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CHANGES IN LAND USE CONFLICT AND ZONING OPTIMIZATION IN RAPIDLY DEVELOPING MOUNTAINOUS CITIES: A CASE STUDY OF GUIYANG, CHINA

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Highlights:
- land use conflicts in rapidly developing mountainous cities are intensifying;
- the most severe conflict occurs between production and living spaces;
- rational land use zoning can help mitigate these conflicts.

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Abstract. Mountainous cities, influenced by complex human activities and terrain, face severe land use conflict issues. However, the spatiotemporal characteristics of land use conflict changes and the scientific questions regarding their management in rapidly developing mountainous cities remain unresolved. Therefore, Guiyang, a typical mountainous city in China, was chosen as the study area. With the support of ArcGIS technology, this research analyzed land use conflict changes and conducted zoning optimization. The study reveals a rapid intensification of land use conflicts, with high conflict areas increasing by 369%, while moderate, general, and low conflict areas declined. The conflict between production and living spaces is the predominant one, expanding by 385%. Additionally, high conflict areas between production and ecological spaces rose by 760%. Integrating land suitability, conflict, and functional differences in zoning optimization enhances core functions, mitigates conflicts, and guides land use management. The results are valuable for optimizing land use patterns and promoting healthy urban development in mountainous cities.

Keywords: conflict characteristics, production-living-ecological spaces, suitability evaluation, spatial distribution, zoning optimization, mountainous cities.

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1. Introduction

National territorial space, encompassing production, living, and ecological spaces (hereafter referred to as "three types of space"), serves as the primary carrier of natural and human elements and their interactions, fulfilling multiple functions such as production, living, and ecology (Zhao et al., 2022; Peng et al., 2023). With rapid urbanization, issues such as resource depletion, ecological imbalance, and human-land conflicts have become increasingly prominent. The economically driven land use model has triggered competition and conflict among the three types of space, severely hindering the sustainable development of urban territorial space (Sun et al., 2020; Wang & Wang, 2022a; Tan et al., 2023). Therefore, identifying the characteristics of land use conflict changes and achieving land use optimization are crucial guarantees for sustainable urban development and have gradually become a research focus in academia (Wang et al., 2022; Yang et al., 2023a).

Conflicts among the three types of space essentially represent land use conflicts, manifesting as competition and contention over land use methods and spatial resources due to the discordant and uncoordinated use of land resources by different interest groups in the same location (Zhou et al., 2017; Cheng et al., 2022; Zhang et al., 2024). In recent years, scholars worldwide have explored land use conflicts from various perspectives. For instance, some researchers have focused on theoretical frameworks, aiming to deepen the understanding of land use conflicts in different contexts (Raska et al., 2023; Yang et al., 2023b). Others have dedicated their efforts to identifying and categorizing land use conflicts, proposing different approaches for accurate detection and classification (Chen et al., 2024; Ma et al., 2024). Furthermore, significant attention has been given to governance mechanisms and management strategies to resolve or mitigate land use conflicts, with a growing body of research focusing on policy interventions, regulatory measures, and community engagement (Scholl & Coolen, 2023; Zheng et al., 2024). The primary methods for analyzing land use conflicts include landscape pattern analysis, index evaluation, and modeling, which have been extensively employed to study spatial dynamics and conflict hotspots (Wang et al., 2023; Mo et al., 2023; Zhao et al., 2023). Despite the progress made, the integration of suitability evaluation methods for the three types of space in land use conflict analyses remains limited. Additionally, research specifically addressing mountainous cities–characterized by unique geographical features and complex land use dynamics–has been relatively scarce.

Land use optimization research has also evolved, mainly focusing on optimizing land use from diverse perspectives, such as improving land use structure, enhancing spatial efficiency, and analyzing the effects of land use optimization (Li et al., 2023c; Shen & Wang, 2023; Yang et al., 2025). Numerous scholars have contributed to land use optimization studies from viewpoints like ecosystem service value, low-carbon development, socio-economic and ecological balance, environmental quality, and ecological security (Jiang et al., 2022; Yu et al., 2022; Bayer et al., 2023; Wu et al., 2023b; Zhao et al., 2024). The evaluation of optimization results typically includes economic, ecological, and landscape effects, which are used as metrics to assess the success of optimization processes (Zheng et al., 2019; Li et al., 2023b). Research methods in land use optimization involve both structural and spatial optimization. Structural optimization often employs mathematical models, such as linear programming models (Li et al., 2023a; Yang et al., 2024), while spatial optimization relies on spatial models like PLUS models (Yang et al., 2022; Xie et al., 2024). However, a gap remains in integrating land use conflicts into the land use optimization process, which is a critical issue for more comprehensive and effective land use planning. This study seeks to address this gap by incorporating land use conflict analysis into land use optimization, particularly in mountainous cities, where such conflicts are especially complex and prevalent.

Mountainous cities are an important type of city globally (Bellout et al., 2020; Karunaratne et al., 2022). Influenced by terrain conditions and intense human activities, land use in these cities faces problems such as unreasonable structure, chaotic layout, and low utilization efficiency of the three types of space, which are particularly prominent in Chinese mountainous cities (Zhong et al., 2023; Mou et al., 2023). Clarifying the characteristics of land use conflict changes in rapidly developing mountainous cities and achieving land use optimization are critical issues that need to be addressed (Li et al., 2023d). These issues are particularly significant as they directly affect the sustainable development and livability of these cities. In this context, understanding and resolving land use conflicts is crucial for ensuring both environmental sustainability and economic development in mountainous regions. Therefore, this study selected Guiyang, a typical mountainous city in China, as a case study to analyze the spatiotemporal characteristics of land use conflicts in mountainous cities and to conduct zoning optimization. Guiyang was chosen because of its rapid urbanization and distinct challenges in land use management, making it an ideal representative for studying land use conflicts in similar mountainous cities. The goal is to provide decision-making support for the formulation of scientific and reasonable land use policies and the coordination of production-living-ecological spaces in mountainous cities.

2. Data and methods

2.1. Study area overview

Guiyang City (26°35′30″N, 106°44′40″E) is located in the eastern part of the Yunnan-Guizhou Plateau, China, and is a typical mountainous city and one of the important cities in Southwest China (Figure 1). It covers a total area of approximately 8043 km², characterized by a subtropical monsoon humid climate with mild temperatures, abundant precipitation, and concurrent rainy and hot seasons. The average annual temperature is around 15.3 °C, with an average annual precipitation of about 1096 mm. The terrain is predominantly mountainous and hilly, with steep slopes and high landscape heterogeneity, encompassing mountainous areas that account for 52.30% of the total area. Guiyang City is situated at the watershed between the Yangtze River Basin to the north and the Pearl River Basin to the south (Luo & He, 2023). Over the past 30 years (1990–2020), the population of Guiyang City has increased from 2.8515 million to 5.9898 million, and its GDP has grown from 6.022 billion yuan to 4311.65 billion yuan, nearly a 70-fold increase. The urbanization rate has risen from 43.91% to 80.07%, representing an increase of 36.16%. Accompanying urban spatial development needs, the built-up area has expanded from 80.85 km² to 369 km². Concurrently, the ecological environment of Guiyang has shown continuous improvement, with forest coverage increasing from 14.5% to 55% (Chen et al., 2023; Han et al., 2023).

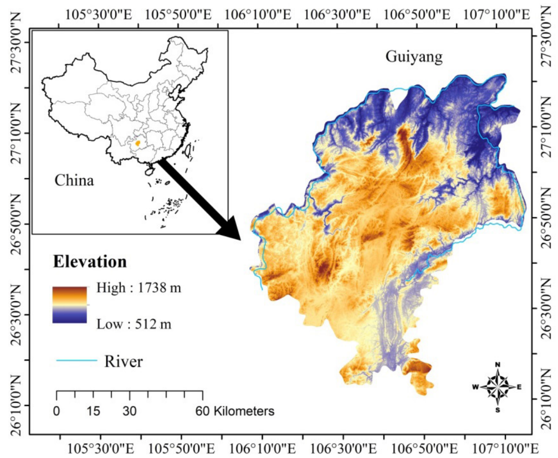

Figure 1. Location and topographic map of Guiyang city

2.2. Data

The data sources primarily include: (1) Land use data for Guiyang City in 2000, 2010, and 2020 were chosen to capture key changes in land use patterns over two decades, reflecting both long-term trends and short-term shifts that are essential for analyzing urban development and environmental changes. The data were collected on May 4, 2000, May 16, 2010, and May 3, 2020, all of which fall within the month of May when vegetation growth is typically optimal, ensuring that the data accurately represent various land use types. This timing also minimizes the seasonal influence on land use classification. The data were derived from Landsat remote sensing image interpretation (http://www.gscloud.cn). Using ENVI v5.6, maximum likelihood classification was employed to classify land use types into six categories: cultivated land, forestland, grassland, water bodies, construction land, and unused land. To validate the accuracy of the remote sensing interpretation, 200 sample points were selected and verified using high-resolution Google Earth maps, achieving an accuracy rate of 93%, which meets the research requirements. (2) The DEM (Digital Elevation Model), slope, and vegetation index data are sourced from Geographic Spatial Data Cloud with a spatial resolution of 30 meters (https://www.gscloud.cn/). Using elevation and slope data, terrain position index and terrain ruggedness index were calculated following methods described in relevant literature (Wang & Wang, 2022b). (3) The temperature and precipitation data are derived from daily records at nine meteorological stations in Guiyang City provided by the Guizhou Climate Center. Spatial distribution maps were generated using the Kriging interpolation method in ArcGIS spatial analysis tools. (4) Soil organic matter content data sourced from the China Soil Database. (5) Road networks, urban centers, educational infrastructure data are sourced from Amap (https://www.amap.com/) and georeferenced, vectorized using ArcGIS v10.2. (6) Population, food production data are sourced from the Statistical Yearbook of Guiyang City.

2.3. Research methods

2.3.1. Suitability assessment of production-living-ecological spaces

(1) Indicator Selection and Weight Calculation

To ensure the scientific rigor and objectivity of the suitability assessment, this study establishes a comprehensive evaluation framework based on systematic literature review (Zhang et al., 2023b; Zuo et al., 2022) and the specific characteristics of the study area. The selection of evaluation indicators follows the principles of representativeness, measurability, and independence, ensuring that the chosen factors effectively reflect the suitability of production, living, and ecological spaces. Production space suitability is primarily determined by factors that significantly influence agricultural production, including climate conditions (temperature, precipitation), topography (slope, elevation), soil quality (fertility, texture), and accessibility to agricultural resources. Living space suitability considers factors affecting residents' quality of life, such as topography (terrain constraints), transportation infrastructure (road network density, proximity to urban centers), public service availability (education, healthcare), and population distribution. Ecological space suitability emphasizes environmental sustainability and is assessed based on ecological quality (vegetation coverage, biodiversity), landscape pattern (fragmentation index, connectivity), land use type, and human disturbance intensity. Each indicator is categorized into four levels (I, II, III, IV), with assigned values of 4, 3, 2, and 1, respectively, to facilitate quantitative assessment. The Analytic Hierarchy Process (AHP) is employed to determine the relative importance of each indicator. Pairwise comparisons are conducted using expert judgment, and the weight coefficients are computed through eigenvector analysis (Table 1).

Table 1. Indicator system for suitability assessment of production-living-ecological spaces

Spatial types	Indicators	I (4)	II (3)	III (2)	IV (1)	Weight
Suitability of production space	10 °C accumulated temperature / °C	High	Relatively high	Relatively low	Low	0.064
	Annual average precipitation / mm	High	Relatively high	Relatively low	Low	0.072
	Slope / °	6	6–15	15–25	>25	0.279
	Distance to roads / m	1000	1000–2000	2000–3000	>3000	0.103
	Distance to residential areas / m	1000	1000–2000	2000–3000	>3000	0.144
	Soil organic matter %	>5.5	4.1–5.5	3.4–4.1	<3.4	0.242
	Concentration of arable land	= 0	0–10	10–20	>20	0.096
Suitability of living space	Aspect / °	135–225	225–315	45–135	0–45, 315–360	0.039
	Terrain roughness	0–62	62–112	112–192	>192	0.123
	Distance to educational facilities / m	1000	1000–2000	2000–3000	>3000	0.186
	Distance to urban centers / m	2000	2000–3500	3500–5000	>5000	0.238
	Road network density / m/ha	<5	5–10	10–15	>15	0.253
	Population density	High	Relatively high	Relatively low	Low	0.162
Suitability of ecological space	Land use type	Forestland	Grassland, water body	Cultivated land	Construction land, unused land	0.061
	Landscape fragmentation	<0.1	0.1–0.2	0.2–0.3	>0.3	0.174
	Vegetation index	>0.75	0.70–0.75	0.65–0.70	<0.65	0.215
	Anthropogenic disturbance	<0.1	0.1–0.2	0.2–0.3	>0.3	0.202
	Habitat quality	>0.9	0.70–0.90	0.50–0.70	<0.50	0.261
	Terrain position index	<0.5	0.5–1	1–1.5	>1.5	0.087

(2) Suitability Assessment Methods

Given the multifactorial nature of land suitability, this study employs a multi-factor weighted summation method to derive a comprehensive suitability score. The calculation equation is as follows:

$$S = \sum_{i=1}^{n} F_i \times W_i, \quad (1)$$

where S is the suitability score; F_i is the grade value of indicator i, and W_i is the weight of indicator i.

To enhance the scientific robustness of the classification process, the Jenks Natural Breaks Classification method is applied to categorize suitability levels. Based on the characteristics of the study area, the final classification consists of four levels: highly suitable, moderately suitable, low suitable, and unsuitable.

This study integrates the concept of sustainable development into the land suitability assessment framework, emphasizing a comprehensive evaluation of environmental, economic, and social benefits. Within this framework, the research not only focuses on the physical suitability of land but also considers the impact of land use on environmental sustainability. This comprehensive evaluation method can better guide regional sustainable development and land use planning (Wang et al., 2021). Additionally, the study introduces more refined and systematic indicators, including habitat quality and human disturbance, which have not been widely applied in the existing literature (Tang et al., 2016). By incorporating these new indicators, this research not only enhances the depth of the suitability assessment but also provides a better reflection of the actual changes in the ecological environment within the region.

2.3.2. Land use conflict analysis methods

To ensure the scientific rigor and systematic approach of land use conflict analysis, this study integrates land suitability evaluation, land use conflict theory, and quantitative spatial analysis methods to establish a comprehensive conflict identification and assessment framework. Building upon the land use conflict classification framework proposed by Zong et al. (2022) and considering the spatial characteristics of the study area, this study classifies land use conflicts based on the suitability assessment results of production-living-ecological spaces. Different combinations of suitability levels determine the corresponding conflict types (Table 2). To ensure the quantification and visualization of land use conflicts, this study employs GIS-based spatial analysis techniques to examine the spatiotemporal distribution patterns and evolutionary characteristics of land use conflicts.

Table 2. Types of land use conflicts

Primary conflict type area	Secondary conflict type area	Suitability combination of production space, living space, and ecological space		
		Suitability of production space	Suitability of living space	Suitability of ecological space
1	2	3	4	5
Suitable land area	Production suitability area	HS	MS, LS, US	MS, LS, US
		MS	LS, US	LS, US
	Living suitability area	MS, LS, US	HS	MS / LS / US
		LS, US	MS	LS, US
	Ecological suitability area	MS, LS, US	MS, LS, US	HS
		LS, US	LS, US	MS
High conflict area	High conflict area between production space and living space	HS	HS	MS, LS, US
	High conflict area between production space and ecological space	HS	MS, LS, US	HS
	High conflict area between living space and ecological space	MS, LS, US	HS	HS
	High conflict area among production space, living space, and ecological space	HS	HS	HS
Moderate conflict area	Moderate conflict area between production space and living space	MS	MS	LS, US
	Moderate conflict area between production space and ecological space	MS	LS, US	MS
	Moderate conflict area between living space and ecological space	LS, US	MS	MS
	Moderate conflict area among production space, living space, and ecological space	MS	MS	MS
General conflict area	General conflict area between production space and living space	LS	LS	US
	General conflict area between production space and ecological space	LS	US	LS

End of Table 2

1	2	3	4	5
	General conflict area between living space and ecological space	US	LS	LS
	General conflict area among production space, living space, and ecological space	LS	LS	LS
Low conflict area	Low conflict area	US	US	LS, US
		LS, US	US	US
		US	LS, US	US

Notes: HS – Highly suitable; MS – Moderately suitable; LS – Low suitable; US – Unsuitable.

2.3.3. Land use zoning optimization methodology

To enhance the scientific rigor and systematic approach of land use zoning optimization, this study integrates land suitability evaluation, land use conflict analysis, and spatial optimization modeling to establish a comprehensive zoning framework.

(1) Determination of Zoning Units

To ensure the spatial precision and administrative feasibility of land use zoning, this study adopts township-level administrative districts as the fundamental zoning units. This selection aligns with regional governance structures and allows for the effective implementation of zoning policies to mitigate land use conflicts.

(2) Division of Advantageous Functional Zones

Recognizing the spatial heterogeneity in production, living, and ecological functions, this study adopts a quantitative classification method to delineate land use functional zones. Referring to land use function theory and prior research (Bao et al., 2021), the classification is based on key spatial indicators reflecting urbanization, agricultural productivity, and ecological integrity. The zoning criteria are as follows: Urban Functional Advantage Zones: Identified based on urbanization rates; townships with an urban population proportion exceeding 60% are classified as urban functional dominant areas. Agricultural Production Advantage Zones: Determined based on grain cultivation area; townships where grain production land exceeds 50% of the city's total are designated as agricultural production dominant areas. Ecological Conservation Advantage Zones: Defined based on ecological land coverage (forests, grasslands, water bodies); townships with ecological land exceeding 55% of total area are designated as ecological protection zones. It is worth noting that when multiple zoning categories are satisfied, the zoning type is determined based on the suitability score, with higher scores indicating the prioritized zoning type. This classification ensures that each zoning category is backed by empirical thresholds and spatial data analysis, strengthening the scientific validity of the zoning framework.

(3) Zoning Optimization Based on Land Use Conflicts

To refine the spatial allocation of functional zones, zoning optimization is conducted by integrating land suitability analysis with land use conflict intensity calculations. The optimization process follows a data-driven adjustment approach, where zoning thresholds are recalibrated using the following equation:

$$V_p = \frac{S_p / A}{(C_{pl} + C_{pe}) / A}; \tag{2}$$

$$V_l = \frac{S_l / A}{(C_{pl} + C_{le}) / A}; \tag{3}$$

$$V_e = \frac{S_e / A}{(C_{pe} + C_{le}) / A}, \tag{4}$$

where V_p, V_l, V_e are scores representing the dominance values of agricultural production, urban functional, and ecological protection in each zoning unit; S_p, S_l, S_e represent the areas of production suitable zones, living suitable zones, and ecological suitable zones in each zoning unit; C_{pl}, C_{pe}, C_{le} represent the areas of production-living conflict zones, production-ecological conflict zones, and living-ecological conflict zones in each zoning unit; A represents the area of each zoning unit; Values of V_p, V_l, V_e greater than 1 indicate reasonable zoning of the units. Conversely, values less than 1 suggest zoning inconsistencies. Adjustments are made based on the highest values among V_p, V_l, V_e to finalize the zoning configuration.

To further enhance the robustness of zoning decisions, this study employs GIS-based overlay analysis to refine zoning boundaries. This ensures that zoning optimization is scientifically sound, data-driven, and spatially coherent, providing a strong basis for sustainable land use planning and conflict mitigation.

3. Results

3.1. Suitability characteristics of production-living-ecological spaces

In 2000, Guiyang's production space was mainly moderately suitable or unsuitable due to infrastructure limitations, inefficient agriculture, and topographical constraints. By 2010 and 2020, improved land management, technological advancements, and urban expansion increased land suitability. Living space was largely unsuitable in 2000 and 2010, as urbanization outpaced infrastructure development. By 2020, better planning, resource allocation, and policies led to a more balanced distribution across all suitability levels. Ecological space remained highly suitable from 2000 to 2020 due to conservation policies. Over this period, unsuitable and low-suitability production areas decreased, while moderately and highly suitable areas expanded, reflecting improved land use and ecological restoration. For living space, reductions in lower-suitability areas from 2000 to 2010 and the expansion of highly suitable areas from 2010 to 2020 highlight urban renewal and infrastructure development. Ecological suitability changes, including increases in highly suitable and low-suitability areas, resulted from enhanced environmental protection and conservation efforts (Table 3).

The production space had more unsuitable areas in the north, east, and west due to topographical and climatic constraints, while suitable areas were concentrated in the central and southern regions. From 2000 to 2020, land reclamation reduced unsuitable areas in the north, and urban expansion improved suitability in the south (Figure 2a–2c).

Table 3. Changes in production-living-ecological spaces area in different suitability levels km²

Spatial types	Suitability levels	2000	2010	2020	2000–2010	2010–2020	2000–2020
Production space	Highly suitable	343.87	893.72	1718.19	549.85	824.47	1374.32
	Moderately suitable	1905.15	2796.79	3364.12	891.64	567.33	1458.97
	Low suitable	3638.46	3166.17	2310.52	–472.29	–855.65	–1327.94
	Unsuitable	2076.36	1107.05	571.01	–969.31	–536.04	–1505.35
Living space	Highly suitable	1063.28	1373.76	2008.72	310.48	634.96	945.44
	Moderately suitable	1183.96	1143.83	1694.27	–40.13	550.44	510.31
	Low suitable	1810.81	1704.85	2084.53	–105.96	379.68	273.72
	Unsuitable	3700.84	3536.45	1971.37	–164.39	–1565.08	–1729.47
Ecological space	Highly suitable	3470.52	4378.49	4410.38	907.97	31.89	939.86
	Moderately suitable	1554.14	838.06	767.02	–716.08	–71.04	–787.12
	Low suitable	561.38	1459.01	1531.71	897.63	72.70	970.33
	Unsuitable	2223.18	1232.73	1201.03	–990.45	–31.70	–1022.15

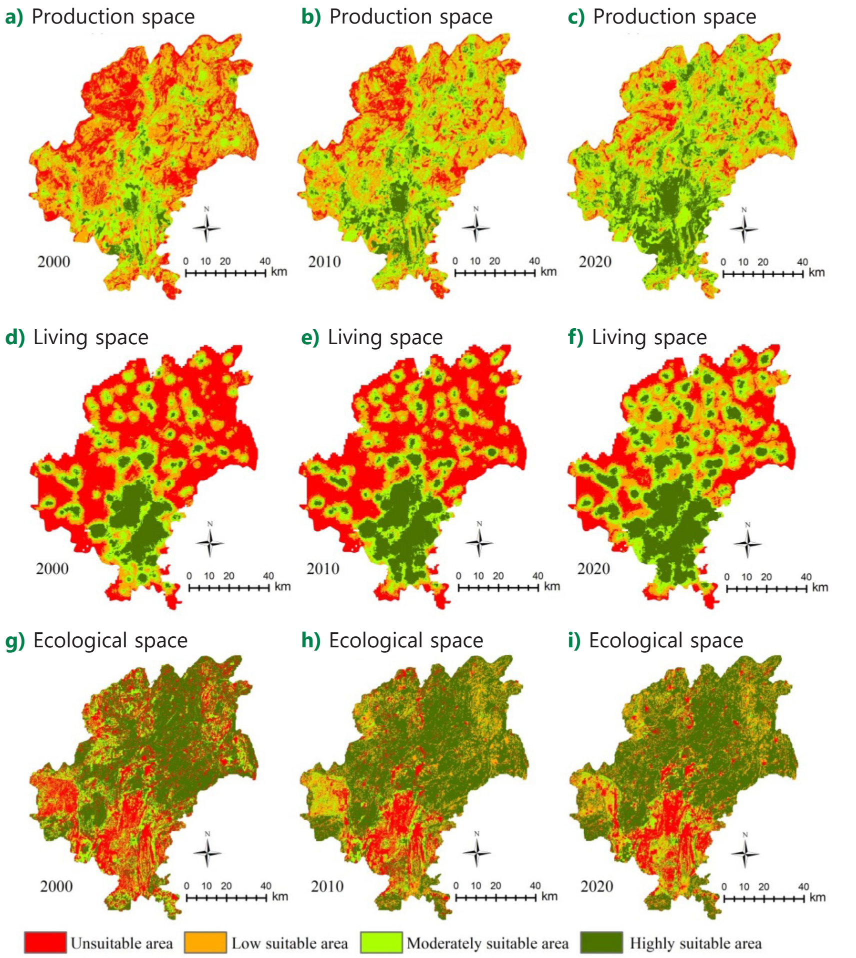

Figure 2. Distribution of suitability levels for production, living, and ecological spaces in 2000, 2010, and 2020

For living space, lower-suitability areas were mainly in the north and west, while the south had more suitable areas due to socio-economic development and planning. The expansion of suitable areas in both the north and south from 2000 to 2020 reflects the effectiveness of land use policies (Figure 2d–2f). In ecological space, the south and west had more unsuitable areas, while the north had a concentration of highly suitable areas, influenced by natural environmental conditions. Improvements in the west resulted from ecological restoration, while changes in the north reflected continued conservation efforts (Figure 2g–2i).

3.2. Characteristics of land use conflicts

(1) Changes in Area and Spatial Distribution of Primary Land Use Conflict Types

In 2000, low conflict areas were predominant, reflecting early urbanization with minimal land use intensity and few conflicts. By 2010 and 2020, high conflict areas grew due to rapid urbanization, population pressure, and increased competition for land, especially in overlapping production, living, and ecological spaces. The significant rise in high conflict areas from 2010 to 2020 was due to faster urbanization and infrastructure development. Low conflict areas decreased, particularly from 2010 to 2020, as land use diversified. The reduction in moderate conflict areas may reflect improved land planning, though some new conflicts emerged by 2020. The decline in general conflict areas after 2010 was likely due to targeted land-use policies (Table 4).

In 2000, 2010, and 2020, low conflict areas were mainly in the west, with moderate conflict in the north and west, and high conflict zones in the central and southern regions. Between 2000 and 2020, low and general conflict areas in the west decreased due to urbanization and land use changes, while high conflict zones expanded in the south and north due to increasing competition for land and urban growth. Minimal changes in moderate conflict areas suggest stable land use dynamics in those regions (Figure 3).

(2) Changes in Area and Spatial Distribution of Secondary Land Use Conflict Types

In 2000, 2010, and 2020, high and moderate conflicts were mainly between production and living spaces. By 2010 and 2020, conflicts involving ecological space grew significantly, reflecting increased urbanization and environmental pressures. Between 2000–2020, high conflict areas expanded in this order: production-living, production-ecology, living-ecology, and all three spaces. The growth from 2010–2020 was larger than from 2000–2010, indicating intensifying land use. Moderate conflicts between production and living space increased, while conflicts with ecological space decreased, likely due to industrial stabilization and stronger environmental protection. General conflicts in production-living space decreased, except from 2010–2020. Low conflict zones decreased across the periods, reflecting greater land competition (Table 5).

In 2000, 2010, and 2020, high conflict zones between production and living spaces were mainly in the southern region, with other high conflict zones localized in the north. Changes from 2000 to 2020 were concentrated in the southern and localized northern regions (Figure 4a–4f). Moderate conflict zones were dispersed, with production-living space conflicts sporadically in the southwest and northern regions, and living-ecological space conflicts mainly in the west and northeast. Production-ecological space conflicts were focused in the northwest. Changes in the production-livelihood-ecological spaces in moderate conflict zones were sporadic in the south (Figure 4g–4i). General conflict zones in 2000, 2010, and 2020 were scattered across the west, north, and northeast, with notable changes in all four types (Figure 4j–4l). Low conflict zones,

Table 4. Changes in area of primary land use conflict types km^2

Conflict types	2000	2010	2020	2000–2010	2010–2020	2000–2020
High conflict area	357.87	885.24	1679.09	527.37	793.85	1321.22
Moderate conflict area	590.27	479.04	511.46	–111.23	32.42	–78.81
General conflict area	424.91	531.09	365.58	106.18	–165.51	–59.33
Low conflict area	804.68	266.42	86.83	–538.26	–179.59	–717.85

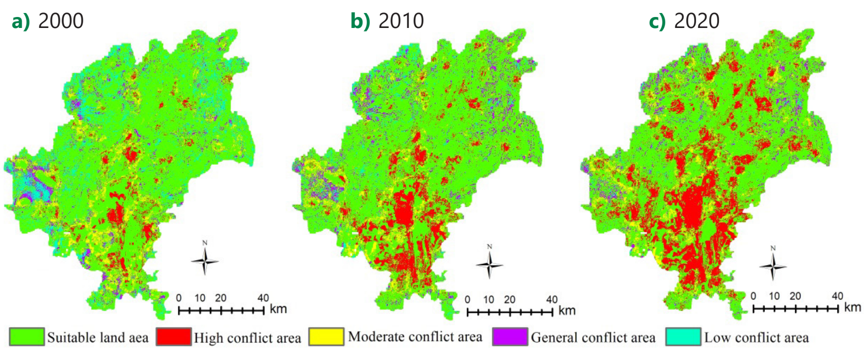

Figure 3. Spatial distribution of major land use conflict types in 2000, 2010, and 2020 across five levels

Table 5. Changes in area of secondary land use conflict types km^2

Conflict types	2000	2010	2020	2000–2010	2010–2020	2000–2020
High conflict area between production space and living space	170.88	434.66	827.97	263.78	393.31	657.09
High conflict area between production and ecological space	43.31	168.22	369.61	124.91	201.39	326.3
High conflict area between living space and ecological space	123.8	201.78	336.68	77.98	134.9	212.88
High conflict area among production, living, and ecological spaces	19.88	80.58	144.83	60.7	64.25	124.95
Moderate conflict area between production space and living space	183.72	199.4	272.95	15.68	73.55	89.23
Moderate conflict area between production and ecological space	162.37	144.31	98.34	–18.06	–45.97	–64.03
Moderate conflict area between living space and ecological space	151.69	54.18	40.54	–97.51	–13.64	–111.15
Moderate conflict area among production, living, and ecological spaces	92.49	81.15	99.63	–11.34	18.48	7.14
General conflict area between production space and living space	236.74	55.73	33.27	–181.01	–22.46	–203.47
General conflict area between production and ecological space	98.17	295.37	171.52	197.2	–123.85	73.35
General conflict area between living space and ecological space	25.26	38.49	26.82	13.23	–11.67	1.56
General conflict area among production, living, and ecological spaces	64.74	141.5	133.97	76.76	–7.53	69.23
Low conflict area	804.68	266.42	86.83	–538.26	–179.59	–717.85

initially in the north and west in 2000, reduced significantly by 2010 and 2020 (Figure 4m–4o). The southern concentration of high conflict zones can be attributed to urban expansion and industrialization, increasing land competition. The localized northern changes are likely driven by infrastructure development. The reduction in low conflict zones reflects growing development pressures from urbanization and intensified agriculture.

(3) Conflict Characteristics of Different Land Use Types

From 2000 to 2020, high conflict areas for all six land types increased, with construction land and forestland seeing the largest increases. This trend is due to rapid urban expansion and infrastructure development, increasing competition for land, especially in construction and forest areas. Moderate conflict areas for cultivated land, construction land, and unused land increased, while those for forestland and grasslands steadily decreased, and water bodies initially increased before declining. The rise in moderate conflict for cultivated and construction land reflects ongoing development, while the decrease in forestland and grasslands suggests encroachment from urbanization and agriculture, reducing ecological land. Except for cultivated land, general conflict areas for the other five land types decreased. The reduction, particularly for unused land, is likely due to its repurposing for urban or agricultural use. Low conflict areas for all land types decreased, with cultivated land experiencing the most significant drop. This decline is driven by urbanization, agricultural intensification, and infrastructure development, which reduce available low-conflict land (Figure 5).

3.3. Optimization and pathways of land use zoning

Following land use zoning optimization, ecological protection leading areas take precedence, followed by agricultural production leading areas, with urban function leading areas having the smallest proportion. Urban function leading areas are primarily located in the central-southern part of Guiyang City, constituting the core area of urban expansion. In this region, there is significant conflict between production and living spaces. Including this area in residential spaces could provide sufficient room for urban development. Agricultural production leading areas are mainly distributed in the western and northern parts of Guiyang City, surrounding the urban function leading areas. The northern and western agricultural production leading areas meet the needs of grain production, ensuring food security, while the areas surrounding urban function leading areas can support the development of specialized agriculture required for urban development. Ecological protection leading areas are primarily located in the eastern, central-western, and southern parts of Guiyang City, where there is a high proportion of ecological land and relatively low population density, making them suitable for ecological conservation areas (Table 6 and Figure 6).

To ensure the full functionality of each zoning area and reduce land use conflicts within them, the following safeguard pathways are proposed: (1) In agricultural production leading areas, priority should be given to advancing the construction of high-standard cultivated land to

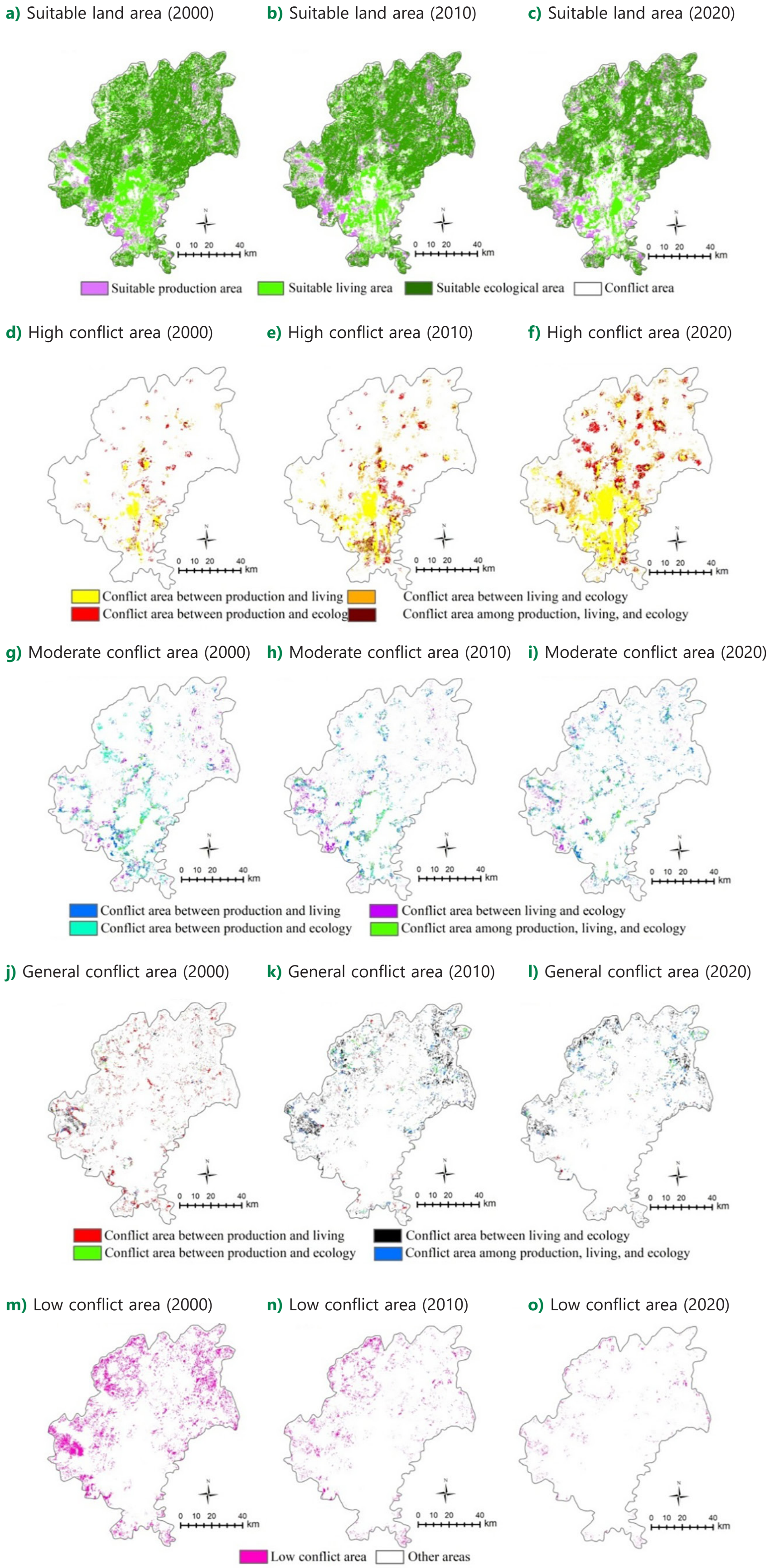

Figure 4. Spatial distribution of land use conflict types between production, living, and ecological spaces in 2000, 2010, and 2020 across five levels

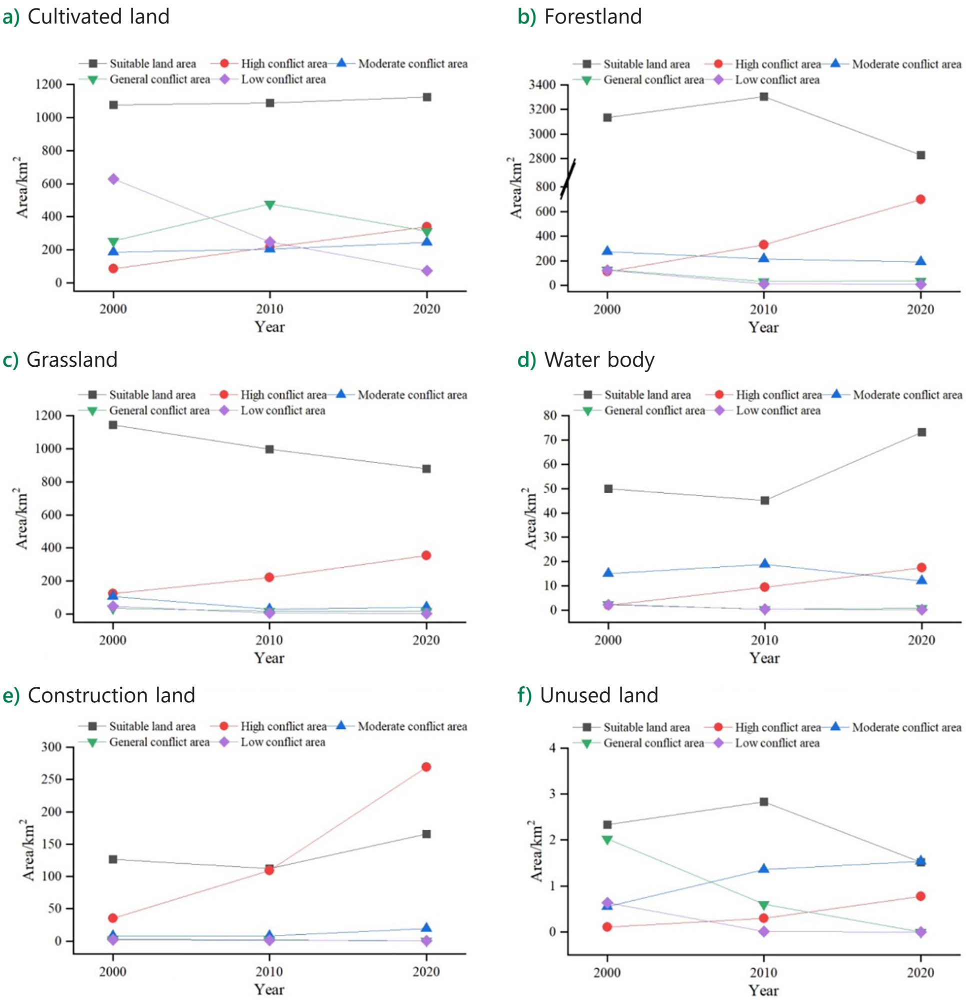

Figure 5. Area changes of conflict types across different land use types in 2000, 2010, and 2020 for five levels

improve the quality of cultivated land and ensure food production security. Surrounding urban areas should focus on developing high-value-added specialty agriculture (such as floriculture and fruit and vegetable cultivation), enhancing their capacity to serve urban needs. Expansion of rural settlements in this area should be controlled to prevent encroachment on cultivated land. (2) Within urban functional leading areas, efforts should focus on optimizing

Table 6. Statistical summary of land use zoning optimization

Zone types	Number of towns	Percentage of towns/%	Area/ km^2	Percentage of area/%
Agricultural production leading area	25	30.86	2516.86	31.35
Urban function leading area	18	22.22	1276.3	15.90
Ecological protection leading area	38	46.91	4235.17	52.75

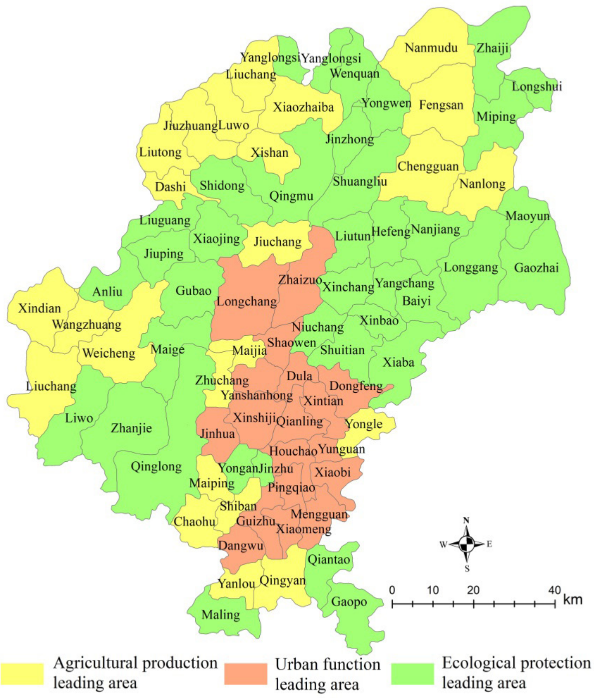

Figure 6. Land use zoning optimization map at the township scale

the urban system structure, delineating urban expansion boundaries, and enhancing the efficient and intensive use of construction land. Non-agricultural functions of urban areas should be fully utilized, alongside improving green infrastructure to enhance ecological functions of green spaces. (3) Ecological protection leading areas should prioritize the protection of ecological land as a core objective, leveraging the ecological functions of forests, grasslands, and water bodies. Measures should prevent an increase in cultivated land within this area, aiming to reduce the proportion of sloping cultivated land through initiatives such as converting it back to forest or grassland. Additionally, measures such as ecological compensation and ecological relocation should be utilized to minimize human activities' impact on ecological land.

4. Discussion

4.1. Formation causes of land use conflict characteristics

Analyzing land use conflicts in mountainous cities is a crucial foundation for achieving sustainable and efficient utilization of land resources in mountainous regions (Zhang et al., 2023a). This study reveals that high conflict areas constitute the primary type of land use conflict in mountainous urban areas, and these conflicts have escalated significantly (marked reduction in low conflict areas and sharp increase in high conflict areas). The reasons behind this trend are closely linked to rapid urbanization and economic development in the study area (Liu et al., 2021). This finding aligns with similar studies by Dong et al. (2021) and Li et al. (2025) conducted in other urban contexts. Additionally, conflicts between production and living spaces emerge as the most prominent type, particularly pronounced in the southern regions of the study area, attributable to rapid urban expansion and complex terrain. Specifically, the choice of flat areas surrounding urban peripheries for rapid urban expansion, which are also suitable for agricultural production (Han et al., 2022), exacerbates conflicts between production and living spaces. The southern part of the study area, characterized by basin topography, serves equally well for production and living spaces, intensifying conflicts in this region (Figure 7).

It is noteworthy that there is heterogeneity in the changes in conflict areas across different land types, influenced by their spatial distribution and varying characteristics. For instance, the construction land in the study area is predominantly distributed in the southern region and in scattered areas in the northern region. Under the impact of urban expansion, construction land has rapidly increased, resulting in severe conflicts between living spaces and other spaces (production spaces and living spaces), thus exhibiting the most pronounced changes in high conflict areas. In contrast, grassland, primarily located in the western regions, experiences minimal variation, characterized by relatively low human disturbance, thereby showing comparatively minor changes in high conflict areas (Figure 7).

4.2. Comparison between mountainous cities and other cities

Mountainous cities exhibit unique land use conflict patterns compared to other urban areas due to their distinct topographical and ecological constraints (Ye et al., 2018). Unlike flatland cities, where urban expansion is relatively unrestricted, mountainous cities face severe spatial limitations, leading to intensified competition for land among production, living, and ecological spaces. Steep slopes and fragmented terrain constrain large-scale urban development, forcing cities to expand along valley floors and limited flatlands, which often coincide with prime agricultural land (Yin et al., 2022). As a result, conflicts between production and living spaces are particularly pronounced in mountainous cities. Moreover, construction costs and engineering challenges associated with steep slopes further complicate urban expansion, making land use conflicts more difficult to resolve (Li et al., 2024).

Despite these challenges, mountainous cities also have unique advantages in land use planning and conflict mitigation. The complex terrain provides natural barriers that help contain urban sprawl and promote compact city development, reducing uncontrolled land expansion. Additionally, the rich ecological resources of mountainous regions offer opportunities for integrating ecological

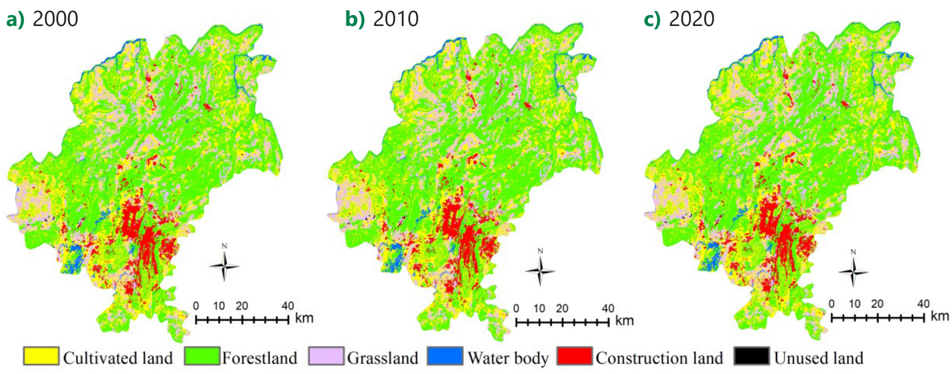

Figure 7. Land use distribution map for 2000, 2010, and 2020 across different land types

conservation with economic development through sustainable land use practices such as agroforestry, ecotourism, and green infrastructure (Fang et al., 2024). Policy solutions tailored to mountainous cities should emphasize adaptive urban planning that accounts for topographical constraints, strategic zoning to balance competing land demands, and infrastructure designs that minimize environmental impacts while enhancing land use efficiency (Wu et al., 2023a).

4.3. Policy recommendations to alleviate land use conflicts

To effectively mitigate land use conflicts, land use restructuring should be tailored to local conditions, emphasizing the rational layout and optimization of production-living-ecological spaces. This approach aims to enhance urban-rural spatial integration while ensuring sustainable land use development (Luo et al., 2022; Wang et al., 2024). Differentiated land use management strategies should be formulated based on the severity and nature of conflicts in different regions.

(1) High conflict areas: In high-conflict areas where production, living, and ecological spaces strongly compete, strict land use controls should be enforced with targeted strategies based on specific conflict types. For production-ecology conflicts, key ecological zones such as watersheds, forest reserves, and biodiversity hotspots should receive strict protection, while agricultural practices should align with ecological carrying capacity through sustainable methods like agroforestry and ecological restoration-based farming. The expansion of agricultural land must be strictly regulated to prevent environmental degradation. In production-living conflicts, urban expansion should be directed toward underutilized or already developed land to minimize encroachment on high-quality agricultural areas, while high-efficiency, space-saving production models such as vertical farming and smart agriculture should be promoted. For living-ecology conflicts, strict zoning regulations and ecological red lines should be implemented to control the spread of residential areas into ecologically sensitive zones, while infrastructure development should adopt low-impact designs, integrating green building principles and eco-friendly urban planning to reduce environmental disruption while ensuring necessary development.

(2) Moderate conflict areas: In regions experiencing moderate land use conflicts, the focus should be on enhancing land use efficiency while strengthening ecological protection. Sustainable forestry and agroforestry should be promoted to enable economic utilization of forest resources without compromising ecological stability, while understory economies, such as medicinal plant cultivation and eco-tourism, can provide alternative livelihoods that preserve ecological integrity. In high-altitude and sloping terrain areas where agricultural expansion threatens ecological balance, land use should be adapted to local environmental conditions through strategies like contour farming, soil conservation practices, and afforestation programs. Additionally, optimizing industrial and residential layouts is essential – agricultural and industrial land should be consolidated where feasible to improve efficiency and reduce land fragmentation, while well-planned industrial clusters in peri-urban areas can minimize scattered development, alleviating conflicts between production and living spaces.

(3) General conflict areas and low conflict areas: Although these areas experience minimal land use conflicts, proactive planning is essential to prevent future issues. Strict enforcement of urban growth boundaries can curb unchecked sprawl, ensuring the preservation of agricultural and ecological lands while promoting compact city development and land-efficient urban designs. Encouraging multifunctional land use, such as urban agriculture, green infrastructure, and community-based land management, can integrate production, ecological, and social functions, enhancing overall land efficiency. Additionally, protecting high-quality farmland remains crucial–strengthening farmland protection policies, implementing soil fertility improvement programs, and supporting agricultural modernization can enhance land productivity while maintaining ecological balance.

4.4. Limitations and research prospects

Through the analysis of land use conflicts in mountainous cities, this study has deepened the understanding of human-induced disturbances in mountainous land spatial research. However, there are areas that require further enhancement and improvement. This study constructs a land use conflict index evaluation system based on the suitability of production-living-ecological spaces and representative indicators. Nevertheless, the factors influencing land use conflicts are diverse, and some indicators are difficult to quantify spatially due to data availability constraints (such as distribution of cultivated land irrigation rates), which limits the completeness of the index system. Future research will enrich the index system and enhance the scientific and rational nature of the study. Additionally, this study only conducted basic land zoning optimization based on land use conflicts, without utilizing spatial models to conduct refined land use spatial optimization, which represents an important direction for future research.

5. Conclusions

Based on multi-period land use, socio-economic, and ecological environmental data, we have revealed the spatiotemporal characteristics of land use conflicts in mountainous urban areas and achieved land use zoning optimization. The study draws the following main conclusions: Despite a decrease in moderate conflict areas, general conflict areas, and low conflict areas from 2000 to 2020 in mountainous cities, high conflict areas have rapidly increased, indicating significant land use conflict pressures faced by mountainous urban areas in China. Conflicts between production and living spaces dominate in high and moderate conflict areas, reflecting the serious conflicts arising from rapid urban expansion consuming substantial amounts of cultivated land due to China's rapid economic development. The southern regions concentrate high conflict areas, while moderate, general, and low conflict areas are sporadically distributed in the western, northern, and eastern parts. Variations in land use conflicts among different land types correlate with spatial distributions and changes in these areas. Furthermore, coupling land suitability, land use conflicts, and dominant functional disparities propose an optimized land use zoning method, which enhances the core role of dominant functional zones while alleviating land use conflicts, providing insights for urban zoning regulations. Future research will focus on refining land use spatial optimization based on improving the evaluation index system for land use conflicts.

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Author contributions

Methodology, Software, Writing–original draft, H. H.; Review and editing, K. Z.; Data curation, Resources, G. M. All authors have read and agreed to the published version of the manuscript.

Disclosure statement

The authors declare no conflict of interest.

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