Impacts of Land Use Change on Spatial Patterns of Cultivated Land and Prediction in Arid Regions: A Case Study of Changji City (Postprint)

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Abstract

This study examines the impact of land use change on the spatial pattern of cultivated land to provide references for optimizing land use patterns and strengthening cultivated land protection. Based on five-phase land use data from 2000 to 2020, the research employs a land use change intensity analysis framework, the PLUS model, and spatial autocorrelation analysis methods to investigate the influence of future land use changes on cultivated land space in Changji City. The results indicate that: land use types in Changji City are dominated by grassland, cultivated land, and unused land, with cultivated land and construction land exhibiting a continuous growth trend; the conversion from forestland/grassland to cultivated land and construction land, and from cultivated land to construction land constitutes the main characteristics of land use change in Changji City. Regarding conversion intensity, significant differences exist in conversion intensity between various land types and cultivated land, with both the transfer-in and transfer-out intensities between cultivated land and construction land exceeding the average conversion intensity, which substantially impacts the regional land use/cover structure. The PLUS model simulation results demonstrate that under the natural development scenario, cultivated land protection scenario, and sustainable development scenario, cultivated land area decreases by 36.21 km2, increases by 28.19 km2, and decreases by 25.66 km2, respectively; the sustainable development scenario better balances the dual demands of economic development and cultivated land protection. Changes in cultivated land pattern exhibit distinct spatial agglomeration characteristics, predominantly high-high clustering, mainly distributed in Yushugou Town, Erliugong Town, and Daxiqu Town in the central region, as well as Sangong Town in the southwestern part of the main urban area. The spatial distribution of high-high clustering remains basically similar across different scenarios, though the quantity varies. Finally, relevant recommendations are proposed from aspects such as coordinating cultivated land protection with economic development and optimizing the spatial

layout of land use. The research findings provide references for balancing the relationship between economic development and cultivated land protection in arid oasis cities.

Full Text

Abstract

This study investigates the impact of land use change on arable land space to provide a reference for optimizing land use patterns and strengthening farmland protection. Based on five periods of land use data from 2000 to 2020, we introduced the land use change intensity analysis framework, PLUS model, and spatial autocorrelation analysis to explore the influence of future land use changes on arable land space in Changji City. The results show that land use types in Changji City are dominated by grassland, arable land, and unused land, with arable and construction lands exhibiting a continuous growth trend. The conversion of forest and grassland to arable and construction lands, and of arable land to construction land, constitutes the main characteristic of land use change in Changji City. Regarding conversion intensity, significant differences exist in the conversion intensity between various land types and arable land, with both transfer-in and transfer-out intensities between arable and construction lands exceeding the average conversion intensity; such conversions will substantially impact the regional land use/cover structure. PLUS model simulations reveal that under natural development, arable land protection, and sustainable development scenarios, arable land area will decrease by 36.21 km^2, increase by 28.19 km^2, and decrease by 25.66 km^2, respectively. The sustainable development scenario better balances the dual demands of economic development and farmland protection. Changes in arable land patterns show distinct spatial agglomeration characteristics, dominated by high-high clustering, primarily distributed in Yushugou Town, Erliugong Town, and Daxiqiu Town in the central region, as well as Sangong Town in the southwestern part of the main urban area. The spatial distribution of high-high clustering is basically similar across different scenarios, though differences exist in the number of types. Finally, recommendations are proposed for coordinating arable land protection with economic development and optimizing land use spatial layout. The research results provide a reference for balancing economic development and farmland protection in oasis cities of arid regions.

Keywords: urbanization; cropland protection; intensity analysis; PLUS model; spatial autocorrelation; Changji

Introduction

Food security depends on agriculture, which in turn relies on land. Arable land constitutes the crucial foundation for national food security. Urbanization development cannot proceed without land support, and suburban farmland faces risks of quantitative reduction, quality decline, and landscape fragmentation.

The protection of high-quality farmland, especially permanent basic farmland, presents a severe challenge. Previous research indicates that construction land occupation represents the primary cause of farmland loss during urbanization. Current studies on the spatial impacts of land use change on farmland protection predominantly focus on economically developed regions, with few scholars conducting relevant research in northwest arid zones from a scenario simulation perspective. Simulating and predicting future land use patterns to identify hotspots of farmland conversion can provide references for scientifically delineating farmland functional zones and formulating zonal protection strategies. Oasis towns represent ecologically vulnerable areas in arid regions with intense human activity and tense human-land relationships. Coordinating the relationship between economic and social development and farmland protection constitutes an important issue for sustainable development in arid zone towns.

Changji City is located in the core area of the "Silk Road Economic Belt," with considerable potential for urbanization development. It hosts the Xinjiang Changji National Agricultural High-tech Industry Demonstration Zone, highlighting its prominent agricultural production role. Regarding future land use pattern simulation, the PLUS model is most widely applied, demonstrating high accuracy in landscape pattern, location, and quantity, with strong applicability for land use simulation research in northwest arid zones. Existing research on PLUS model applications in this region has primarily coupled it with the InVEST model to study the spatiotemporal evolution of carbon storage and ecosystem service value based on land use pattern changes, with limited further exploration of conversion information between arable land and other land types.

In 2020, Changji City's total population reached 5.88$ $\times 10^{\{5\}, with permanent resident urbanization rate of 70.8}$ {2}, *indic* of arable land, serving as an important grain production area for Changji Prefecture and even the entire Xinjiang region. The planning and construction of the Xinjiang Free Trade Zone Urumqi area will bring more opportunities for industrialization and urbanization development to Changji City. How to coordinate future economic and social development with farmland protection represents a critical issue for Changji City's sustainable development.

1.1 Study Area Overview

Changji City is situated at the northern foothills of the Tianshan Mountains, in the hinterland of the Eurasian continent, and on the southern margin of the Junggar Basin. It borders the regional capital Urumqi to the east, lies in the core area of the "Silk Road Economic Belt," and covers an area of 7,970.98 km^2. The terrain slopes from high in the south to low in the north, with mountains, plains, and desert distributed in a stepped pattern. The region features a continental arid climate, representing a typical arid zone oasis city (Fig. [Figure 1: see original paper]). Note: The base map is drawn using the standard map of the Ministry of Natural Resources, with review number GS(2023)2767, without modification of boundary lines. The same applies below.

1.2 Data Sources

Land use data used in this study were obtained from the Resources and Environmental Science Data Center of the Chinese Academy of Sciences, with a resolution of 30 m$\times$30*m.DatasourcesfordrivingfactorsareshowninTable.Alldataunderwentprojectiontransform*
m.

1.3.1 Land Use Transfer Matrix

The land use transfer matrix possesses spatiotemporal quantification characteristics. We used the land use transfer matrix to obtain the quantity and direction of land type conversions in Changji City from 2000 to 2020, analyzing the general patterns of land use change. The calculation method is as follows:

$$S_{ij} = \begin{vmatrix} S_{11} & S_{12} & \cdots & S_{1n} \\ S_{21} & S_{22} & \cdots & S_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ S_{n1} & S_{n2} & \cdots & S_{nn} \end{vmatrix}$$

where S represents land area (km^2); i and j denote land use types before and after conversion, respectively; and n is the number of land use types.

1.3.3 Future Land Use Pattern Simulation

The PLUS model integrates a rule-mining framework for land expansion analysis strategies and a multi-type random patch seed mechanism based on the CA model, which can fully explore the drivers of various land type changes and simulate patch-level land use changes. Combining information reflected by the land use transfer matrix and intensity analysis framework, we adjusted transfer probabilities between land types to establish three scenarios—natural development, arable land protection, and sustainable development—to predict future land use patterns and provide references for optimizing land use structure and formulating rational land use strategies in Changji City. Scenario settings are as follows:

1) **Natural Development Scenario.** Based on land use change trends from 2010 to 2020, this scenario uses the Markov model to predict the scale of each land type and serves as the comparative baseline for the other two scenarios.

2) **Arable Land Protection Scenario.** Adhering to the goal of "storing grain in the land," this scenario strengthens farmland protection and reduces non-agricultural construction occupation of arable land. Referencing existing research findings, we reduced the transfer probability from arable land to construction land by 50% and increased the transfer probability from grassland and unused land to arable land by 30% based on the natural development scenario to ensure arable land area.

3) **Sustainable Development Scenario.** This scenario seeks unity among economic development, farmland protection, and ecological benefits. Grassland plays an important ecological function and a crucial role in maintaining the quantitative balance of various land uses in arid zone towns. Considering Changji City's location advantages, future development opportunities, and land use change characteristics, we reduced the transfer probability from arable land to construction land by 30% and from grassland to construction land by 50% based on the natural development scenario to balance economic development, farmland protection, and ecological security.

Neighborhood Weight Setting. Neighborhood weights represent the expansion capacity of each land type, with values ranging from 0 to 1. Larger values indicate stronger expansion capacity. The complex relationship between driving factors and land use change makes direct calculation of expansion intensity difficult. Research shows that the historical expansion scale of each land type during the study period best reflects its expansion capacity. Drawing on this parameter setting method, we standardized the expansion area of each land type during the study period and, after multiple adjustments, obtained final neighborhood weights as shown in Table .

1.3.4 Arable Land Instability Hotspot Analysis

We used global and local spatial autocorrelation analysis to examine the spatial agglomeration characteristics of arable land spatial pattern changes in Changji City. Global spatial autocorrelation determines whether spatial clustering exists in arable land pattern changes, while local spatial autocorrelation reflects the correlation degree between local research units and neighboring units regarding the same attribute, indicating similar or different change trends. Global Moran's I and local Moran's I are calculated using formulas (1) and (2), respectively:

$$\text{Moran's I} = \frac{n\sum_i \sum_j W_{ij}(Y_i - \bar{Y})(Y_j - \bar{Y})}{\sum_i \sum_j W_{ij} \sum_i (Y_i - \bar{Y})^2}$$

$$I_i = \frac{(Y_i - \bar{Y})}{S^2} \sum_j W_{ij}(Y_j - \bar{Y})$$

where n is the number of research units; $S^2 = \frac{1}{n}\sum_i (Y_i - \bar{Y})^2$; $\bar{Y}$ is the mean of Y_i; i and j represent different research units; Y_i and Y_j denote the proportion of potential arable land transfer in research units i and j; and W_{ij} is the spatial weight matrix. Moran's I ranges from -1 to 1. A positive index indicates positive correlation, with stronger correlation as the absolute value approaches 1, and weaker correlation otherwise. An index of 0 indicates no correlation.

2.1 Land Use Structure Characteristics

The spatial distribution of land use in Changji City exhibits obvious vertical characteristics, with grassland, arable land, and unused land distributed sequentially from south to north, accounting for over 90% of the total area. Forestland, construction land, and water bodies occupy relatively small proportions (Fig. [Figure 2: see original paper]). Arable land is mainly distributed in the alluvial plains of the central region, grassland and forestland are primarily located on the northern slopes of the Tianshan Mountains, and unused land lies in the northern Gurbantünggüt Desert, with urban construction land surrounded by arable land on three sides.

From 2000 to 2020, the areas of arable land and construction land showed overall growth trends, while grassland area first increased then decreased, and unused land showed the opposite pattern. Forestland and water body areas decreased significantly. The main sources of arable land transfer-in were grassland and unused land, receiving 143.92 km^2 and 210.65 km^2, respectively. Construction land transfer-in mainly came from arable land and grassland, receiving 88.76 km^2 and 51.63 km^2, respectively. Grassland area decreased overall but showed a growth trend, with main transfer-in sources being forestland and unused land (402.37 km^2 and 174.39 km^2, respectively). Forestland and water body areas decreased noticeably, with forestland mainly converting to grassland and arable land (131.92 km^2 to arable land), and water bodies primarily converting to unused land (31.83 km^2). The main transfer-in source for unused land was grassland and water bodies, with 251.39 km^2 from grassland (Table). The conversion of ecological land such as forestland and grassland to arable and construction lands, and the conversion between arable and construction lands, represent the main trends of land use change in Changji City, consistent with general patterns of land use system change.

2.2 Arable Land Conversion Intensity

The land use conversion intensity analysis framework was used to analyze the impact of land type conversions on regional land use/cover structure. The relative conversion intensities of various land types to arable land were 0.27%, 1.44%, 0.32%, 0.54%, and 0.31%, with an average transfer-in intensity of 0.30% (Fig. [Figure 3: see original paper]). Conversion intensity is greatly influenced by the base area of land types. Although grassland and unused land contributed the largest transfer-in area to arable land, their large base areas resulted in transfer-in intensities below the average. Construction land transfer-in to arable land was small in quantity, but its small base area led to a transfer-in intensity significantly higher than the average. Arable land transfer-out intensities to various land types were 0.00%, 0.11%, 0.47%, 2.23%, and 0.01%, with an average transfer-out intensity of 0.56%. In absolute terms, arable land and grassland contributed the largest transfer-out area to construction land. However, due to its smaller base area compared to grassland, arable land's transfer-out intensity to construction land was significantly higher than the average level. Changji

City's main urban area is surrounded by arable land, and construction land expansion tends to occupy nearby arable land with good natural conditions, convenient transportation, and lower development costs. The intensity analysis framework identifies that the conversion between arable land and construction land should be the focus of future land use processes in Changji City, considering both base area and spatial layout.

2.3.1 Comparison of Multi-Scenario Land Use Simulation Results

Based on 2020 land use data, combined with driving factors and development potential data for each land type, we continuously adjusted model parameters to simulate 2030 land use patterns. Comparing the 2020 actual land use results, the Kappa coefficient was 0.88 and overall accuracy reached 88.78%, indicating high simulation precision. We predicted land use demand for each land type under three development scenarios (Table), with multi-scenario simulation results shown in Fig. [Figure 4: see original paper].

Under the natural development scenario, arable land, forestland, grassland, and water bodies all show decreasing trends, with reductions of -2.46%, -2.66%, -15.37%, and -12.15%, respectively. Construction land expansion is significant, with a cumulative increase of 74.61 km^2 (37.54%). Without restrictive factors, substantial amounts of suburban arable land and grassland are occupied to meet socioeconomic development demands, posing considerable threats to regional food security and ecological security.

Under the arable land protection scenario, arable land area receives maximum protection, increasing by 28.19 km^2 (1.91%). However, construction land growth draws more from ecological land such as forestland, grassland, and water bodies, with reduction rates of -2.75%, -16.06%, and -12.27%, respectively—all greater than under the natural development scenario. This indicates that while the arable land protection scenario can effectively curb construction land expansion into arable land, its occupation of ecological land is detrimental to regional ecological protection and sustainable socioeconomic development.

Under the sustainable development scenario, arable land, forestland, and grassland areas decrease by 25.65 km^2 (-1.74%), 2.64 km^2 (-2.64%), and 553.59 km^2 (-15.32%), respectively. The decline rate of arable land slows, construction land increment is 58.42 km^2, and unused land quantity is basically the same as under the arable land protection scenario. Overall, the sustainable development scenario integrates the land use characteristics of both natural development and arable land protection scenarios, balancing economic development with farmland protection and facilitating regional sustainable development.

2.3.2 Analysis of Factors Influencing Construction Land Expansion

Land use spatiotemporal pattern changes result from comprehensive natural and socioeconomic factors. We selected expansion driving factors from three aspects—natural geographical conditions, socioeconomic development, and traffic accessibility—and analyzed driving factors of land use expansion based on the PLUS model. Construction land expansion in Changji City is primarily extensive, with flat terrain, relatively concentrated population, proximity to the G30 Expressway, traffic arteries, obvious government policy support, and location advantages making it the main area for future construction land expansion. The driving force ranking for construction land expansion is traffic accessibility > natural geographical conditions > socioeconomic development. In traffic accessibility, the factors with greatest driving force are distance to expressways and railways (0.58 and 0.57, respectively). As an important node city of the "Silk Road Economic Belt," the southwestern part of the main urban area is the primary construction zone for future industry-city integration and smart logistics development. Convenient freight transportation is essential for logistics industry development, making this area a hotspot for construction land expansion. Construction land expansion is primarily extensive, and socioeconomic factors have relatively small driving force on construction land expansion. Road construction plays a guiding role in future construction land expansion.

2.4 Spatial Autocorrelation Analysis of Arable Land Spatial Pattern Evolution

Using GeoDa software and comparing spatial autocorrelation analysis effects, we selected 2 km$×$2 km fishnets as basic evaluation units to conduct spatial autocorrelation analysis on the proportion of potential arable land transfer area to current arable land area within each evaluation unit. Global Moran's I values for arable land spatial pattern evolution under the three scenarios are 0.47, 0.46, and 0.47, with Z-values of 31.83, 31.22, and 31.83, respectively (all $P < 0.01$), indicating that arable land spatial pattern evolution in Changji City has significant positive spatial correlation, permitting local spatial autocorrelation analysis.

Overall, Changji City's construction land expansion is primarily extensive. The spatial distribution of clustering characteristics for arable land spatial pattern evolution is similar across the three scenarios (Fig. [Figure 5: see original paper]), dominated by high-high and low-high clustering, though the number of clustering types differs among scenarios (Table). Under the natural development scenario, construction land has the strongest expansion capacity, with obvious expansion in existing built-up areas and locations with greater location advantages, resulting in the most high-high clustering units and the fewest low-high clustering units. Under the arable land protection scenario, arable land expansion capacity is enhanced and the transfer probability from arable land to construction land is reduced, decreasing high-high clustering units. The sustainable development scenario shows similar land type change trends to the natural development scenario but with moderated change amplitude, so the number of high-high clustering units falls between the natural development and arable land protection scenarios.

High-high clustering areas are mainly located between the main urban area and the high-tech development zone, connecting the eastern bank of the Santun River to the southwestern part of the main urban area, and in the Yushugou Town Agricultural Science and Technology Park. These areas have flat terrain, relatively concentrated populations, proximity to the G30 Expressway, obvious traffic arteries, government policy support, and location advantages, with active economic development, making them the main areas for future construction land expansion. Low-high clustering areas are mainly distributed in Miaoergou Township in the north-central part and the northwestern part of the main urban area. In the northwestern part of the main urban area, traffic network and municipal facility construction have caused obvious farmland fragmentation, with some arable land already surrounded by construction land spatially. This is not conducive to large-scale urban development, resulting in a smaller transfer-out proportion and exhibiting low-high clustering characteristics. In the low-high clustering areas of northern Miaoergou Township, most of the arable land was reclaimed through human cultivation, with relatively stable land use types. However, affected by water resource shortages and wind-sand erosion, the risk of arable land degradation is relatively high, thus forming the low-high clustering type.

3 Discussion

Arable land protection concerns national food security, ecological security, and social stability. This study examines future land use evolution trends and explores the impact of land use change on arable land space in Changji City, an oasis city in arid zones. During the study period, the main sources of construction land transfer-in were grassland and arable land, consistent with current general patterns of land conversion. As global climate warms and snow melts in southern mountainous areas, exposed surfaces lead to increased unused land and decreased water body area. Changji City's main urban area is surrounded by arable land, and urban construction tends to occupy suburban arable land. However, constrained by the farmland requisition-compensation balance policy, the government reclaims grassland to compensate for construction-occupied arable land losses. This shares similarities with land use change in the Lanzhou-Xining urban agglomeration studied by Li et al., indicating that land use change in northwest arid zones also has regional specificity.

Using the intensity analysis framework to further explore land use transfer matrix information, changes in land use/cover structure are influenced by the base area of land types. Although cumulative conversion area from grassland and unused land to arable land reached 354.57 km^2, the large base area of these land types means this conversion has relatively small impact on regional land use/cover structure. The conversion intensity between arable land and construction land is significantly higher than the average conversion intensity, and this land conversion type will have more substantial impacts on regional land use/cover structure.

Focusing on the main conversion types in Changji City, we used the PLUS model to simulate future land use demand under different scenarios. The overall simulation accuracy and Kappa coefficient are high, demonstrating the good applicability of the PLUS model for land use simulation in arid zones and corroborating existing research findings. This study examined the impact of future land use change on arable land space, but several limitations remain. Due to the complexity of land use behaviors and data acquisition limitations, factors such as regional policy planning and individual farmer behaviors were not considered. Further research should conduct comprehensive suitability evaluation of arable land use and functional zoning studies to address the differentiated utilization of suburban arable land and balance the relationship between economic and social development and farmland protection.

Based on the research results and current land use status in Changji City, we propose measures to strengthen farmland protection from both "source expansion" and "consumption reduction" perspectives. First, grassland is an important source of arable land transfer-in. We should strengthen desertification prevention and land use supervision, strictly prohibit cultivation in desert edges, farming-pastoral transition zones, and around important ecosystems, protect the ecological environment, prevent grassland degradation, and proactively prepare farmland requisition-compensation balance indicator reserves. Second, we should improve the land use planning system by analyzing current land resource utilization, socioeconomic development potential, and future urban development plans to scientifically predict land demand, conduct rural land consolidation, reclaim abandoned industrial and mining land, transform medium- and low-yield fields, tap into urban stock land, and promote intensive and economical land use to reduce occupation of high-quality suburban arable land.

4 Conclusion

This study selected five periods of land use data from 2000 to 2020 in Changji City and used land use transfer matrix, land use change intensity analysis framework, PLUS model, and spatial autocorrelation analysis to examine land use change characteristics and predict the impact of future land use change on arable land space. The following conclusions were drawn:

1) As an oasis town in arid zones, Changji City's land use is dominated by grassland, arable land, and unused land. The conversion of forest and grassland to arable and construction lands, and the conversion between arable and construction lands, constitute the main forms of land use change in Changji City. Grassland is the primary source of arable

land transfer-in and plays an important role in maintaining regional land use balance.

2) In absolute terms, although the transfer-in quantity and contribution rate of arable land to construction land show a declining trend, they remain at 45.96%, making it the main source of urban construction land expansion. Regarding conversion intensity, although grassland conversion area is relatively large, its conversion intensity is lower due to its large base area. In contrast, the conversion intensity between arable land and construction land is significantly higher than the average conversion intensity, and conversions between these two land types will have more pronounced impacts on regional land use/cover structure.

3) Under different scenarios, the spatial layout of various land types is basically similar. Influenced by Changji City's narrow east-west and long north-south zoning, construction land expansion is primarily extensive, with the expansion direction connecting the eastern main urban area with the western high-tech development zone. Compared with natural development and arable land protection scenarios, the sustainable development scenario can better balance the dual demands of economic development and farmland protection.

4) Spatial autocorrelation analysis results of arable land pattern evolution are dominated by high-high clustering, mainly distributed in Yushugou Town, Erliugong Town, and Daxiqiu Town in the central region, as well as Sangong Town in the southwestern part of the main urban area. Low-high clustering is mainly distributed in the north-central Miaoergou Township and northwestern part of the main urban area. The spatial distribution of arable land conversion clustering types is basically similar across different scenarios, but differences exist in the number of types.

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