

Article

Study on Urban Land Simulation under the Perspective of Local Climate Zoning—A Case Study of Guiyang City

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Abstract: The examination of land-use change simulations across a range of scenarios represents a pivotal research avenue for the advancement of sustainable development analysis. Nevertheless, the extant research merely categorises all building land in a land-use classification into a single category, which is unable to provide a detailed analysis of the dynamic internal spatial form of the city. This paper analyses 17 LCZ land-use types in Guiyang City in 2013 and 2022, and reclassifies them into 7 RLCZ land-use types based on the height of urban building sites. It also proposes three possible scenarios of BAU, WLC, and SPC in 2040 and simulates their land-use changes using the PLUS model. The results demonstrate that (1) the size of low-rise buildings in Guiyang has declined significantly over the past decade; (2) built-up land within cities is significantly affected by drivers such as night-time lighting, topography, elevation, and roads; (3) the SPC scenario emphasises a development pattern of land intensification and a focus on high density in urban built space. It also protects the stability of the ecosystem. The scenario can provide informative suggestions for spatial pattern changes in rapidly developing cities such as Guiyang.

Keywords: local climate zoning; urban space; PLUS model; Guiyang City; multi-scenario simulation



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1. Introduction

The study of land-use and land-cover change (LUCC) is an essential element of research into socio-economic and geographic environmental systems. As a significant conduit for the impact of human activities on the natural environment, LUCC represents a key area of focus for research into global environmental change and sustainable development [1–3]. As the most densely populated area for human activities, cities exhibit a distinctive pattern of land-use and land-cover change. Consequently, the ecological consequences of land use are more pronounced in these areas, particularly in those undergoing rapid urbanisation. Since the reform and opening up, China's urbanisation rate has increased from 17.92% to 66.16%. The acceleration of urbanisation has resulted in significant changes to land-use patterns in many cities. There has been a notable increase in construction land, accompanied by a rapid loss of natural resources, including water and arable land. This has led to the emergence of an urban heat island effect and environmental pollution. The rational allocation of land resources within urban areas has thus become a significant social issue. Early land-use research focused on feeding back land-use change patterns from single dimensions such as food security and climate environmental response based on historical trends [4]. The analysis focuses on two major land-use types: farmland and forests [5–7]. In this stage, cellular automaton (CA) [8] models and Markov [9,10] models are mainly used as the main research methods. As scholars continue to study the complexity of land-use change in depth, models conversion of land use and its effects at small region extent (CLUE-S) model [11,12], future land-use simulation (FLUS) model [13–15], and patch-generating land-use simulation (PLUS) model [16–18], and many other models

have emerged to analyse land-use change from the socio-economic and ecological perspectives, revealing the spatial and temporal characteristics of land use. Concurrently, a multidimensional perspective is considered in the modelling of future scenarios, gradually increasing the involvement of land-use change stakeholders in the scenarios [19,20].

The extant research on land-use change simulation (LUCC) offers certain insights that can inform planning and decision-making processes. However, the LUCC framework primarily relies on a traditional classification system comprising six categories: cultivated land, forest land, grassland, water area, construction land, and unused land. This classification system is based on the current land-use classification standard [21]. The system is only capable of a rudimentary analysis of the conversion relationship between building land and other land, and is, thus, unable to provide an accurate description of the specific architectural spatial form within the city. Accordingly, this study employs the concept of local climate zones (LCZ), as proposed by Stewart and Oke [22]. The LCZ is defined as ‘an area of uniform surface cover, structure, materials and human activity that spans horizontally from hundreds of metres to several kilometres’. Previous studies have focused on climate assessment at large scale zones and neglected urban morphological changes in different cities at small scales, resulting in homogenous differences [22,23]. Local climate zones are divided into 17 basic zones based on urban form criteria: land cover, materials, urban form, and human activities. These criteria are further subdivided into 10 established categories and 7 land-use cover categories [24,25]. The guide has now been applied to many cities around the world [26,27], and this city-by-city mapping approach fills in for small-scale environmental studies. LCZs have been used in interdisciplinary research with the objective of overcoming the rigid boundaries between urban and rural areas, which have traditionally been the focus of separate and distinct research endeavours. To illustrate, with respect to urban form and thermal conditions, LCZ maps are an effective tool for examining alterations in urban landscapes [28] and the associated temperature characteristics [29], with the objective of implementing suitable urban renewal and planning strategies. In China–Taiwan [30], and Islamabad, Pakistan [31], LCZ maps are employed to map the rapid evolution of temperature changes in urban environments. At the same time, LCZ maps can help urban planners to formulate new development policies by looking at the climate of the city, taking into account aspects such as the urban fabric [32]. Furthermore, LCZs can also be used to conduct research on climate-responsive design [33] and the reduction in climate-related health problems [34]. At present, there is a paucity of research on the multi-scenario simulation of LCZ maps. Only Chen constructs LCZ classification maps of Guangdong–Hong Kong–Macao Greater Bay Area through FLUS modelling and validates the definition of complex transitions between urban low-rise, mid-rise, and high-rise building land [35]. Zhou Liang, Ma Lei, and others established a coupled scenario simulation under SSP-RCPs to create a future local climate zoning map of Nanjing city [36].

Guiyang, the capital city of Guizhou Province in southwestern China, exemplifies the “strong provincial capital” archetype and has attained notable outcomes in high-quality development. The process of urbanisation is occurring at a rapid pace. Secondly, Guiyang is a city that exemplifies the characteristics of a karst mountainous city, exhibiting a distinctive land classification and landscape features [37]. Consequently, optimising the land layout is of paramount importance. The objective of this study is to present illustrative examples of the methodology employed in simulating land resources within urban contexts. This is with a view to providing valuable insights into future urban land use, particularly in rapidly developing cities, and to offering a benchmark for assessing changes in urban spatial form. Further details regarding the research field and methodology will be provided subsequently, followed by the presentation of the findings and an analysis of their implications.

2. Study Area and Data

Guiyang, situated in Guizhou Province in the southwestern region of China (26°11′N–26°55′ N, 106°07′ E–107°17′ E), is one of the cities that has experienced the most rapid urbanisation in recent years. The total area is 8043.45 km², and the permanent population

is approximately 5987,000. Since the 18th National People's Congress, the city of Guiyang has adhered to the concept of transportation leading development. It has one of the largest concentrations of mega data centres in the world, with big data as the main value add, accounting for 21% of the region's GDP. Big data have provided strong support for Guiyang City's economic growth rate to remain the first in the country's capital cities for six consecutive years. The city has experienced rapid economic growth and urban expansion, accompanied by notable changes in its internal spatial form. This study encompasses the urban area of Guiyang City, comprising six districts (Yunyan, Nanming, Huaxi, Wudang, Baiyun, and Guanshanhu) and three counties (Xiuwen, Xifeng, and Kaiyang) as well as Qingzhen City. Additionally, it includes four national-level development zones. The aforementioned areas encompass a multitude of urban forms, including commercial, industrial, residential, agricultural, and forested areas. As the central city of southwestern China, Guiyang exemplifies the developmental trajectory of numerous proximate urban centres (Figure 1).

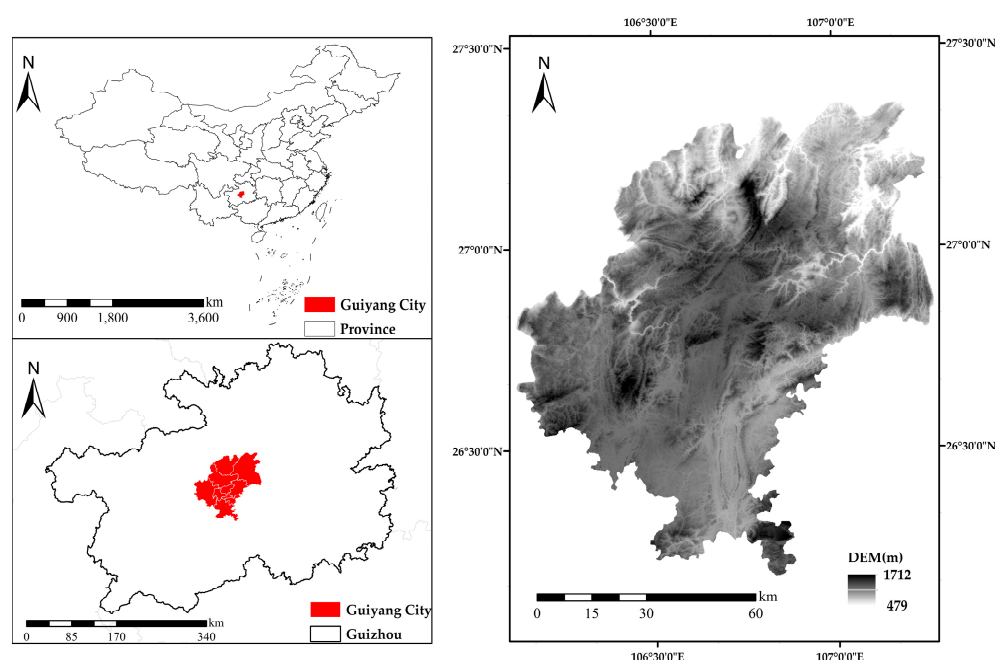


Figure 1. Location and scope of the study area.

The Landsat data required for the local climate zone (LCZ) maps are derived from Landsat and Moderate Resolution Imaging Spectroradiometer (MODIS) satellite images. Due to the special geographical location of Guiyang City, it is subject to cloud and rain disturbances all the year round, and in order to ensure the accuracy and completeness of the images, the satellite maps are screened for the time period when the cloudiness is less than 10% and there is no rain, so the 2013 and 2022 Landsat 8 images were used in the study to ensure the accuracy of the analysis results. Finally, LCZ mapping was performed through the World Urban Database and Access Portal Worker (WUDAPT) proposed by Bechtel.

The study selected a total of 11 indicators, chosen from 3 distinct categories: socio-economic factors, accessibility factors, and natural geography. One factor related to socio-economics is population, which directly influences the intensity of land use and is a determinant of a place's development potential. The accessibility of a city can be determined by a number of factors, including the distance from main roads, secondary roads, expressway, and railways, which serve as a measure of the city's accessibility. Additionally, the distance from downtown is a useful indicator of a place's locational advantage, while the distance from river indicates the natural advantages of the area. These indicators play a significant role in determining the suitability of a city for development. The remaining factors, related to aspect of slope, elevation, and slope, are instrumental in determining the

difficulty of urban land development. Furthermore, the intensity of night light affects the possibility of gradually expanding the area of land suitable for building, which may then undergo semi-urbanisation and, subsequently, urbanisation. The data sources utilised to calculate each impact factor are presented in Table 1.

Table 1. Remote sensing data set of driving factors.

Category	Name	Factor	Time/Year	Data Sources
Socio-economic	POP	Population	2020	LandScan 1 km
Accessibility	ZGD	Distance from main road	2022	OSM
	Cigandao	Distance from secondary trunk road	2022	
	SZX	Distance from downtown	2022	
	Kuaisulu	Distance from expressway	2022	
	Railway	Distance from railway	2022	
	River	Distance from river	2022	
Natural geographic	Aspect	Aspect of slope	2022	ALOS12.5M DEM NASA
	DEM	Elevation	2022	ALOS12.5M DEM NASA
	Slope	Slope	2022	ALOS12.5M DEM NASA
	YJDG	Night light	2022	DMSF-OLS

3. Methods

3.1. LCZ Map

In the field of LCZ mapping, scholars from a range of international research institutions have employed a variety of machine learning techniques, including decision trees [38], random forests [39,40], and support vector machines [41,42], to facilitate the classification of LCZ types. This study employs the World Urban Database and Portal Tool (WUDAPT) model due to its capacity to retrieve the pertinent urban spatial forms and functions in cities across the globe, facilitating dissemination among diverse communities and platforms [43]. The following section will provide a comprehensive overview of the WUDAPT tool and the specific process employed in the production of the Guiyang LCZ map.

WUDAPT is a local climate zoning portal developed by Bechtel and other scholars [44]. It employs fully open satellite images and data processing software to obtain urban data. The production of the LCZ classification map is divided into four steps within this portal [45]. The initial step is to download the satellite map from the USGS and then to pre-process it. Secondly, each type of sample should be selected in Google Earth and sketched 20–30 times in order to facilitate digital matching. Thirdly, the pre-processed satellite map and the trained land-use type samples were loaded into SAGAGIS, whereupon the local climate regions were classified using the random forest classification method, thereby generating the initial LCZ classification map. Fourthly, the results were imported into Google Earth for verification, and the inconsistent areas were resampled. This process was repeated until a compliant LCZ classification map was constructed.

The LCZ map-making sample data set, generated by Google Earth, will be divided into a training data set and a test data set in a ratio of 7:3. Subsequently, the tool will facilitate the conversion and upload of the submitted parameter information and sample data set from the Google Earth engine platform to the WUDAPT database platform. Subsequently, a random forest classifier is employed to generate an LCZ map with a resolution of 100 m via the WUDAPT platform. The resulting accuracy is evaluated in accordance with the training and test data sets. Ultimately, the LCZ-classified land-use data for Guiyang in both 2013 and 2022 were obtained through the utilisation of ArcGIS tools, specifically the cutting, reclassification, and resampling processes. The spatial pattern of the LCZ changes with urbanisation as the urban climate is influenced not only by global greenhouse gas emissions but also by regional urbanisation processes [46]. Land-use classification is, therefore, inextricably linked to LCZ maps. The LCZ classification system is employed to differentiate between urban surface morphology, categorising these areas as either built-up

or natural cover types. This study reclassifies the 17 types of urban surface morphology of LCZ into 7 types RLCZ categories (Table 2), comprising RLCZ 1 (high-rise building), RLCZ 2 (middle-rise building), RLCZ 3 (low-rise building), RLCZ 4 (forest land), RLCZ 5 (low jungle land), RLCZ 6 (bare land), and RLCZ 7 (water bodies). The reclassification of the study to RLCZ was based on the observation that the 10 categories of building surface morphology within the building cover types exhibit a greater degree of complexity, including other factors such as permeable/impermeable coverage, building materials, and function. This paper starts from the perspective of building heights, mainly reflecting the changes in heights in 10 types of building landforms, with the aim of investigating the results of scenario modelling to predict the changes in the interactions between different building lands and other lands under a single feature. In natural cover types, due to the similarities between different land types, this study integrates lands with analogous characteristics with the objective of circumventing the potential complications that could arise from modelling scenario studies.

Table 2. RLCZ land classification.

LCZ Land Type	Type Characteristics	RLCZ Land Type
Compact high-rise (LCZ 1)	Dense high-rise buildings with more than 10 floors	Land for high-rise (RLCZ 1)
Compact mid-rise (LCZ 2)	Dense middle-rise buildings with 3–9 floors	Land for middle-rise (RLCZ 2)
Compact low-rise (LCZ 3)	Dense low-rise buildings with 1–3 floors	Land for low-rise (RLCZ 3)
Open high-rise (LCZ 4)	Low density high-rise buildings with more than 10 floors	Land for high-rise (RLCZ 1)
Open mid-rise (LCZ 5)	Low-density middle-rise buildings with 3–9 floors	Land for middle-rise (RLCZ 2)
Open low-rise (LCZ 6)	Low density low-rise buildings with 1–3 floors	Land for low-rise (RLCZ 3)
Lightweight low-rise (LCZ 7)	Single storey dense building	Land for low-rise (RLCZ 3)
Large low-rise (LCZ 8)	Large low-density low-rise buildings with 1–3 floors	Land for low-rise (RLCZ 3)
Sparsely built (LCZ 9)	Small and medium-sized buildings with low building density	Land for low-rise (RLCZ 3)
Heavy industry (LCZ 10)	Medium and low rise heavy industrial plant	Land for low-rise (RLCZ 3)
Dense trees (LCZ A)	High density woodland	Woodland (RLCZ 4)
Scattered Trees (LCZ B)	Low density woodland	Woodland (RLCZ 4)
Bush, Scrub (LCZ C)	Low density shrub	Low jungle land (RLCZ 5)
Low Plant (LCZ D)	Grass or herb, less trees	Low jungle land (RLCZ 5)
Bare Rock or Paved (LCZ E)	Rock or hard paving	Bare land (RLCZ 6)
Bare Soil or Sand (LCZ F)	Soil or sand	Bare land (RLCZ 6)
Water bodies (LCZ G)	Large open water body	Water bodies (RLCZ 7)

3.2. Land-Use Simulation Based on Plus Model

The land-cover/land-use change (LUCC) model is employed to simulate prospective land-use scenarios based on a range of potential futures. This study employs the PLUS model, which was developed by the High-performance Spatial Computing Intelligent Laboratory of China University of Geosciences (Wuhan) (<https://github.com/HPSCIL>, accessed on 24 May 2024) Team R&D. The PLUS model is a raster data-based model that can be employed for the simulation of patch-scale land-use/land-cover change. The framework proposes a rule mining strategy based on the land expansion analysis strategy (LEAS) and a CA framework based on multiple random seeds (CARS), which can be used to explore the driving factors of land expansion and landscape change. The model needs to input 2 different periods of land-use data, obtain the dynamic elements of land-use changes during the evolution process through superposition analysis, represent the corresponding image element changes in the form of raster data, analyse the correlation between different land-use types and driving factors by using the random forest algorithm, and establish reliable mathematical models to reveal the rule of change. Thus, the potential transfer probability and development trend of land-use conversion are obtained, and the corresponding image patches are generated according to the parameters [47].

In comparison to other models, the plus model demonstrates notable advantages when simulating the mutual transformation between land uses. To illustrate, the Sleuth model is capable of simulating a single type of land-use expansion [48,49], the CLUE-S model is limited to estimating the occurrence probability of each land-use type [50]. The FLUS model is extremely general in its estimation of the effects of subsequent land develop-

ment [51]. Overall, many existing CA models still suffer from the following shortcomings: (1) weakness in revealing potential drivers of land-use change [52]; (2) inability to capture the evolution of multiple land uses [53,54]. The PLUS model solves these defects, which not only simulating the mutual transformation of multiple types of land, but also of mining the driving factors of land expansion and landscape change [47]. Furthermore, it employs the random forest algorithm to analyse the correlation between different land-use types and driving factors, thereby establishing a reliable mathematical model that reveals the change law [55].

This study employs the RLCZ classified land-use data of Guiyang in 2013 and 2022 as the fundamental data set. It then extracts the land-use expansion during the specified period and unifies the driving factor data into TIFF data with a spatial resolution of $100\text{ m} \times 100\text{ m}$. Finally, it projects these data into the same coordinate system as the LCZ map classified land-use data (WGS_1984_UTM_Zone_48N). In light of the aforementioned evidence, a land expansion analysis strategy from 2013 to 2022 is calculated. Subsequently, a RLCZ simulation map for 2022 is predicted based on the RLCZ map for 2013. This is then compared with the actual RLCZ map for 2022. In accordance with the development policy, three scenarios of the study area have been established, and the simulated RLCZ classified land-use data for 2022 has been employed as the fundamental data set. The land-use spatial pattern changes of the three scenarios in 2040 are simulated by the PLUS model, thereby providing an important reference point for the future development direction of the study area.

In order to evaluate the potential for change in the RLCZ land use in the study area, we have referred to the dual carbon planning and the general land and space planning of Guiyang (2021–2035) and other relevant documents. Based on this analysis, we have formulated three different scenarios.

(1) BAU (natural operation) scenario: The scenario entails the prediction of the spatial distribution of RLCZ land in 2040, with reference to the change trend of LCZ land in Guiyang from 2013 to 2022. This scenario is not subject to any constraints or adjustments to policy. The purpose of this scenario is to determine the impact of the continuation of the development approach of Guiyang City in the previous period on the change of land use in Guiyang City in the future period.

(2) WLC (ecological protection) scenario: In order to comply with China's 'ecological red line' protection policy, the concept of 'green development leads to high-quality development' is emphasised. The objective of this scenario is to achieve an overall improvement in the quality of the natural ecological environment. The probability of conversion from forest land and low jungle land to building land is reduced by 70%, and the probability of conversion from forest land, low jungle land, and water body to bare land is reduced by 50%. With the exception of water and low jungle land, the probability of other land being transferred to forest land increased by 30%.

(3) Strong provincial capital (SPC) scenario: The implementation of the 'Stronger Provincial Capitals' initiative represents a strategic choice in response to the country's drive to enter a new phase of high-quality development of provincial capitals. This is implemented in order to accelerate the establishment of a megacity that is conducive to living, working, and visiting, and to promote high-quality development centred on the provincial capital city. In this scenario, the likelihood of conversion from building land to other land is reduced by 50%. The probability of land conversion from low-rise buildings to middle-rise and high-rise buildings was increased by 50%. The likelihood of forest land being transformed into construction land and bare land was reduced by 70%. The probability of transfer from low jungle land to building land and bare land was reduced by 50%. The probability of conversion from bare land to construction land increased by 50%, while the probability of conversion to woodland and low jungle land increased by 30%. It is recommended that restricted conversion areas be established, and that conversion be prohibited in important wetland parks.

4. Results

4.1. LCZ Map of Guiyang

Figure 2 illustrates the land-cover and land-use (LCZ) map of Guiyang in 2013 and 2022, generated using Landsat 8 satellite imagery and a 100 m grid resolution for training samples. The distribution of 17 LCZ types across 10 districts and counties of Guiyang was subjected to analysis. In 2013, areas designated as high-density buildings, including LCZ 1, LCZ 2, and LCZ 3, were predominantly concentrated in Yunyan District and Nanming District. Conversely, woodlands designated as LCZ A and LCZ B were primarily distributed in northern areas, such as Xifeng County and Kaiyang County. By 2022, a number of low-density buildings in the central area of Guiyang are scheduled for conversion into high-density structures, particularly in the Guanshanhu District and Baiyun District. Concurrently, the area of high-density construction in the neighbouring counties and districts is also demonstrating an upward trajectory, while the degree of protection afforded to the water area is relatively robust.

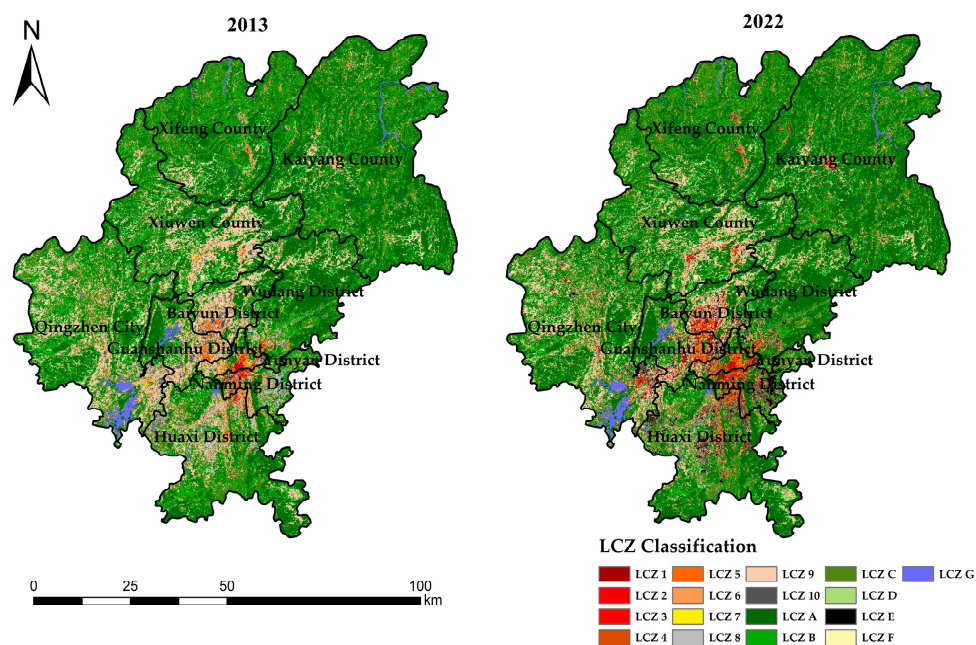


Figure 2. LCZ classification map of Guiyang City.

Figure 3 illustrates the overall accuracy of 17 LCZ classifications in Guiyang. The kappa coefficient for 2013 was 0.69, resulting in an overall accuracy rate of 72%. In 2022, the kappa coefficient was 0.70, leading to an overall accuracy of 74%. In comparison with the studies conducted in high-density areas, such as Hangzhou (72%) [56], Guangzhou (66%) [57], and Hong Kong (58%) [58], this value is deemed to be satisfactory.

4.2. Analysis of Land-Use Change in RLCZ

In order to meet the parameter setting of the PLUS model simulation and consider the interaction under different urban land densities, the 17 types of urban land surface morphology of LCZ are reclassified into 7 types of RLCZ (Table 2 above), thus enabling the analysis of the temporal and spatial characteristics of land use from 2013 to 2022. The simulated and actual land-use data of the study area in 2022 are compared and analysed to verify that the overall accuracy is 0.80 and the kappa coefficient is 0.70. These results demonstrate that the data are sufficiently accurate to meet the needs of follow-up research, and to simulate the evolution characteristics of RLCZ land use under different scenarios in Guiyang. Furthermore, the data provide a valuable reference point for the development direction of land use in urban space.

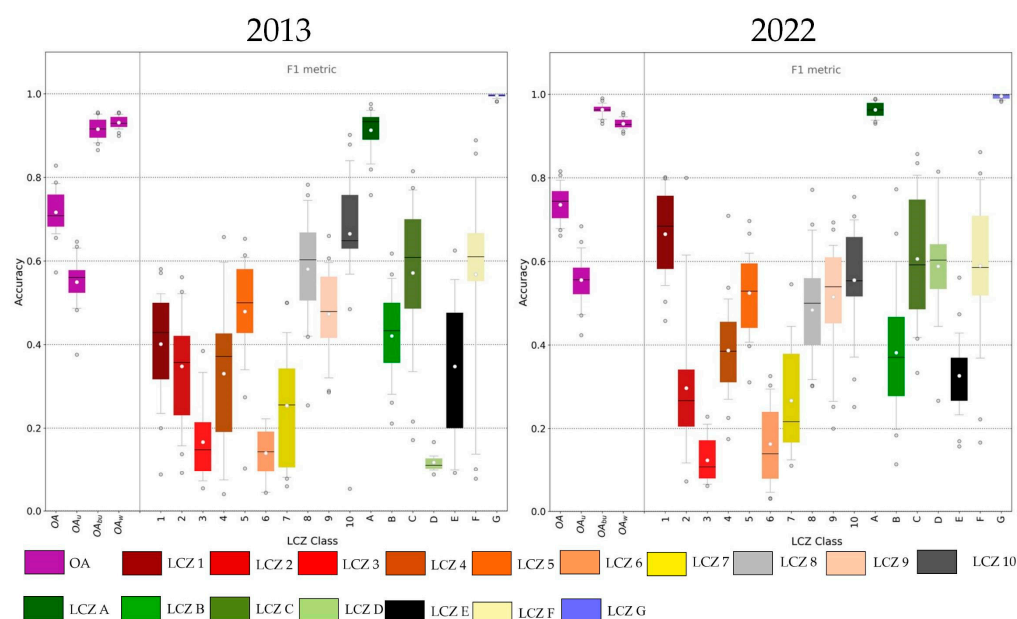


Figure 3. Overall accuracy of 17 LCZ classifications in Guiyang.

4.2.1. Analysis of RLCZ Land-Use Evolution from 2013 to 2022

Table 3 presents a visual representation of the structural alterations observed in RLCZ land in Guiyang between the years 2013 and 2022. During this period, the proportion of forest land area remained the highest, while the area of low jungle and bare land continued to increase. Conversely, the forest and water area exhibited a downward trend. The data indicate an increasing trend in the area of land allocated for high-rise and middle-rise buildings, while the area of land designated for low-rise buildings has decreased. This suggests a gradual shift in the development mode of construction land in Guiyang from high-density small volume to compact large volume. Additionally, the total area of construction land has decreased from 1875.6 km² to 1732.73 km², indicating a transition from rapid expansion to high-quality development. The area designated for high-rise buildings has undergone a notable expansion, with a 119.59 km² increase from 2013 to 2022, signifying a growth rate of 0.74%. The area designated for middle-rise buildings has been expanded by 33.71 km². Conversely, the land designated for low-rise buildings experienced a decline of 3.68%. Additionally, forest land saw a reduction of 20.13 km², while low jungle land and bare land expanded by 84.59 km² and 90.31 km², respectively. However, water area contracted by 11.9 km².

Table 3. Area of urban form land type in Guiyang from 2013 to 2022 (km²).

	RLCZ 1	RLCZ 2	RLCZ 3	RLCZ 4	RLCZ 5	RLCZ 6	RLCZ 7
2013	59.43	112.63	1703.54	4644.61	1349.16	37.64	135.94
2022	179.02	146.34	1407.37	4624.48	1433.75	127.95	124.04
2013–2022	119.59	33.71	−296.17	−20.13	84.59	90.31	−11.9

As illustrated in Table 4, the conversion rate of low-rise building land demonstrates the highest growth from 2013 to 2022, reaching 587.65 km², predominantly transferred to low jungle land. Conversely, the conversion area received by low forest land is the largest, with a total area of 400.35 km², derived primarily from low-rise building land and forest land. Figure 4a illustrates the spatial distribution of the transfer of RLCZ land-use types in Guiyang, while Figure 4b presents a visual representation of the predominant change patterns using the Sankey diagram. The conversion of land designated for high-rise

and middle-rise buildings is predominantly concentrated within the central urban zone of Guiyang. The conversion of forest land is distributed relatively uniformly across the city.

Table 4. Land transfer matrix of urban form in Guiyang from 2013 to 2022 (km²).

		2022						
		RLCZ1	RLCZ2	RLCZ3	RLCZ4	RLCZ5	RLCZ6	RLCZ7
2013	RLCZ 1	27.39	12.36	6.61	11.87	0.82	0.01	0.37
	RLCZ 2	18.13	56.91	32.84	3.48	0.86	0.38	0.03
	RLCZ 3	97.77	61.85	1115.89	120.86	232.52	74.31	0.34
	RLCZ 4	12.48	8.94	123.05	4317.79	163.45	17.25	1.65
	RLCZ 5	6.93	4.34	121.05	166.04	1033.4	16.24	1.16
	RLCZ 6	8.56	1.17	7.03	0.82	0.4	19.46	0.2
	RLCZ 7	7.76	0.77	0.9	3.62	2.3	0.3	120.29

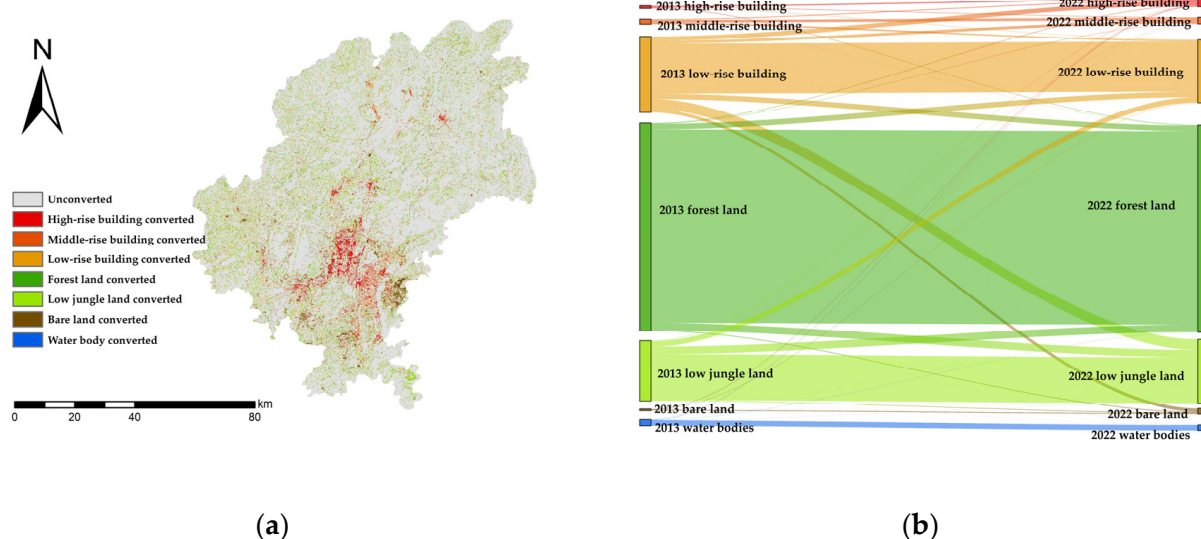


Figure 4. (a) The area where the urban form land has changed; (b) Sankey diagram of mutual conversion of land-use types in different urban forms.

In conclusion, the land designated for low-rise buildings, in addition to middle-rise and high-rise buildings, will be predominantly converted to woodland and low jungle land between 2013 and 2022. This is in alignment with the objective of Guiyang City to demolish illegal buildings and restore the construction of buildings and deforestation in the area. This reflects Guiyang's significant emphasis on the ecological environment and its policy of maintaining equal attention to control and governance.

4.2.2. Analysis on Driving Factors of RLCZ Land Use

The analysis of potential drivers of land-use change was carried out in the LEAS panel of the PLUS model, with an explicit methodology for measuring the contribution of multiple drivers as variables to all land-use types through a random forest model. The analysis of driving factors allows us to elucidate the role of each factor in the transformation of each land-use type [47]. Figure 5 illustrates the contribution of the identified driving factors to the transformation of various urban land uses. The probability of high-rise, multi-rise, and low-rise urban building land use is largely dependent on the impact of night light, slope, elevation, and road. The greatest impact on land designated for high-rise buildings is attributed to night light, with a contribution rate of 0.1791. The slope has the most significant impact on bare land and water, with contribution rates of 0.1909 and 0.4876, respectively. It can be observed that the layout of expressways and the orientation of slopes exert the most significant influence on the suitability of land for middle-rise and low-rise buildings,

with respective contribution rates of 0.1711 and 0.1712. In addition to water, DEM has a significant impact on the other six types of land, indicating that elevation plays a pivotal role in the development and construction of land use. Furthermore, DEM constitutes the primary contributing factor for woodland and low jungle land, with respective contribution rates of 0.1539 and 0.1921.

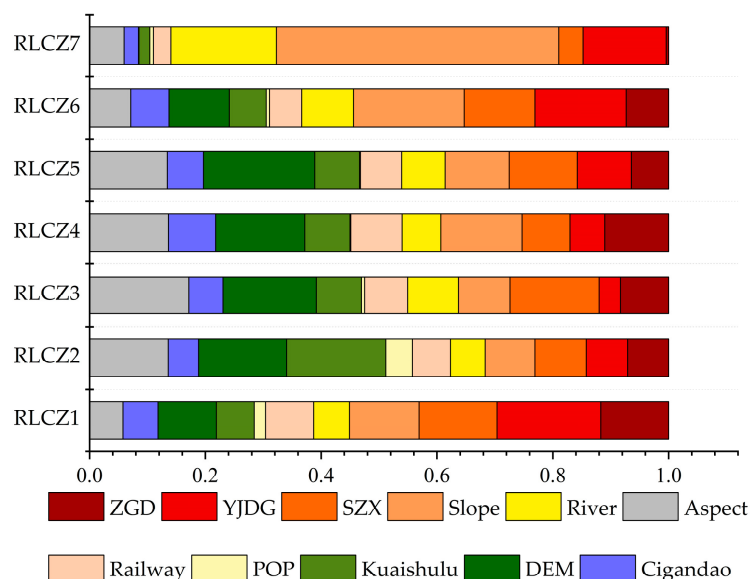


Figure 5. Contribution rate of driving factors to RLCZ land use.

4.2.3. Simulation of RLCZ Land Use in Multi Scenario

In this study, the CARS module of the PLUS model is employed for the simulation of the urban form and land use of Guiyang in 2040. Table 5 illustrates the projected alterations in land use under various scenarios by the year 2040. In consideration of the transformation of land area, the land-use structure of the urban form in the three scenarios will continue to be predominantly constituted by forest land by 2040. The three scenarios exhibit a consistent trend of increasing land area devoted to high-rise and middle-rise buildings, and a corresponding decrease in forest land, low-rise buildings, and water. In the context of urbanisation, a gradual transition from low-rise to mid-rise building land represents a more adaptable layout for intensive land development models. This shift aligns with an intensive land development mode that is more conducive to meeting the needs of a growing urban population.

Table 5. Changes of RLCZ land use types in Guiyang under different scenarios in 2040 (km²).

Land Type	Parameter	BAU	WLC	SPC
RLCZ 1	Area (km ²)	276.77	224.44	351.27
	Percent (%)	3.44	2.79	4.37
RLCZ 2	Area (km ²)	149.08	173.91	262.31
	Percent (%)	1.85	2.16	3.26
RLCZ 3	Area (km ²)	1240.18	865.61	1214.07
	Percent (%)	15.42	10.76	15.09
RLCZ 4	Area (km ²)	4626.31	4931.51	4641.66
	Percent (%)	57.52	61.31	57.71
RLCZ 5	Area (km ²)	1461.43	1610.81	1342.02
	Percent (%)	18.17	20.03	16.69
RLCZ 6	Area (km ²)	174.77	129.32	118.59
	Percent (%)	2.17	1.61	1.47
RLCZ 7	Area (km ²)	114.41	107.35	113.03
	Percent (%)	1.42	1.33	1.41

The BAU scenario projected an increase in land area designated for high-rise and middle-rise buildings, with a predicted expansion of 97.75 km² and 2.74 km², respectively. Conversely, the land area allocated for low-rise buildings is expected to decline by 167.19 km². Additionally, the land designated for woodland, low jungle, and bare land is anticipated to expand by 1.83 km², 27.68 km², and 46.82 km², respectively. Conversely, the water body is projected to contract by 9.63 km².

In the three scenarios, the area of woodland and low jungle land under the WLC scenario increased by 307.03 km² and 177.06 km², respectively, and the proportion of woodland reached 61.31%. The bare land area was reduced by only 1.37 km². Concurrently, the expansion of land designated for high-rise and middle-rise buildings was relatively modest, whereas the land allocated for low-rise buildings experienced a net reduction of 541.76 km². This suggests that the WLC scenario improves the systemic quality of the ecosystem by removing and converting a significant amount of low-rise building land into ecological land such as woodland.

The SPC scenario considers the development strategy of “strengthening the provincial capital” of Guiyang and the planning requirements of the overall land and space planning of Guiyang (2021–2035). In comparison to the BAU and WLC scenarios, the area designated for high-rise and middle-rise construction has increased by 172.25 km² and 115.97 km², respectively. The area of forest land increased by 17.18 km², accounting for 57.71 per cent of the total area, and the coverage rate remained above 55 per cent, meeting the requirements of the current round of Guiyang City’s territorial spatial planning. The areas of low jungle, bare land, and water decreased by 91.73 km², 9.36 km², and 11.01 km², respectively. The change trend was relatively gentle. This scenario demonstrates that it is possible to achieve the dual objectives of ensuring the stability of the ecosystem and meeting the needs of economic construction and development.

When considered alongside the WLC scenario in 2040 and the SPC simulation results, it becomes evident that economic development is a crucial means of “strengthening the provincial capital” cities. However, human activities have resulted in the degradation of existing forests, grasslands, and other ecological land, which has ultimately led to the disruption of ecosystem stability. It is, therefore, recommended that appropriate measures be taken to delineate the protected area and facilitate reasonable economic development, while ensuring that ecological protection is not compromised.

Figure 6 shows a projection of the spatial pattern of urban form sites, analysing the amount of growth and loss for each urban form site type in terms of spatial variation under the three scenarios. In all three scenarios, the expansion of land designated for middle-rise and high-rise buildings is primarily concentrated in the central urban area of Guiyang. In the WLC scenario, the expansion of woodland and low jungle land is more pronounced than in the BAU scenario, particularly in Xifeng County, Xiuwen County, and Qingzhen City. In the context of the SPC scenario, the expansion behaviour of middle-rise and high-rise buildings is particularly evident in the case of Yunyan District, Nanming District, Guanshanhu District, and Huaxi District. The reduction in land designated for low-rise buildings is accompanied by an increase in land allocated for middle-rise and high-rise buildings. This suggests that, in this scenario, the majority of land previously designated for low-rise buildings is now being redeveloped for middle-rise and high-rise buildings, in line with the urban intensive land development mode. Furthermore, a notable distinction is the transformation of unoccupied land. In particular, the conversion of bare land in the BAU scenario and the WLC scenario is derived from low-rise building land, given that the demolition of low-rise buildings results in the creation of wasteland. Conversely, in the SPC scenario, the bare land demonstrates a declining trend due to the conversion of the land to building land.

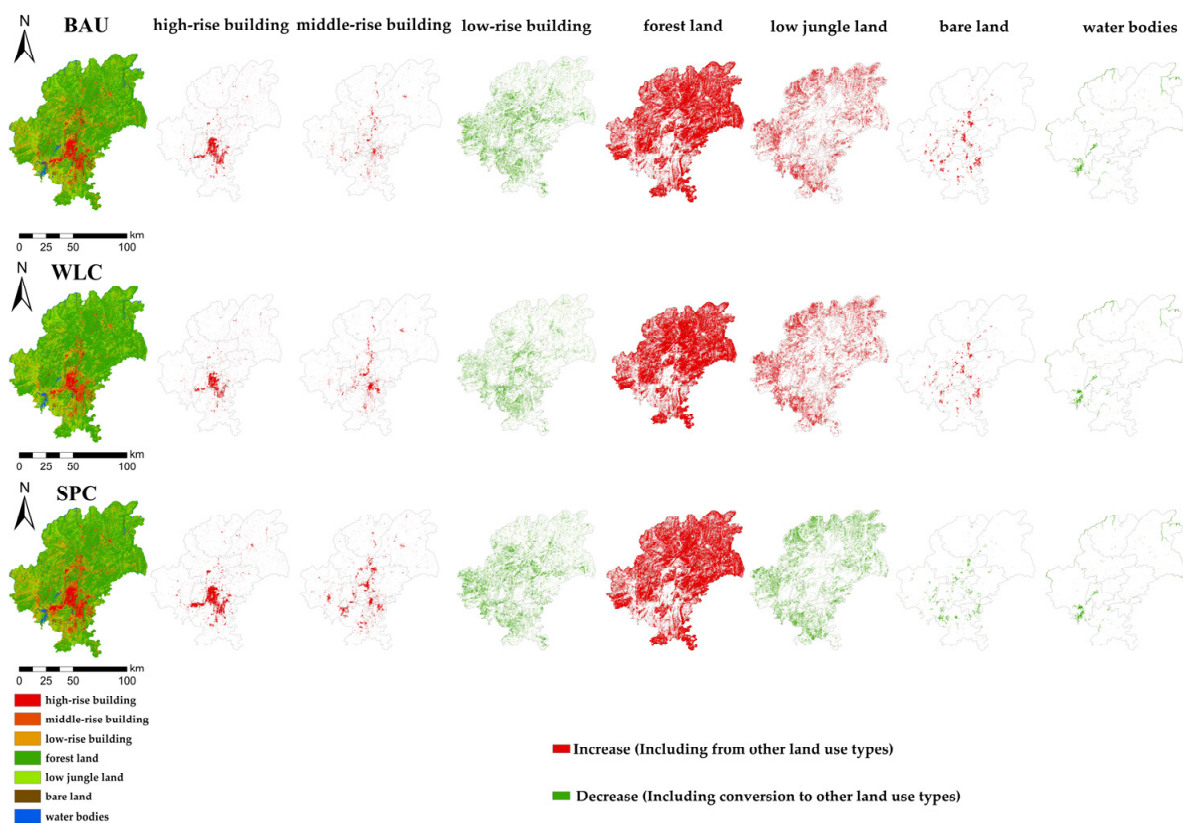


Figure 6. Spatial pattern of RLCZ land conversion under different scenarios in Guiyang in 2040.

5. Discussion

5.1. Study on the Coupling of LCZ and LUCC

Land-use change represents the most direct form of interaction between human activities and the natural environment. Prior research has demonstrated the significance of optimising land use, which entails the distribution of land resources in accordance with economic and social influences [59]. As a significant determinant of regional economic and social dynamics, it is imperative to examine the evolution of land-use patterns to facilitate optimal resource allocation. In contrast to previous research, this study employs the use of local climate zones (LCZ) to simulate intricate transformations in diverse urban settings for land definition. The findings demonstrate that the model integrating LCZ and LUCC can effectively illustrate the mutual conversion relationship between building land and other land types within urban areas. Nevertheless, the prediction of the rules governing the relationship between urban land may necessitate the consideration of more complex information than that which is addressed in this article. This article presents a concise typology of 17 land-use categories (LCZ), yet it is unable to forecast the planning attributes of building land, with the exception of height. Nevertheless, the approach outlined in this article has the potential to inform the prediction of complex land-use conversions within urban environments.

In comparison to the LUCC method, the integration of the LCZ scheme and the LUCC model allows for a more comprehensive understanding of the interactions between land and its various components, particularly within urban contexts. This is due to the fact that the LCZ classification method takes into account the physical and geometric characteristics of land-use cover, with land-use/land-cover change being primarily based on the classification of land-cover types. Consequently, the LCZ method enables the refinement of land classification, thereby facilitating the acquisition of a greater number of land types by researchers. In suburban areas, the classification logic and results for natural land are comparable to those of the LUCC classification. However, the results

of the study in inner urban areas are more precise than those of the LUCC classification. To illustrate, the simulation of land use in Guizhou Province over the next thirty years is informed by an emphasis on the potential ecological and resource values of cultivated land, forests, and grasslands. This approach is designed to circumvent the pitfalls of excessive development and ecological damage. Nevertheless, a simplified analysis of the expansion of construction land is insufficient for determining the planning standards for different building land within urban spaces [60]. The existing research on land use predominantly categorises it according to traditional land-use standard systems [61–63]. While some scholars concentrate attention on the potential of land-use simulation in the context of local climate zones, other scholars direct their attention to the following aspects: (1) the utilisation of local climate zones for mapping predominantly entails an examination of existing land-use patterns, with a paucity of attention devoted to the prospective simulation of future scenarios [64]; (2) the objective of the research is to ascertain the accuracy of maps obtained under different classification systems in LCZ [35]. This article places emphasis on the rational prediction of complex land-use conversion relationships within future urban spaces under appropriate LCZ and LUCC classification systems. Furthermore, it proposes constructive suggestions for urban development. It is, therefore, imperative that the concepts put forth in this article be employed in order to ascertain the most optimal development model for building land in urban settings.

5.2. Temporal and Spatial Pattern Evolution of RLCZ Land Use

The study revealed that the transfer of urban form land types over the past decade exhibited a notable decline in the area designated for low-rise construction in Guiyang, accompanied by a relatively stable utilisation of other land. In this regard, a potential explanation is that Guiyang has undertaken extensive demolition and reconstruction of low-rise buildings in recent years, resulting in an increase in middle-rise and high-rise buildings, as well as in ecological land and some wasteland. To illustrate, the flower orchard project situated in the heart of Guiyang represents the most extensive shanty town reconstruction initiative in China, encompassing a demolition area of over 4 million square meters. The simulation analysis of Guiyang in the future indicates that the woodland area will continue to undergo a stable change trend. This is due to the geographical advantages of Guiyang as a mountainous city and the favourable impact of recent years' efforts to protect the ecological environment. In accordance with the BAU scenario, the ongoing development trend observed over the past decade has resulted in a continued reduction in the availability of land designated for low-rise buildings. In the SPC scenario, the trend of change in low-rise building land is similar to that observed in the BAU scenario. However, the increase in middle-rise and high-rise building land is significantly greater than that observed in the BAU scenario. This demonstrates that the transformation of low-rise building land under the SPC scenario is distinct from the demolition mode observed under the BAU scenario. The majority of this land is converted to middle-rise and high-rise building land through upgrading and reconstruction. In the WLC scenario, the protection of ecological resources and the maintenance of environmental balance will inevitably result in a significant conversion of land previously used for low-rise buildings to woodland and low jungle land.

The setting of the three scenarios is based on the potential for future urban land-use development as outlined in national policy guidance, in conjunction with the anticipated trajectory of urban development. A comparison of the three scenarios reveals that they have disparate impacts on the prospective urban land-use transformations in Guiyang. Each scenario is constrained by specific limitations. It is evident that the BAU scenario plays a pivotal role in the context of comparative analysis, providing a benchmark for evaluating other scenarios, but the BAU scenario merely perpetuates the historical trajectory of land-use change. However, future changes in land-use structure are unlikely to remain unaltered, given the inevitable influence of policies, opportunities, and resources. The WLC scenario places a premium on the stability of the ecological environment and underscores

the importance of safeguarding ecological land. However, a gradual approach to urban development may not be optimal for cities undergoing rapid urbanisation. The SPC scenario provides a comprehensive analysis of the urban development needs of Guiyang's "strong provincial capital" strategy, while ensuring the reasonable protection of ecological land. While there is a discrepancy between the spatial distribution of land use and the actual policy requirements, this scenario is more closely aligned with the actual development needs of the study area.

The proposed results can be used to predict and analyse the changes and reasons for land use under different future scenarios. Furthermore, it can facilitate the advancement of predictive research aimed at addressing future climate change. It should be noted that the findings of this study are limited to the simulation results of future land-use scenarios. However, by focusing on the planning and selection of density, permeability, and material properties within the LCZ classification system, the results can be employed to evaluate potential future climate change scenarios and construct alternative climate adaptation strategies. Meanwhile, in urban areas, the two principal sources of greenhouse gas emissions are transportation and construction. There is a significant correlation between land use and carbon emissions. The model system presented in this article has the potential to enhance the classification standards for construction land, and to integrate pertinent models for the analysis of the carbon emission relationship associated with different land types. This will facilitate more precise calculations of total carbon emissions under diverse scenarios in the future, thereby advancing the objective of low-carbon development. In summary, the concepts presented in this article have the potential to transcend the constraints of preceding research. By establishing a mutual relationship between models, more precise outcomes can be achieved, thus enhancing the internal spatial configuration of cities and optimising the selection of sustainable development models. The objective of future research will be to further explore these issues.

5.3. Policy Impact

The geographical distribution of land has an impact on the ecological processes that occur within ecosystems and on the spatial distribution of ecosystem services. Furthermore, policies also serve to direct the alteration of land-use patterns. To illustrate, the forest and grassland areas in Guiyang City exhibited an upward trajectory from 2000 to 2006, which can be attributed to the Guiyang Municipal Government's enhanced oversight of undeveloped land transfer and the regulation of undeveloped construction land. Conversely, from 2006 to 2010, the forest and grassland areas experienced a decline, which can be attributed to the encouragement and support of local governments in developing and utilising undeveloped land, and in converting such land into construction land with the objective of achieving maximum value [65].

In recent years, a significant number of low-rise buildings in Guiyang have been demolished and transformed in order to meet the city's development needs. Nevertheless, should the current trajectory of land-use transformation persist, the scarcity of urban construction land is likely to intensify in the future. Thus, it is evident that the implementation of disparate policies at varying points in time is essential to guarantee a reasonable degree of development. The land and space planning of Guiyang (2021–2035) is consistently aligned with the overarching development concept of "strengthening the provincial capital". The city demonstrates a commitment to economic, ecological, and social development, reflecting a conceptual framework of sustainable development. In consequence, the SPC scenario adheres to the development policy of Guiyang City, consistently pursuing the overarching objective of "strong provincial capital". This is achieved through a dual focus on intensive land use and ecological environment protection. The results generated by this scenario simulation are deemed to be appropriate for the actual development needs and goals of Guiyang City. It is evident that the pertinent policies and systems in the region exert a significant influence on the local land-use change patterns. In scenario simulation settings, it is of paramount importance to consider the development policy requirements of

the research area in order to guarantee the efficacy and practicality of the predictions made in the study, which is of significant value to the advancement of research.

5.4. Limitations

The simulation of different scenarios can facilitate a certain degree of adaptability in response to the challenges posed by the government in the context of future urban expansion [66]. The objective of this study is to provide a reference for sustainable development planning by 2040 by simulating the changes in urban form and land-use patterns of Guiyang City under different scenarios. However, it should be noted that the study is not without its limitations. Firstly, the study area, due to its distinctive geographical characteristics, is susceptible to the effects of clouds and rainfall. This has resulted in the LCZ map obtained by WUDAPT having a lower degree of accuracy, which subsequently impacts the reliability of the subsequent scenario simulation. It is recommended that future research adopt a more rigorous approach to sample selection in order to obtain more reliable results. Secondly, the composition of urban form land, when considered in conjunction with the ability of land-use models to predict transformation and the transition of 17 types of land-cover zone (LCZ) land into seven types of land-use/cover/function (RLCZ) land from building height, is unable to accurately reflect the full range of nuances associated with urban land, including aspects such as infiltration/impermeable coverage, building materials, and functions. Subsequent research will concentrate on the character of urban land in order to facilitate more comprehensive investigation.

6. Conclusions

The current research on land-use change patterns in urban areas has certain advantages. However, the information generated by a single form of construction land is insufficient for predicting spatial changes in land-use patterns, particularly within cities. In order to facilitate the prediction of land-use change, this study employs a combination of the land-use concept (LCZ) and land-use/cover classification (LUCC) to simulate the conversion between multiple types of urban land. The study sets three future scenarios and a current scenario for the city of Guiyang and evaluates the land-use development mode, exploring the relationship between the changes in urban land-use pattern under the influence of different scenarios. The study revealed the following findings: (1) between 2013 and 2022, there was a notable decline in the construction of low-rise buildings, with a significant proportion of this decline being absorbed by the development of middle-rise and high-rise buildings, as well as low-density land. (2) Among the numerous factors that exert influence, the area of land designated for construction is primarily affected by the driving factors of night-time lighting, topography, elevation, and roads. Of these, night-time luminosity represents the most significant driving factor affecting the area designated for high-rise construction. (3) In the context of the multi-scenario, the BAU scenario represents a continuation of the observed trend of change in the use of urban land in Guiyang over the past decade. This trend has resulted in a net loss of land allocated for low-rise buildings. The WLC scenario safeguards woodlands and low-lying bushland, thereby ensuring the maintenance of ecological balance. Nevertheless, the development of construction land is subject to considerable restrictions, particularly in the case of low-rise construction. The SPC scenario places significant emphasis on the development of high-density urban areas, with a particular focus on the conversion of low-rise building land into middle-rise and high-rise building land. In addition, it pays due attention to the protection of woodland and low jungle land, thereby ensuring the stability of the ecosystem.

The method of mapping through WUDAPT provides ease of access to LCZ maps, most cities at home and abroad have submitted samples to the WUDAPT website, and the framework of land-use classification and land-use/land-cover change is a common concept. Therefore, the LCZ and LUCC coupled approach can provide directional prediction ideas for other geographic regions, and the findings from the coupled model can be extrapolated to other cities. It is also replicable at research scales, with related aspects currently being

conducted in the Guangdong–Hong Kong–Macao Greater Bay Area (GHMA) [35] and Nanjing [36], where the results are used as an input data set for predicting future urban land-use changes and, thus, capturing structural changes within the city, as well as providing necessary inputs for urban climate forecasting. Despite the lack of coupling studies at other scales, based on the summary of the accumulated research results of LUCC, the LCZ coupled with LUCC is applicable to the county/city/regional/global scales. Therefore, the model has strong validity and adaptability. The model permits the input of flexible data and allows for the explicit representation of spatial attributes, thus facilitating the actualisation of planning objectives. The proposed methodological framework can provide valuable insights into future urban land-use and facilitate the prediction, mitigation, and adaptation of changes in urban spatial patterns. Because spatial differences in climate impacts and energy consumption based on different planning choices constitute multiple mitigation scenarios for achieving future sustainable development goals, such as ‘dual carbon’, policymakers and urban planners can designate different adaptation scenarios based on the region’s developmental resources, developmental strengths, and other aspects. The framework can also assist local authorities in devising sustainable development strategies through the simulation of urban internal land use.

Focusing on Guiyang’s development policy as a ‘strong provincial capital’, this study builds a simulation scenario based on Guiyang’s unique natural resource conditions and development potential, emphasising Guiyang’s actual policies to guide the scenario simulation, and, thus, proposing Guiyang’s future development strategy. It is suggested that Guiyang’s future development should make use of existing building land to shift to a compact, high-density building development pattern, limit the expansion of urban land, and protect ecological land in order to realise the development policy of economic and ecological development. Furthermore, this strategy may serve as a valuable reference for other rapidly urbanising cities.

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