Spatiotemporal Evolution of Land-Use Conflicts in Urumqi City from an Ecological Security Perspective: Postprint

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Abstract

From the perspective of ecological security, identifying regional land use conflicts and managing the coordinated relationship between urban development and land use is particularly crucial for achieving regional sustainable development. Under the theoretical analysis framework of land use conflict and the "Pressure-State-Response" (PSR) model, a land use conflict measurement model was constructed by employing ecosystem service value and ecological risk assessment factors. The spatiotemporal evolution patterns of land use conflicts in Urumqi City for the years 2000, 2010, and 2020 were analyzed, and the FLUS model was utilized to simulate and predict changes in land use conflicts for 2030. The results indicate that: (1) During 2000–2020, over 73% of the area in Urumqi City consisted of conflict-free and low-conflict zones. Hotspot areas of land use conflicts expanded from the northern and southwestern parts of Urumqi' s central urban area to the peripheries of mountainous forest lands in its southern and northern regions, as well as to the alluvial fans on both sides of the salt lake in Dabancheng District, with an enlarged distribution range; coldspot areas were primarily concentrated around the central urban area and within the mountainous forest lands in the eastern and southern parts. (2) Natural factors such as climate and topography remain the dominant drivers of spatial differentiation in land use conflict intensity. (3) A spatial positive correlation exists between ecosystem service value and land use conflicts, whereas a significant spatial negative correlation is observed between ecological risk and land use conflicts. (4) By 2030, although high-conflict areas in Urumqi City will experience the greatest increase, conflict-free and low-conflict areas will still maintain a dominant position. The research findings provide a diagnostic indicator system and methodology for land use conflicts in Urumqi City, offering empirical evidence and scientific support for a deeper understanding of the spatiotemporal evolution characteristics and underlying mechanisms of land use conflicts in Urumqi.

Spatiotemporal Pattern Evolution Analysis of Land Use Conflict in Urumqi City from the Perspective of Ecological Security

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Abstract

Identifying regional land use conflicts from the perspective of ecological security and effectively managing the coordination between urban development and land use is crucial for achieving sustainable regional development. Within the theoretical analysis framework of land use conflict and the pressure-state-response (PSR) model, this study constructs a land use conflict measurement model by integrating ecosystem service value and ecological risk evaluation factors to analyze the spatiotemporal evolution patterns of land use conflict in Urumqi City for the years 2000, 2010, and 2020. Furthermore, the future land use simulation (FLUS) model is employed to simulate and predict changes in land use conflict by 2030. The results indicate that: (1) From 2000 to 2020, more than 73% of Urumqi' s area was characterized by no conflict or mild conflict. Hotspots of land use conflict expanded from the northern and southwestern areas of the central urban district to surrounding mountainous woodlands in the southern and northern regions, as well as to alluvial fans on both sides of the salt lake in Dabancheng District, with an expanded distribution range. Cold spot areas were primarily concentrated around the central urban district and within the mountainous woodland areas in the eastern and southern parts. (2) Natural factors such as climate, topography, and geomorphology remain the dominant drivers of spatial differentiation in land use conflict intensity. (3) A positive spatial correlation exists between ecosystem service value and land use conflict, while a significant negative spatial correlation exists between ecological risk and land use conflict. (4) By 2030, although the area of high-conflict zones in Urumqi shows the largest increase, conflict-free and low-conflict zones continue to maintain their dominant position. This study provides a diagnostic index system and methodology for analyzing land use conflict in Urumqi, offering both an illustrative case and scientific support for in-depth understanding of the spatiotemporal evolution characteristics and underlying mechanisms of land use conflict in the region.

Keywords: land use conflict; ecosystem service value; ecological risk; FLUS model; Urumqi City

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1.1 Study Area Overview

Urumqi City (43°40 ~44°50 N, 87°10 ~88°55 E) is located in inland Asia, on the northern foothills of the Tianshan Mountains. As a typical arid oasis city in northwestern China, Urumqi features complex and diverse landforms, sparse vegetation, low precipitation, and a fragile ecological environment. According to the seventh national census, the city covers approximately 11,133.6 km^2 with a permanent population of 2.5852 million, representing a 40.39$×10^{4}$ increase compared to previous figures, yielding a population density of 258.52 persons per km^2. Rapid urbanization and population growth have dramatically altered land use patterns, generating multifaceted environmental impacts of varying intensity. As a representative of accelerated urbanization, Urumqi must continuously utilize more land resources to meet human settlement and development demands, which in turn intensifies contradictions and conflicts between ecological protection and oasis land use.

1.2 Data Sources

This study utilized Landsat imagery from three periods: 2000, 2010, and 2020, representing different stages of land use policy implementation. The spatial remote sensing data were obtained from the China Geographic Spatial Data Cloud (http://www.gscloud.cn), comprising Landsat-5 TM data with 30 m spatial resolution. All Landsat images contained less than 5% cloud cover. DEM data were also sourced from the China Geographic Spatial Data Cloud with 30 m resolution. Elevation and slope data were derived from this DEM dataset. Administrative boundaries, roads, district centers, and other vector data were primarily obtained from Urumqi City vector layers. Statistical data on GDP, population, grain yield, and grain prices were mainly collected from the *Urumqi Statistical Yearbook (2001-2021)*, *Urumqi National Economic and Social Development Statistical Bulletin (2001-2021)*, *Xinjiang Statistical Yearbook (2001-2021)*, and the *National Agricultural Product Cost-Benefit Compilation.*

1.3.1 Construction of the Land Use Conflict Measurement Model

From an ecological security perspective, land use conflict in Urumqi primarily manifests as spatial competition and contradictions arising from the mismatch and overlap among cultivated land, construction land, and ecological security spaces under intensive human activity. The pressure-state-response (PSR) model and its extensions can evaluate complex environmental issues, resource security, and land sustainability problems. This approach combines fuzzy mathematics to establish evaluation criteria for land ecosystems, analyzes causal relationships among various influencing factors, and monitors continuous feedback mechanisms among indicators. The PSR model is systematic and comprehensive, providing an effective pathway to identify causal chains between human activities and ecosystem impacts, making it suitable for diagnosing land ecosystem states and responses resulting from land use pressures.

Under the guidance of the PSR model and considering Urumqi’ s resource and environmental characteristics, this study determined three key indices: the system disturbance index (AWMPFD), vulnerability index (FI), and stability index (SI) to construct the comprehensive land use conflict index (F). The calculation results require standardization to the range [0,1]. The formulas are as follows:

The land use conflict indicator system comprises three components. **Pressure (AWMPFD)** refers to the intensity of land resource development and utilization and its changing trends, representing the impact and stress on the cultivated land ecosystem from human factors. As the primary external cause and risk source of land use conflict, the land use disturbance index expresses the landscape’ s ability to resist external interference and self-recover. The formula is:

$$\mathrm{AWMPFD} = \sum_{i=1}^{m} \sum_{j=1}^{n} \left[\frac{2\ln(0.25 \times P_{ij})}{\ln(A_{ij})} \right]$$

where P_{ij} is the perimeter of the j-th patch of land use type i, A_{ij} is the area of the j-th patch of land use type i (km^2), m is the total number of land use types, and n is the number of patches within the regional unit.

State (FI), as a parameter reflecting changes in land ecological environmental elements, is expressed through the vulnerability index to represent a state of damage due to insufficient capacity to adapt to environmental and social changes. The formula is:

$$FI = \sum_{i=1}^{m} \frac{a_i}{A} \times F_i$$

where a_i is the area of land use type i within the regional unit (km^2), F_i is the vulnerability of land use type i, and A is the total area of all land use types within the regional unit (km^2). Vulnerability assignments are: construction land 0.9, unused land 0.8, water bodies 0.6, cultivated land 0.5, grassland 0.3, and forest land 0.1.

Response (SI) primarily reflects measures taken by society or individuals to stop, reduce, prevent, or restore changes detrimental to the land ecosystem. The stability index represents both the consistency and continuity of system production and the continuity and heritability of system states or spatial patterns. The formula is:

$$SI = 1 - PD = 1 - \frac{\sum_{i=1}^{m} n_i}{A}$$

where PD is patch density (patches $\cdot$ km^{-2}), A is the total area of all land use types within the regional unit (km^2), and n_i is the number of patches of land use type i.

1.3.2 Simulation of Land Use Conflict Spatial Distribution Prediction

To obtain the spatial distribution characteristics of land use in Urumqi for 2030, this study employed the FLUS model, which integrates neural networks (ANN) and cellular automata (CA) with an adaptive inertia competition mechanism. The model consists of two modules. First, using one period of land use data combined with geographical detection factors, ANN calculates the occurrence probability of each land use type in every pixel, yielding development probability. Second, a roulette selection-based competition mechanism generates the predicted land use map. The selected factors include elevation, slope, distance to rivers, distance to district centers, distance to roads, population density, and GDP per capita (Figures 3 and 4). After processing the 2020 land use data, the FLUS model simulated the 2030 land use spatial distribution. The Kappa coefficients between simulated and actual land use data were 0.82, 0.85, and 0.87 for the three periods, with overall simulation accuracies of 88.76%, 90.34%, and 91.45%, respectively, meeting the research requirements.

1.4.2 Ecological Risk Assessment System

In landscape ecology, landscape ecological risk assessment requires sample areas to be 2–5 times the average patch area to effectively reflect landscape pattern information. The average patch area of land use landscapes in the study region ranges between 0.3–0.4 km^2. To effectively identify potential ecological risks and optimize landscape structure, this study constructed a relationship model between land use and ecological risk based on grid sampling. Using 0.60 km × 0.60 km square grid units across the study area, the ecological risk index was calculated as:

$$ERI_i = \sum_{i=1}^{N} \frac{A_{ki}}{A_k} \times R_i$$

where ERI_i is the ecological risk index of risk cell i (proportional to risk degree), A_{ki} is the area of land use type i in risk cell k (km^2), A_k is the area of risk cell k (km^2), and R_i is the landscape loss index of land use type i, representing differences in ecological loss when disturbed.

The landscape loss index is calculated as:

$$R_i = S_i \times V_i$$

where S_i is the landscape disturbance index and V_i is the landscape vulnerability index.

2.1.1 Spatiotemporal Evolution Characteristics of Land Use Conflict

Using ArcGIS software and the natural breaks method, land use conflict types were classified into five levels: no conflict [0.00, 0.30), mild conflict [0.30, 0.36), moderate conflict [0.36, 0.42), high conflict [0.42, 0.50), and severe conflict [0.50, 1.00]. Given the limited research on precision evaluation methods for land use conflict classification, Kappa coefficients were applied for accuracy and consistency assessment. The minimum Kappa coefficient was 0.81, meeting research requirements (Table 2).

From 2000 to 2020, land use conflict in Urumqi showed an overall upward trend, though the conflict situation eased by 2020 and remained basically controllable (Figure 5). Specifically, conflict-free areas decreased annually, with their proportion dropping from 52.85% to 35.77%. Mild conflict areas showed a decrease followed by an increase, rising by 563.76 km^2 overall, though the net change was a slight increase of 20.88 km^2. Combined, conflict-free and mild conflict areas accounted for over 73% of Urumqi' s total area, representing the dominant conflict types. Moderate conflict areas increased annually, rising by 584.64 km^2. High and severe conflict areas followed similar trends, decreasing initially then increasing after 2010, with overall significant increases. High conflict areas showed the largest growth at 187.35%, while severe conflict areas increased by 1321.92 km^2.

2.1.2 Local Spatial Heterogeneity Analysis of Land Use Conflict

The cold/hotspot analysis reveals that from 2000 to 2020, land use conflict hotspots expanded from the northern and southwestern parts of central Urumqi to surrounding mountainous woodlands in the south and north, as well as to alluvial fans near the salt lake in Dabancheng District. Cold spot areas aligned with decreasing high-conflict zones, concentrating around the urban periphery and in eastern and southern mountainous woodlands. This occurs because internal land use types in cold spots tend toward homogenization, reducing patch complexity and alleviating conflict (Figure 7).

As a spatial variable, the comprehensive land use conflict index exhibits both structural and random spatial variation characteristics. Geostatistical semivariogram analysis can identify dominant factors in spatial differentiation (Table 3). Spatial heterogeneity results from combined structural factors (climate, topography) and random factors (human activities). The nugget-to-sill ratio [$C_0/(C_0+C)$] < 0.20 indicates strong spatial autocorrelation dominated by structural factors; > 0.70 indicates weak spatial autocorrelation dominated by random factors; and 0.20–0.70 indicates moderate spatial autocorrelation.

Results show that at scales below 600 m, natural factors remain the dominant drivers of spatial differentiation in land use conflict intensity. The alluvial plains of the lower Urumqi River have suitable hydrothermal conditions for crop growth, making them primary areas for socioeconomic activity and initial conflict zones. However, subsequent guidance and regulation of ecological protection and socioeconomic development demands have increased random variation in land use conflict at small scales, reducing the influence of natural factors.

2.1.3 Response of Land Use Conflict to Ecosystem Service Value

Bivariate spatial autocorrelation (Bivariate Moran' s I) reveals relationships between spatial unit attributes and neighboring attributes. Calculations for land use conflict and ecosystem service value show that eastern and southern mountainous woodlands, despite being high ecosystem service value areas, experience natural ecological succession and human disturbance that destabilizes land use structure, creating severe conflict. These areas show strong positive spatial correlation (high-high clusters) with severe conflict zones. From 2010, high-high clusters decreased significantly under ecological protection policies, with only minimal increases near Wulabo Wetland in Tianshan District. Low-low clusters, representing medium ecosystem service value areas with no conflict, align with grassland distribution and showed increased aggregation. Low-high clusters, indicating low ecosystem service value areas with high conflict, are strongly negatively correlated and mainly distributed in central urban areas, expanding to surrounding areas after 2010, particularly near construction land in Urumqi County and Dabancheng District (Figure 8).

2.1.4 Response of Land Use Conflict to Ecological Risk

The bivariate LISA cluster map of land use conflict and ecological risk indicates that as construction land expands into surrounding grassland and cultivated land, stability and connectivity deteriorate, creating hotspot zones around construction land and mountainous woodlands. However, these areas will decrease with ongoing urbanization. Cold spot areas, influenced by ecological succession, are mainly distributed around salt lakes, Chaiwobao Lake, and mountainous woodlands (Figure 9).

2.2 Land Use Conflict Spatial Prediction Simulation

The 2030 simulation results show that land use conflict spatial distribution remains similar to 2020, dominated by no-conflict and mild-conflict zones. No-conflict areas increased by 788.40 km^2, indicating overall improvement. However, high-conflict and severe-conflict areas increased by 194.40 km^2 and 740.52 km^2, respectively, showing localized intensification. Severe-conflict zones cover the largest area (1178.64 km^2), with obvious clustered aggregation in intensively managed cultivated land north and south of the central urban district (Figure 10).

Cold/hotspot analysis for 2020–2030 reveals that due to construction land expansion into grassland and cultivated land, hotspots will appear around construction land and mountainous woodlands but with reduced area. Cold spots will be influenced by ecological succession, mainly distributed around salt lakes, Chaiwobao Lake, and mountainous woodlands (Figure 12).

3 Discussion

Despite rising land use conflict trends, Urumqi' s *Urban Master Plan (2017-2035)* has produced obvious regulatory effects, slowing conflict and maintaining basic controllability, consistent with findings by Tian Liulan et al. and Wang Shanshan et al. Land use conflict results from multiple factors. The coupling responses among ecological risk, ecosystem service value, and land use conflict show clear spatial differences. High-level coupling occurs between construction space and ecological space, where increasing land use conflict corresponds with rising ecological risk and ecosystem service value. Low-level coupling is scattered in agricultural space, where land use changes have minimal impact on ecological risk and ecosystem service value. Harmonious ecological and land use development is mutually reinforcing: improving ecological security reduces land use conflict intensity, while inconsistent development constrains both.

Although overall land use conflict is projected to improve by 2030, localized high-conflict and severe-conflict areas will intensify, particularly in intensively managed cultivated land north and south of the central urban district. Therefore, strict control should be implemented over ecological protection red lines to ensure no reduction in ecological function, area, or quality. Minimum ecological flow, water surface area, and wetland area of the Urumqi River, Shuimo River, and Chaiwobao Lake should be gradually restored to maintain watershed ecological functions and effectively control environmental risks. Resource utilization must comply with the *Xinjiang Ecological Environment Protection 14th Five-Year Plan* targets for total amount and intensity control to improve resource use efficiency. Drinking water source protection and ecological space maintenance should be prioritized for water conservation and soil retention functions. Scientific delimitation of ecological protection red lines, permanent basic farmland, and urban development boundaries should be implemented, along with establishing and improving land use risk assessment, early warning, and response mechanisms to enhance supervision and risk prevention for land use and ecological security.

4 Conclusions

This study analyzed the spatiotemporal evolution of land use conflict in Urumqi from 2000 to 2020 and predicted 2030 patterns, yielding four main conclusions:

1) From 2000 to 2020, over 73% of Urumqi' s area was conflict-free or mildly

conflicted. Although land use conflict area increased annually, the situation remained basically controllable. Hotspots concentrated in the northern and southwestern central urban district, spreading to surrounding mountainous woodlands and alluvial fans near Dabancheng District' s salt lake. Cold spots were mainly located around the central urban district and in eastern and southern mountainous woodlands.

2) Natural factors such as climate and topography remain the dominant drivers of spatial differentiation in land use conflict intensity. However, under regulation of ecological protection and socioeconomic development demands, random variation in land use conflict at small scales has increased, reducing the influence of natural factors.

3) Positive spatial correlation exists between ecosystem service value and land use conflict, while significant negative spatial correlation exists between ecological risk and land use conflict.

4) From 2000 to 2020, land use types showed a "three increases, three decreases" trend: construction land, forest land, and water bodies increased, while grassland, cultivated land, and unused land decreased. Conflict-free and mild-conflict zones dominated, though high-conflict and severe-conflict zones increased, with high-conflict zones showing the largest growth rate.

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Figure Captions

[Figure 1: see original paper] Schematic diagram of the study area
[Figure 2: see original paper] Analytical framework
[Figure 3: see original paper] Spatial distributions of natural factors
[Figure 4: see original paper] Spatial distributions of social factors
[Figure 5: see original paper] Changes in the area of land use conflict types
[Figure 6: see original paper] Distribution pattern of land use conflict types
[Figure 7: see original paper] Temporal and spatial evolution of cold and hot spots of land use conflict
[Figure 8: see original paper] Bivariate Lisa aggregation diagram of ecosystem service value and land use conflict
[Figure 9: see original paper] Bivariate Lisa aggregation diagram of land use ecological risks and conflicts
[Figure 10: see original paper] Distribution of land use conflict pattern from 2020 to 2030
[Figure 11: see original paper] Changes in land use conflicts from 2020 to 2030
[Figure 12: see original paper] Temporal and spatial evolution of cold and hot spots of land use conflicts from 2010 to 2030

Table Captions

Ecosystem service value coefficient per unit area of each land use type (10^4 yuan $\cdot$ km^{-2})
Kappa coefficient of land use conflict classification
Fitting model parameters of land use conflict variance functions

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