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Conflicts at the Crossroads: Unpacking Land-Use Challenges in the Greater Bay Area with the “Production–Living–Ecological” Perspective

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Abstract: Under the influence of factors such as extreme weather and accelerated urbanization, China has witnessed a sharp escalation in conflicts between various land-use functions, leading to a significant rise in tensions between people and land. The coordination of production, living, and ecological functions is particularly important for strengthening ecological civilization and achieving regional high-quality development. The concept of “Production–Living–Ecological” (PLE) Spaces, proposed as part of China’s ecological civilization initiative, refers to a spatial framework that integrates production spaces (land for agriculture, industry, and commerce), living spaces (land for housing, consumption, and public services), and ecological spaces (land supporting ecosystem regulation and biodiversity). Based on this perspective, this paper investigates the current situation and potential of land-use function conflicts in the Guangdong–Hong Kong–Macao Greater Bay Area in 2020. Utilizing the multi-criteria evaluation analysis method, the study develops a land-use function-evaluation model. Furthermore, the paper establishes a diagnostic model for the intensity of land-use function conflicts based on the different permutations and combinations of land unit function intensities. The land-use function conflicts are categorized into ten types and four stages. The main findings are as follows: (1) In 2020, the overall production, living, and ecological functions of Guangdong, Hong Kong, and Macao Greater Bay Area were at high, medium-high, and low levels, respectively. The land in the stable and controllable stage, the largely controllable stage, the largely out-of-control stage, and the severely out-of-control stage accounted for 39.22%, 28.73%, 25.41%, and 6.64%. The focal points of the intensity of land-use function conflicts were mainly located in Guangzhou, Foshan, Shenzhen, and Dongguan. (2) The study area was exposed to varying degrees of risk from land-use function conflicts, and the area proportion of low conflict potential area, with the proportions of low, general, higher, and high-conflict-potential areas being 47.88%, 23.43%, 22.14%, and 6.54%, respectively. (3) The primary hotspots of conflict potential were concentrated in Dongguan City and the administrative border areas of “Foshan–Zhaoqing”, “Foshan–Jiangmen”, and “Guangzhou–Zhongshan”.

Keywords: land-use conflict; land-use conflict potential; production–living–ecological spaces; Guangdong–Hong Kong–Macao Greater Bay Area; China

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1. Introduction

Land is a vital resource for human survival. Since the implementation of China’s reform and opening-up policy, the country has experienced steady population growth, along with rapid industrialization and urbanization. By 2020, the population had reached 1.41 billion, and the urbanization rate had risen to 63.9%. These changes have underscored the scarcity of land resources and intensified competition among various land uses. China is currently undergoing a profound transformation in land use and ranks among the countries most affected by land-use conflicts (LUCs). Consequently, these conflicts have become a significant focus of research within the academic community in China [1].

The concept of "production–living–ecological" spaces (PLEs) was proposed by the Chinese government as part of its ecological civilization initiative to promote sustainable land use. This framework has spurred extensive academic research in China, focusing on its conceptual framework, functional classification, regional applications, and theoretical development. Scholars have examined PLEs from diverse perspectives, including land functions, ecological roles, and landscape dynamics, resulting in the development of a functional classification system to identify the primary spatial roles of different land types [2,3]. Quantitative analyses of PLEs have further explored functional intensities, providing a basis for assessments of spatial suitability, carrying capacity, and spatial coordination [4,5]. The spatiotemporal evolution of PLEs, landscape pattern changes, LUCs diagnosis, and the analysis of driving forces are also included, offering valuable insights for future applications and policymaking [6–9].

LUCs is a global challenge that has attracted significant attention from researchers and the public. Studies have examined various aspects of LUCs, including their causes, classifications, intensity, and strategies for prevention and resolution. Early research primarily attributed LUCs to competition among stakeholders and interest groups [10,11]. However, more recent studies have identified additional contributing factors, such as natural disasters [12], land-use externalities [13,14], and the complexities of multifunctional land use [15]. Current research on LUCs primarily focuses on tensions between construction land and agricultural land, conflicts among different land-use functions [16], and the competing demands of economic development, food security, and ecological conservation [17,18]. Other perspectives, such as the encroachment of urban residential land on farmland and the degradation of forest and grassland due to marginal land cultivation, have also gained scholarly attention [19,20]. To better analyze LUCs, researchers have developed frameworks incorporating environmental, geographic, socio-economic, and policy factors to quantify conflict intensity [21,22]. High-resolution remote sensing enables large-scale pattern analysis, while landscape ecology provides systematic evaluation methods [6,23]. Metrics such as land scarcity, competitiveness, and suitability differences are key for assessing conflict intensity, offering practical strategies for mitigation and management [24,25].

Despite progress in LUC research, significant gaps remain. First, most studies focus on macro-level analyses, neglecting the complexity and diversity of land use within regions [26]. The interplay between urban expansion, ecological conservation, and industrial development demands further exploration. Second, limited spatial resolution and the lack of fine-scale methods hinder the accurate identification of LUCs, leaving regional variations underexamined [27]. Third, current research often fails to offer actionable strategies for managing specific types of LUCs, limiting its practical value for policy guidance. Addressing these issues requires deeper investigation into regional and urban LUCs to uncover root causes and provide targeted, implementable solutions for decision-makers.

As China undergoes rapid urbanization and globalization, the transformation of agricultural and ecological land into construction land has intensified, shifting the drivers of LUCs from stakeholder competition to tensions between limited land resources and the demands of economic growth [28]. The Guangdong–Hong Kong–Macao Greater Bay Area (GBA), one of China's most dynamic and innovative regions, exemplifies these challenges with its accelerated land-use changes and mounting ecological pressures.

This paper contributes to the literature by integrating the intensity and potential of LUCs in the GBA for 2020. The remainder of this study is structured as follows. Section 2 introduces the materials and methods, including the study area, data sources, and the research framework. It also details the construction of the Production–Living–Ecological Function-Evaluation Model, the development of the Identification and Intensity Diagnosis Model of LUC Zones, and the analysis of the spatial relationships of LUCs. Section 3 presents the results, focusing on the spatial distribution characteristics of land-use function intensity, the LUCs zones, and the spatial relationships of land-use conflicts. Section 4 discusses the findings through comparative analysis, insights from the GBA, and policy recommendations tailored to address LUCs. Finally, Section 5 concludes the study with a summary of the main findings and their implications for sustainable land management.

2. Materials and Methods

2.1. Study Area and Data Source

The GBA, a prominent coastal urban cluster in southern China, is geographically situated between 22°00′ N and 24°00′ N latitude and 112°00′ E and 115°00′ E longitude. Spanning an area of approximately 56,000 square kilometers, the GBA encompasses nine major cities in Guangdong Province—Guangzhou, Shenzhen, Foshan, Dongguan, Huizhou, Zhuhai, Zhongshan, Jiangmen, and Zhaoqing—along with the Hong Kong and Macau Special Administrative Regions (Figure 1). Located at the core of the Pearl River Delta and bordering the South China Sea, the GBA features a subtropical monsoon climate with an average annual temperature of 22 °C and abundant rainfall. Its diverse terrain includes a dense river network, delta plains, hills, coastal bays, and islands, providing favorable natural conditions and rich ecological resources.

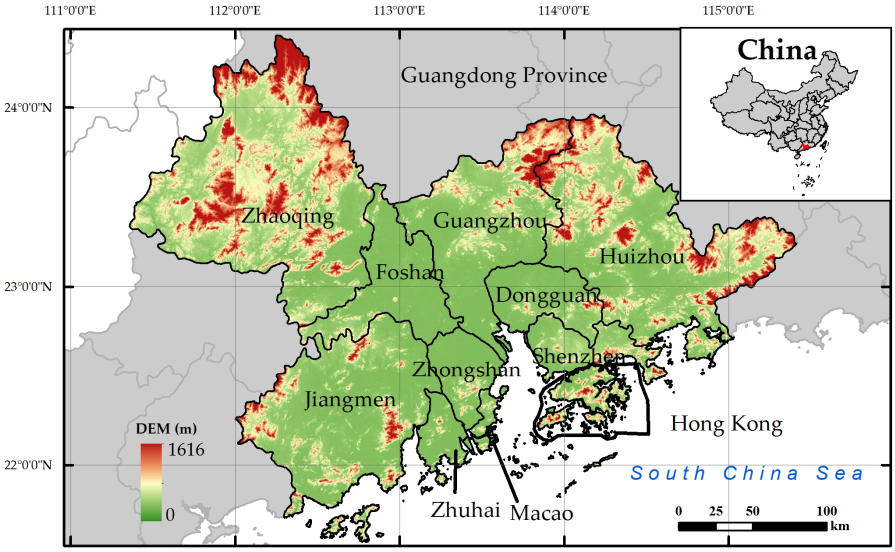

Figure 1. The location of the GBA.

Data types used in this study include remote-sensing land-use data, DEM elevation data, vectorized road data, geographic coordinate points of interest (POI) data, and socio-economic data for the Guangdong–Hong Kong–Macao Greater Bay Area (GBA) in 2020 (Table 1). Remote-sensing land-use data, including land-use types, geomorphic characteristics, distances to urban and rural settlements, water bodies, forest coverage, and greening coverage, were obtained from the Chinese National Land Use and Cover Change Dataset (CNLUCC) [29]. DEM elevation data were downloaded from the Geospatial Data Cloud [30] to derive slope and aspect information for the study area. Road vector data indicating distances to major roads were sourced from OpenStreetMap [31]. Geographic coordinate data, including distances to major ports, educational and medical facilities, and pharmacies, were extracted from the Baidu Map Platform [32]. Socio-economic data, such as GDP, the output of agriculture, forestry, animal husbandry, and fishery, industrial output proportion, government fiscal metrics, consumer price index, urban per capita disposable income, and rainfall, were collected from the China Statistical Yearbook (2021) [33] and the Guangdong Statistical Yearbook (2021) [34].

Table 1. Data source.

Data Types	Involved Indicators	Data Sources	Remarks
Remote-sensing image data	Land-use types (LUT); Geomorphic data (GED); Distance from urban land (DUL); Distance from rural residential areas (DRA); Distance from water bodies (DWB); NPP; Edge density (ED); Forest land coverage (FLC); Green land coverage (GLC)	Downloaded from the Resources and Environmental Science and Data Center (https://www.resdc.cn (accessed on 19 October 2021))	The land-use classification data are derived from the Chinese National Land-Use and Cover Change Dataset (CNLUCC), which is available through the Resource and Environmental Science Data Center (RESDC). Based on the Landsat TM image of the United States, the data were generated through manual visual interpretation. The spatial resolution of the data is 1 km, and the comprehensive accuracy is more than 90%. Distance datasets were calculated by the “Euclidean Distance” analysis function of ArcGIS10.8.
Terrain data	Slope (SLP); Aspect (APC)	Downloaded from the Geospatial Data Cloud (https://www.gscloud.cn (accessed on 11 November 2021))	Based on the Aster GDEM global digital elevation model, the spatial resolution is 30 m. The slope and aspect of the divided units were calculated by the “Slope” and “Aspect” analysis functions of ArcGIS10.8.
Vectorized data	Distance from major roads (DMR)	Downloaded from OSM website (www.openstreetmap.org (accessed on 15 November 2021))	Distance datasets were calculated by the “Euclidean Distance” analysis function of ArcGIS10.8.
Geographic coordinate data	Distance from major ports (DMP); Distance from educational land (DEL); Distance from medical facilities (DMF); Distance from pharmacies (DFP)	Extract from Baidu map geographic coordinate device	Conduct vector diagram and position calibration by ArcGIS10.8. Distance datasets were calculated by the “Euclidean Distance” analysis functions of ArcGIS10.8.
Socio-economic data	GDP; Total agricultural, forestry, animal husbandry, and fishery output (TAO); Proportion of industrial output value (PIV); Government fiscal revenue (GFR); Government fiscal expenditure (GFE); Consumer price index (CPI); Per capita disposable income of urban residents (CIU); Precipitation (PPT)	Statistical Yearbook of China (2021) (http://www.stats.gov.cn/sj/ndsj/2021/indexch.htm (accessed on 1 February 2023)); Statistical Yearbook of Guangdong Province (2021) (http://tjnj.gdstats.gov.cn:8080/tjnj/2021/ (accessed on 7 February 2023))	

The data processing was conducted as follows. Firstly, based on the National Land-Use/Cover Classification System for Ecological Remote-Sensing Monitoring [29], 20 land-use types were identified in the study area, with their respective names and codes: paddy field (11), dry land (12), forest land (21), shrub (22), sparse woodland (23), other forest land (24), high-coverage grassland (31), medium-coverage grassland (32), low-coverage grassland (33), river and canal (41), lake (42), reservoir and pond (43), tidal flat (45), beach land (46), urban land (51), rural residential areas (52), other construction land (53), sandy land (61), swamp land (64), and bare land (65). Secondly, a 500 m × 500 m grid was overlaid with the 2020 land-use data to create 268,493 evaluation units. This approach ensured consistency and accuracy in the assessment of land-use functionality and conflict intensity while also effectively reflecting spatial variations across the study area.

2.2. Research Framework

In the GBA, LUCs arise from imbalances among production, living, and ecological functions. To address these challenges, this study implements a comprehensive framework comprising three key models and analytical stages:

1. Production–Living–Ecological Function-Evaluation Model:

Using remote-sensing, terrain, vectorized data, geographic coordinates, and socio-economic indicators, the production, living, and ecological functions of land units were evaluated. Functional strengths were classified into three levels—strong, moderate, and weak—using the natural breaks method, establishing the foundation for conflict identification.

2. Identification and Intensity Diagnosis Model of LUCs Zones:

This model identified 10 distinct types of LUCs by comparing the functional strengths within land units. These conflict types were further categorized into four intensity stages, enabling a diagnostic framework to delineate and classify LUC zones across the GBA.

3. Spatial Relationship of LUCs:

Spatial hotspot analysis was conducted to determine the distribution characteristics of LUCs, highlighting regions with high conflict concentrations. Neighborhood analysis was employed to evaluate the spatial relationships and escalation potential of conflict areas, offering insights into interdependencies and regional vulnerabilities.

4. Policy Recommendations for Sustainable Land Management:

Based on the results from the three stages, governance strategies were proposed to mitigate LUCs and promote sustainable land management. These strategies emphasize the balance of production, living, and ecological functions tailored to the specific natural, social, and economic conditions within the GBA.

A cohesive link is established between the PLEs and production, living, and ecological functions in this study. By integrating these interdependent dimensions, the research provides a structured approach to analyzing LUCs, offering a comprehensive understanding of their dynamics within the PLE framework. This approach not only highlights the interactions among production, living, and ecological functions but also lays a robust foundation for proposing targeted governance strategies that address specific LUC challenges. Furthermore, it contributes to advancing sustainable land management practices by aligning analytical methods with the holistic perspective of PLEs.

2.3. Construction of Production–Living–Ecological Function-Evaluation Model

The production–living–ecological function-evaluation model developed in this study represents a novel approach to comprehensively assessing land-use functions. It integrates the production, living, and ecological functions of land into a unified evaluation framework. By incorporating multiple indicators and leveraging advanced methods, such as the entropy weight method for index weighting and comprehensive scoring, this model provides a more holistic and nuanced understanding of land-use functionality. This innovative framework not only bridges gaps in existing research but also offers practical insights for balancing economic development, social well-being, and ecological sustainability in land management.

2.3.1. Selection of Production–Living–Ecological Function-Evaluation Index

LUCs arise from the interaction of various factors. This study developed evaluation models for production, living, and ecological functions by selecting indicators from natural, locational, and social categories. Fundamental natural indicators included land-use type and geomorphic features, with slope, aspect, and NPP index applied to the production function model; slope and aspect to the living function model; and patch edge density to the ecological function model. Locational indicators for all models included distances to urban areas, rural settlements, water bodies, roads, and ports. Additional metrics, such as distances to educational facilities, medical facilities, and pharmacies, were integrated into the living function model. Socio-economic factors for the production function model included GDP, agricultural and forestry output, and the share of industrial output. The living function model incorporated public expenditure, public income, consumer price index, and urban per capita disposable income, while the ecological function model used forest coverage, rainfall, and greening coverage as indicators.

To account for the diversity of data types, different processing methods were used. For locational and distance-related indicators, the natural breaks method was applied, assigning scores based on proximity to the target. Natural factors were scored according to the functional characteristics of land-use types, drawing on existing research, with slope and aspect evaluated using a standardized framework [25,35,36]. Socio-economic indicators were scored based on their deviation from the mean value of each metric (Table 2).

Table 2. Evaluation indicators, classification, and weights of production–living–ecological spaces.

Target Layer	Criteria Layer (Weights)	Factor Layer			Factor Grading and Score				
		Indexes	Value	Weights	100	80	60	40	20
Land-use production function	Natural Factors (0.2903)	LUT	/	0.139	11, 12	24, 51, 52	21, 31, 41, 43, 53	22, 23, 32, 33, 42	45, 46, 61, 64, 65
		GED	/	0.115	Low-elevation hills	Low-elevation alluvial plains, low-elevation slightly undulating mountainous areas	Low-elevation alluvial terraces, low-elevation marine-alluvial plains, low-elevation moderately undulating mountainous areas, underwater slopes, underwater deltas	Underwater terraces, low-elevation erosion terraces, low-elevation alluvial-diluvial terraces, low-elevation marine plains, mid-elevation highly undulating mountainous areas	/
		SLP	degrees	0.285	<3	3~8	8~15	15~25	≥25
		APC	/	0.240	Sunny slope	Semi-sunny slope	Semi-shady slope	Shady slope	/
		NPP	Pg	0.221	≥1600	1600~4000	4000~6500	6500~9000	<9000
	Location Factors (0.2318)	DUL	m	0.339	≤5700	5700~13,700	13,700~22,700	22,700~33,000	>33,000
		DRA	m	0.209	≤2700	2700~5600	5600~9200	9200~15,700	>15,700
		DWB	m	0.133	≤2240	2240~5150	5150~9340	9340~18,900	>18,900
		DMR	m	0.069	≤425	425~1340	1340~2580	2580~4330	>4330
		DMP	m	0.250	≤10,000	10,000~21,500	21,500~35,500	35,500~55,500	>55,500
	Socio-Economic Factors (0.4779)	GDP	yuan	0.372	Higher	High	General	Low	Lower
		TAO	yuan	0.302	Higher	High	General	Low	Lower
		PIV	%	0.326	Higher	High	General	Low	Lower

Table 2. *Cont.*

Target Layer	Criteria Layer (Weights)	Factor Layer			Factor Grading and Score				
		Indexes	Value	Weights	100	80	60	40	20
Land-use living function	Natural Factors (0.1886)	LUT	/	0.128	51	52	11, 12, 21, 22, 31, 32, 41, 43	23, 24, 33, 42, 53	45, 46, 61, 64, 65
		GED	/	0.223	Low-elevation marine-alluvial plains	Low-elevation alluvial terraces, low-elevation alluvial plains, low-elevation hills, low-elevation slightly undulating mountainous areas	Low-elevation alluvial-diluvial terraces, low-elevation marine plains, low-elevation moderately undulating mountainous areas	Low-elevation erosion terraces, mid-elevation highly undulating mountainous areas	Underwater slopes, underwater terraces, underwater deltas
		SLP	° degrees	0.345	≤3	3~8	8~15	15~25	≥25
		APC	/	0.304	Sunny slope	Semi-sunny slope	Semi-shady slope	Shady slope	/
	Location Factors (0.2802)	DUL	m	0.169	≤5700	5700~13,700	13,700~22,700	22,700~33,000	>33,000
		DRA	m	0.165	≤2700	2700~5600	5600~9200	9200~15,700	>15,700
		DWB	m	0.091	≤2240	2240~5150	5150~9340	9340~18,900	>18,900
		DMR	m	0.101	≤425	425~1340	1340~2580	2580~4330	>4330
		DMP	m	0.17	>55,500	35,500~55,500	21,500~35,500	10,000~21,500	≤10,000
		DEL	m	0.113	≤2000	2000~5000	5000~9800	9800~18,000	>18,000
		DMF	m	0.107	≤3600	3600~8300	8300~18,000	18,000~38,000	>18,500
		DFP	m	0.084	≤4300	4300~10,300	10,300~22,000	22,000~42,500	>42,500
	Socio-Economic Factors (0.5312)	GFR	yuan	0.385	Higher	High	General	Low	Lower
		GFE	yuan	0.319	Higher	High	General	Low	Lower
		CPI	%	0.024	Higher	High	General	Low	Lower
		CIU	yuan	0.272	Higher	High	General	Low	Lower
Land-use ecological function	Natural Factors (0.1294)	LUT	/	0.464	21, 31	22, 32, 42	11, 12, 23, 24, 33, 41, 43, 45, 46	51, 52, 53, 64	61, 65
		GED	/	0.130	Low-elevation marine plains, low-elevation hills, low-elevation slightly undulating mountainous areas, underwater slopes, underwater terraces, underwater deltas	Low-elevation alluvial-diluvial terraces, low-elevation alluvial plains, low-elevation moderately undulating mountainous areas	Low-elevation erosion terraces, low-elevation alluvial terraces, low-elevation marine-alluvial plains, mid-elevation highly undulating mountainous areas	/	/
		ED	m/km^2	0.406	≤11	11~21	21~33	33~50	>50
	Location Factors (0.5560)	DUL	m	0.262	>33,000	22,700~33,000	13,700~22,700	5700~13,700	≤5700
		DRA	m	0.225	>15,700	9200~15,700	5600~9200	2700~5600	≤2700
		DWB	m	0.189	≤2240	2240~5150	5150~9340	9340~18,900	>18,900
		DMR	m	0.047	>4330	2580~4330	1340~2580	425~1340	≤425
		DMP	m	0.277	>55,500	35,500~55,500	21,500~35,500	10,000~21,500	≤10,000
	Socio-Economic Factors (0.2082)	FLC	%	0.440	Higher	High	General	Low	Lower
		PPT	mm	0.349	Higher	High	General	Low	Lower
		GLC	%	0.211	Higher	High	General	Low	Lower

2.3.2. Weight Calculation of Production–Living–Ecological Function-Evaluation Index

This study applied the entropy weight method to calculate the weights of indicators within each evaluation model. The calculation process was as follows:

The data for each evaluation model were first compiled into a matrix X:

$$X = \left(x_{ij}\right)_{m\times n} = \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ldots & \vdots \\ x_{\mathrm{m}1} & \cdots & x_{mn} \end{bmatrix} \tag{1}$$

where x_i represents the initial value of the index i in the jth functional evaluation model (i = 1, 2, 3).

The second step normalizes the data, scaling each index to a 0–1 range. The calculation process was as follows:

$$\text{Positive index}: \ z_i = \frac{(x_i - Min(x))}{(Max(x) - Min(x))} \tag{2}$$

$$\text{Negative index}: \ z_i = 1 - \frac{(x_i - Min(x))}{(Max(x) - Min(x))} \tag{3}$$

where x_{ij} is the initial value of index i in jth evaluation models; z_{ij} is the standardized value of x_{ij}; $Max(x_i)$ and $Min(x_i)$ are the respective maximum and minimum values of index i in each function-evaluation model.

The third step determines the proportion of each index's average value to the total sum of all indices. The calculation formula is as follows:

$$p_{ij} = \frac{z_{ij}}{\sum_{j=1}^{n} z_{ij}} \tag{4}$$

where z_{ij} is the standardized value of the ith index in the jth evaluation model.

The fourth step calculates the entropy of each index within each evaluation system. The calculation formula is as follows:

$$H_i = -k\sum\nolimits_{i=1}^{n} p_{ij} ln p_{ij} \tag{5}$$

where n is the total number of observed values, representing the number of units, n = 268,493, $k \geq 0$, $k = 1/ln(n)$, $Hi \geq 0$. When $p_{ij} = 0$, $p_{ij} ln p_{ij} = 0$.

The fifth step is to calculate the weight of each index and each criterion layer in each index system. The calculation formula is as follows:

$$\text{Index weight}: \ w_{ij} = \frac{1 - H_i}{\sum_{i=1}^{m}(1 - H_i)}; (0 \leq w_{ij} \leq 1), \sum\nolimits_{i=1}^{m} w_{ij} = 1 \tag{6}$$

$$\text{Criterion layer weight}: \ W_{vj} = \frac{1 - H_i}{\sum_{v=1}^{v}(1 - H_i)}; (0 \leq W_{vj} \leq 1), \sum\nolimits_{v=1}^{v} W_{vj} = 1 \tag{7}$$

where w_{ij} is the weight of the ith index in the jth evaluation model, $1 - H_i$ is the deviation degree of the ith index, indicating the difference between the indexes of the evaluation unit, m is the number of evaluation indexes, W_{vj} is the weight of the vth criterion layer in the jth evaluation model, and y is the number of indexes in the factor layer.

2.3.3. Comprehensive Scoring of Production–Living–Ecological Function-Evaluation Model

Calculate the comprehensive score of each unit in each evaluation model. The calculation formula is as follows:

$$F_{ij} = \sum\left(W_{vj} \times w_{ij} \times f_{ij}\right) \tag{8}$$

where F_{ij} represents the score of the ith evaluation unit in the jth evaluation model. The greater the value, the greater the corresponding functional intensity. W_{vj} and w_{ij} are the weights of the criterion layer and the factor layer, respectively, and f_{ij} is the score of the index.

2.4. Identification and Intensity Diagnosis Model of LUCs Zones

The evaluation model for production, living, and ecological land-use functions calculated scores for each unit. Using the natural breaks method, these scores were divided into three categories—strong (S), moderate (M), and weak (W)—corresponding to high, medium, and low functional zones for each dimension. By combining the functional levels across the three categories, 27 unique functional relationships were identified [37]. These were further grouped into 10 types of LUC zones based on their shared characteristics and distinctions (Table 3).

Table 3. Composition and types of production–living–ecological function conflicts.

Number	Production	Living	Ecological	Conflict Types
I	W	W	W	Weak multifunctional conflict zone
II	M W W	W M W	W W M	Dual-function low-intensity conflict zone
III	S W W	W S W	W W S	Dual-function low-intensity strong conflict zone
IV	M M W	M W M	W M M	Dual-function moderate-intensity conflict zone
V	S M W W S M	W W S M M S	M S M S W W	Complex multifunctional conflict zone
VI	M	M	M	Moderate multifunctional conflict zone
VII	S M M	M S M	M M S	Dual-function moderate-intensity strong conflict zone
VIII	S S W	S W S	W S S	Dual-function high-intensity conflict zone
IX	S S M	S M S	M S S	Dual-function high-intensity strong conflict zone
X	S	S	S	Severe multifunctional high-intensity conflict zone

Building on existing research, this study categorizes LUC intensity into four stages: stable and controllable stage, basic controllable stage, basic out-of-control stage, and basic out-of-control stage [17,35,37]. This framework allows for a detailed analysis of conflict levels. At the stable and controllable stage, conflicts are minimal or latent, with no significant impact on land use. The basic controllable stage involves emerging conflicts that are largely constructive and can be managed with minimal interventions to reduce potential risks. The basic out-of-control stage marks escalating conflicts and a loss of control over land-use transitions, requiring prompt action to restore balance. In the serious out-of-control stage, conflicts fully escalate, necessitating urgent administrative, legal, and economic measures to prevent further deterioration and potential social instability.

2.5. Spatial Relationship of LUCs

Hotspot analysis was employed to explore the spatial relationships of LUCs and their potential, identifying “cold spots” and “hot spots” to pinpoint areas of clustering and conflict intensity.

Significant differences in conflict levels between neighboring units suggest stronger interactions, potentially intensifying conflicts in adjacent areas. A “3 × 3” rectangular grid was used, with the neighborhood analysis function in ArcGIS 10.8 calculating the standard deviation of the central unit to assess the influence of surrounding units. The formula is as follows:

$$\mathrm{Y_i} = \sqrt{\frac{\sum_{\mathrm{i}=1}^{\mathrm{N}}(\mathrm{x_i} - \overline{\mathrm{x}})^2}{\mathrm{N}}} \tag{9}$$

where Y_i represents the standard deviation of the ith unit, which means that the greater the conflict level difference between the surrounding unit and the central unit, the greater the conflict potential of the land-use function of the central unit, and the more likely it is to develop into a unit with higher conflict level. x_i represents the conflict level of the central unit, which is replaced by the intensity of eight conflict areas (x_i = 1, 2, 3, . . ., 8). The greater the value, the stronger the conflict intensity, x represents the average value of the conflict level of units in the range, and N is the number of units in the range (n = 2, 3, 4, . . ., 9).

3. Results

3.1. Spatial Distribution Characteristics of Land-Use Function Intensity

3.1.1. Spatial Distribution Characteristics of Production Function Intensity

In 2020, production functions in the GBA were categorized into low, medium, and high levels, accounting for 37.16%, 31.19%, and 31.65% of the total area, respectively (Table 4). Over 60% of the units were classified as medium or high production zones, primarily featuring urban land, paddy fields, and forested areas, reflecting relatively strong production functionality overall. Significant spatial differences were observed in the distribution of production zones, specifically in the varying levels of production functionality across different regions. High-level production zones were concentrated in the central and southeastern regions, particularly in Guangzhou, Shenzhen, and Foshan (Figure 2a). These areas are characterized by advanced economies, high urbanization, and abundant resources, which enhance regional production efficiency and facilitate integration into global value chains. Globalization plays a critical role in these regions, fostering export-oriented industries, innovation clusters, and logistics networks that support high-level production functionality. Medium-level production zones, on the other hand, were distributed across the eastern and southern regions, including Huizhou, Dongguan, Zhongshan, and Hong Kong. These cities benefit from geographic advantages, policy support, and integration into global production and trade networks. Acting as essential links between high-level zones and peripheral areas, they contribute to resource allocation, logistics management, and workforce distribution. Such dynamics highlight how globalization impacts regional production, shaping both medium- and high-level zones through interconnected trade and economic activities.

Table 4. Composition of land use for production–living–ecological functions in the GBA.

Land-Use Type	Production (%)			Living (%)			Ecological (%)			Total (%)
	W	**M**	**S**	**W**	**M**	**S**	**W**	**M**	**S**	
Paddy field	4.05	5.43	6.86	5.67	5.56	5.09	9.39	5.47	1.47	16.34
Dry land	2.49	2.32	2.22	3.10	2.35	1.58	3.66	2.91	0.46	7.03
Forest land	19.37	12.15	6.82	20.28	11.19	6.87	6.27	18.45	13.62	38.34
Shrub	0.78	0.48	0.47	1.03	0.28	0.42	0.62	0.90	0.22	1.73
Sparse woodland	2.44	1.93	1.20	2.88	1.62	1.06	2.84	2.20	0.52	5.57

Table 4. *Cont.*

Land-Use Type	Production (%)			Living (%)			Ecological (%)			Total (%)
	W	M	S	W	M	S	W	M	S	
Other forest land	1.71	1.61	1.29	2.03	1.43	1.15	1.91	1.48	1.22	4.61
High-coverage grassland	1.31	0.95	0.51	1.35	0.64	0.79	1.03	1.06	0.69	2.77
Medium-coverage grassland	0.15	0.13	0.03	0.15	0.13	0.04	0.08	0.14	0.09	0.31
Low-coverage grassland	0.00	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.00	0.02
River and canal	0.63	0.83	1.20	0.83	0.68	1.15	2.03	0.54	0.09	2.66
Lake	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Reservoir and pond	1.70	1.61	1.86	1.83	1.58	1.76	3.52	1.31	0.34	5.17
Tidal flat	0.07	0.00	0.01	0.02	0.05	0.01	0.04	0.03	0.00	0.08
Beach land	0.09	0.05	0.08	0.11	0.04	0.08	0.09	0.10	0.03	0.22
Urban land	0.61	1.56	4.93	0.26	1.43	5.41	6.44	0.65	0.00	7.10
Rural residential areas	0.80	1.03	1.66	0.99	1.25	1.24	2.85	0.58	0.06	3.49
Other construction land	0.96	1.09	2.50	0.83	1.51	2.20	3.85	0.62	0.08	4.55
Sandy land	0.00	0.00	0.01	0.00	0.00	0.01	0.01	0.00	0.00	0.01
Swamp land	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Bare land	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0
Total	37.16	31.19	31.65	41.38	29.75	28.87	44.65	36.46	18.89	100.00

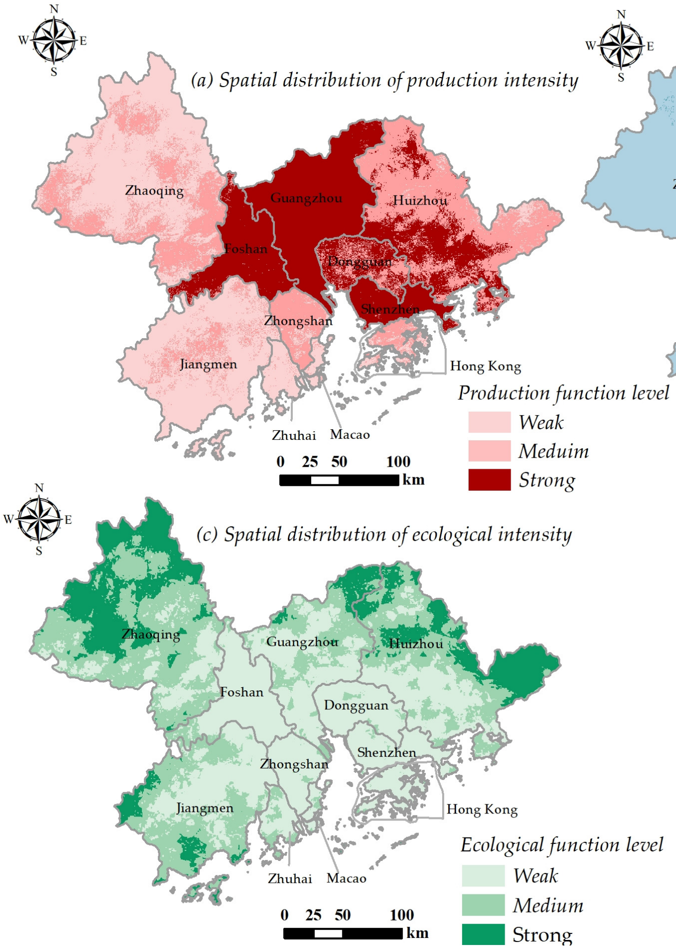

Figure 2. Spatial distribution of PLEs intensities in the GBA.

3.1.2. Spatial Distribution Characteristics of Living Function Intensity

In 2020, living functions in the GBA were divided into low, medium, and high levels, accounting for 41.38%, 29.75%, and 28.87% of the total area, respectively (Table 4). Approximately 60% of the land fell into medium or high living zones, indicating moderately high overall functionality. High-level living zones, dominated by urban land, paddy fields, and forested areas, were concentrated in central and southern regions such as Guangzhou, Shenzhen, Foshan, Dongguan, Hong Kong, and Macao (Figure 2b). These areas benefit from advanced infrastructure, high urbanization levels, and favorable living conditions. Hong Kong's internationalized economy and Macao's tourism-oriented development contributed significantly to their classification as high-function zones, supported by efficient public services, advanced healthcare systems, and rich cultural resources. Medium-level zones, including Zhuhai, Huizhou, and Zhongshan, provided relatively adequate living services but remained less developed compared to core cities. Low-level zones were concentrated in the northwest and southwest, particularly in Zhaoqing and Jiangmen, where geographic remoteness, limited industrial diversification, and weaker economic activity hindered progress in living standards.

3.1.3. Spatial Distribution Characteristics of Ecological Function Intensity

The spatial clustering of ecological functions in the GBA was less distinct compared to production and living functions, with limited connectivity between areas of varying ecological function intensity. High-level ecological zones were primarily located in peripheral cities such as Zhaoqing, Jiangmen, and Huizhou, where forested land and water bodies dominate, supported by lower urbanization and more intact natural ecosystems (Figure 2c). Medium-function zones formed transitional areas between urban cores and peripheral regions, consisting largely of mixed agricultural and forested land. In contrast, low-level ecological zones were concentrated in highly urbanized cities such as Guangzhou, Shenzhen, Hong Kong, and Macao, where urban and industrial land uses significantly reduced ecological functionality. Despite localized conservation efforts, urban expansion and intensive human activity continue to exert pressure on ecological environments. Low, medium, and high ecological function zones accounted for 44.65%, 36.46%, and 18.89% of the total area, respectively (Table 4), reflecting relatively weak ecological functionality, with nearly half of the area classified as low-function zones. Hong Kong and Macao, heavily urbanized and constrained by limited green space, experienced particularly high ecological strain. The spatial pattern of ecological functionality reflects a center-periphery gradient, where ecological intensity improves with distance from urban cores.

3.2. Spatial Distribution Characteristics of LUCs Zones

According to Table 3, the spatial distribution in Figure 3a shows that weak multifunctional conflict zones, dual-function low-intensity conflict zones, and dual-function low-intensity strong conflict zones cover 39.22% of the study area (Table 5). These zones are mainly located in the western and southern regions, concentrated in Zhuhai, Zhongshan, Zhaoqing, Jiangmen, and Macao (Figure 3b). Forested land dominates these areas, accounting for 18.72%, followed by paddy fields at 4.97%. Other land types include dry land, sparse woodland, reservoirs and ponds, high-coverage grassland, and various other uses, including urban and rural residential land, ranked in descending order by area. These zones are in a stable and controllable stage, characterized by low development levels and minimal multifunctional overlap. Predominantly ecological, these areas exhibit limited functional demands, reducing the likelihood and intensity of LUCs.

Dual-function moderate-intensity conflict zones, complex multifunctional conflict zones, and moderate multifunctional conflict zones account for 28.73% of the study area (Table 5). These zones are primarily located in the eastern and central-eastern regions, concentrated in Dongguan, Huizhou, and Hong Kong (Figure 3c). Forested land dominates these areas, comprising 9.50%, followed by paddy fields at 5.51%. These zones are in a basic controllable stage, where urbanization and human activity increase the likelihood of LUCs but remain within manageable limits. In Hong Kong, despite challenges from high urbanization and limited land resources, effective land-use planning and strict development controls have kept overall conflict levels lower compared to other core cities in the GBA.

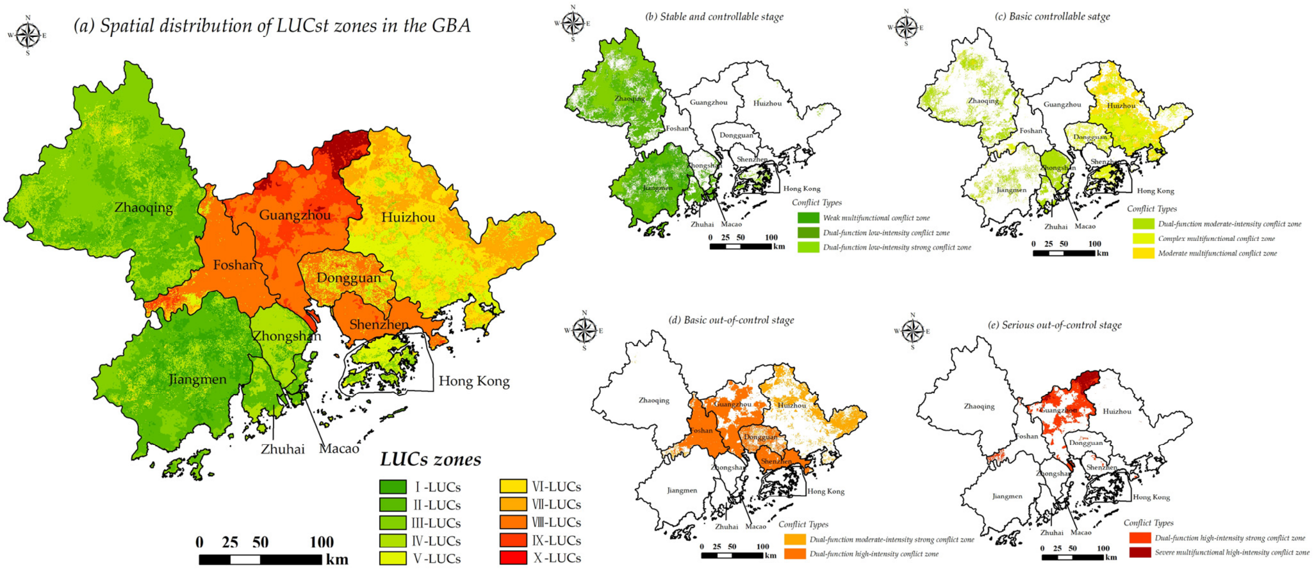

Figure 3. Spatial distribution of LUCs and conflicts stages in the GBA.

Table 5. Composition of LUCs levels by Area in the GBA.

Land-Use Type	**Stable and Controllable (%)**			**Basic Controllable (%)**			**Basic Out-of-Control (%)**		**Serious Out-of-Control (%)**	
	I	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**X**
Paddy field	0.93	3.28	0.76	2.64	1.73	1.14	0.88	3.87	0.99	0.10
Dry land	0.52	1.92	0.31	1.26	0.77	0.51	0.33	1.22	0.21	0.00
Forest land	0.90	9.50	8.32	3.48	2.04	3.99	4.40	2.06	2.53	1.12
Shrub	0.07	0.61	0.20	0.24	0.10	0.10	0.04	0.28	0.11	0.00
Sparse woodland	0.58	1.64	0.52	0.87	0.76	0.34	0.21	0.47	0.18	0.00
Other forest land	0.26	0.93	0.66	0.50	0.38	0.34	0.51	0.81	0.16	0.05
High-coverage grassland	0.16	0.61	0.57	0.24	0.38	0.17	0.26	0.22	0.14	0.02
Medium-coverage grassland	0.02	0.08	0.05	0.04	0.03	0.04	0.04	0.00	0.01	0.00
Low-coverage grassland	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
River and canal	0.18	0.55	0.07	0.49	0.23	0.05	0.03	0.99	0.07	0.00
Lake	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Reservoir and pond	0.38	1.49	0.18	0.85	0.42	0.12	0.15	1.31	0.22	0.05
Tidal flat	0.00	0.05	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Beach land	0.01	0.07	0.02	0.02	0.01	0.01	0.01	0.06	0.01	0.01
Urban land	0.09	0.44	0.12	0.81	0.98	0.02	0.05	4.14	0.46	0.00
Rural residential areas	0.30	0.71	0.05	0.59	0.52	0.11	0.04	1.11	0.05	0.01
Other construction land	0.30	0.72	0.09	0.59	0.69	0.12	0.07	1.83	0.12	0.01
Sandy land	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
Swamp land	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bare land	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	4.69	22.61	11.92	12.63	9.04	7.06	7.02	18.38	5.25	1.38
		39.22			28.73		25.40		6.63	

Dual-function moderate-intensity strong conflict zones and dual-function high-intensity conflict zones cover 25.41% of the study area (Table 5), predominantly located in the central, northern, and east-central regions, including Guangzhou, Shenzhen, and Foshan (Figure 3d). These areas form a spatially concentrated conflict pattern along the Guangzhou-Shenzhen-Foshan axis, reflecting their status as core hubs of economic, political, and cultural activity within the GBA. Land-use competition in these zones is driven by high multifunctionality, with forested land comprising 6.45% and paddy fields 4.76%, alongside urban land, other construction land, dryland, reservoirs, sparse woodland, and rural residential areas. Smaller contributions from grassland, shrubland, beaches, and wetlands further diversify the land-use structure. The mixture of urban and ecological functions intensifies conflicts as development pressures intersect with conservation demands. The spatial conflict pattern highlights the dual role of these regions: as economic and administrative cores with dense urbanization, they attract significant development, yet their ecological functions remain vital for regional sustainability. The competition between these functions has created basic out-of-control zones where land-use demands often exceed the capacity for balanced management. Addressing these challenges requires strategies to reconcile urban growth with ecological preservation, especially given the pivotal role these areas play in the broader regional economy.

Dual-function high-intensity strong conflict zones and severe multifunctional high-intensity conflict zones occupy 6.64% of the study area, primarily concentrated in the northern peripheral regions of the GBA (Figure 3e). Forested land accounts for 3.66%, and paddy fields for 1.09% of these zones (Table 5). These areas are mainly located in the northern parts of Guangzhou, characterized by intense production and living functions while also serving as ecologically sensitive zones. The high intensity of competing land-use functions places these regions in a serious out-of-control state. The strong functional demands lead to frequent conflicts as production and living activities increasingly encroach upon ecological priorities, intensifying the struggle for limited land resources. This spatial pattern underscores the challenges of balancing high-intensity land use with ecological conservation in regions where all functions are expressed at their peak. Effective conflict mitigation strategies are critical to manage these zones and prevent further ecological degradation or disruption of essential urban functions.

3.3. Spatial Relationship of Land-Use Function Conflicts Area

Hot spots of LUC intensity were predominantly located in the central-eastern regions of the study area, including Guangzhou, Foshan, Shenzhen, Dongguan, and northeastern Huizhou (Figure 4a). These areas are marked by rapid economic growth, advanced urbanization, and extensive transportation networks. The convergence of production, living, and ecological demands in these regions has created highly complex and diversified land-use patterns, intensifying conflicts as these functions compete for limited resources. The concentration of conflicts in these areas reflects their role as economic and urban hubs within the region. Rapid development amplifies pressures on land resources, with urban expansion often encroaching on agricultural and ecological spaces. Moreover, the integration of these areas into global production and trade networks further complicates land-use dynamics as industrial, residential, and environmental priorities intersect. Addressing these challenges requires integrated land management strategies that balance development with ecological and social needs to ensure sustainable growth in these high-conflict zones.

The neighborhood analysis reveals a moderate risk of LUCs across the study area, with low, general, high, and extreme conflict potential zones accounting for 47.88%, 23.43%, 22.14%, and 6.54% of the total area, respectively. Extreme conflict potential zones are primarily concentrated in Dongguan, Jiangmen, and the central areas of Zhaoqing and Zhongshan (Figure 4b). These regions require immediate intervention through measures such as restricting urban expansion or protecting ecological green spaces. Effective spatial boundary controls are essential to regulate internal land development and minimize the influence of adjacent units, preventing further escalation of conflicts. High-conflict-potential zones are mainly distributed in Zhaoqing, Jiangmen, Huizhou, Hong Kong, and Macao. These areas face increasing pressure from competing land-use demands, and proactive measures are needed to maintain a balance between production, living, and ecological functions. Strategic planning should prioritize the prevention of intensifying conflicts, ensuring long-term sustainability in these high-risk regions.

A cold and hot spot analysis was conducted to examine the spatial distribution of LUC potential across different units in the GBA. The results indicate that hot spots of conflict potential were concentrated in Dongguan and along the administrative boundaries of "Foshan–Zhaoqing", "Foshan–Jiangmen", and "Guangzhou–Zhongshan" (Figure 4c). These areas are not only high-conflict zones but also regions with elevated conflict potential, highlighting their critical stage of land-use competition. The conflicts between production, living, and ecological functions in these zones are likely to escalate without timely intervention.

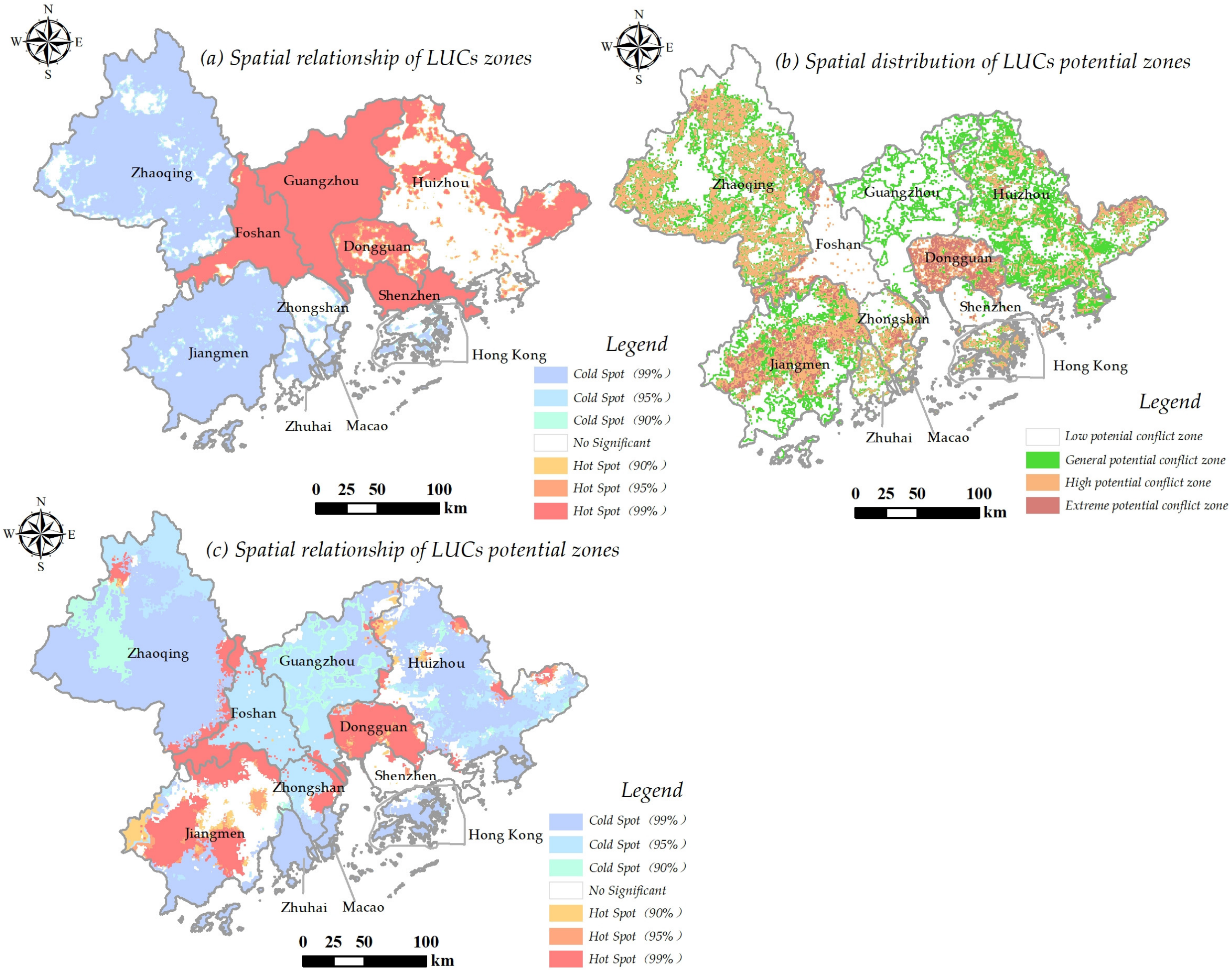

Figure 4. Spatial relationship of LUCs and LUCs potential zones in the GBA.

4. Discussion

4.1. Comparative Analysis of LUCs Dynamics: Insights from Western Jilin Province

Previous research studied LUCs in western Jilin Province, an inland province in China, focusing on conflicts in ecologically fragile areas [36]. This study chose the GBA, a coastal region, as a new research area, highlighting distinct dynamics compared to western Jilin. The GBA, spanning 56,000 square kilometers, is significantly larger than Jilin's 4.67 million hectares, requiring additional evaluation indicators to address its complexity. Unlike Jilin's ecologically fragile zones, the GBA exhibits high-intensity LUCs driven by rapid urbanization and economic growth. Core cities such as Guangzhou, Shenzhen, and Dongguan prioritize production and living functions due to industrialization and urban expansion, resulting in weak ecological functionality and heightened land-use competition. In contrast, peripheral cities like Zhaoqing and Jiangmen maintain stronger ecological functions and lower conflict levels, forming a clear core-periphery gradient.

To capture the unique characteristics of the GBA, this study introduced several new indicators. Geomorphic features were included to reflect the region's diverse terrain, while the NPP index provided a more detailed assessment of land productivity beyond basic land classifications used in Jilin. The critical role of ports in regional production was also considered, recognizing their influence on the GBA's economic activities. For living functions, POI data for education and medical resources were incorporated to evaluate quality of life from a broader perspective. These additions enhanced the evaluation framework, enabling a more nuanced understanding of the GBA's land-use dynamics and better addressing its challenges as a globally significant bay area. Several key distinctions emerge between the two regions:

(1) Function Distribution: In Jilin, production functions are weak, with ecological functions dominating in northern and peripheral areas. For example, fragile ecological zones in western Jilin focus on grassland and wetland conservation to mitigate desertification. In contrast, the GBA showcases a highly urbanized structure, where cities like Guangzhou and Shenzhen prioritize production and living functions, driven by industrialization and rapid urban growth, often at the expense of ecological functionality.

(2) Conflict Intensity: In Jilin, LUCs are stable or manageable, such as localized disputes in farming areas or grassland conservation zones. However, the GBA faces escalating pressures, particularly along the Guangzhou-Shenzhen-Dongguan axis, where competition between production, living, and ecological functions has led to intensified conflicts, as seen in cases of urban sprawl replacing agricultural and green spaces.

(3) Hot Spot Distribution: While Jilin's LUCs hot spots are scattered, often tied to specific conservation projects or localized economic activities (e.g., forestry zones in Changbai Mountain), the GBA's hot spots are concentrated in dense urban centers like Shenzhen, where global economic activities and industrial hubs amplify land-use tensions.

(4) Policy Implications: Western Jilin's land-use policies emphasize ecological preservation, such as the "Three North Shelterbelt" program targeting desertification. In contrast, the GBA requires innovative solutions, like multifunctional zoning and cross-border collaborations, to balance urban demands with ecological restoration. Examples include integrating green infrastructure with urban planning in the Guangzhou-Foshan metropolitan area.

By contrasting these two regions, this study highlights the critical need for context-specific land-use strategies. The lessons from Jilin emphasize the importance of maintaining ecological stability in fragile areas, while the GBA's findings call for innovative governance frameworks to manage urbanized landscapes and mitigate LUCs. Both cases underscore the value of tailoring land-use management to local dynamics, balancing ecological, economic, and social priorities for sustainable development.

4.2. Insights from the GBA's LUCs and Policy Recommendations

4.2.1. Spatial Distribution and Underlying Drivers of LUCs in the GBA

The spatial distribution of LUCs in the GBA demonstrates a distinct core-periphery pattern, as revealed in our findings for 2020. Core cities such as Guangzhou, Shenzhen, Foshan, and Dongguan represent high-conflict zones due to their rapid economic growth, intensive urbanization, and concentrated production and living functions. However, these areas often exhibit weak ecological functions, making them hotspots of LUCs. Urban expansion in these core cities, as noted in related studies, significantly disrupts landscape patterns and reduces habitat quality, leading to ecological vulnerabilities that exacerbate land-use conflicts [38]. In contrast, peripheral cities like Zhaoqing and Jiangmen experience lower conflict levels, as slower economic development and stronger ecological functions reduce land-use competition. This spatial disparity reflects the combined influence of urbanization, economic development, policy planning, and natural conditions [39]. Core cities prioritize production and living functions to support manufacturing, technological innovation, and service industries, intensifying land-use pressures. For instance, the high-density urban expansion in Shenzhen has significantly reduced ecological spaces despite being a center for technological and industrial growth. Conversely, peripheral areas like Zhaoqing maintain a higher proportion of ecological land, highlighting the uneven development patterns within the GBA.

The findings also underline the role of policy planning in shaping LUCs. National strategies position the GBA as a core region for technological and economic collaboration, incentivizing cities to allocate land for industrial and economic functions. For example, Shenzhen prioritizes land for high-tech industrial parks and business centers, leading to concentrated production functions at the expense of ecological spaces. The lack of coordinated regional land-use policies further exacerbates these conflicts, as cities such as Dongguan and Jiangmen face challenges during industrial transformation and land-use changes. Natural conditions also contribute significantly to the region's land-use dynamics. Core cities like Guangzhou and Shenzhen have limited ecological carrying capacities due to historical urbanization and industrialization, resulting in ecological vulnerabilities. Meanwhile, peripheral cities like Zhaoqing and Jiangmen, with preserved natural areas, maintain stronger ecological functions. This core-periphery contrast underscores the need for balanced development that considers both natural and socio-economic factors.

4.2.2. Insights from Global Bay Areas for Managing LUCs

The GBA's LUCs highlight the challenge of balancing production, living, and ecological needs in a densely developed region. Lessons from global bay areas offer valuable strategies, including urban growth boundaries, multifunctional zoning, green infrastructure, and participatory governance. Adapting these measures to the GBA's unique context can foster sustainable land-use practices, aligning economic growth with ecological and social goals.

(1) Balancing Urban Expansion and Ecological Preservation

The San Francisco Bay Area uses urban growth boundaries and strict wetland protection policies to limit development in sensitive ecological zones, effectively balancing economic growth with conservation [40]. For the GBA, where urban expansion threatens ecological zones in areas like Zhaoqing and Jiangmen, implementing urban growth boundaries and prioritizing wetland and green space protection can help mitigate LUCs and enhance long-term ecological sustainability.

(2) Integrated Zoning and Ecological Restoration

Tokyo Bay combines multifunctional zoning with large-scale ecological restoration to manage LUCs. Designating specific zones for industrial, residential, and ecological purposes ensures balanced development, while coastal restoration protects fragile ecosystems [41]. For the GBA, particularly in cities like Dongguan and Shenzhen, adopting similar zoning practices and restoring degraded ecological areas would address land-use competition and strengthen ecological resilience.

(3) Green Infrastructure for Urban Development

The New York Bay Area reduces LUCs by integrating green infrastructure, such as urban greenways, rain gardens, and green roofs, into urban planning. These initiatives alleviate ecological pressures while maintaining urban functionality [42]. In the GBA, high-density areas like Hong Kong and Macao can incorporate green infrastructure to balance urbanization with ecological preservation, creating more sustainable urban environments.

(4) Participatory Land-Use Governance

Sydney Bay emphasizes public participation and community-driven planning to manage LUCs effectively. Adaptive policies developed through community consultation address local needs while safeguarding ecological functions [43]. For the GBA, involving local communities in planning decisions can help resolve localized LUCs, particularly in cities like Guangzhou and Foshan, while improving policy acceptance and ensuring sustainable outcomes.

4.2.3. Policy Recommendations for GBA

Effectively addressing LUCs in the GBA requires a thorough understanding of stakeholders, resource requirements, and the challenges associated with implementation. The GBA is characterized by its diversity in development stages and land-use priorities, ranging from urbanized cores like Shenzhen and Guangzhou to peripheral cities like Zhaoqing and Jiangmen. This diversity necessitates the involvement of various stakeholders, including local governments, urban planners, enterprises, environmental NGOs, and community members. Local governments are responsible for enforcing policies and ensuring cross-regional coordination, enterprises are key drivers of industrial transformation and green development, and NGOs and communities play vital roles in ecological restoration and public engagement.

Implementing mitigation strategies for LUCs requires substantial financial and technical resources. For instance, establishing green development funds to support ecological restoration and urban renewal will depend on both public funding and private investment. Advanced technical tools, such as GIS-based conflict diagnostics and ecological restoration technologies, are also crucial to ensure effective and efficient implementation.

However, the region faces several challenges, including policy inconsistencies among cities, conflicting priorities among stakeholders, and constraints in funding. Core cities often prioritize economic growth and industrial expansion over ecological protection, while peripheral cities may face limitations in resources and lower levels of public awareness or engagement. Overcoming these challenges requires enhanced coordination mechanisms and tailored strategies that account for the specific needs and conditions of each city and stage of development.

Based on these considerations, the following policy recommendations are proposed to address LUCs in the GBA:

(1) Enhancing Cross-Border Collaboration

Cross-border collaboration is critical for optimizing resource allocation and reducing LUCs in the GBA. Coordinated policies among Guangdong, Hong Kong, and Macao can promote the balanced development of production, living, and ecological functions. Core cities such as Guangzhou, Shenzhen, and Foshan should establish partnerships with peripheral cities like Zhaoqing and Jiangmen to integrate ecological protection into industrial planning. Establishing unified land-use management mechanisms and holding regular interregional discussions on ecological and developmental goals can improve policy coordination and resource efficiency. The creation of a green development fund requires financial input from local governments and private enterprises. However, challenges related to differing regional priorities and fund allocation mechanisms must be addressed through transparent decision-making and consensus-building efforts.

(2) Implementing Fine-Grained Land Management

Fine-grained land management is essential to addressing LUCs effectively. Utilizing MCE and conflict diagnostics allows differentiated policies to be applied based on the specific needs of each region. Local governments and planning agencies should lead the implementation of these measures, supported by technical expertise from international organizations where needed. For high-conflict zones such as Foshan and Dongguan, stricter controls on land-use changes and financial incentives for transitioning industrial zones into green industries are critical. Evidence from global practices suggests that "land functional zoning" can clarify dominant land-use functions, minimizing conflicts and optimizing land efficiency. However, resistance from industries due to perceived economic costs remains a potential barrier and requires carefully designed incentive structures.

(3) Promoting Ecological Restoration and Protection

Ecological restoration is crucial for enhancing the ecological carrying capacity of the GBA. Urban renewal initiatives in core cities like Guangzhou and Shenzhen should focus on increasing green coverage and developing urban parks to enhance ecological services. Strict ecological redlines and environmental impact assessments must guide land-use decisions to ensure a balance between production, living, and ecological needs. Peripheral cities with stronger ecological functions, such as Zhaoqing, should prioritize preserving these areas to prevent over-development. Municipal governments, environmental NGOs, and private developers must collaborate to secure funding and technical expertise to support large-scale restoration projects. Challenges such as limited enforcement of ecological redlines and the high costs associated with restoration initiatives highlight the need for stronger regulatory mechanisms and financial frameworks.

(4) Stage-Specific Management Strategies

Effective management of LUCs in the GBA requires a comprehensive understanding of stakeholder roles, resource allocation, and the challenges associated with each stage of conflict intensity. Different stages of LUCs involve varying degrees of stakeholder participation, funding requirements, and distinct levels of potential challenges. Strategies must, therefore, be tailored to address the specific conditions of each stage.:

- Stable and Controllable Stage

Regions in the stable and controllable stage, such as Zhaoqing and parts of Jiangmen, exhibit low conflict intensity, characterized by balanced land-use functions dominated by ecological lands. These areas face minimal competition among production, living, and ecological functions and the primary goal is to maintain this stability. Ecological preservation should be prioritized through the establishment of nature reserves and the promotion of low-impact activities such as eco-tourism and organic farming. Local governments and environmental NGOs play a central role in implementing these strategies, while community engagement ensures the sustainability of conservation initiatives. These measures require modest financial support, primarily directed toward ecological monitoring, public awareness campaigns, and small-scale reforestation projects. However, challenges include limited public awareness and insufficient coordination among stakeholders, which may undermine the effectiveness of preservation efforts. Long-term ecological planning, including biodiversity conservation and habitat restoration, is crucial to enhancing ecosystem resilience and preventing potential conflicts from emerging in the future.

- Basic Controllable Stage

Moderate conflict zones, such as parts of Huizhou, Dongguan, and Jiangmen, reflect increasing urbanization and industrial transformation, resulting in intensified competition among land-use functions. In these regions, proactive management strategies are required to balance production, living, and ecological functions and to prevent conflicts from escalating. Local governments and planning agencies must collaborate with industrial associations and enterprises to implement multifunctional zoning systems that integrate land uses effectively. For example, developing green industrial parks and eco-urban areas can reduce ecological pressures while sustaining urban productivity. These initiatives require significant investment in green infrastructure, such as urban parks and rainwater gardens, as well as advanced technical expertise for land-use diagnostics and zoning design. Challenges in these regions include resistance from industries to adopt sustainable practices, as well as insufficient inter-city coordination that can impede the consistent application of strategies. Clear policy frameworks that incentivize green development and align urban planning with ecological preservation are essential to address these barriers.

- Basic Out-of-Control Stage

Regions like the fringes of Guangzhou and Shenzhen face significant land-use conflicts due to heightened competition between production and living functions, leading to ecological degradation and strained land resources. Immediate and decisive interventions are required to prevent further deterioration and to restore ecological balance. Regulatory controls should enforce strict zoning policies to limit urban sprawl and manage industrial expansion. Ecological restoration initiatives, including wetland rehabilitation and urban reforestation, are critical to recovering degraded land and improving ecosystem services. Adaptive urban planning should focus on integrating green spaces into urban designs to enhance land-use efficiency. Implementing these measures demands substantial financial resources and close collaboration among municipal governments, developers, and environmental experts. However, challenges include conflicting priorities between rapid urban growth and ecological preservation, as well as enforcement difficulties in high-growth areas. Strengthened stakeholder coordination and the integration of ecological goals into urban development policies are necessary to overcome these barriers.

- Serious Out-of-Control Stage

Urban cores like Shenzhen and parts of Guangzhou experience severe conflicts among production, living, and ecological functions, characterized by ecological degradation and resource depletion. These regions require the strongest interventions to prevent irreversible ecological damage and to ensure sustainable land use. Immediate priorities include the protection of critical ecological areas through strict ecological redlines and the halting of development in sensitive zones. Robust measures, such as vertical green infrastructure, ecological compensation systems, and innovative urban planning, must be adopted to alleviate urban and industrial pressures. These measures demand substantial funding and advanced technical expertise to implement large-scale ecological restoration and create innovative urban solutions. Interregional coordination among Hong Kong, Macao, and mainland cities is crucial for managing shared ecological resources and addressing cross-border pressures. However, significant challenges remain, including the high costs of implementation, political complexities arising from multi-regional governance, and resistance from stakeholders prioritizing economic growth over ecological protection. To address these challenges, clear policy mandates, sustained regional collaboration, and long-term investments in green infrastructure and restoration technologies are essential for ensuring ecological sustainability and balanced land-use management.

The GBA demonstrates a higher intensity of LUCs, particularly in its urbanized cores, driven by rapid economic growth, urbanization, and industrialization. These challenges necessitate stricter zoning policies, enhanced ecological restoration efforts, and stronger interregional coordination mechanisms. Addressing LUCs in the GBA requires adaptive strategies that not only consider the unique challenges of each conflict stage but also align with the involvement of diverse stakeholders, including local governments, enterprises, planning agencies, and community groups. Adequate resources, such as financial investments in green infrastructure and technical expertise for ecological restoration, are essential to ensure the success of these interventions. However, potential barriers, including conflicting stakeholder priorities, policy inconsistencies, and funding constraints, must be proactively addressed. By balancing production, living, and ecological functions, the GBA can achieve sustainable development and serve as a model for integrated land-use management in high-density urban regions.

5. Conclusions

This study constructed a production–living–ecological function-evaluation model using MCE, combined with an intensity diagnostic model, to analyze the spatial distribution and relationships of LUCs intensity and potential in the GBA for 2020. Using hot spot and neighborhood analyses, the following conclusions were drawn:

(1) In 2020, the GBA exhibited relatively high production functionality, moderately high living functionality, and relatively low ecological functionality. High-level production and living function zones were primarily concentrated in the central and southeastern areas, including Guangzhou, Shenzhen, and Foshan. Living functionality in Hong Kong and Macao was also classified as high. Ecological functionality displayed a clear "center-periphery" distribution pattern, weakening in urban cores like Guangzhou, Shenzhen, and Foshan and strengthening in peripheral areas such as Zhaoqing and Jiangmen.

(2) The proportions of the stable and controllable stage, basic controllable stage, basic out-of-control stage, and serious out-of-control stage accounted for 39.22%, 28.73%, 25.41%, and 6.64% of the study area, respectively. Hot spots of LUC intensity were concentrated in the central-eastern part of the GBA, particularly in Guangzhou, Foshan, Shenzhen, and Dongguan, where high urbanization and industrial activities dominate. Cold spots were primarily distributed in peripheral regions such as Zhaoqing, Jiangmen, and Macao, where lower economic activity and stronger ecological functions reduce conflict levels.

(3) The study area faced varying degrees of conflict potential, with low, general, high, and extreme potential zones occupying 47.88%, 23.43%, 22.14%, and 6.54% of the total area, respectively. Extreme conflict potential was concentrated in the central areas of Dongguan and Jiangmen, as well as the urban cores of Zhaoqing and Zhongshan. High-potential conflict zones were distributed across Zhaoqing, Jiangmen, Huizhou, Hong Kong, and Macao. Hot spots of conflict potential overlapped with administrative boundary areas such as "Foshan–Zhaoqing", "Foshan–Jiangmen", and "Guangzhou–Zhongshan", highlighting areas of intensified land-use competition.

The GBA plays a pivotal role in driving China's economic development, characterized by rapid urbanization and intensive industrial activity. The findings of this study underscore the importance of balancing economic growth with ecological sustainability to address the region's complex land-use challenges. Given its critical economic mission, the GBA requires land-use strategies that balance growth with sustainability. Policy frameworks should emphasize integrated planning to manage conflicts in high-pressure zones while preserving ecological integrity in less-developed areas. This balance is essential not only for the GBA's sustainable development but also as a model for managing land-use conflicts in other high-density urban regions. Future research should further refine evaluation methods and indicators to enhance the understanding of LUC dynamics and support effective, evidence-based policymaking. The urgency of addressing land-use conflicts in the GBA cannot be overstated, as timely and effective actions are critical to ensuring long-term regional sustainability.

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