land

Article

The Assessment of Land Suitability for Urban Expansion and Renewal for Coastal Urban Agglomerations: A Pilot Study of the Guangdong-Hong Kong-Macao Greater Bay Area

Tingting Pan [1,2,3], Fengqin Yan [4,5,*], Fenzhen Su [4,5] and Liang Xu [6]

[1] Donghai Academy & Zhejiang Ocean Development Think Tank Alliance, Ningbo University, Ningbo 325211, China
[2] Zhejiang Collaborative Innovation Center for Land and Marine Spatial Utilization and Governance Research, Ningbo University, Ningbo 325211, China
[3] Department of Geography and Spatial Information Techniques, Ningbo University, Ningbo 325211, China
[4] State Key Laboratory of Resources and Environmental Information System, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China
[5] College of Resources and Environment, University of Chinese Academy of Sciences, Beijing 100101, China
[6] School of Earth Sciences, Zhejiang University, Hangzhou 310058, China
* Correspondence: yanfq@lreis.ac.cn

Abstract: Effectively and rationally allocating land resources, while coordinating urban expansion with internal renewal strategies, is crucial for achieving high-quality regional development in coastal urban agglomerations. Land-use suitability assessment (LSA) is a key method for coastal land-use planning, but it is primarily used to delineate ecological redlines or areas for urban expansion, often overlooking the spatial analysis needed for urban renewal. This is particularly critical in coastal urban agglomerations facing land scarcity and ecological fragility. Here, we combined land use and the Analytical Hierarchical Process (to consider stakeholder priorities) in a Minimum cumulative resistance model (MCRM) to determine suitable coastal urban growth and renewal based on a suite of 12 indicators relevant to development intensity and stock space. Application to the Guangdong-Hong Kong-Macao Greater Bay Area (GBA) indicates a dominance of the Ecological Buffer Zone (70.5%), and the available stock space in the GBA comprises only 9.2% of the total area. Our modeling framework tailored different development strategies for different cities: Huizhou and Zhaoqing had space for urban expansion to varying degrees, while other cities were found to be suitable for urban renewal due to low stock space and high development intensity. Our modeling approach, incorporating stakeholder input and objective evaluation of geographic land-use information, can assist planners in improving ecological security while promoting high-quality developments in coastal areas.

Keywords: Guangdong-Hong Kong-Macao Greater Bay Area; land-use suitability assessment; Minimum cumulative resistance model (MCRM); coastal urban agglomerations; high-quality development

check for updates

Citation: Pan, T.; Yan, F.; Su, F.; Xu, L. The Assessment of Land Suitability for Urban Expansion and Renewal for Coastal Urban Agglomerations: A Pilot Study of the Guangdong-Hong Kong-Macao Greater Bay Area. *Land* **2024**, *13*, 1729. https://doi.org/10.3390/land13111729

Academic Editor: Thomas W. Sanchez

Received: 1 September 2024
Revised: 17 October 2024
Accepted: 19 October 2024
Published: 22 October 2024

1. Introduction

Over the last three decades, global urbanization has resulted in a significant increase in the demand for land in coastal areas [1,2]. The constant expansion of urban areas places immense pressure on land [3], leading to escalating conflicts across diverse land use types, particularly in coastal urban agglomerations. This has given rise to increasingly pressing eco-environmental concerns, including land resource shortages, ecosystem degradation, and landscape fragmentation [4–6]. Some of these challenges can be traced to the inadequate evaluation of land-use plans or policies implemented by governments [7]. In response, urban renewal strategies along with land-use suitability assessment (LSA) have been proposed as solutions to address these issues and assist in urban planning strategies [8,9].

The goal of land-use suitability assessment (LSA) is to identify the most appropriate spatial patterns for land-use layout optimization, offering policymakers crucial guidance on whether to prioritize urban expansion or urban renewal as part of their development strategies [10]. Much of the current focus in LSA research remains centered on ecological security and urban expansion [9,11], neglecting the spatial analysis necessary to inform urban renewal strategies. Meanwhile, studies on LSA in coastal urban agglomerations are relatively limited, with most focusing on individual cities or local scales, such as Ismailia Governorate in Egypt [12], Nong Khai in Thailand [13], and Beijing [14], and Nanchang [15] in China. Coastal urban regions present additional challenges due to their diverse land-use types, such as aquaculture land, mangroves, numerous seaports, and ecological protection areas, all of which impact spatial planning and ecological conservation efforts [16,17]. Thus, LSA in coastal urban agglomerations should incorporate considerations of the ocean's economic contributions and the ecological impacts on landscape patterns.

In coastal urban agglomerations, where environmental sensitivity, economic pressures, and urban expansion need to be carefully balanced, the combination of AHP and MCRM offers a powerful approach to sustainable land use planning. Advances in spatial analysis tools have evolved LSA in coastal areas from simple overlays of physical factors to multi-dimension analysis [18]. Multi-Criteria Decision Analysis (MCDA), combined with stakeholder input on relative priorities, employs the Analytic Hierarchy Process (AHP) as a prevalent method for LSA [19,20]. Land use in coastal areas involves various complex factors, and AHP can organize these factors hierarchically, facilitating systematic analysis and comparison. At the same time, it can handle quantitative data and convert qualitative judgments into quantifiable indicators, making it suitable for the diverse and uncertain environment of coastal areas. However, AHP may potentially oversimplify the complexity of LSA by aggregating various inputs in a single/simple way, failing to effectively reflect the ecological processes in specific regions.

To address this limitation, the Minimum cumulative resistance model (MCRM) has been proposed as a complementary approach, incorporating spatial resistance to balance ecological protection with urban development expansion [21–23]. MCRM is an assessment method based on the simulation of landscape diffusion processes, emphasizing the cumulative effects of resource resistance over spatial distances, with its core focusing on optimizing the landscape pattern by considering ecological processes [24,25]. Although MCR can achieve spatial suitability assessment, its drawback lies in its inability to undertake multi-dimension analysis. Thus, combining AHP and MCRM allows for both the prioritization of key criteria (via AHP) and the consideration of spatial resistance to ecological protection (via MCR), ensuring a comprehensive land use assessment in coastal areas.

The Guangdong-Hong Kong-Macao Greater Bay Area (GBA) is one of the fastest-growing coastal urban agglomerations in China [26]. However, it faces significant challenges, including human-land conflict and ecological environment deterioration, which have limited high-quality development [16,27,28]. With many ecologically sensitive areas/reserves and uneven urban growth, historical development strategies that emphasized urban expansion are now hampered by the scarcity of land resources, compelling cities to shift towards urban renewal [29]. Bearing in mind these issues, we developed an LSA modeling framework specifically designed for coastal urban agglomerations, using the GBA as the study area. This framework encompasses a suitability index system that integrates seaports and coastal protection areas to emphasize the characteristics of coastal urban agglomerations. MCRM and AHP were used for LSA, while development intensity and available stock space were used to measure the development status in the GBA. This paper establishes a sound modeling basis for evaluating urban growth and renewal in the GBA, which can guide future high-quality development.

2. Study Area and Data

Located in southern China, the GBA is one of the world's fastest-growing and most densely populated coastal urban agglomerations, containing 11 cities: Guangzhou (GZ), Shenzhen (SZ), Zhuhai (ZH), Zhaoqing (ZQ), Huizhou (HZ), Jiangmen (JM), Dongguan (DG), Foshan (FS), Hong Kong (HK), and Macao [16]. The GBA has experienced unprecedented urbanization and economic development, leading to significant land-use changes. With a population exceeding 90 million and a total GDP exceeding 11 trillion RMB in 2020, the GBA has become a vital engine for China's economic growth.

However, rapid urbanization has intensified the demand for land resources, placing significant pressure on the coastal ecological environment. The GBA's proximity to ecologically sensitive areas—such as coastal zones, wetlands, and forested mountains—has made the region particularly vulnerable to ecological degradation. With land resources becoming increasingly scarce and the ecosystem highly fragile, there is an urgent need for comprehensive ecological suitability assessments. Integrating ecological suitability assessments into regional planning is essential for maintaining the delicate balance between growth and conservation, ultimately ensuring that development in the GBA is both environmentally sustainable and economically resilient.

All the data are from the year 2020. Based on national and regional guidelines, expert knowledge, and available data, the selection of suitability factors included economic demands and natural factors. All the data were resampled to 30 m resolution. The location of the GBA is shown in Figure 1, and the data sources are described in Table 1.

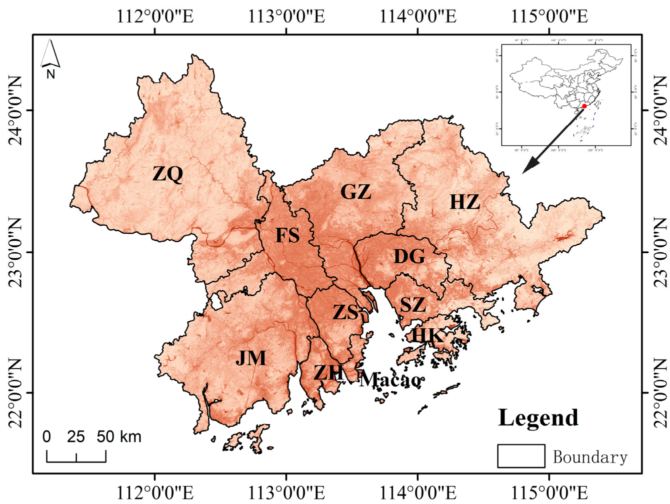

Figure 1. Location map of the GBA.

Table 1. Data sources for the GBA in 2020.

Name	Data Source
Ecological Control Area	Ministry of Natural Resources of the People's Republic of China (http://g.mnr.gov.cn/, accessed on 1 May 2023)
Road Network	OpenStreetMap (https://www.openstreetmap.org/, accessed on 1 June 2024)
Boundary of GBA	Resource and Environmental Science Data Platform (https://www.resdc.cn/, accessed on 12 June 2023)
Land-use	
NDVI	
Terrain	
DEM	Shuttle Radar Topography Mission (SRTM, https://earthexplorer.usgs.gov, accessed on 1 May 2023)
Population Density	WorldPop (https://www.worldpop.org, accessed on 1 May 2023)
GDP	Statistical yearbook of various cities in the GBA

3. Method

The LSA model for coastal urban agglomeration initially identifies pivotal factors influencing land suitability, including geographical conditions, the ecological environment, and human disturbances. Recognizing the economic and ecological conservation requirements of coastal urban agglomerations, the assessment criteria encompass seaports and coastal protection areas as indicators. Subsequently, the model develops a suitability assessment framework for coastal urban agglomerations, analyzing both available stock space and development intensity. The technical structure is illustrated in Figure 2.

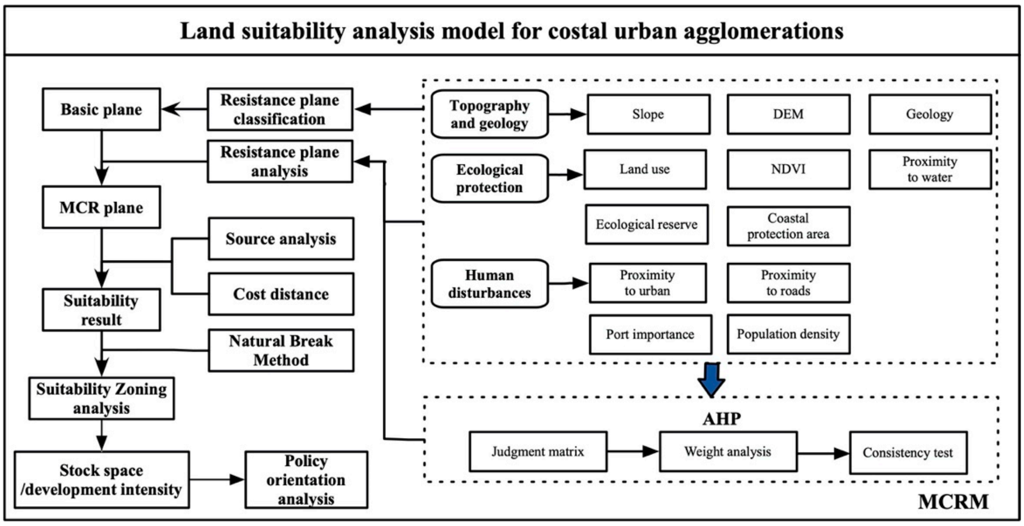

Figure 2. Technical structure diagram.

The Minimum cumulative resistance model (MCRM) calculates the minimum process-related cost to overcome the resistance of all homogeneous or heterogeneous landscape units from a "source" or "sink". It consists of three main parts: source, resistance plane, and resistance coefficient to another landscape:

$$MCR = fmin\sum_{j=n}^{i=m} D_{ij} \times R_i \quad (1)$$

where D_{ij} denotes the spatial distance from source j to landscape unit I; R_i denotes the resistance coefficient in the transition from landscape unit $_i$ to source j.

Comparative resistance between ecological land and construction land was measured using the minimum cumulative resistance difference, as shown in Figure 3, where along the x-axis pathway, E denotes the ecological expansion source, U denotes the construction expansion source, and EC and UC denote the cumulative resistance expansion curves of ecological land and construction land, respectively. Between M and U, MCR for ecological expansion is greater; hence, construction land is more suitable for the M -> U pathway, and conversely, ecological land is favored between M -> E.

The MCR difference formula is as follows:

$$\text{MCR}_d = \text{MCR}_e - \text{MCR}_u \quad (2)$$

where MCR_d represents the MCR difference between the two expansion processes, MCR_u and MCR_e for MCR of expansion of construction land and ecological land, respectively.

$MCR_d < 0$, indicates ecological land is easier to enlarge, and $MCR_d > 0$ indicates construction land is favored.

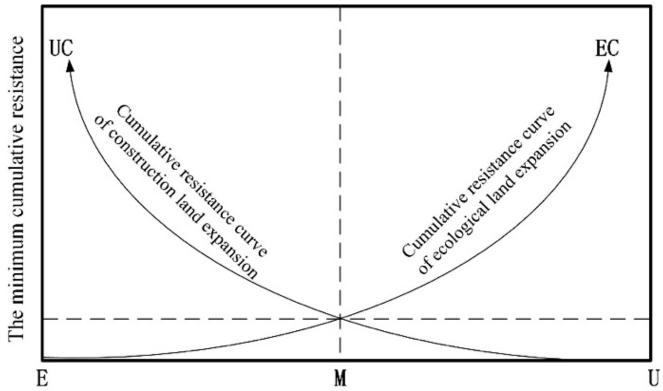

Figure 3. Balance of suitable construction land and ecological land based on MCR (modified from Ref. [30]).

(1) Source selections

Expansion sources are sources of ecological land that are rich in biodiversity and ecosystem services. In the GBA, such "ecological sources" include rivers, lakes, drinking water resources, significant wetlands, natural landscape reserves, and high mountains with rich natural resources. In principle, urban expansion must not encroach on this type of land in the GBA (Figure 4a). Also, construction land in 2020 is set as "sprawl sources" as shown in Figure 4b.

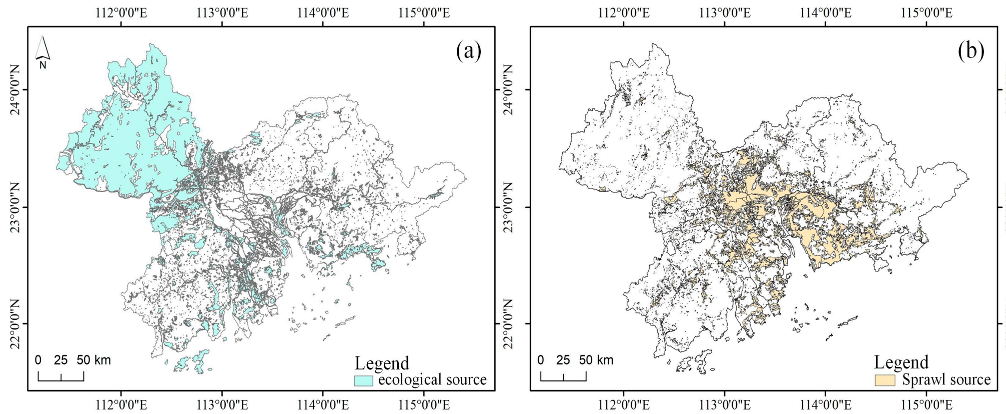

Figure 4. Ecological sources (**a**) and sprawl sources (**b**) in the GBA.

(2) Resistance plane and coefficient

The resistance coefficient reflects the difficulty of each landscape unit in impeding the expansion of construction land or ecological land [31,32]. From the perspective of ecological processes, there is a competitive relationship between ecological land and construction land [33]. Generally, to ensure that ecological expansion and construction expansion can be compared on the same scale, a unified resistance evaluation system needs to be established. In this evaluation system, the grade assignment for the two is reversed.

In this study, the resistance plane is based on a thorough review of existing scientific research [22,34–36], with support from a panel of experts. All the resistance planes are divided into three main categories (primary indicators): Topography and geology, Ecological protection and Human disturbances. Each category is further subdivided into 12 subcategories, as shown in Table 2 and Figure 5.

Table 2. Valuation system for resistance factors for ecological and construction land.

		Ranking						
Resistance Plane of Construction Land		**V**	**IV**	**III**	**II**	**I**	**Weight for Construction Land**	**Weight for Ecological Land**
Resistance Plane of Ecological Land		**I**	**II**	**III**	**IV**	**V**		
Topography and geology	Slope	>25	10–25	5–10	2–5	<2	0.102	0.146
	Geological condition	Mountains, Depressions, Floodplains, Lakes	Hills, Terraces	/	/	Plain	0.051	0.073
	DEM	>160	120–160	80–120	40–80	1–40	0.073	0.105
Ecological protection	NDVI	>0.8	0.6–0.8	0.4–0.6	0.2–0.4	<0.2	0.053	0.074
	Land use	Water, Other forest, Aquaculture	Grassland	Economic forest	Cropland	Transportation, Industrial, Residential, Public	0.066	0.092
	Proximity to water (km)	<1	1–2	2–3	3–4	>4	0.094	0.131
	Ecological reserve	Ecological control land	-	-	-	Other area	0.053	0.074
	Coastal protection area	Guanghai Bay, Daya Bay	Coastal zone areas, Islands	Coastal zone forests	-	others	0.057	0.080
Human disturbances	Proximity to urban areas (km)	<0	0–0.5	0.5–1	1–1.5	>1.5	0.158	0.079
	Proximity to roads (km)	>4	3–4	2–3	1–2	0–1	0.123	0.062
	Population density	0–200	200–400	400–700	700–1000	>1000	0.093	0.046
	Port importance	0	1–2	2–5	5–8	>8	0.076	0.038

These include:

(1) Slope: It affects risk management and resilience to coastal processes, potentially undermining the economic feasibility of the project.

(2) Geological conditions: The geological composition of coastal areas influences how they will respond to sea-level rise. Areas with stable geological formations are more resistant to erosion and land loss, while low-lying areas composed of soft sediments are more vulnerable to flooding and permanent inundation.

(3) DEM: It helps assess terrain, slope, flood risk, and elevation changes. Excessive elevation can hinder accessibility and increase flood risks in lower-lying areas.

(4) NDVI: It measures vegetation health, helps identify green spaces, and supports ecological preservation. Higher NDVI values indicate denser, healthier vegetation, supporting ecological preservation.

(5) Land use: Land use shapes existing development patterns, resource distribution, and environmental impact. It plays a key role in guiding sustainable planning by balancing ecological preservation and economic activities, especially in densely populated coastal regions.

(6) Proximity to water: The presence of water is essential for the lifecycle in the coastal urban agglomeration.

(7) Ecological reserve: It protects biodiversity, preserves critical habitats, and mitigates environmental degradation, which is crucial for future land planning.

(8) Coastal protection area: It safeguards shorelines from erosion, mitigates storm impacts, preserves marine ecosystems, and ensures sustainable development by protecting vulnerable coastal environments from degradation and climate-related risks.

(9) Proximity to urban areas: It influences access to infrastructure and services, promotes efficient land development, and reduces transportation costs.
(10) Proximity to roads: It enhances accessibility, supports efficient transportation, and facilitates connectivity between urban areas.
(11) Population density: It influences infrastructure demand, resource allocation, and environmental pressure in coastal areas.
(12) Port importance: It facilitates international trade and promotes economic growth. Seaport importance is an index of the economic radiation intensity of ports across different cities.

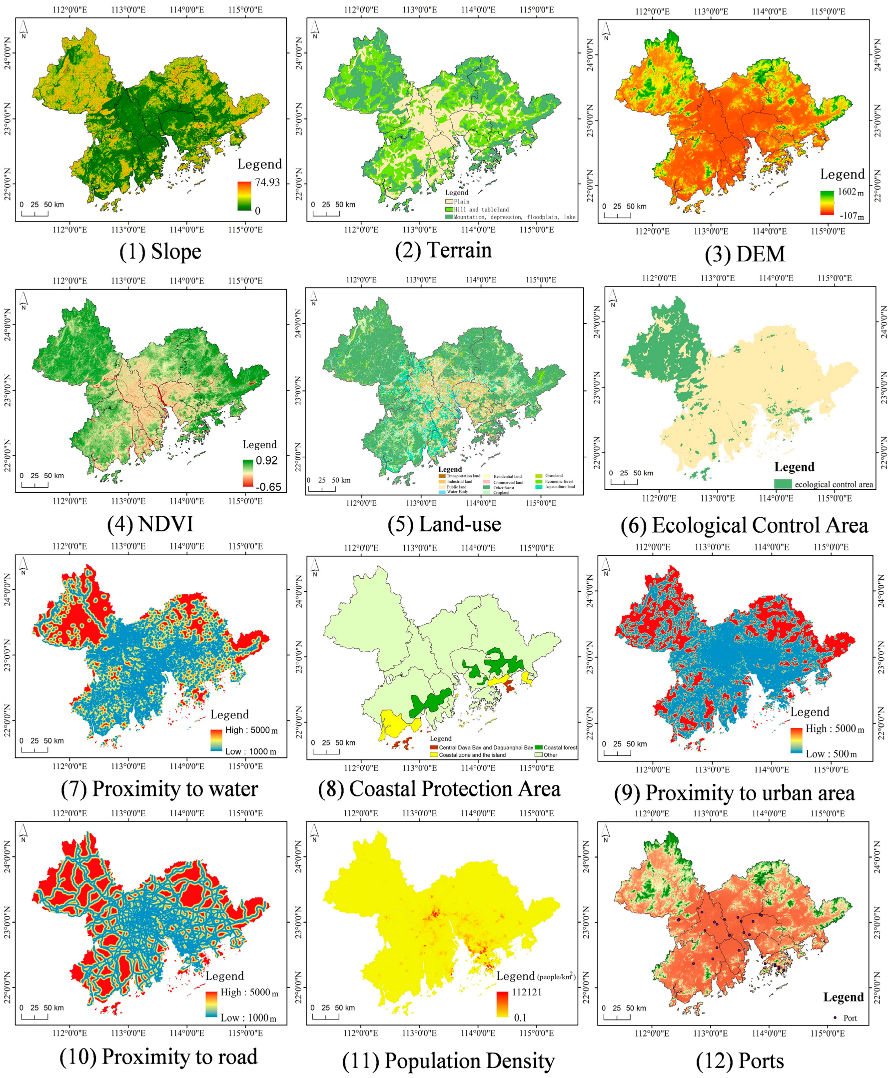

Figure 5. Spatial distribution of resistance indicators in 2020.

In constructing resistance planes, suitability indicators were scored and ranked from I to V, where smaller values implied less resistance for the "source" to overcome in expansion. Since ecological land competes with construction land, indicators were assigned using the opposite-assignment method.

As previously mentioned, AHP is one of the most common and comprehensive methodologies, theorized by Saaty in 1980 [37]. Various papers about LSA employ the AHP to initiate the weights for their analyses [20,35,38]. It is suitable for solving problems where the factors can be organized in a hierarchical way [39]. The AHP calculation typically involves three main steps: first, constructing a hierarchical structure model; second, developing a judgment matrix; and finally, conducting a hierarchical ranking and consistency test [40]. The consistency test is a validation method used to determine whether the hierarchical ranking is feasible. At the same time, evidence of the validation can be found in the sensitivity analysis (Section 4.3), whose results clearly state that the factors have been addressed soundly.

In the AHP, experts were asked to define the importance of every sub-indicator on a scale from 1 (least important) to 9 (most important). The same was done for the three primary indicators (Topography and geology, Ecological protection, and Human disturbances). The study first set the weights for the resistance plane. Since the primary indicators differ in their level of importance for ecological land and construction land, different judgment matrices were used for calculating the weights of the primary indicators for ecological land and construction land, while the judgment matrix for the sub-indicators remained unchanged. The weights of each indicator, calculated using the AHP, are shown in Table 2, and the analysis results (Table 3) show that all CR values are less than 0.1, indicating they have passed the consistency test.

Table 3. Results of the consistency test.

Indicators for Weight Assignment	Consistency Ratio (CR)
Primary indicators of construction land	0.033
Primary indicators of ecological land	0.033
Sub-indicators of Topography and geology	0.033
Sub-indicators of Ecological protection	0.002
Sub-indicators of Human disturbances	0.004

The method for delineating zoning thresholds often adopts the natural break method [31]. This study initially categorizes the region into two major classes based on the positive and negative relationships of the minimum cumulative difference: suitable for ecological land (difference less than 0) and suitable for construction land (difference greater than 0). Further subdivision of areas suitable for ecological and construction land is conducted using the natural break method. The zoning thresholds are outlined in Table 4, resulting in four categories: Ecological Control Zone (ECZ), Ecological Buffer Zone (EBZ), Suitable Construction Zone (SCZ), and Prior Construction Zone (PCZ).

Table 4. Threshold ranges for land suitability zoning.

Landscape Type	Land Suitability Zoning	Threshold Range
Ecological land	ECZ: Ecological Control Zone	−67,927.9 to −23,161.5
	EBZ: Ecological Buffer Zone	−23,161.4 to 0
Construction land	SCZ: Suitable Construction Zone	0 to 6356.7
	PCZ: Prior Construction Zone	6356.8 to 23,395.4

4. Results

4.1. Spatial Characteristics of Suitable Areas for Urban Expansion and Ecological Protection

It can be observed in Figure 6 and Table 3 that the GBA primarily consists of EBZ, which accounts for 70% of the area, covering 39,289 km^2. This is followed by SCZ, which accounts for 22.8% or 12,706 km^2. The areas designated as ECZ and PCZ are comparatively smaller, measuring 2452 km^2 and 1282 km^2, respectively.

The EBZ is mainly located in the northwest and northeast parts of the GBA, with Zhaoqing, Huizhou, and Jiangmen each exceeding 7000 km^2 in area. Most EBZs are adjacent to SCZs, which act as buffer zones between suitable and unsuitable areas for urban development, such as water, cropland, and other forest. The cost of constructing infrastructure in such areas is relatively high. It is crucial to prioritize ecological preservation while ensuring rational utilization to prevent overdevelopment.

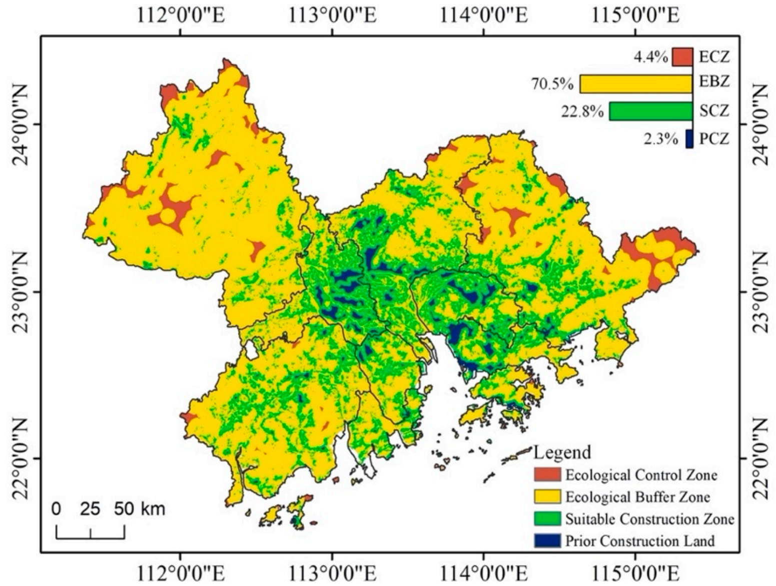

Figure 6. Land suitability zoning map of GBA.

The SCZ is concentrated in peri-urban areas around original settlements and along main roads on either side of the Pearl River. These areas possess a favorable resource environment foundation and offer good conditions for economic and population agglomeration. They are the regions prioritized for urban expansion now and for a certain period in the future.

The PCZ is primarily concentrated in the core areas of various cities. These regions are typically characterized by dense populations and intense human activity, with a long history of urban development. The land use in these areas is deeply influenced by historical factors and does not exhibit a high degree of intensive utilization. Balancing high-quality development is challenging in these zones. Therefore, the current model of urban development urgently requires optimization and adjustment.

ECZ is sporadically distributed in the mountainous areas of northwest GBA and southern islands. These areas may either serve as important nature reserves with significant ecological importance, subject to strict policy controls, or are islands with scarce resources and high development challenges, unsuitable for large-scale development. Such regions should prioritize ecological protection unequivocally, enhance ecological construction, and harness ecological functions to promote the optimization of the regional ecological environment.

The proportion of suitability zoning in each city, as presented in Figure 7, indicates that over half of the GBA is predominantly categorized as EBZ. Zhaoqing, owing to its abundant forest and farmland, has the highest area of ECZ and EBZ. Guangzhou has the highest SCZ, while PCZ is highest in Shenzhen. The overlay of suitability zones for urban development with construction land, as shown in Figure 8, indicates significant urban expansion in the GBA, which nearly encompasses the entire area of the SCZ and the PZC. The areas suitable for urban expansion are mainly located in the northern part of Guangzhou, the southern part of Foshan, the bordering region between Huizhou and Shenzhen, as well as the surrounding areas of the built-up zone in Jiangmen.

Analyzing the proportion of each land use type in the suitability zones (Figure 9), we observe that water and other forests account for over 95% of the ECZ and EBZ. Only a portion of cropland, grassland, and other forests is suitable for urban expansion. The inclusion of some transportation land in the EBZ is due to the distribution of certain roads within the EBZ. In summary, the suitability results show significant differences in ecological environments and economic development among the cities within the GBA. The overall suitability zoning exhibits a distinct central-peripheral distribution pattern, decreasing from the core cities of Shenzhen, Dongguan, Guangzhou, and Foshan towards the northern and western inland areas of Guangdong.

	ECZ(%)	EBZ(%)	SCZ(%)	PCZ(%)
Guangzhou	1.8	61.8	33.1	3.3
Shenzhen	0.9	43.9	41.6	13.6
Zhuhai	0.1	61.2	38.5	0.2
Foshan	0.4	45.7	45.0	8.9
Jiangmen	1.2	75.8	22.5	0.5
Zhaoqing	6.8	87.6	5.6	0.0
Huizhou	10.2	72.4	16.5	0.9
Dongguan	0.1	35.9	55.8	8.2
Zhongshan	0.5	57.1	40.0	2.4
Hongkong	0.1	76.8	20.4	2.7
Macao	0.1	33.8	66.1	0.0
Total area (km^2)	2457	39057	12605	1271

Total area (km^2)

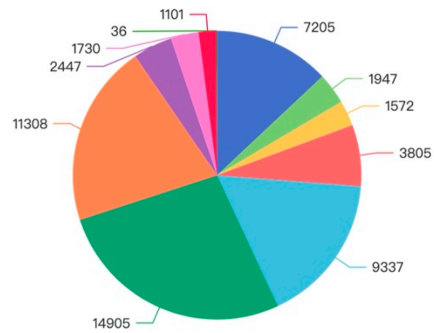

Figure 7. Proportion of land suitability zoning in the GBA.

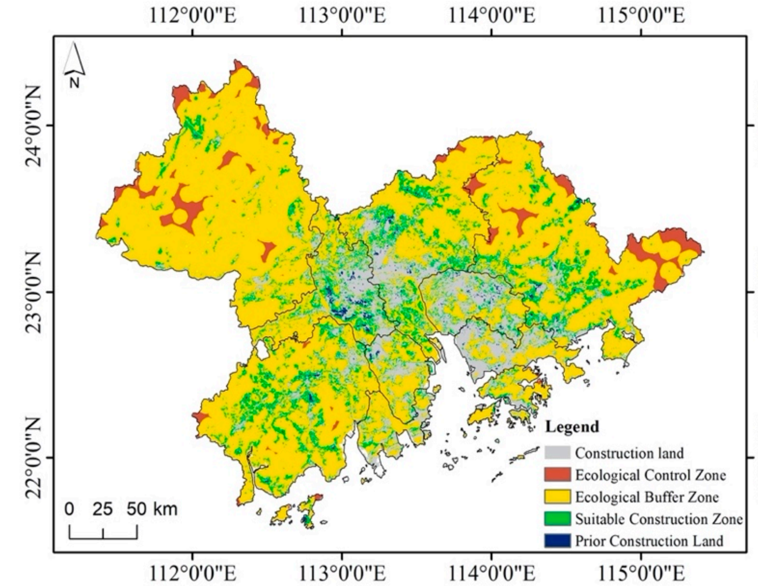

Figure 8. Comparison between construction land in 2020 and different suitability zones in the GBA.

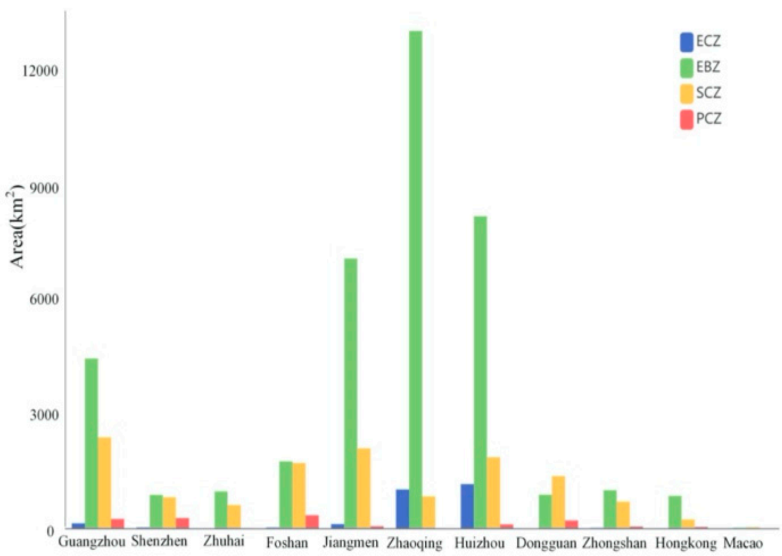

Figure 9. Histogram of areas of different suitability zones within GBA.

4.2. LSA Heterogeneity Analysis

To better analyze development status, the total proportion of construction land in SCZ and PCZ, or "development intensity", was used to characterize overall development, and available construction land for future expansion in SCZ and PCZ was characterized as "stock space".

Nearly half of the GBA has a development intensity exceeding 70%, and the total stock space accounts for only 9.2% of the entire region (Figures 10 and 11). Zhaoqing, Jiangmen, and Huizhou have large expandable potential in the future, but careful analyses are needed to adjust the regional development direction as the area is mainly mountainous. These areas are the three largest regions in the GBA with a notably uneven east-west development. Jiangmen and Huizhou have relatively low development intensity (<50%) and relatively high stock space (>1200 km^2).

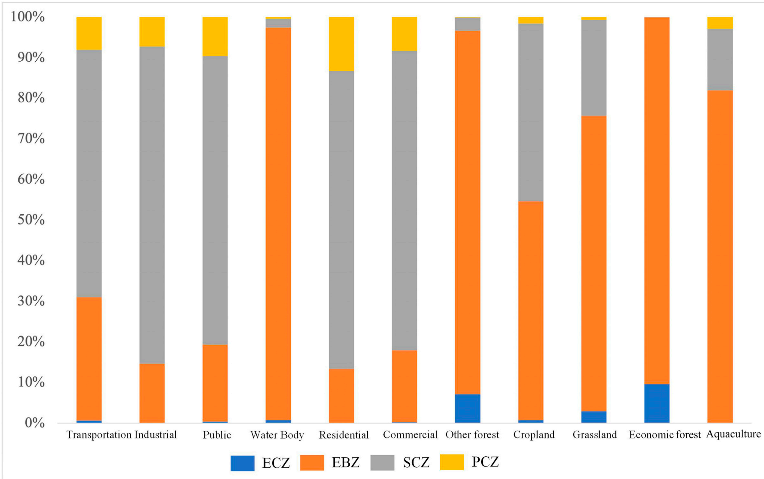

Figure 10. The percentage of different land use under the different suitability zones in the GBA.

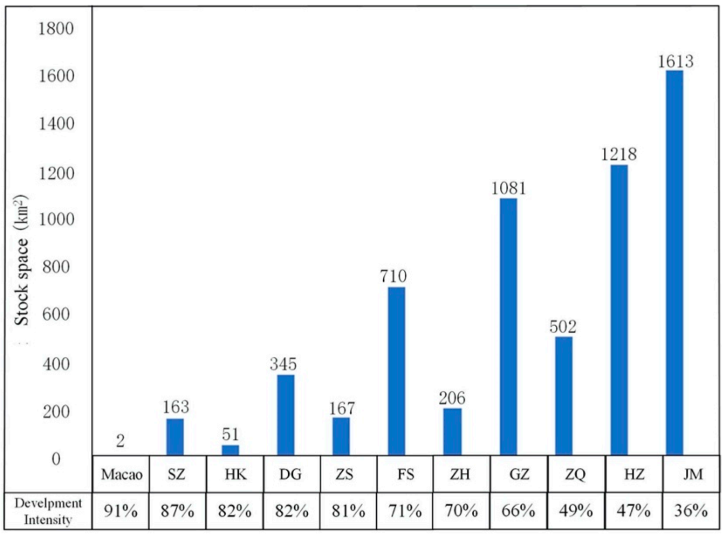

Figure 11. Development intensity and total stock space in the GBA.

Macao, Shenzhen, Hong Kong, Zhongshan, and Dongguan need to seek regional development strategies that are intensive, compact, and efficient. The development intensity in these areas exceeds 80%, while their stock space is less than 400 km^2. These areas' priority should be given to exploring already developed areas and promoting urban renewal to minimize the encroachment on the ecological space in these regions. Larger stock areas are often constrained by regional geography and ecological conditions, posing greater difficulties in development. Meanwhile, regions with higher levels of economic development exhibit significantly greater development intensity, suggesting limited available land for external expansion.

4.3. Sensitivity Analysis

The results of an MCDM analysis can be compromised by a large number of experts with divergent opinions on criteria selection and weight determination. This may stem from decision-makers' incomplete awareness of their criteria preferences or uncertainty about the criteria's nature and scale [41]. The validation of the results is, therefore, an important part of the analysis [42]. Sensitivity analysis is essential for the validation and calibration of numerical models, as it helps evaluate the robustness of the outcomes. In this study, sensitivity analysis was performed using a one-at-a-time approach, where the weights of each criterion were gradually increased while proportionally decreasing the weights of the others. This method allows for a clear assessment of the individual importance of each factor [43].

In this case, the weights of each criterion were increased by 2% at a time, up to a maximum of 20%. A total of 120 scenarios were analyzed. For each iteration, the changes in areas within each suitability zone are shown in Table 5, reflecting the modifications made to the 'Slope' indicator. The row marked as "2%" signifies an incremental augmentation of 2% in the weight attributed to the indicator 'Slope'. Notably, SCZ experiences an increase in count, while ECZ and PCZ show a decrease. It is essential to emphasize that the cumulative sum remains unchanged.

Table 5. Changes in the area belonging to an indicator (columns) in the "Slope" criterion after every 2% increase (rows). The suitability analysis row represents the values after the sensitivity analysis.

Weight Increment (%)	ECZ (km^2)	EBZ (km^2)	SCZ (km^2)	PCZ (km^2)
2%	2199	38,762	12,947	1481
4%	2184	38,769	12,970	1467
6%	2161	38,780	12,997	1453
8%	2208	38,721	12,989	1472
10%	2183	38,733	13,017	1457
12%	2158	38,746	13,044	1441
14%	2132	38,759	13,152	1346
16%	2105	38,773	13,102	1410
18%	2077	38,787	13,131	1394
20%	2092	38,761	13,173	1365

Due to the numerous indicators involved in the sensitivity analysis, only the more representative indicators are presented. The result shows that the 'Geology condition' is the least sensitive criterion, which produces minimal changes in SCZ. 'Proximity to water' is the most sensitive one, meaning that increases in its weight cause the most significant changes (Figure 12). Other sensitive criteria are 'Proximity to urban areas', 'land use', and 'Proximity to roads', all of which are high in the weight importance rank (Figures 13 and 14). The least sensitive criteria, which produce minimal changes, are 'NDVI' and 'Ecological reserve'. In conclusion, the prioritization of most criteria remained consistent, suggesting that weights were reliable even before the results were obtained. Therefore, the proposed model is deemed appropriate for the study.

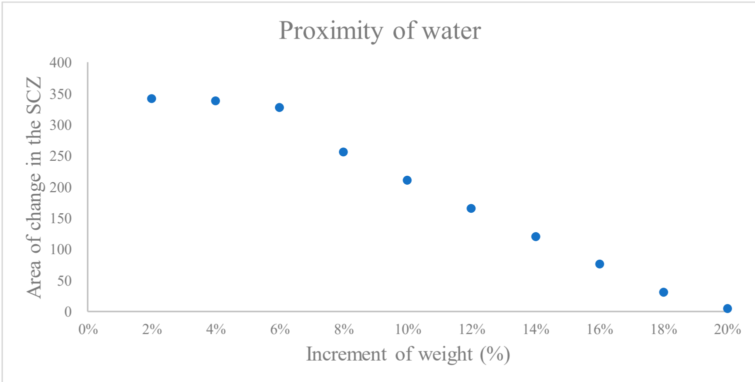

Figure 12. Area changes of the 'Proximity to water' indicator with each 2% increase.

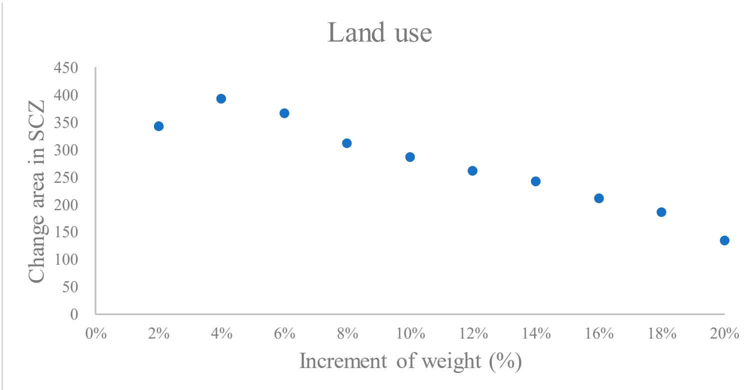

Figure 13. Area changes of the 'Land use' indicator with each 2% increase.

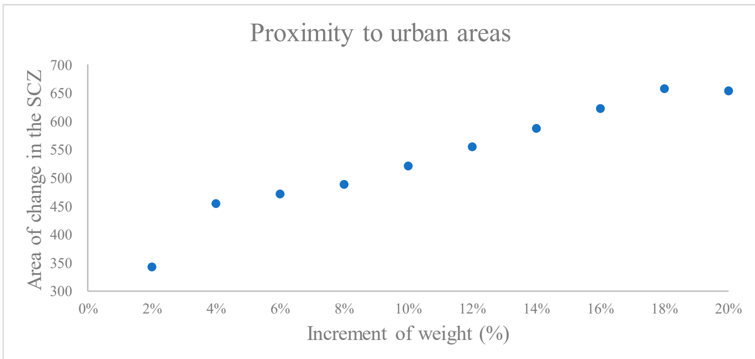

Figure 14. Area changes of the 'Proximity to urban areas' indicator with each 2% increase.

5. Discussion

Coastal urban agglomerations face the dual challenges of land scarcity and ecological fragility [44]. Without proper regulation and control, coastal areas may sprawl disorderly, leading to ecological degradation and waste of land resources [7]. Urban renewal strategies, combined with land-use suitability assessments (LSAs), have been proposed as essential tools for land-use planning in coastal regions [45]. Previous studies have primarily focused on land-use suitability assessments (LSAs) applications for urban expansion and ecological security within localized or city-specific contexts [13,23,39], overlooking the spatial analysis required for urban renewal in these complex coastal regions. Thus, this study provides a comprehensive LSA framework that integrates the AHP and the MCRM to address the complex spatial planning needs of coastal urban agglomerations. Using the GBA as a case study, we demonstrate how this combined approach allows for a more holistic assessment of land-use suitability, balancing urban expansion and renewal with ecological preservation.

This study emphasizes the spatial challenges posed by diverse coastal land-use types based on 12 criteria, focusing on their impact on both coastal ecological protection and economic development [16,17]. Although Ref. [34] constructed an LSA framework for the GBA, it did not fully account for the economic contributions and ecological impacts of the unique landscapes and seaports within coastal zones. Our framework specifically addresses these factors, offering a more comprehensive assessment tool that incorporates both ecological and economic considerations in coastal urban agglomerations. In addition, the integration of the AHP and the MCRM demonstrates the value of combining qualitative decision-making tools with spatially explicit models to address the challenges posed by coastal environments [33,46]. This integrated approach is particularly important in coastal urban agglomerations like the GBA, where the competition between urban development and ecological protection is heightened due to the diverse land-use types and sensitive ecosystems [47].

Furthermore, by incorporating the spatial analysis of stock space and development intensity, our study shifts attention to the underexplored area of urban renewal, which is increasingly critical as land resources become scarcer in rapidly urbanizing regions like the GBA. The results reveal significant spatial heterogeneity in the availability of stock space across the GBA, with cities such as Zhaoqing, Jiangmen, and Huizhou showing greater potential for future expansion. In contrast, cities like Shenzhen, Hong Kong, and Macao exhibit high development intensity and limited stock space, highlighting the pressing need for urban renewal strategies. Our findings suggest that LSA can be a valuable tool for guiding renewal strategies. This aligns with recent calls in the literature for urban renewal in urban planning, which emphasize the importance of optimizing existing urban spaces to reduce environmental impacts and promote sustainable development [29,45].

Despite the contributions of this study, several limitations should be acknowledged. First, while the integration of AHP and MCRM provides a comprehensive framework for LSA, the reliance on AHP for multi-criteria decision-making may oversimplify the complexity of certain land-use interactions, as noted by previous studies [19,20]. Another limitation lies in the availability of data, particularly in accurately assessing the long-term ecological impacts of land-use changes in coastal regions. Future studies could benefit from dynamic datasets, better account for human-driven factors, and regularly update zoning classifications to align with evolving policy and environmental conditions. These limitations provide directions for future research, which could further refine the LSA framework to better account for the complex ecological, social, and economic interactions that influence land-use decisions in coastal urban areas.

6. Conclusions

In this study, we developed an LSA modeling framework specifically designed for coastal urban agglomerations, with the GBA as the study area. This framework encompasses a suitability index system consisting of 12 factors. AHP and MCRM were designed for LSA modeling, while development intensity and stock space were calculated for LSA heterogeneity analysis. This involves evaluating the development potential of regions and comparing suitability status outcomes for construction options among different cities in coastal urban agglomerations.

Results show that the GBA displays a distinct central-peripheral pattern. The GBA primarily consists of Ecological Buffer Zones (EBZs), accounting for 70.5%, mainly located in the northwest and northeast regions such as Zhaoqing, Huizhou, and Jiangmen. The focus on ecological preservation is paramount in these zones due to the high cost and challenges of developing infrastructure there. Surrounding these areas are Suitable Construction Zones (SCZs), covering 22.8% of the GBA, where urban expansion is prioritized due to favorable economic conditions and resource availability.

Prior Construction Zones (PCZs), concentrated in the core areas of the cities, face challenges due to dense populations and historical urbanization, making high-quality development difficult. There is a strong need for urban renewal in these zones. Ecological

Control Zones (ECZs), found in mountainous regions and southern islands, prioritize ecological protection due to their critical environmental importance and developmental limitations. The overlay analysis indicates that areas for urban expansion primarily exist in the northern part of Guangzhou, southern Foshan, and areas between Huizhou and Shenzhen. The land suitability analysis reveals significant disparities between cities, with Shenzhen and Guangzhou's core regions being more developed than other inland areas of the GBA.

Development intensity across the GBA shows that half of the region's urban areas are over 70% developed, yet only 9.2% of the total land has potential for future expansion. Our modeling comparison of the GBA shows that Guangzhou is a central city for future development from north to east, which will strengthen regional services and radiation functions. Cities with higher economic development levels, such as Shenzhen, Dongguan, Macao, and Hong Kong, have limited space for expansion, highlighting the need for compact and efficient urban renewal strategies to minimize ecological disruption. Zhuhai and Zhongshan should focus on land resource utilization as overall stock space is limited (<300 km^2). Foshan, adjacent to Guangzhou, has more than 700 km^2 of stock space, so it has the potential to expand. Cities like Zhaoqing, Jiangmen, and Huizhou have larger areas for potential expansion but face ecological and geographical constraints due to their mountainous terrain.

In conclusion, this study offers a significant contribution to the literature by advancing the methodology of LSA for coastal urban agglomerations and expanding its application to urban renewal. The combined use of AHP and MCRM offers a comprehensive framework for addressing the unique land-use challenges in these regions. Our modeling approach, incorporating stakeholders' input and objective evaluation of complex geographic land-use information in coastal urban agglomerations of varying development stages, can assist planners to improve ecological security while promoting appropriate high-quality developments.

Author Contributions: Conceptualization, T.P. and F.S.; methodology, T.P.; writing—original draft preparation, T.P.; writing—reviewing and editing, F.S., F.Y. and L.X. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by the Open Funding of Zhejiang Collaborative Innovation Center for Land and Marine Spatial Utilization and Governance Research (NO. LHGTXT-2024-003), The Open Funding of Donghai Academy & Zhejiang Ocean Development Think Tank Alliance (NO. DHNB202401YB09).

Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors on request.

Conflicts of Interest: No conflict of interest exists in the submission of this manuscript, and the manuscript is approved by all authors for publication. We confirm that this work is original and has not been published elsewhere, nor is it currently under consideration for publication elsewhere, in whole or in part. All the authors listed have approved the manuscript that is enclosed.

References

1. Han, B.; Jin, X.; Zhao, Q.; Chen, H. Spatiotemporal Patterns and Mechanisms of Land-Use Conflicts Affecting High-Quality Development in China. *Appl. Geogr.* **2023**, *155*, 102972. [CrossRef]
2. Sengupta, D.; Chen, R.; Meadows, M.E. Building beyond Land: An Overview of Coastal Land Reclamation in 16 Global Megacities. *Appl. Geogr.* **2018**, *90*, 229–238. [CrossRef]
3. Ran, Z.; Gao, S.; Zhang, B.; Guo, C.; Ouyang, X.; Gao, J. Non-Linear Effects of Multi-Dimensional Urbanization on Ecosystem Services in Mega-Urban Agglomerations and Its Threshold Identification. *Ecol. Indic.* **2023**, *154*, 110846. [CrossRef]
4. Asabere, S.B.; Acheampong, R.A.; Ashiagbor, G.; Beckers, S.C.; Keck, M.; Erasmi, S.; Schanze, J.; Sauer, D. Urbanization, Land Use Transformation and Spatio-Environmental Impacts: Analyses of Trends and Implications in Major Metropolitan Regions of Ghana. *Land Use Policy* **2020**, *96*, 104707. [CrossRef]
5. Dadashpoor, H.; Azizi, P.; Moghadasi, M. Land Use Change, Urbanization, and Change in Landscape Pattern in a Metropolitan Area. *Sci. Total Environ.* **2019**, *655*, 707–719. [CrossRef] [PubMed]
6. Hu, Q.; Shen, W.; Zhang, Z. How Does Urbanisation Affect the Evolution of Territorial Space Composite Function? *Appl. Geogr.* **2023**, *155*, 102976. [CrossRef]

7. Akbari, M.; Neamatollahi, E.; Neamatollahi, P. Evaluating Land Suitability for Spatial Planning in Arid Regions of Eastern Iran Using Fuzzy Logic and Multi-Criteria Analysis. *Ecol. Indic.* **2019**, *98*, 587–598. [CrossRef]
8. Franco, L.; Magalhães, M.R. Assessing the Ecological Suitability of Land-Use Change. Lessons Learned from a Rural Marginal Area in Southeast Portugal. *Land Use Policy* **2022**, *122*, 106381. [CrossRef]
9. Luan, C.; Liu, R.; Peng, S. Land-Use Suitability Assessment for Urban Development Using a GIS-Based Soft Computing Approach: A Case Study of Ili Valley, China. *Ecol. Indic.* **2021**, *123*, 107333. [CrossRef]
10. Michael Griffel, L.; Toba, A.-L.; Paudel, R.; Lin, Y.; Hartley, D.S.; Langholtz, M. A Multi-Criteria Land Suitability Assessment of Field Allocation Decisions for Switchgrass. *Ecol. Indic.* **2022**, *136*, 108617. [CrossRef]
11. Wei, B.; Li, Y.; Suo, A.; Zhang, Z.; Xu, Y.; Chen, Y. Spatial Suitability Evaluation of Coastal Zone, and Zoning Optimisation in Ningbo, China. *Ocean. Coast. Manag.* **2021**, *204*, 105507. [CrossRef]
12. Ramadan, M.S.; Effat, H.A. Geospatial Modeling for a Sustainable Urban Development Zoning Map Using AHP in Ismailia Governorate, Egypt. *Egypt. J. Remote Sens. Space Sci.* **2021**, *24*, 191–202. [CrossRef]
13. Bamrungkhul, S.; Tanaka, T. The Assessment of Land Suitability for Urban Development in the Anticipated Rapid Urbanization Area from the Belt and Road Initiative: A Case Study of Nong Khai City, Thailand. *Sustain. Cities Soc.* **2022**, *83*, 103988. [CrossRef]
14. Huang, H.; Li, Q.; Zhang, Y. Urban Residential Land Suitability Analysis Combining Remote Sensing and Social Sensing Data: A Case Study in Beijing, China. *Sustainability* **2019**, *11*, 2255. [CrossRef]
15. Huang, R.; Nie, Y.; Duo, L.; Zhang, X.; Wu, Z.; Xiong, J. Construction Land Suitability Assessment in Rapid Urbanizing Cities for Promoting the Implementation of United Nations Sustainable Development Goals: A Case Study of Nanchang, China. *Environ. Sci. Pollut. Res.* **2021**, *28*, 25650–25663. [CrossRef] [PubMed]
16. Gao, L.; Ma, C.; Wang, Q.; Zhou, A. Sustainable Use Zoning of Land Resources Considering Ecological and Geological Problems in Pearl River Delta Economic Zone, China. *Sci. Rep.* **2019**, *9*, 16052. [CrossRef]
17. Zong, S.; Hu, Y.; Bai, Y.; Guo, Z.; Wang, J. Analysis of the Distribution Characteristics and Driving Factors of Land Use Conflict Potentials in the Bohai Rim Coastal Zone. *Ocean. Coast. Manag.* **2022**, *226*, 106260. [CrossRef]
18. Xu, K.; Kong, C.; Li, J.; Zhang, L.; Wu, C. Suitability Evaluation of Urban Construction Land Based on Geo-Environmental Factors of Hangzhou, China. *Comput. Geosci.* **2011**, *37*, 992–1002. [CrossRef]
19. Mokarram, M.; Mirsoleimani, A. Using Fuzzy-AHP and Order Weight Average (OWA) Methods for Land Suitability Determination for Citrus Cultivation in ArcGIS (Case Study: Fars Province, Iran). *Phys. A Stat. Mech. Its Appl.* **2018**, *508*, 506–518. [CrossRef]
20. Pilevar, A.R.; Matinfar, H.R.; Sohrabi, A.; Sarmadian, F. Integrated Fuzzy, AHP and GIS Techniques for Land Suitability Assessment in Semi-Arid Regions for Wheat and Maize Farming. *Ecol. Indic.* **2020**, *110*, 105887. [CrossRef]
21. Li, Y.-Y.; Zhang, Y.-Z.; Jiang, Z.-Y.; Guo, C.-X.; Zhao, M.-Y.; Yang, Z.-G.; Guo, M.-Y.; Wu, B.-Y.; Chen, Q.-L. Integrating Morphological Spatial Pattern Analysis and the Minimal Cumulative Resistance Model to Optimize Urban Ecological Networks: A Case Study in Shenzhen City, China. *Ecol. Process.* **2021**, *10*, 63. [CrossRef]
22. Wang, H.; Peng, P.; Kong, X.; Zhang, T.; Yi, G. Evaluating the Suitability of Urban Expansion Based on the Logic Minimum Cumulative Resistance Model: A Case Study from Leshan, China. *IJGI* **2019**, *8*, 291. [CrossRef]
23. Zhang, W.; Li, B. Research on an Analytical Framework for Urban Spatial Structural and Functional Optimisation: A Case Study of Beijing City, China. *Land* **2021**, *10*, 86. [CrossRef]
24. Adriaensen, F.; Chardon, J.P.; De Blust, G.; Swinnen, E.; Villalba, S.; Gulinck, H.; Matthysen, E. The Application of 'Least-Cost' Modelling as a Functional Landscape Model. *Landsc. Urban Plan.* **2003**, *64*, 233–247. [CrossRef]
25. Knaapen, J.P.; Scheffer, M.; Harms, B. Estimating Habitat Isolation in Landscape Planning. *Landsc. Urban Plan.* **1992**, *23*, 1–16. [CrossRef]
26. Huang, Z.; Chen, Y.; Zheng, Z.; Wu, Z. Spatiotemporal Coupling Analysis between Human Footprint and Ecosystem Service Value in the Highly Urbanized Pearl River Delta Urban Agglomeration, China. *Ecol. Indic.* **2023**, *148*, 110033. [CrossRef]
27. Dong, Y.; Xu, L. Aggregate Risk of Reactive Nitrogen under Anthropogenic Disturbance in the Pearl River Delta Urban Agglomeration. *J. Clean. Prod.* **2019**, *211*, 490–502. [CrossRef]
28. Meng, G.; Guo, Z.; Li, J. The Dynamic Linkage among Urbanisation, Industrialisation and Carbon Emissions in China: Insights from Spatiotemporal Effect. *Sci. Total Environ.* **2021**, *760*, 144042. [CrossRef]
29. Chen, X.; Duan, J. What They Talk about When They Talk about Urban Regeneration: Understanding the Concept 'Urban Regeneration' in PRD, China. *Cities* **2022**, *130*, 103880. [CrossRef]
30. Liu, X.; Shu, J.; Zhang, L. Research on Applying Minimal Cumulative Resistance Model in Urban Land Ecological Suitability Assessment: As an Example of Xiamen City. *Shengtai Xuebao/Acta Ecol. Sin.* **2010**, *30*, 421–428. [CrossRef]
31. Xu, L.; Huang, Q.; Ding, D.; Mei, M.; Qin, H. Modelling Urban Expansion Guided by Land Ecological Suitability: A Case Study of Changzhou City, China. *Habitat Int.* **2018**, *75*, 12–24. [CrossRef]
32. Guo, P.; Zhang, F.; Wang, H.; Qin, F. Suitability Evaluation and Layout Optimization of the Spatial Distribution of Rural Residential Areas. *Sustainability* **2020**, *12*, 2409. [CrossRef]
33. Li, F.; Ye, Y.; Song, B.; Wang, R. Evaluation of Urban Suitable Ecological Land Based on the Minimum Cumulative Resistance Model: A Case Study from Changzhou, China. *Ecol. Model.* **2015**, *318*, 194–203. [CrossRef]
34. Pan, T.; Zhang, Y.; Yan, F.; Su, F. Collaborative Optimal Allocation of Urban Land Guide by Land Ecological Suitability: A Case Study of Guangdong–Hong Kong–Macao Greater Bay Area. *Land* **2023**, *12*, 754. [CrossRef]

35. Bagheri, M.; Zaiton Ibrahim, Z.; Mansor, S.; Manaf, L.A.; Akhir, M.F.; Talaat, W.I.A.W.; Beiranvand Pour, A. Land-Use Suitability Assessment Using Delphi and Analytical Hierarchy Process (D-AHP) Hybrid Model for Coastal City Management: Kuala Terengganu, Peninsular Malaysia. *IJGI* **2021**, *10*, 621. [CrossRef]
36. Ke, L.; Zhao, Y.; Wang, Q.; Yin, S.; Liu, W. Construction of Coastal Zone Ecological Network Based on the Perspective of Land-Sea Integration: A Case Study of Jinzhou City, China. *Ocean. Coast. Manag.* **2024**, *254*, 107204. [CrossRef]
37. Saaty, T.L. Making and Validating Complex Decisions with the AHP/ANP. *J. Syst. Sci. Syst. Eng.* **2005**, *14*, 1–36. [CrossRef]
38. Taherdoost, H.; Madanchian, M. Multi-Criteria Decision Making (MCDM) Methods and Concepts. *Encyclopedia* **2023**, *3*, 77–87. [CrossRef]
39. Zaniboni, A.; Tassinari, P.; Torreggiani, D. GIS-Based Land Suitability Analysis for the Optimal Location of Integrated Multi-Trophic Aquaponic Systems. *Sci. Total Environ.* **2024**, *913*, 169790. [CrossRef]
40. Foroozesh, F.; Monavari, S.M.; Salmanmahiny, A.; Robati, M.; Rahimi, R. Assessment of Sustainable Urban Development Based on a Hybrid Decision-Making Approach: Group Fuzzy BWM, AHP, and TOPSIS–GIS. *Sustain. Cities Soc.* **2022**, *76*, 103402. [CrossRef]
41. Chen, Y.; Yu, J.; Khan, S. Spatial Sensitivity Analysis of Multi-Criteria Weights in GIS-Based Land Suitability Evaluation. *Environ. Model. Softw.* **2010**, *25*, 1582–1591. [CrossRef]
42. Zhao, H.; Gao, J.; Cheng, X. Electric Vehicle Solar Charging Station Siting Study Based on GIS and Multi-Criteria Decision-Making: A Case Study of China. *Sustainability* **2023**, *15*, 10967. [CrossRef]
43. Malczewski, J. GIS-based Multicriteria Decision Analysis: A Survey of the Literature. *Int. J. Geogr. Inf. Sci.* **2006**, *20*, 703–726. [CrossRef]
44. Pan, T.; Su, F.; Yan, F.; Lyne, V.; Wang, Z.; Xu, L. Optimization of Multi-Objective Multi-Functional Landuse Zoning Using a Vector-Based Genetic Algorithm. *Cities* **2023**, *137*, 104256. [CrossRef]
45. Cao, K.; Deng, Y. The Impact and Interactive Effects of Multi-Level Spatial Policies on Urban Renewal: A Case Study of Shenzhen, China. *Habitat Int.* **2023**, *142*, 102952. [CrossRef]
46. Zhou, L.; Zhao, Y.; Zhu, C.; Shi, C. Route Selection for Scenic Byways in Karst Areas Based on the Minimum Cumulative Resistance Model: A Case Study of the Nanpan–Beipan River Basin, China. *Ecol. Indic.* **2024**, *163*, 112093. [CrossRef]
47. Li, Q.; Wu, J.; Su, Y.; Zhang, C.; Wu, X.; Wen, X.; Huang, G.; Deng, Y.; Lafortezza, R.; Chen, X. Estimating Ecological Sustainability in the Guangdong-Hong Kong-Macao Greater Bay Area, China: Retrospective Analysis and Prospective Trajectories. *J. Environ. Manag.* **2022**, *303*, 114167. [CrossRef]