial revolution (Gang, et al. 2010). After the occurrence of this problem, a large number of scholars are aware of

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its harm and are committed to studying the ecological and environmental problems caused by urban expansion. The research elements have gradually developed from a single to diversified research on the ecological and environmental effects based on land use transformation (Liu, et al. 2007; Zhao et al. 2022). The collaborative study of land use transformation and eco-environmental effects has become a key issue in this field (Coetzer, et al. 2013; Yang et al. 2015). The change of ecological environment caused by land use transformation is one of the important contents of studying the sustainable development of global ecological environment. The urban spatial expansion mode at the expense of agricultural cultivated land will inevitably cause irreversible damage to the ecological environment. The balanced development between the two is the basis of urban sustainable development. The eco-environmental effects caused by land use/cover change directly affect human well-being and are related to the coordinated development of society, economy, and environment (Wang, et al. 2010; Yang et al. 2018). There are two kinds of studies on the eco-environmental effects caused by land use change. The first is to study the single factor ecological environment caused by land use change, such as the impact of land use change on environmental factors (Yang et al. 2019; Han, et al. 2021). The second is to analyze the comprehensive eco-environmental effects caused by land use change on a national or regional scale, mainly including landscape pattern index analysis, ecosystem service value estimation, and ecological risk assessment (Basu and Das, 2021).

The Chinese government has set the development goal of "promoting intensive and efficient production space, appropriate living space and beautiful ecological space." Coordinating production-living-ecological spaces has become an important basis for optimizing the rational allocation of land resources and the construction of ecological civilization (Yang, et al. 2020). The land space development mode has changed from the production space to the coordinated mode of production-living-ecological spaces (Wang, 2021). One of the manifestations of land use transformation is the transformation of the leading functions of land use, namely, the transformation between the three leading functions of production, ecology, and living of land use (Sanchez and Leakey, 1997; Deal and Schunk, 2004; Rerkasem et al. 2009; Amin and Helmi, 2021). It is a dynamic process of quantitative and spatial reconfiguration of limited land resources among various leading functions (Groot, 2006; Vivcharenko, 2019). The transformation of land use function has a far-reaching impact on the structure, function, and ecological process of regional ecosystem (Hitchcock, 2014; Yang et al. 2021). Studying the ecological environment effect of land use function transformation is one of the methods to understand and predict the quality and change characteristics of regional ecological environment (Lax, et al. 2017). Exploring the coordination mechanism between land use transformation and eco-environmental protection management, clarifying the relationship between eco-environmental protection and economic sustainable development under production-living-ecological space, and exploring the path of Shaanxi Province to promote ecological protection and high-quality development of the Yellow River Basin can provide reference for China's ecological security construction.

The theoretical significance of this paper is to construct the eco-environmental quality index of production-living-ecological spaces in order to enrich the research methods. Moreover, the secondary classification of land use with high eco-environmental resolution is proposed to further develop the theory of land use classification. The practical significance of this paper is to provide quantitative and targeted decision-making space for the establishment of effective ecological environment protection and high-quality development in Shaanxi Province.

From the perspective of production-living-ecological land use function classification, this paper obtained land use change data of Shaanxi Province in 2000, 2010, and 2020, calculated the land use transfer matrix, ecological environment quality index, and ecological contribution rate of land use transformation, and quantitatively analyzed the temporal and spatial evolution of production-living-ecological spaces and the eco-environmental effects of land use structure transformation in Shaanxi Province. The remainder of the paper is organized as follows: "Study area and data collection" section provides introduction of study area and data collection. "Methods" section describes methods used in this paper. "Results and discussions" section provides the results and discussion of the research. "Conclusion" section concludes this research.

Study area and data collection

Study area

The Yellow River Basin is a dense area of important ecological barriers in China. With the further promotion of the high-quality development of Xi'an Central City and Guanzhong Plain urban agglomeration, the land use function of Shaanxi Province has undergone a drastic transformation (Fu, et al. 2004). In addition, the natural ecological background of the Yellow River Basin is fragile (Qiang, et al. 2008; Zhang, et al. 2021a, b; Wang, et al. 2021a, b, c). In order to fully restore and effectively protect the ecology of the Yellow River Basin, Shaanxi Province is a good sample to study land use transformation and ecological environment protection.

Shaanxi Province is located in central and western China, between 105°29′–111°15′ east longitude and 31°42′–39°35′ north latitude (Fig. 1). The province covers an area of 205,600 km^2 and is directly connected to the eight provinces in the central and western regions. It is an important location

connecting the east and the west, connecting the north and the south, and the center of the Asian section of the "New Eurasian Continental Bridge." Shaanxi Province is long and narrow from north to south, forming three distinctive natural areas from north to south. The Loess Plateau in northern Shaanxi is an important energy storage area in the country; the centrally flat Guanzhong area is an important land for food production and urban construction in the country; the South Qinba Mountains are an important national ecological protection area. The altitude of the whole area ranges from 174 to 3677 m. The terrain is undulating and the climate varies greatly. The average annual precipitation is about 576 mm.

Data collection

The land use raster data and administrative division data of Shaanxi Province are derived from the resource and environment data cloud sharing platform of the Chinese Academy of Sciences from 2000 to 2020, a total of 3 phases of 1 km × 1 km raster remote sensing monitoring data (http://www.resdc.cn), the statistical data comes from the National Bureau of Statistics (http://www.stats.gov.cn) and the Shaanxi Provincial Bureau of Statistics (http://tjj.shaanxi.gov.cn) and related documents. Land use types include 6 primary types and 25 secondary types of cultivated land, woodland, grassland, waters, urban and rural industrial and mining residential land, and unused land. According to the different aspects of human needs, land use types can be divided into different types of production function, ecological function, and life function. According to different land use dominant functions of "production, ecology, and living," different land use types are covered, and new land use is established. The classification system reflects the multiple dimensions pursued by the economic and social development of Shaanxi Province. However, a land use type may have multiple functions (Vivcharenko, 2019). For example, in terms of production function, cultivated land has the function of agricultural production and grain storage. In terms of ecological functions, the agricultural crops on the cultivated land have a certain impact on the local ecological environment and have the function of ecological land. In terms of living functions, cultivated land has certain functions such as life, education, and entertainment, and has the function of living land. However, in terms of people's main demand for the use of cultivated land, the main function of cultivated land is the production of agricultural crops, that is, the production function. Therefore, the cultivated land is classified as a production land type.

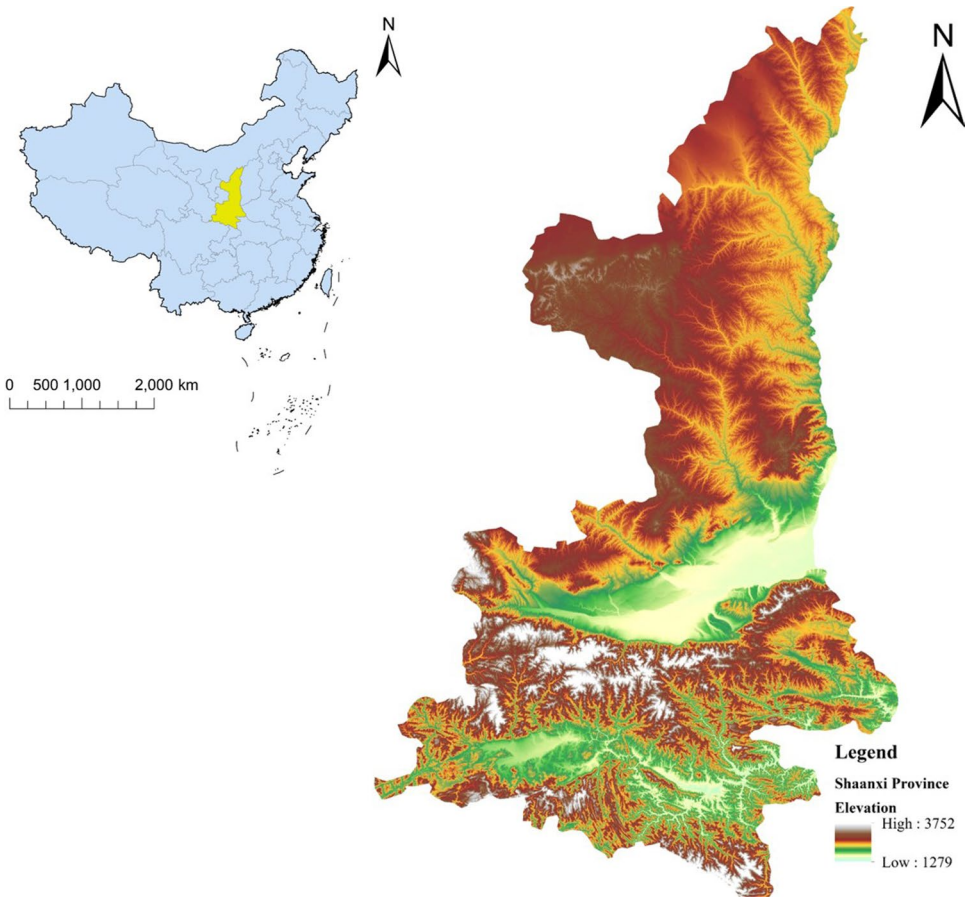

Fig. 1 Study area

In order to make the land use function classification system of Shaanxi Province more accurate and complete, this paper classifies production land, ecological land, and living land, and adds a secondary classification of land use types that can reflect the ecological differences of different land use functions. At the same time, the eco-environment index refers to the eco-environment indexes of different secondary land types developed by domestic and foreign experts and scholars on the evaluation of the value of land use function ecosystem services (Table 1). Mainly based on ecological environment quality value (Cui and Zang, 2013; Gao., et al. 2020), it was revised according to the actual situation of the ecosystem in Shaanxi Province. Combined with the classification system of the dominant land use functions of the production-living-ecological space, the area weighting method is used to fuzzy assign the ecological environment quality index of the production-living-ecological space land in Shaanxi Province.

Methods

Land use transformation

Land use transfer matrix is the application of Markov model in land use change (Cui and Zang, 2013; Gao., et al. 2020). Markov model can not only quantitatively show the transformation between different land use types but also reveal the transfer rate between different land use types (Cui and Zang, 2013; Gao., et al. 2020). The land use transfer matrix comes from the quantitative description of system state and state transfer in system analysis (Wen-Bo, et al. 2008). In the land use transfer matrix, the row represents the land use type at the previous time point, and the list shows the land use type at the later time point (Han, et al. 2012). The land use transfer matrix shows the quantitative relationship between the land cover types in two different periods in the form of matrix, which can comprehensively reflect the value and transfer direction of a regional land cover type (Table 2).

ArcGIS software is used for data fusion and superposition analysis of any two phases of land use data, and the data are exported. The transfer matrix is made by Excel to obtain the land use transfer matrix for the three phases of 2000–2010, 2010–2020, and 2000–2020, so as to analyze the transformation process of land use functional structure in Shaanxi Province.

Ecological environment effect

The impact of land use function transformation on eco-environmental effects in Shaanxi Province can be analyzed and studied through eco-environmental quality index and ecological contribution rate of land use function transformation.

(1) Ecological environment quality index. According to the classification of land use function from the perspective of ecological environment, different land use types have obvious ecological differences. Through the eco-environmental index and its area proportion of different land use functions under the classification of production-living-ecological spaces in Shaanxi Province, the eco-environmental quality index is used to quantitatively express the overall situation of eco-environmental quality in three different time periods in Shaanxi Province.

$$EV_i = \frac{S_i}{S} R_i (i = 1, 2n) \quad (1)$$

$$EV = \sum_{i=1}^{n} \frac{S_i}{S} R_i \quad (2)$$

where *EV* is the eco-environmental quality index of the region in a certain period. *EVi* is the eco-environmental quality index of a certain land type in a certain period. *n* is the number of regional land use types. *Si* and *S* are the area and total area of the land use type *i*

Table 1 Production-living-ecological spatial land use function classification and its ecological environment index

Production-living-ecological spatial land use function classification		Secondary classification of land use types	Ecological environment index
Primary land type	Secondary land type		
Production land	Cultivated production land	Paddy field and dry land	0.30
Ecological land	Forest ecological land	Woodlands, shrubs, open woodlands, and other woodlands	0.80
	Grassland ecological land	High coverage grassland, medium coverage grassland, and low coverage grassland	0.70
	Water ecological land	Canals, lakes, reservoirs, ponds, permanent glaciers, snow, beaches	0.55
	Unused ecological land	Sandy land, gobi, gobi saline alkali land, swamp, bare land, bare rock land, others	0.03
Living land	Urban and rural construction and living land	Urban land, rural residential areas, and other construction land	0.20

Table 2 Schematic diagram of transfer matrix

T_L \ T_N	C_1	C_2	…	C_n	T_{LS}	T_{LO}
C_1	S_{11}	S_{12}	…	S_{1n}	S_{1*}	S_{1*}-S_{11}
C_2	S_{21}	S_{22}	…	S_{2n}	S_{2*}	S_{2*}-S_{22}
…	…	…	…	…	…	…
C_n	S_{n1}	S_{n2}	…	S_{nn}	S_{n*}	S_{n*}-S_{nn}
T_{NS}	S_{*1}	S_{*2}	…	S_{*n}	—	—
T_{NI}	S_{*1}-S_{11}	S_{*2}-S_{22}	…	S_{*n}-S_{nn}	—	—

T_L represents the upper phase and T_N represents the lower phase. C_1 to C_N represent different land cover types. Assume that the row $C_N = C_I$ (land type of upper phase) and the column $C_N = C_J$ (land type of lower phase). S_{IJ} represents the area amount from the upper phase C_i to the lower phase C_J, S_{i*} represents the sum of the land cover type areas of the upper phase C_i, and S_{*J} represents the sum of the land cover type areas of the lower phase C_J. S_{i*}-S_{ii} is the outflow of C_i land type, that is, the total area of other land types transferred to the next phase in the previous phase C_i land. The above S_{IJ} can also be replaced by P_{IJ} to show the proportion of the transfer amount in the whole, which can reflect the relationship between the whole and the part.

in a certain period of the region. *Ri* is the ecological environment index of the land use type *i*.

(2) Ecological contribution rate of land use structure transformation. The change of regional ecological quality caused by the land type change of a certain dominant function of land use. The index quantifies the impact of the mutual conversion of various functional land on the regional ecological environment, which is conducive to the analysis of the dominant factors causing the change of regional ecological environment.

$$LEI = (EV_{t1} - EV_{t0})LA/ \quad (3)$$

where *LEI* is the ecological contribution rate of land use structure transformation. EV_{t0} and EV_{t1} are the eco-environmental quality indexes at the initial and final stages of change reflected by different types of land use changes. *LA* is the change area of the land use type. *TA* is the total area of the area. The ecological contribution rate of land use structure transformation has both positive and negative values. Through the analysis of positive and negative aspects, we can comprehensively judge the land use types affecting the change of ecological environment quality in Shaanxi Province, which is conducive to analyze the leading factors of ecological environment improvement and degradation in Shaanxi Province.

Results and discussions

Production-living-ecological spatial land use area change

The production land in production-living-ecological space of Shaanxi Province, i.e., cultivated production land, is mainly distributed in the middle of Guanzhong Plain. Living land includes urban land, rural residential areas, and other construction land, which are mainly distributed in the middle and some scattered in the West. Ecological land includes forest land ecological land, grassland ecological land, water area ecological land, and unused land. Ecological land is widely distributed (Fig. 2). Among the land use types of production-living-ecological space in Shaanxi Province from 2000 to 2020, the area of ecological land is the largest, followed by production land and living land (Table 3).

Production land

The area of production land has been decreasing from 2000 to 2020. From 71,867 in 2000 to 67,006 km^2 in 2020, it decreased by 4861 km^2 in 2020 compared with 2000. The proportion of production land decreased from 34.93 in 2000 to 32.57% in 2020, and the proportion of production land decreased by 2.36%. Due to the policy of returning farmland to forest and grassland in Shaanxi Province in recent years, the cultivated land area continues to decrease and the ecological land area has increased (Wang, et al. 2021a, b, c). The reduction of production land area from 2010 to 2020 is more than that from 2000 to 2010.

Table 3 Land use area of production-living-ecological space in Shaanxi Province from 2000 to 2020.

Unit: km^2.

Year	2000	2010	2020
Production land	71,867	70,136	67,006
Ecological land	130,796	132,114	133,117
Living land	3063	3476	5603

Ecological land

The area of ecological land has been increasing from 2000 to 2020. From 130,796 in 2000 to 133,117 km^2 in 2020, a total increase of 2321 km^2. The proportion of ecological land area has slowly increased from 63.58 to 64.71% in 20 years, an increase of 1.13%. The protection of ecological environment in Shaanxi Province has been paid more and more attention by the government and all sectors of society. The implementation of the policy of returning farmland to forest and grassland has promoted the management of ecological environment in Shaanxi Province (Wei, et al. 2021).

Living land

The area of living land has been increasing from 2000 to 2020. From 3063 in 2000 to 5603 km^2 in 2020, a total increase of 2540 km^2. The proportion of living land area has increased from 1.49 in 2000 to 2.72% in 2020, an increase of 82.93%. Among them, the growth rate from 2010 to 2020 is greater than that from 2000 to 2010, indicating that the urbanization process of Shaanxi Province is faster, the demand for living land is increased, the expansion speed is faster, and the contradiction between land supply and demand is further intensified (Zhang, et al. 2021a, b).

Transformation of land use structure

From 2000 to 2020, the land use pattern of Shaanxi Province has changed significantly. This paper superimposes and analyzes the land use data in different periods through ArcGIS software, obtains three land use transfer matrices from 2000 to 2010, 2010 to 2020, and 2000 to 2020, and defines the transformation direction and quantity between different land use types. From 2000 to 2010, the change of land use structure was small, and the transfer in and transfer out area of various land uses was small (Table 4). From 2010 to 2020, the land use structure changed greatly, and the transfer in and transfer out area of various land uses was large (Table 5). It can be seen that the transformation of land use structure has developed rapidly in recent 10 years (Niu and Du, 2021). Among them, the total area of water ecological land increased slightly from 2000 to 2010, but decreased from 2010 to 2020. The increase and decrease trend of other land types has not changed.

From the transfer out and transfer in area of land use structure transformation in Shaanxi Province from 2000 to 2020 (Table 3 and Table 6), the overall ecological land use is increasing from 130,796 in 2000 to 133,117 km^2 in 2020. Among them, the largest change in the transferred-out area is grassland ecological land, with a total transferred-out area of 34,301 km^2, accounting for 38.07% of the total transferred-out area. At the same time, grassland ecological land is also the largest transferred area, with a total transferred area of 35,822 km^2, accounting for 39.76% of the total transferred area, and the overall area has increased. In addition, among the ecological land, the transfer out area of forest ecological land is 16945 km^2 and the transfer in area is 18361 km^2. The transfer in area is greater than the transfer out area, and the overall area increases. The transferred-out area of water ecological land is 1245 km^2 and the transferred in area is 1080 km^2. The transferred-out area is larger than the transferred in area, and the overall area decreases. In addition, the transferred-out area of unused ecological land is 2049 km^2 and the transferred in area is 1598 km^2, and the overall area is also decreasing.

Table 4 Land use transfer matrix of production-living-ecological space in Shaanxi Province from 2000 to 2010.

Unit: km^2.

2000	2010							
	Cultivated production land	Woodland ecological land	Grassland ecological land	Water ecological land	Urban and rural construction living land	Unused ecological land	Total	Transfer out
Cultivated production land	69,873	766	744	132	348	4	71,867	1994
Woodland ecological land	12	46,431	47	5	24	10	46,529	98
Grassland ecological land	121	579	76,756	24	34	40	77,554	798
Water ecological land	98	7	13	1742	5	2	1867	125
Urban and rural construction living land	1	—	3	—	3059	—	3063	4
Unused ecological land	31	8	131	4	6	4666	4846	180
Total	70,136	47,791	77,694	1907	3476	4722	—	—
Transfer in	263	1360	938	165	417	56	—	—

Table 5 Land use transfer matrix of production-living-ecological space in Shaanxi Province from 2010 to 2020

Unit: km^2.

2010	2020							
	Cultivated production land	Woodland ecological land	Grassland ecological land	Water ecological land	Urban and rural construction living land	Unused ecological land	Total	Transfer out
Cultivated production land	38,075	5924	22,133	572	3092	340	70,136	32,061
Woodland ecological land	5701	30,093	11,514	98	236	149	47,791	17,698
Grassland ecological land	20,272	11,619	43,605	329	835	1035	77,694	34,089
Water ecological land	597	82	424	637	97	70	1907	1270
Urban and rural construction living land	1902	107	285	36	1138	8	3476	2338
Unused ecological land	458	119	1116	31	204	2793	4722	1929
Total	67,006	47,945	79,075	1702	5603	4395	—	—
Transfer in	28,931	17,852	35,470	1065	4465	1602	—	—

In the production land from 2000 to 2020, the transfer out of cultivated land production land also changed greatly, with a transfer out area of 33,469 km^2. Among them, 22,974 km^2 of cultivated land production land is converted to grassland ecological land, with the largest transfer out area. Secondly, 6328 km^2 of cultivated land production land is transferred to forest land ecological land, and the transfer out area is the second. The third transfer out area is urban and rural construction and living land, with a transfer out area of 3240 km^2. It can be seen that most of the cultivated land production land is transferred out to grassland and forest land ecological land, followed by urban and rural construction and living land. This is closely related to the ecological protection policy of returning farmland to forest and grassland in Shaanxi Province in recent years (Wang, et al. 2021a, b, c).

In addition, with the acceleration of urbanization, various types of land are constantly transferred to urban and rural construction and living land. The transferred in area is 4635 km^2 and the transferred-out area is 2095 km^2. The transferred in area is larger than the transferred-out area, the total area increases, and the scope of urban and rural construction and living land continues to expand.

To sum up, with the development of urbanization, there are a large number of ecological land and living land occupying production land in Shaanxi Province. In this regard, Shaanxi Province should actively promote the protection of cultivated land, the balance of cultivated land occupation and compensation, and the linkage between the increase and decrease of construction land, improve the rational planning and layout of land use, and achieve the coordinated development of production, ecology, and living land space. It should not only improve the level of ecological environment governance and protection in Shaanxi Province but also protect cultivated land and other agricultural production land, and optimize the living land for urban and rural construction and industrial development pattern.

Ecological environmental effect of land use structure transformation

From the land area and eco-environmental quality index of production-living-ecological space in Shaanxi Province from 2000 to 2020 (Table 7), it can be found that the eco-environmental quality index of Shaanxi Province shows a continuous upward trend. The change of eco-environmental quality index reflects the development level of the overall ecological environment in Shaanxi Province, but the relative stability of the change range does not mean that there is no change in the ecological environment. The mutual transformation between local classes may have positive or negative effects on the ecological environment. In the change of ecological environment in Shaanxi Province, the impact of the transformation of various land use types on the ecological environment of Shaanxi Province is judged by analyzing the transformation of main functional land types and their ecological contribution rate of production-living-ecological space in Shaanxi Province from 2000 to 2020.

From the land type transformation of production-living-ecological space and its ecological contribution rate in Shaanxi Province from 2000 to 2020 (Table 8), it can be seen that the conversion of cultivated land production land to grassland ecological land is the leading factor for the improvement of ecological environment quality in Shaanxi Province, accounting for about 62.13% of the positive effect contribution rate of ecological environment. In addition, the conversion of cultivated land production land to forest land ecological land and forest land ecological land to grassland ecological land have also improved the ecological

Table 6 Land use transfer matrix of production-living-ecological space in Shaanxi Province from 2000 to 2020.

Unit: km^2.

2000	2020							
	Cultivated production land	Woodland ecological land	Grassland ecological land	Water ecological land	Urban and rural construction living land	Unused ecological land	Total	Transfer out
Cultivated production land	38,398	6328	22,974	595	3240	332	71,867	33,469
Woodland ecological land	5484	29,584	10,991	91	233	145	46,529	16,945
Grassland ecological land	20,343	11,733	43,253	335	853	1036	77,554	34,301
Water ecological land	586	81	407	622	94	77	1867	1245
Urban and rural construction living land	1717	96	246	29	968	7	3063	2095
Unused ecological land	477	122	1204	31	215	2797	4846	2049
Total	67,006	47,945	79,075	1702	5603	4395	—	—
Transfer in	28,608	18,361	35,822	1080	4635	1598	—	—

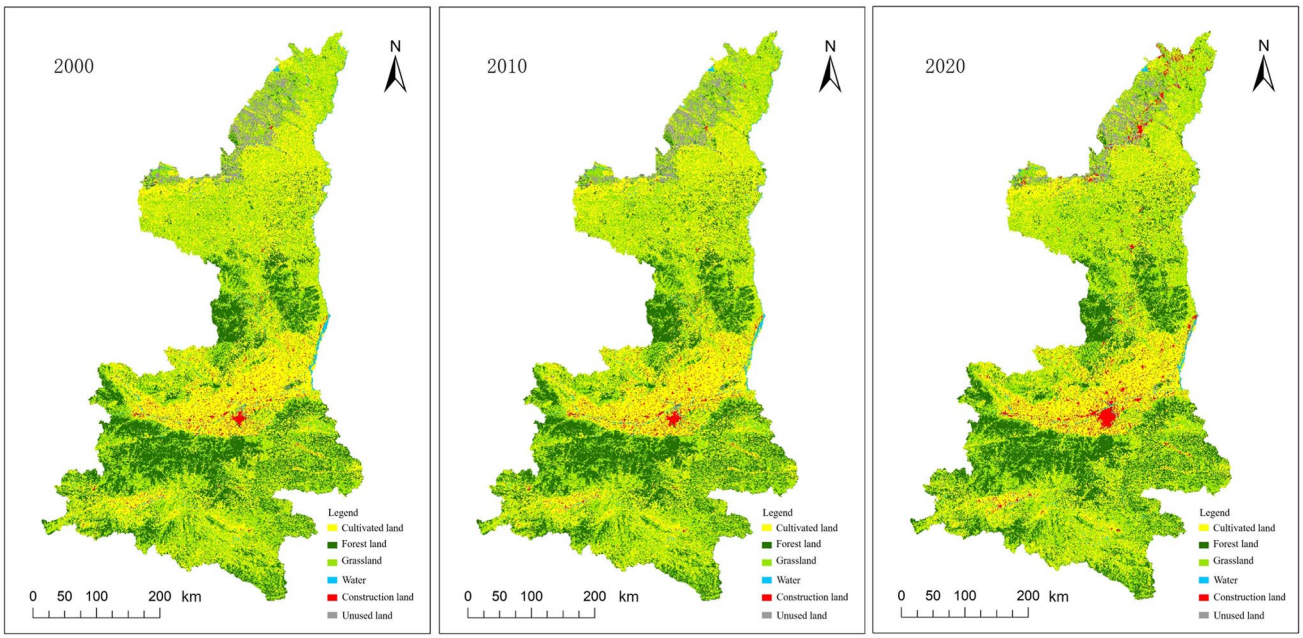

Fig. 2 Land use map of production-living-ecological space in Shaanxi Province from 2000 to 2020

Table 7 Land area and eco-environmental quality index of production-living-ecological space in Shaanxi Province from 2000 to 2020

	Area			Eco-environmental quality index		
	2000	2010	2020	2000	2010	2020
Cultivated production land	71,867 km^2	70,136 km^2	67,006 km^2	0.1048	0.1023	0.0977
Woodland ecological land	46,529 km^2	47,791 km^2	47,945 km^2	0.1809	0.1858	0.1864
Grassland ecological land	77,554 km^2	77,694 km^2	79,075 km^2	0.2639	0.2644	0.2691
Water ecological land	1867 km^2	1907 km^2	1702 km^2	0.0050	0.0051	0.0046
Urban and rural construction living land	3063 km^2	3476 km^2	5603 km^2	0.0030	0.0034	0.0054
Unused ecological land	4846 km^2	4722 km^2	4395 km^2	0.0007	0.0007	0.0006
Total	205,726 km^2	205,726 km^2	205,726 km^2	0.5583	0.5616	0.5639

environment quality of Shaanxi Province to a certain extent, accounting for nearly one-quarter of the positive effect contribution rate of ecological environment. Secondly, the conversion of unused ecological land to grassland ecological land and the conversion of urban and rural construction and living land to cultivated land production land account for about 5.32% and 2.68% of the positive effects of ecological environment, respectively. The transformation of land use structure for the improvement of ecological environment in Shaanxi Province is relatively concentrated. First, other land types are transformed into grassland ecological land, then cultivated land production land is transformed into forest land ecological land, and urban and rural construction and living land is transformed into cultivated land production land, which account for more than 97% of the total contribution rate of positive effects of ecological environment. In the negative effects of ecological environment, the conversion of grassland ecological land to other land types is an important factor leading to the decline of ecological environment quality in Shaanxi Province, accounting for more than 83% of the contribution rate of negative effects of ecological environment. Among them, the conversion of grassland ecological land to cultivated land production land accounts for 58.03% of the negative contribution rate of ecological environment. In addition, the conversion of forest land ecological land to cultivated land production land and cultivated land production land to urban and rural construction and living land account for about 7.83% and 5.53% of the negative effects of ecological environment, respectively.

The improvement trend of ecological environment in Shaanxi Province is greater than the deterioration trend of ecological environment. Overall, the overall

Table 8 Land area and eco-environmental quality index of production-living-ecological space in Shaanxi Province from 2000 to 2020

Unit: km^2.

Eco-environmental effect	Land use structure transformation	Conversion area/km^2	Ecological contribution rate	Percentage of contribution/%
Positive effect of ecological environment	Cultivated production land—Woodland ecological land	6328	0.002511	8.5052
	Cultivated production land—Grassland ecological land	22,974	0.018343	62.1252
	Woodland ecological land—Grassland ecological land	10,991	0.004708	15.9452
	Water ecological land—Cultivated production land	582	0.000262	0.8884
	Water ecological land—Woodland ecological land	81	0.000071	0.2420
	Water ecological land—Grassland ecological land	407	0.000522	1.7693
	Water ecological land—Urban and rural construction living land	94	0.000001	0.0034
	Urban and rural construction living land—Cultivated production land	1717	0.000791	2.6778
	Urban and rural construction living land—Woodland ecological land	96	0.000086	0.2900
	Urban and rural construction living land—Woodland ecological land	246	0.000318	1.0776
	Urban and rural construction living land—Water ecological land	29	0.000001	0.0034
	Unused ecological land—Cultivated production land	477	0.000225	0.7618
	Unused ecological land—Woodland ecological land	122	0.000110	0.3730
	Unused ecological land—Grassland ecological land	1204	0.001571	5.3190
	Unused ecological land—Water ecological land	31	0.000001	0.0020
	Unused ecological land—Urban and rural construction living land	215	0.000005	0.0168
Total			0.029526	100.0000
Negative effects of ecological environment	Cultivated production land—Water ecological land	595	−0.000290	1.0242
	Cultivated production land—Urban and rural construction living land	3240	−0.001565	5.5273
	Cultivated production land—Unused ecological land	332	−0.000168	0.5941
	Woodland ecological land—Cultivated production land	5484	−0.002218	7.8313
	Woodland ecological land—Water ecological land	91	−0.000078	0.2757
	Woodland ecological land—Urban and rural construction living land	233	−0.000199	0.7025
	Woodland ecological land—Unused ecological land	145	−0.000127	0.4492
	Grassland ecological land—Cultivated production land	20,343	−0.016432	58.0270
	Grassland ecological land—Woodland ecological land	11,733	−0.004417	15.6076
	Grassland ecological land—Water ecological land	335	−0.000422	1.4878
	Grassland ecological land—Urban and rural construction living land	853	−0.001072	3.7831
	Grassland ecological land—Unused ecological land	1036	−0.001326	4.6811
	Water ecological land—Unused ecological land	77	−0.000002	0.0057
	Urban and rural construction living land—Unused ecological land	7	−0.000001	0.0035
Total			−0.028316	100.0000

eco-environmental quality index remained between 0.55 and 0.57 from 2000 to 2020 (Table 7). The eco-environmental quality maintained a relative balance to a certain extent, but the local changes in its internal environment could not be ignored. Therefore, Shaanxi Province should timely adjust the land use structure and layout, improve relevant policies and planning, so as to promote the continuous improvement of ecological environment and the coordinated development of production, ecology, and living space.

Implications

The theoretical implications of this paper include (1) putting forward the secondary classification of land use with high eco-environmental resolution, (2) formulating the eco-environmental quality value of the secondary classification of land use based on ecosystem service value, and (3) constructing the eco-environmental quality index of land transformation in Shaanxi Province; the practical implication of this paper is to provide quantitative reference and guidance for the effective protection and high-quality development of ecological environment in Shaanxi Province.

Conclusion

Based on the collaborative perspective of production-living-ecological space, this paper analyzes the transformation of land use structure in Shaanxi Province through the land use transfer matrix, and quantitatively analyzes the effects of land use structure transformation on the ecological environment in Shaanxi Province from 2000 to 2020 by using the eco-environmental quality index and ecological contribution rate. The main conclusions are listed as follows:

(1) From 2000 to 2020, among the land use types in Shaanxi Province based on production-living-ecological space, the area of ecological land is the largest, the area of production land is the second, and the area of living land is the smallest. Land use change in Shaanxi Province is mainly reflected in the continuous reduction of production land area, with a total reduction of 4861 km^2. The area of ecological land continues to increase, with a total increase of 2321 km^2. The area of living land continues to increase, with a total increase of 2540 km^2.

(2) From 2000 to 2020, among the secondary land types, the water ecological land increased slowly at first and then decreased, with an overall decrease of 165 km^2. Forest ecological land increased rapidly at first and then slowly. Among other land use types, cultivated land production land and unused land ecological land continued to decrease, and the reduction rate increased. Urban and rural construction living land and grassland ecological land continued to increase, and the increase rate increased. In the transformation of land use structure in Shaanxi Province, the biggest change in area is the mutual transformation between cultivated land production land and grassland ecological land. The area of cultivated land transferred out into grassland is 22974 km^2, and the area of grassland transferred into cultivated land is 20343 km^2. The overall area of grassland has increased. Other land types have different degrees of mutual transformation.

(3) From 2000 to 2020, the eco-environmental quality index of Shaanxi Province showed a continuous upward trend. The conversion of cultivated land production land to grassland ecological land is the leading factor to improve the quality of ecological environment in Shaanxi Province. The occupation of grassland ecological land by other land types is an important factor leading to the decline of ecological environment quality.

The effect of land use structure transformation on eco-environmental quality is not only related to the transformation area of land use structure transformation studied in this paper but also related to the patch size, shape, and landscape pattern index of different land types. Therefore, in the follow-up research, the existing evaluation methods can be improved according to the more accurate remote sensing images and geospatial data, so as to more accurately calculate the impact of various land use structure transformation on the ecological environment, and further coordinate the layout and timing of production, ecological, and living land construction in Shaanxi Province, as well as the steady improvement of ecological environment effect.

Author contribution Chenxi Li and Jingyao Wu contributed to the conception of the study; Chenxi Li performed the experiment; Jingyao Wu contributed significantly to analysis and manuscript preparation; Chenxi Li performed the data analyses and wrote the manuscript; and Jingyao Wu helped perform the analysis with constructive discussions.

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

Declarations

Ethics approval Not applicable.

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Consent for publication Not applicable.

Conflict of interest The authors declare no competing interests.

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