Evolution of Territorial Spatial Pattern and Its Driving Mechanisms Based on Land Use Transfer Flows: A Case Study of Yuanzhou District, Ningxia (Postprint)

Authors: Caihong Ma

Date: 2022-06-09T00:00:00+00:00

Abstract

This study proposes a traceability analysis method based on land use transfer flows, combined with social network analysis and kernel density analysis, to investigate the evolution of territorial spatial patterns and their dynamic mechanisms in Yuanzhou District from 2000 to 2018. The results indicate that: (1) The production-living-ecological spaces in Yuanzhou District evolved toward enhanced production space efficiency, expanded living space capacity, and improved ecological space quality, with the structure of production, living, and ecological land adjusting from 44.76%, 2.90%, and 52.34% in 2000 to 41.17%, 6.29%, and 52.54% in 2018. (2) The changes in Yuanzhou District' s production-living-ecological spaces demonstrate high compatibility with current territorial spatial optimization objectives. The transfer-in of ecological land primarily occurred in areas unsuitable for cultivation or habitation, reflecting the "beautiful ecological space" orientation. Production space enhanced intensive utilization levels of water and soil resources through slope-to-terrace conversion and irrigation provision, reflecting the "intensive and efficient production space" orientation. The expansion of living space mainly occurred in valley areas with more favorable living conditions, reflecting the "livable living space" orientation. (3) The evolution of the production-living-ecological spatial pattern exhibited significant spatial agglomeration, characterized by belt-shaped high-value areas in the Liupan Mountain humid zone, scattered high-value areas in the loess hilly-gully region, and clustered high-value areas in the Qingshui River valley, with distinct spatial agglomeration characteristics for different land use type changes. (4) Based on the land use transfer flow traceability method, a "driving force-response-result" transmission dynamic mechanism for the evolution of Yuanzhou District's production-living-ecological spaces was proposed. Ecological construction represents the most important driving force for territorial spatial pattern evolution, followed by intensive utilization of water and soil resources, both making significant contributions to territorial spatial pattern optimization. Soil erosion serves as an important driving force for the conversion of various land use types to unused land, and efforts to control soil erosion must be intensified in the future. By exploring the characteristics and dynamic mechanisms of territorial spatial changes in areas constrained by both economic and ecological factors, this study provides decision-making references for territorial spatial optimization.

Full Text

Evolution of Territorial Spatial Patterns and Their Driving Mechanisms Based on Land Use Transfer Flow: A Case Study of Yuanzhou District, Ningxia

MA Caihong, AN Siwen, WEN Qi, HUA Yuqi, LI Conghui
(School of Geography and Planning, Ningxia University, Yinchuan 750021, Ningxia, China)

Abstract

This study proposes a traceability analysis method based on land use transfer flow, combined with social network analysis and kernel density analysis, to explore the evolution of territorial spatial patterns and their driving mechanisms in Yuanzhou District from 2000 to 2018. The results show that: (1) The production-living-ecological spaces in Yuanzhou District evolved toward enhanced production space efficiency, expanded living space, and improved ecological space quality. The structure of production, living, and ecological land use shifted from 44.76%, 2.90%, and 52.34% to 41.17%, 6.29%, and 52.54%, respectively. (2) The changes in Yuanzhou District' s production-living-ecological spaces align well with current territorial spatial optimization objectives. The transfer into ecological land mainly occurred in areas unsuitable for cultivation or habitation, reflecting the "beautiful mountains and clear waters" orientation for ecological space. Production space improvements through slope-to-terrace conversion and irrigation provision enhanced intensive water and soil resource utilization, reflecting the "intensive and efficient production" orientation. Living space expansion primarily occurred in valley areas with more suitable living conditions, reflecting the "livable living space" orientation. (3) The evolution of production-living-ecological spatial patterns exhibited significant spatial agglomeration, characterized by a belt-shaped high-value zone in the Liupan Mountain humid region, scattered high-value zones in the loess hilly and gully region, and a clustered high-value zone in the Qingshui River Valley, with different land use types showing distinct spatial agglomeration characteristics. (4) Based on the land use transfer flow traceability method, this study proposes a "driver-process-result" transmission mechanism for production-living-ecological space evolution in Yuanzhou District. Ecological construction is the most important

driving force for territorial spatial pattern evolution, followed by intensive water and soil resource utilization, both making significant contributions to territorial spatial optimization. Soil erosion remains an important driver for the conversion of various land use types to unused land, requiring continued intensified management efforts. By exploring the characteristics and driving mechanisms of territorial spatial changes in areas constrained by both economic and ecological factors, this study provides decision-making references for territorial spatial optimization.

Keywords: territorial spatial optimization; production-living-ecological space; land use transfer flow; driving mechanism; Yuanzhou District

1 Introduction

Territorial space systems are dynamic and complex giant systems formed through the interaction of natural ecological elements and human socio-economic elements of land. According to their functions, they can be divided into production, living, and ecological "production-living-ecological" spaces. Since China' s reform and opening up, rapid population growth and urbanization have intensified conflicts among production-living-ecological spaces. The 18th National Congress of the Communist Party of China proposed the target framework of "intensive and efficient production space, livable and moderate living space, and beautiful mountains and clear waters in ecological space," which has spurred research on production-living-ecological spaces.

The evolution of production-living-ecological spaces results from the combined effects of natural geographical factors and human activities, with significant differences in driving factors and mechanisms across different scales and regional types. At watershed, provincial, and county scales, population growth, economic development, and technological progress are relatively common driving factors. For instance, Zhao Rui et al. used principal component analysis to identify population growth, economic development, and agricultural technological progress as the main drivers of production-living-ecological space changes in the Beijing-Tianjin-Hebei metropolitan area. Song Yongyong et al. employed factor detection and interaction detection modules in geographical detectors to find that urbanization, industrialization, and ecological policies are key drivers of territorial spatial pattern evolution in the Yellow River Basin. Gan Na et al. analyzed driving factors for production-living-ecological space reconstruction in the Sichuan-Yunnan-Tibet border region, concluding that macro-policy driving effects are significant in ecologically fragile areas or important ecological function zones. Dong Jianhong et al. used partial least squares to reveal that ecological policies, population growth, and foreign trade are important driving forces for territorial spatial pattern adjustment in Gansu Province. Jiao Gengying et al. applied redundancy analysis to show that rapid tourism industry development is the core driving force for production-living-ecological spatial pattern evolution in Wuyuan County. Wang Quanxi et al. used bivariate local spatial autocorrelation analysis to explore territorial spatial pattern evolution in Wushan County, pointing out that regional integrated development plays an important role.

At the village scale, production-living-ecological space evolution differs significantly from macro and meso scales. Yu Zhengsong et al., using participatory rural appraisal (PRA) in Qugou Town, Henan Province, found that capable person leadership effects and industrial structure adjustment have significant driving effects on production-living-ecological space evolution in industrial towns. Fan Yina et al., using semi-structured interviews and participatory community resource mapping at the village scale, concluded that agricultural benefit policies and agricultural technological innovation are key driving forces affecting production-living-ecological spatial pattern evolution at the village scale.

In summary, scholars have employed various methods including principal component analysis, geographical detectors, redundancy analysis, partial least squares, and semi-structured interviews to study driving forces of production-living-ecological space evolution at different scales, laying a solid foundation for this field. However, several aspects remain to be explored: First, while these methods have their advantages, they generally belong to inferential estimation analysis, with uncertain results that create difficulties for comparing findings across different spatial and temporal scales. Second, there are many identifications of driving factors, but the dynamic mechanisms need strengthening. Ma Caihong et al. proposed the land use transfer flow research method, which comprehensively considers the vector attributes of land use change and can quantitatively track the quantity, direction, and structural characteristics of land use changes in different periods, offering unique advantages for analyzing driving forces of territorial spatial evolution. This paper employs land use transfer flow for traceability analysis of driving forces behind territorial spatial pattern evolution in Yuanzhou District, Guyuan City, Ningxia, aiming to explore new ideas and methods for analyzing driving forces of territorial spatial pattern evolution.

2 Study Area, Data, and Methods

2.1 Study Area

Yuanzhou District is located in southern Ningxia, formerly known as Guyuan County (renamed in 2001), geographically positioned at 106°00'~106°30'E, 35°45' ~36°31' N. It governs 7 towns, 4 townships, and 3 subdistrict offices, covering an area of 2,739 km^2. It belongs to the semi-humid and semi-arid climate zone and the northern farming-pastoral ecotone. Based on topographic characteristics, it can be divided into the Liupan Mountain humid region (accounting for 20.5% of the area), the Qingshui River Valley plain region (accounting for 28.0% of the area), and the loess hilly and gully region (accounting for 51.5% of the area). Affected by unreasonable human activities such as steep slope reclamation, timber harvesting, overgrazing, and mining, soil erosion is prominent, with frequent natural disasters including drought, frost, and hail. Rural livelihoods are fragile, and the district is known for its extreme poverty, with prominent human-land contradictions. It was considered by UNESCO as an area unsuitable for human survival and is a key poverty alleviation area in China' s "Three West" (Hexi, Dingxi, Xihaigu) program, as well as a deeply impoverished county during the national targeted poverty alleviation period, achieving poverty alleviation in 2020. Since reform and opening up, the economy has developed rapidly and urbanization levels have improved, but problems remain including low competitiveness, disorderly development encroaching on ecological space, and low land use efficiency.

2.2 Data Sources and Processing

Remote sensing image data were obtained from the China Geospatial Data Cloud. Using ENVI 5.3 software, digital images were corrected, mosaicked, segmented, and fused. Combined with field survey data, interpretation keys were established for visual interpretation, with accuracy verification reaching over 85%. Land use data are vector data from national geographical conditions surveys. Due to administrative division adjustments, all place names and administrative scope involved in this paper follow the current administrative division status of Yuanzhou District.

2.3 Methods

2.3.1 Production-Living-Ecological Land Classification System Referring to the dominant function classification system and combining the "Current Land Use Classification" (GB/T 21010-2017) with the Chinese Academy of Sciences Geographic Institute remote sensing interpretation data classification system, land use types in Yuanzhou District were divided into production land, living land, and ecological land (Table 1). Land type names follow the "Current Land Use Classification" (GB/T 21010-2017) standard.

2.3.2 Quantitative Analysis Methods Land Use Transfer Flow Traceability Analysis. Land use transfer flow has attributes marking direction and quantity. This paper proposes a traceability analysis method based on land use transfer flow to trace driving factors and their contribution rates. In land use change, the land use code for period T is set as Ct, and for period T+1 as Ct+1. Overlay analysis is performed on land use for periods T and T+1, generating land transfer flow codes through code operations. For example, if a patch is dryland in period T with code 0303, and becomes irrigated land and orchard land in period T+1 with corresponding codes 0101 and 0201, an area statistics calculator is used to compute transfer quantities. The land use transfer encoding (Cn) formula is:

$$\mathrm{Cn} = \mathrm{Ct} \times 10000 + \mathrm{Ct{+}1}$$

Social Network Analysis. Using Ucinet 6.186 software for land use transfer network mapping and analysis, land use types are represented by codes, transfer directions are marked with arrows, and line types are quantitatively illustrated according to the quantity proportion of land use transfer flows, with important transfer flow quantities marked.

Kernel Density Analysis. Using the kernel density analysis module in ArcGIS 10.6, land use transfer patch data are converted to point format data, with patch area as the value field for kernel density mapping to generate land use transfer rate raster maps (unit: km^2/hm^2).

3 Results

3.1 Structural Changes in Production-Living-Ecological Space

3.1.1 Changes in Production-Living-Ecological Land Structure in Yuanzhou District Production land in Yuanzhou District decreased from 12.25$\times10^{4}$ hm^2 to 11.27$\times10^{4}$ hm^2, living land expanded from 0.79$\times10^{4}$ hm^2 to 1.72$\times10^{4}$ hm^2, and ecological land increased from 14.33$\times10^{4}$ hm^2 to 14.38$\times10^{4}$ hm^2. The structure of production, living, and ecological land adjusted from 44.76%, 2.90%, and 52.34% to 41.17%, 6.29%, and 52.54%, respectively. These changes are closely related to ecological protection and restoration policies, farmland water conservancy construction, and urbanization development.

Since the implementation of the Grain for Green Program in 2000, sloping land has been gradually retired from cultivation. Although the total ecological land showed weak growth, forest land area increased rapidly, other grassland decreased significantly, and the ecological land structure was optimized and quality improved (Table 2).

3.1.2 Characteristics of Production-Living-Ecological Land Transfer Network Structure in Yuanzhou District Complex transfer flows occurred between different land use types, with significant differences in transfer quantities (Figure 2). Key land types with large transfer flows include dryland, forest land, natural grassland, and other grassland, which constitute critical land types for land use transfer in Yuanzhou District. The primary and secondary transfer flows formed among these land types constitute the basic skeleton of the transfer network, determining the fundamental characteristics of land use transfer in Yuanzhou District.

Transfer flows accounting for more than 1% of the total area were statistically analyzed by slope (Figure 3). The areas converted to high-function ecological land mainly occurred in high-altitude, steep-slope regions unsuitable for cultivation and habitation, reflecting the "beautiful mountains and clear waters" orientation for ecological space. Dryland-to-forest transfer accounted for 8.25% of the total area, mainly occurring in slopes of 15°-25°. Other grassland-to-forest transfer accounted for 7.73% of the total area, mainly occurring in slopes of 5°-15°. Through afforestation of suitable land and natural closure of barren hills, natural grassland-to-forest transfer accounted for 5.40% of the total area, and other grassland-to-natural grassland transfer accounted for 4.53% of the total area, mainly occurring in slopes of 10°-15°.

Through land use structure adjustment and land consolidation projects, the production-living-ecological spatial pattern in Yuanzhou District was significantly optimized. Following the spirit of Ningxia Development and Reform Commission Document No. 387 [2010], three major measures were implemented: First, consolidating Grain for Green "basic grain land"achievements and developing irrigated land projects. With the implementation of the Guhai Expansion Irrigation Project, some dryland in the Qingshui River Valley plain was converted to irrigated land and orchard land; water-saving irrigation agriculture was developed in the Dongzhi River and Ruhe River basins in the eastern and western parts of Yuanzhou District where water infrastructure is relatively weak, highlighting efficient water resource utilization and promoting agricultural structural adjustment, thereby improving agricultural land production intensification and achieving agricultural efficiency and farmer income growth for households participating in the Grain for Green Program. Correspondingly, urban and rural settlements showed a concentration trend toward the central valley area. Second, extensive land consolidation was carried out in the gentle hilly areas of the central region and the mountainous gentle slope areas of the southwestern region, converting large areas of sloping farmland and other grassland to terraced dryland, which not only guaranteed residents' basic grain land but also improved soil and water conservation capacity. Third, ecological restoration measures such as Grain for Green, afforestation of barren hills, and natural closure formed a "U" -shaped forest ecological barrier around the central urban area of Yuanzhou District.

Other grassland-to-dryland transfer accounted for 4.32% of the total area, mainly occurring in slopes of 5°-15°, focusing on terrace construction. Dryland-to-irrigated land transfer accounted for 8.06% of the total area, mainly occurring in slopes of 5°-25°. The expansion of living space occurred in areas with more suitable living conditions, reflecting the "livable living space" orientation. Rural residential points occupying dryland accounted for 1.46% of the total area, while urban expansion and other construction land occupying dryland accounted for 1.09% of the total area.

3.2 Spatial Pattern Changes in Production-Living-Ecological Space

3.2.1 Spatial Pattern Changes in Production-Living-Ecological Space in Yuanzhou District Agricultural production land is dominated by dryland, mainly concentrated in the central Qingshui River Valley. In 2000, urban and rural settlements were relatively dense in the Qingshui River Valley plain area, sparse in the Liupan Mountain humid region and loess hilly and gully region; agricultural production land was mainly in the Qingshui River Valley plain area; forest land and grassland were mainly distributed in the Liupan Mountain humid region and loess hilly and gully region.

3.2.2 Agglomeration Characteristics of Production-Living-Ecological Spatial Pattern Evolution The reconstruction of production-living-ecological spatial patterns in Yuanzhou District reflects the "mountain-water-forest-field-lake-grassland" life community theory, optimizing allocation according to suitability as a "unified chessboard." The conversion of production-living-ecological spatial patterns shows obvious spatial agglomeration characteristics (Figure 5). Overall, land use transfer flows present as a north-south extending high-value zone in the Liupan Mountain humid region, scattered high-value zones in the loess hilly and gully region, and clustered high-value zones in the Qingshui River Valley (Figure 5a). Grain for Green and afforestation of barren hills increased ecological land quantity and quality. High-value zones for dryland-to-forest transfer mainly occurred in sloping farmland at altitudes of 1750-2000 m in the Liupan Mountain humid region and in the loess hilly and gully region (Figure 5b). High-value zones for grassland-to-forest transfer existed in the north-south extending belt of the Liupan Mountain humid region and the loess hilly and gully region (Figure 5c). The "slope-to-terrace" action in the loess hilly and gully region and the "dryland-to-irrigated land" action in the Qingshui River Valley formed agglomeration zones for production land quality improvement. With the basic grain land construction project, sloping farmland of 10°-15° and other suitable wasteland were consolidated into new terraces, forming high-value zones in towns such as Tanshan, Zhaike, Touying, Guanting, Kaicheng, Zhonghe, and Zhangyi (Figure 5d). With the implementation of the Guhai Expansion Irrigation Project, the "dryland-to-irrigated land" action in the Qingshui River Valley formed high-value zones in towns such as Huangduopu, Sanying, Touying, and Pengbao (Figure 5e). Yuanzhou District plays an important role in radiating and driving the development of southern Ningxia counties and districts. The urban population ratio increased from 16.47% to 51.19% in 2018, with rapid urban expansion forming high-value zones centered on the urban area and key towns and counties (Figure 5f).

3.3 Driving Mechanisms of Territorial Spatial Pattern Evolution in Yuanzhou District

Yuanzhou District is constrained by both low economic development levels and fragile ecological environments. Through the "Seven-Year Poverty Alleviation Program," east-west paired poverty alleviation cooperation, targeted poverty alleviation, and other stages, 78,000 people migrated out of the county, and 36,700 people migrated within the county from mountainous to valley areas. The ecological migration program mainly aims to solve the population overload problem in Yuanzhou District; ecological restoration and reconstruction mainly address the ecological fragility; and poverty alleviation and development mainly establish an ecological economic system to empower development in impoverished counties.

Corresponding to the above macro policies, based on the transfer flows acting on production-living-ecological spaces, driving factors are attributed, including ecological migration and rural construction, urbanization and industrialization, intensive water and soil resource utilization, and ecological construction. Under these driving factors, land use transfer flows of different scales emerged, acting on corresponding spatial object layers and causing changes in the quantity structure and spatial structure of production-living-ecological spaces. Based on this, a dynamic mechanism of territorial spatial evolution composed of "driver layer-process layer-result layer" is proposed (Figure 6).

The land use transfer flow in Yuanzhou District in 2018 was 15.96×10^{4} hm^2, accounting for 58.35% of the total area of Yuanzhou District. The contribution rates of various driving factors derived from this are shown in Table 3. Ecological construction is the most important driving factor, with a contribution rate of 49.40% to production-living-ecological spatial evolution in Yuanzhou District. Ecological construction actions such as Grain for Green, afforestation of barren hills, and natural closure significantly improved vegetation coverage and enhanced water conservation and biodiversity protection functions. To address severe soil erosion, comprehensive management projects such as the first phase of the Ruhe River, Mashikhao, Kaicheng, Yangdazigou, and Dongzhi River were implemented, improving the capacity of sloping farmland in mountainous areas to intercept runoff and sediment locally. Second, intensive water and soil resource utilization contributed 31.01% to spatial pattern adjustment. The Guhai Expansion Irrigation Project and the construction of nearly 50,000 hm^2 of dryland-to-irrigated land and sloping farmland-to-wide-terrace conversions effectively conserved water and soil, improved agricultural production and ecological conditions, and enhanced intensive water and soil resource utilization levels. The contribution rates of ecological migration and rural construction and urbanization and industrialization are relatively low, at 2.94% and 3.63%, respectively. It should be noted that soil erosion remains an important driving force for the conversion of various land use types to unused land, accounting for 13.02%, requiring continued intensified management.

4 Discussion

4.1 Traceability Analysis of Territorial Spatial Evolution Based on Land Use Transfer Flow

Land use transfer flow is a method that uses land use transfer matrices to calculate transfer quantities and employs source and target codes of land use transfer patches to quantitatively analyze the causes and consequences of land use transfers. Based on the direction of land use transfer flow, deductive methods can qualitatively analyze the reasons driving these land use changes, thereby identifying driving factors. By analyzing land use transfer flows and deducing toward both cause and effect ends, a "driver-process-result" transmission mechanism for production-living-ecological space evolution is established. Traceability analysis reveals that ecological migration and rural construction, urbanization and industrialization, intensive water and soil resource utilization, ecological construction, and soil erosion are driving forces for territorial spatial pattern evolution in Yuanzhou District. The proportions of land use transfer flows involved in each driving factor are converted to a percentage scale to obtain the contribution rates of different driving factors to production-living-ecological spatial pattern changes. This traceability analysis method based on land use transfer flow provides a new perspective and approach for territorial spatial driving force research.

4.2 Implications and Recommendations for Territorial Spatial Pattern Reconstruction

Yuanzhou District is located in an arid region of northwest China with scarce precipitation, low vegetation coverage, and a fragile and sensitive ecosystem. A long-term vicious cycle of "poverty-ecological degradation-poverty" has existed. Over the past 20 years, Yuanzhou District has achieved remarkable results in territorial spatial pattern reconstruction by following the "mountain-water-forest-field-lake-grassland" life community theory and adopting a "human-land-industry" system "unified chessboard" regulation approach. To address population overload, both "pressure reduction" and "capacity expansion" strategies were employed. For fragile ecosystems, ecological restoration and reconstruction were the main strategies. For poverty issues, migration and labor export were primary means, making positive contributions to regional poverty reduction. For the low-level ecological economic system and livelihood deficits, establishing an ecological economic system empowered county development. Overall, using migration as a breakthrough to resolve human-land contradictions, while balancing grain production and ecological protection needs, promoted territorial spatial evolution toward enhanced production space efficiency, expanded living space, and improved ecological space quality.

Future efforts need to further implement the "Two Mountains Theory" transformation requirements and accelerate innovation in ecological product value realization mechanisms to effectively safeguard and further optimize the production-living-ecological spatial pattern and improve quality and efficiency. Key recommendations include: (1) exploring the development and scaled growth of green geographical indication products; (2) exploring the provision of high-quality ecosystem regulation and service products; and (3) establishing effective ecological product trading platforms and high-quality logistics service systems.

5 Conclusions

Using land use transfer flow, social network analysis, and kernel density analysis, this study explored the evolution of territorial spatial patterns and their driving mechanisms in Yuanzhou District from 2000 to 2018. The conclusions are as follows:

(1) The production-living-ecological spaces in Yuanzhou District evolved toward enhanced production space efficiency, expanded living space, and

improved ecological space quality. The production, living, and ecological land use structure shifted from 44.76%, 2.90%, and 52.34% to 41.17%, 6.29%, and 52.54%, respectively, showing decreased production land, considerable living land expansion, and weak ecological land growth.

(2) The transfer trends of production-living-ecological land in Yuanzhou District align well with current territorial spatial optimization objectives. Areas converted to ecological land mainly occurred in regions unsuitable for cultivation or habitation, reflecting the "beautiful mountains and clear waters" orientation for ecological space. Through slope-to-terrace conversion and irrigation provision to enhance intensive water and soil resource utilization, the "intensive and efficient production" orientation for production space was reflected. Living space expansion primarily occurred in valley areas with more suitable living conditions, reflecting the "livable living space" orientation.

(3) The spatial agglomeration characteristics of production-living-ecological space evolution are prominent. Land use transfer flows present as a north-south extending belt-shaped high-value zone in the Liupan Mountain humid region, scattered high-value zones in the loess hilly and gully region, and clustered high-value zones in towns and county seats of the Qingshui River Valley. Transfer flows of different key land types show different spatial agglomeration characteristics.

(4) Based on the land use transfer flow traceability method, a "driver-process-result" transmission mechanism for territorial spatial pattern evolution in Yuanzhou District is proposed. Ecological construction is the most important driving force for territorial spatial pattern evolution in Yuanzhou District, followed by intensive water and soil resource utilization, contributing 49.40% and 31.01% to production-living-ecological space evolution, respectively. Soil erosion remains an important driving force for the conversion of various land use types to unused land, accounting for 13.02%, requiring continued intensified management.

References

[1] Zhang Yanyu, Chen Meijing. Spatial systematic cognition and ideas on spatial planning system reform[J]. China Land Science, 2016, 30(2): 11-21.

[2] Zhang Hongqi, Xu Erqi, Zhu Huiyi. An ecological living industrial land classification system and its spatial distribution in China[J]. Resources Science, 2015, 37(7): 1332-1338.

[3] Wei Jiangwei, Zhao Ruifeng, Li Linghui, et al. Study on the spatial and temporal evolution characteristics and spatial conflicts of the land for production living ecological in arid areas: A case study of the middle reaches of the Heihe River[J]. Research of Soil and Water Conservation, 2021, 28(4): 284-292, 419.

[4] Zhao Xu, Tang Feng, Zhang Pengtao, et al. Dynamic simulation and characteristic analysis of county production living ecological spatial conflicts based on CLUE-S model[J]. Acta Ecologica Sinica, 2019, 39(16): 5897-5908.

[5] Wang Wei, Hu Yecui, Zhang Yulong. Ecological living industrial space structure cognition and transformation control framework[J]. China Land Science, 2020, 34(12): 25-33.

[6] Jiang Dong, Lin Gang, Fu Jingying. Discussion on scientific foundation and approach for the overall optimization of production living ecological space[J]. Journal of Natural Resources, 2021, 36(5): 1085-1101.

[7] Kong Dongyan, Chen Huiguang, Wu Kongsen. The evolution of production living ecological space, eco-environmental effects and its influencing factors in China[J]. Journal of Natural Resources, 2021, 36(5): 1116-1135.

[8] Zhou Peng, Deng Wei, Zhang Shaoyao, et al. Evolution characteristics and its driving force of territory space pattern in the Taihang Mountain, China[J]. Mountain Research, 2020, 38(2): 276-289.

[9] Hu Yuxi, Wu Xiaolei, Ma Shichang, et al. The system dynamics model for the interactive coupling between wetland ecology, production and living: A case study on Xixi National Wetland Park[J]. Economic Geography, 2018, 38(7): 173-180.

[10] Zhao Rui, Liu Xuemin. Analysis on spatial production-living-ecological temporal changes and driving forces spaces in Beijing-Tianjin-Hebei metropolitan area[J]. Ecological Economy, 2021, 37(4): 201-208.

[11] Song Yongyong, Xue Dongqian, Xia Siyou, et al. Change characteristics and formation mechanism of the territorial spatial pattern in the Yellow River Basin from 1980 to 2018, China[J]. Geographical Research, 2021, 40(5): 1445-1463.

[12] Gan Na, Chen Hongli. The role of policy factors in the reconstruction of the space for production, life and ecology in the border area of Sichuan, Yunnan and Tibet: Focusing on the spirit of ecological construction at Tibet work forum of the CPC central committee[J]. Journal of Tibet University, 2021, 36(1): 175-185.

[13] Dong Jianhong, Zhang Zhibin, Da Xiaojun, et al. Eco-environmental effects of land use transformation and its driving forces from the perspective of production-living-ecological space: A case study of Gansu Province[J]. Acta Ecologica Sinica, 2021, 41(15): 1-11.

[14] Jiao Gengying, Yang Xiaozhong, Huang Zhiqiang, et al. Evolution characteristics and possible impact factors for the changing pattern and function of production-living-ecological space in Wuyuan County[J]. Journal of Natural Resources, 2021, 36(5): 1252-1267.

[15] Wang Quanxi, Sun Pengju, Liu Xuelu, et al. Analysis on spatial-temporal pattern of trade-offs and synergies of production-living-ecological function in

loess hilly and gully region: A case study of Wushan County[J]. Chinese Journal of Agricultural Resources and Regional Planning, 2020, 41(11): 122-130.

[16] Yu Zhengsong, Cheng Yeqing, Li Xiaojian, et al. Spatial evolution process, motivation and restructuring of production-living-ecology in industrial town: A case study on Qugou Town in Henan Province[J]. Scientia Geographica Sinica, 2020, 40(4): 646-656.

[17] Fan Yina, Wang Pengfei, An Weiliang. Analysis on the spatial evolution of production-living-ecological space under the production evolution: A case study of Buli Village, Shanxi Province[J]. Journal of Capital Normal University (Natural Science Edition), 2020, 41(6): 41-50.

[18] Ma Caihong, Jia Keli, Zou Shuyan, et al. Study on tracing method of land use change process based on the perspective of land use transfer flow: A case study in Yanchi County in arid area of central Ningxia Hui Autonomous Region[J]. Journal of Northwest Normal University (Natural Science), 2017, 53(4): 101-106.

[19] Ma Caihong, Ren Zhiyuan, Li Xiaoyan. Land use change flow and its spatial agglomeration in the loess platform region[J]. Acta Geographica Sinica, 2013, 68(2): 257-267.

[20] Li Xin, Fang Bin, Yin Rumeng, et al. Spatial-temporal change and collaboration/trade-off relationship of production-living-ecological functions in county area of Jiangsu Province[J]. Journal of Natural Resources, 2019, 34(11): 2363-2377.

[21] Li Hongbo, Wu Jiangguo, Zhang Xiaolin, et al. The distribution characteristics and mechanism of the rural industrial land with the southern Jiangsu pattern[J]. Economic Geography, 2018, 38(1): 152-159.

[22] Lin Jia, Song Ge, Zhang Ying. Synergistic evolution mechanism of production-living-ecology functions in spatial planning system: A case study of Fuxin City[J]. China Land Science, 2019, 33(4): 9-17.

[23] Li Bohua, Cao Can, Dou Yindi, et al. Change of human settlement environment and driving mechanism in traditional villages based on production-living-ecological space[J]. Progress in Geography, 2018, 37(5): 677-687.

[24] Liu Jilai, Liu Yansui, Li Yurui. Classification evaluation and spatial-temporal analysis of production-living-ecological spaces in China[J]. Acta Geographica Sinica, 2017, 72(7): 1290-1304.

[25] Liu Pengfei, Sun Bindong. The spatial pattern of urban production-living-ecological space quality and its related factors in China[J]. Geographical Research, 2020, 39(1): 13-24.

[26] Yang Qingke, Duan Xuejun, Wang Lei, et al. Land use transformation based on ecological-production-living spaces and associated eco-environment effects:

A case study in the Yangtze River Delta[J]. Scientia Geographica Sinica, 2018, 38(1): 97-106.

[27] Zou Yan, Zhao Shaoliang, Xie Yiyi, et al. Spatial distribution and evolution characters of production-living-ecological spaces in Xuzhou City[J]. Science of Surveying and Mapping, 2020, 45(7): 154-162.

[28] Li Hongzhi, Tang Yanliang. From passively coordinated "three rules in one" to actively coordinated spatial planning: A case study of Guyuan Yuanzhou District spatial planning[J]. Planners, 2017, 33(8): 78-84.

Note: Figure translations are in progress. See original paper for figures.