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Research on the Spatio-Temporal Evolution and Driving Forces of Green Spaces in the Central Urban Area of Zunyi City

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Abstract: Green space, as a medium for carrying out urban functions and guiding urban development, is becoming a scarce resource along with the urbanization process and the intensification of environmental problems. In the face of the spatial mismatch between high demand and low supply, it is of great significance to clarify the evolution mechanism of green space to undertake national spatial planning, protect the natural strategic resources in the urban fringe area, and promote the sustainable development of the "three living spaces." The study focuses on the Zunyi City Center, selecting the 20 years of rapid development following its establishment as a city as the study period. It explores the dynamic evolution of green space and the main driving forces during different periods using remote-sensing image data. The study shows that from 2003 to 2023, the total scale of green space has an obvious decreasing trend along with the expansion of the urban built-up area. A large amount of arable land is being converted to construction land, resulting in a sudden decrease in arable land area. In the past 10 years, the comprehensive land use dynamics have accelerated. Still, the spatial difference has gradually narrowed, indicating that the overall development intensity of Zunyi City's central urban area has increased. There is a gradual spread of the trend to the hilly areas. The limiting effect of the mountainous natural environment on the city's development has gradually diminished under the superposition of external factors, such as economic development, industrial technological upgrading, and policy orientation so the importance of the effective protection and rational utilization of urban green space has become more prominent.

Keywords: Green space; Spatio-temporal evolution; Driving force; Zunyi city center

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1. Introduction

The construction of a national spatial planning system is an important task in the construction of China's ecological civilization system, and the delineation of "three zones and three lines" is a core policy tool based on the spatial planning system for all-area and all-type of use control [1]. Green space, as the carrier of all elements of "mountains, water, forests, fields, lakes, and grasses," is an important component of national spatial planning and an ecological base on which urban development depends. It provides multiple irreplaceable services such as supplying resources, improving the environment, and maintaining social stability [2–6]. In recent years, the attention to urban green space research locally and internationally has been increasing year by year. It has become a hot area in which multiple disciplines are involved, especially the quantitative research on green space patterns based on remote sensing images and Geographic Information System (GIS) spatial analysis has made great progress, among which, the analysis of spatial and temporal evolution of green space under the acceleration of the urbanization process is the basis for quantitative research [7–10]. Since the study of the spatial and temporal evolution of green space patterns has important reference value for curbing the disorderly expansion of small and medium-sized cities and promoting their development transformation, this paper takes Zunyi, a provincial sub-center city in Southwest China, as the object of the study, and conducts a periodical comparison study on the rapid transformation process of the green space of the central city in the past 20 years with the help of remote sensing data and reveals the influence of the green space on the urbanization process. Based on the results of the analysis, the driving forces affecting the evolution of green space are revealed to provide a basis for the rational planning of Zunyi's urban ecological structure.

2. Overview of the study area

Zunyi is located in the northern part of Guizhou Province, at the southern foot of Dalou Mountain and the northern bank of the Wujiang River. It is one of the major towns in western China and belongs to the main area of comprehensive development and construction in the middle and upper reaches of the Yangtze River as planned by the state. Zunyi abolished the county and established it as a city in 2000, with a total area of 30,762 km^2. The planning scope of the central urban area has been increased from 216 km^2 as determined by the city general plan in 2000 to 515 km^2 in 2010, and to 1003 km^2 in 2016. In the past 20 years, the population of the central city has increased by nearly five times to 1.3 million, making it the area with the most obvious expansion of construction land and the most serious erosion of green space.

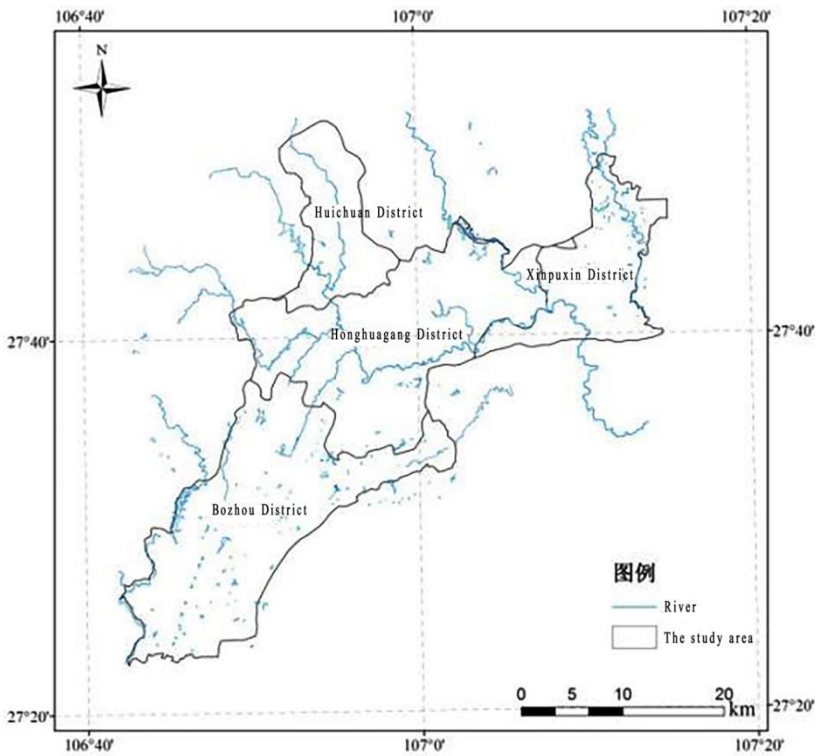

Figure 1. Extent of the study area

3. Data sources

3.1. Remote sensing data acquisition

The remote sensing image data used in this paper were downloaded from the United States Geological Survey (USGS) website for free of charge according to the strip number (path: 127, row: 41), LandsatTM5 data in 2003 and 2013, and LandsatTM8 data in 2023, with the spatial resolution of 30 m × 30 m. In addition, the 30 m resolution of the Digital Elevation Model (DEM) data and Zunyi City administrative map were downloaded through the geospatial data cloud platform of the Chinese Academy of Sciences (CAS) Computer Network Information Center which was supplemented with the interpretation of remote sensing images in combination with the field research data.

3.2. Research methodology

3.2.1. Classification and Decoding

Firstly, the geometric correction, radiometric correction, and atmospheric correction preprocessing procedures were carried out on the ArcGIS10.0 software platform for the 3-phase remote sensing images, and the error of the geometric correction was controlled within 0.5 image elements by the resampling verification method. Secondly, from the actual situation of land use types in Zunyi City, the study area was categorized into two major categories, urban space, and green space, according to the research intention (Table 1). With the help of ENVI5.0 software, the 3-phase remote sensing image maps were categorized using the maximum likelihood supervised classification method based on the established image decoding flags. Finally, the classification results were evaluated by establishing the confusion matrix between each type, and the overall classification accuracy reached more than 90%, with Kappa coefficients ranging from 83.29% to 93.48%, which satisfied the requirements of this study.

Table 1. Spatial classification system of remote sensing image data

First classification	Secondary classification	Contents
Green space	Woodland	Refers to the growth of trees, shrubs, bamboo, and herbaceous plants on the land, which includes tree woodland, shrub woodland, bamboo woodland, pastureland, swamp grassland, and other types of land. It also encompasses parks' green space, green protection space, green space in plazas, accessory green space within urban construction land, and green spaces in urban and rural areas outside of the urban construction land. These areas serve to protect the ecological environment, natural resources, and cultural resources, and provide open space for fitness, security, isolation, species protection, garden seedling production, and other functions.
	Plow land	Refers to land primarily planted with agricultural crops, including vegetables, with sporadic fruit trees or other trees. This includes paddy fields, dry lands, irrigated lands, orchards, tea gardens, other gardens, and other land types.
	Body of water	Refers to natural land of waters and water facilities, including rivers, lakes, reservoirs, ponds and mudflats, ditches, marshes, and other types of land.
Urban space	Building site	Refers to land used for residential living, commerce, services, industrial production, material storage, public administration, public services, transportation, and special functions.

Source: Organized according to Classification of Land Use Status (GB/T21010-2017) [11] and Urban Green Space Classification Standard (CJJ/T85-2020) [12].

3.2.2. Land-use transfer analysis

Using the Markov model to calculate the land use state transfer matrix can comprehensively reflect the area transfer between each land type and with the construction land in different periods [13]. Based on this, the spatial transfer distribution map of each land use type in Zunyi City Center is produced, to specifically portray the direction of land use change guided by urban construction.

$$S_{ij}=\begin{bmatrix} S_{11}\cdots S_{1n} \\ \vdots \ \ddots \ \vdots \\ S_{n1}\cdots S_{nn} \end{bmatrix} \quad (1)$$

where S_{ij} denotes the total area transferred from land class i to land class j during the study period and n is the number of transfers during the study period.

3.2.3. Degree of change in land-use dynamics and spatial variation

The attitude of a single land category can quantitatively reflect the speed of land use dynamics in green space, but it cannot characterize the spatial difference of the phenomenon of strong and weak changes in land use. Thus, with the help of ArcGIS, the 3-period remotely sensed interpretation of classification maps was divided into grids of grid size of 2 km × 2 km, according to the size of the study area divided into grids of 314, and then the Excel software was used to sum up the amount of change in the area of each land category within each grid, and then analyze the statistical characteristics of the annual integrated rate of change of all land categories in different periods. Using Excel software, to sum the amount of area change of each land category in each grid, count the comprehensive dynamic attitude of land use in each grid, and analyze the statistical characteristics of the annual comprehensive rate of change of all land categories in different periods. Then using the Kriging interpolation method, interpolate the spatial localization, and produce a spatial distribution map of the change of the comprehensive dynamics of land use in the Zunyi downtown area in different periods. This map was used to visualize the regional differences in land use changes.

The integrated dynamic variability formula [14]:

$$K =_s \sum_{i=1}^{n} \left| U_b - U_a \right| \times 2 \sum_{i=1}^{n} U_a \times T^1 \times 100\% \quad (2)$$

Where U_a *and* U_b denote the area of a land type at the beginning and the end of the study period respectively, T is the length of the study period, and n is the number of land use types.

4. Results and analysis

4.1. Dynamic evolution of the size of green space land classes

As can be seen from **Figure 2**, Zunyi City Center in the withdrawal of land after the establishment of more than twenty years, along with the continuous advancement of urbanization, the built-up area of the city is a continuous rapid expansion trend, while the green space in the process of urban radial expansion is constantly being eaten up. From as high as 97% of the space in 2003 accounted for a decline of 83% in 2023, of which the cuts in arable land area are the most dramatic, along with the area of forests and grasslands and waters in this period. There are different degrees of increase, but the rise is relatively small. It is also worth noting that in the northwest, northeast, and southwest directions of the city, the urban space stretches towards the mountainous areas, resulting in the fragmentation of forest and grassland with relatively high vegetation cover.

As shown in **Table 2**, during the decade of 2003 to 2013, the area of forest and grassland, water, and construction land all show a small growth trend and only the cultivated land is significantly less, which shows that the new forest and grassland, construction land and water are mostly converted from the cultivated land on the outskirts of the city. Additionally, the expansion of urban space in this period depends on the extension of the river valley and the axis of the traffic trunk line, mainly manifested as the continuous filling along both sides of the axis. 2013 to 2023 is the rapid economic and social development of Zunyi city in the past 10 years, manifested as a drastic change in the area of the green space and the construction space. The loss of a large amount of green space, which is still the largest reduction of cultivated land, and the area of the forested meadow has also appeared to decrease slightly, indicating that in the past 10 years, the area of construction land has also shown a small increase. This indicates that the expansion of construction land in the past 10 years has caused double coercion on cropland and forest grassland, and urban construction has gradually spread to the surrounding mountains and forests.

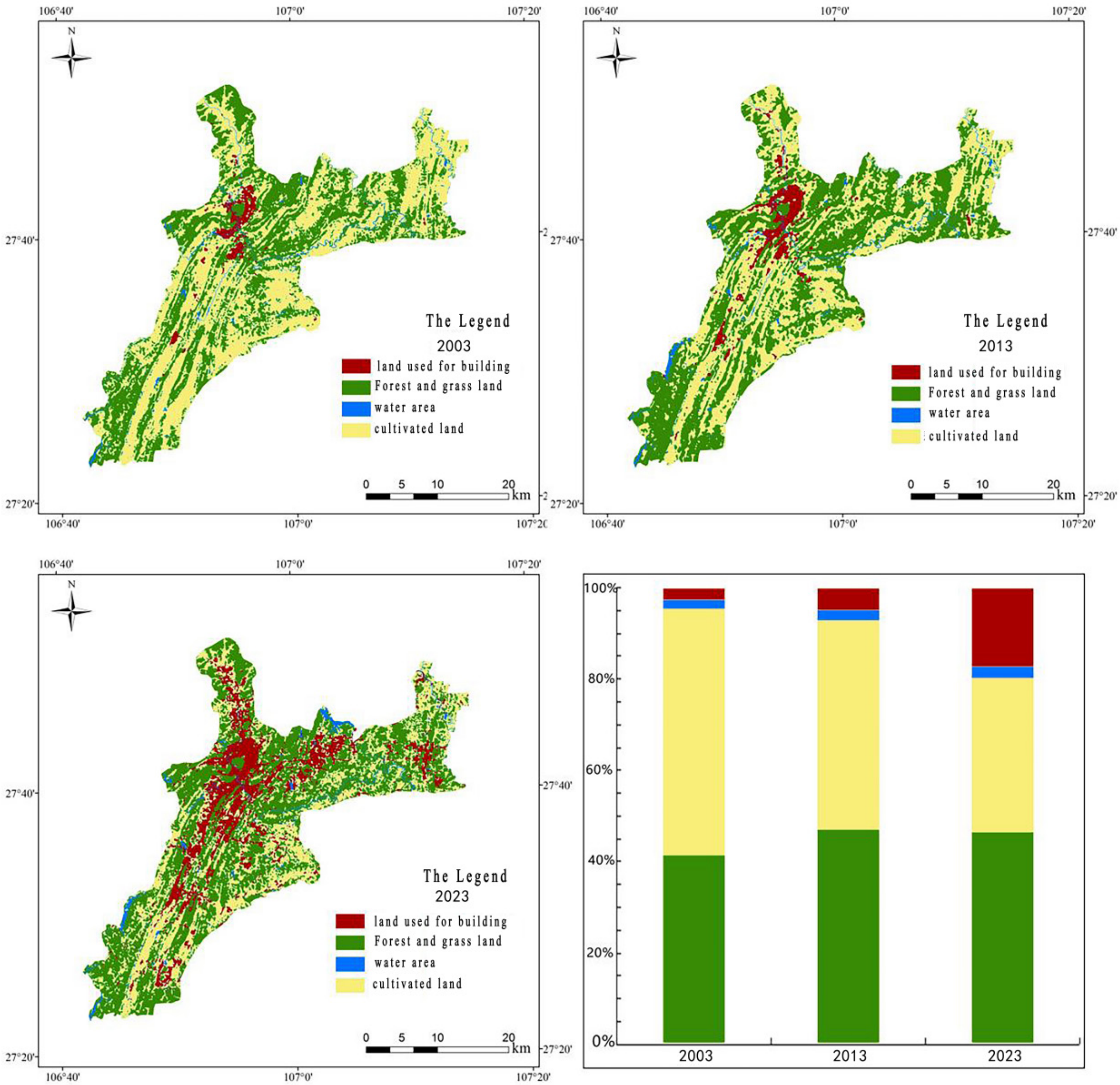

Figure 2. Interpretation of green space classification and area share in Zunyi City Center from 2003 to 2023

Table 2. Area change of green space and urban construction space in Zunyi City Center from 2003 to 2023

Year / The twelve two-hour divisions of the day	Area proportion	Woodland	Plow land	Body of water	Building site	Total	
						Green space	Urban space
2003	Area (km^2)	415.01	540.48	20.87	26.38	976.36	26.38
	Percentage (%)	41.39	53.90	2.08	2.63	97.37	2.63
2013	Area (km^2)	471.57	458.78	23.96	48.42	954.31	48.42
	Percentage (%)	47.03	45.75	2.39	4.83	95.17	4.83
2023	Area (km^2)	466.09	337.67	25.31	173.67	829.07	173.67
	Percentage (%)	46.48	33.67	2.52	17.32	82.68	17.32
2003-2013	Incremental (km^2)	56.56	-81.7	3.09	22.04	-22.05	22.05
	Incremental (%)	13.63	-15.12	14.81	83.55	-2.26	83.59
2013-2023	Incremental (km^2)	-5.48	-121.11	1.35	125.25	-125.25	125.25
	Incremental (%)	-1.16	-26.40	5.63	258.67	-13.12	258.67

4.2. Dynamic evolution of green space land category transfer

From **Table 3** and **Table 4**, it can be seen that green space decreased from 238.6 km^2 to 216.56 km^2 between 2003 to 2013, indicating an increase of 22.04 km^2 in 10 years. The largest conversion was from cultivated land to construction land, and the transfer from green space to construction land increased by 125.26 km^2 between 2013 and 2023, becoming the main source of new construction land. During this period, the increase in construction land primarily resulted from the encroachment of arable land. However, compared to the previous period, the amount of forest and grassland converted to construction land has increased significantly, while the amount of arable land has decreased, resulting in the shrinkage of arable land area and a slight decrease of forest and grassland area. Watersheds experienced a greater net transfer into than out of land compared to other categories in both periods, resulting in a significant increase in their area.

Table 3. Transfer matrix of green space and urban construction space land categories in Zunyi City Center, 2003 to 2013 (unit: km^2)

Classification Plow land		Green space			Urban space	Transferred area	Change in area
		Plow land	Woodland	Body of water	Building site		
Green space	Plow land	387.53	128.57	6.07	18.31	152.95	-81.69
	Woodland	63.91	338.77	5.98	6.35	76.24	56.56
	Body of water	5.09	3.52	11.46	0.80	9.41	3.09
Urban space	Building site	2.26	0.71	0.45	22.96	3.42	22.04
Transferred area		71.26	132.8	12.5	25.46	-	-

Table 4. Transfer matrix of green space and urban construction space land categories in Zunyi City Center, 2013 to 2023 (unit: km^2)

Classification Plow land		Green space			Urban space	Transferred area	Change in area
		Plow land	Woodland	Body of water	Building site		
Green space	Plow land	251.88	108.19	6.43	92.29	206.91	-121.12
	Woodland	79.61	352.67	4.51	34.79	118.91	-5.49
	Body of water	3.31	3.97	14.05	2.64	9.92	1.35
Urban space	Building site	2.87	1.26	0.33	43.96	4.46	125.26
Transferred area		85.79	113.42	11.27	25.46	-	-

4.3. Dynamic evolution of green space land-use categories

As shown in **Figure 3**, although the dynamic change rate of all land classes in the Zunyi City Center urban area was faster, the spatial difference in land use changes was greater during the 10 years from 2003 to 2013indicating localized areas of rapid change. From 2013 to 2023, the spatial distribution of these dynamic changes showed an irregular circular diffusion pattern with a continuous and contiguous trend. While overall land use exhibited rapid changes, the spatial differences in these changes gradually narrowed, primarily characterized by the transformation of green space across categories and a significant transfer of land to construction.

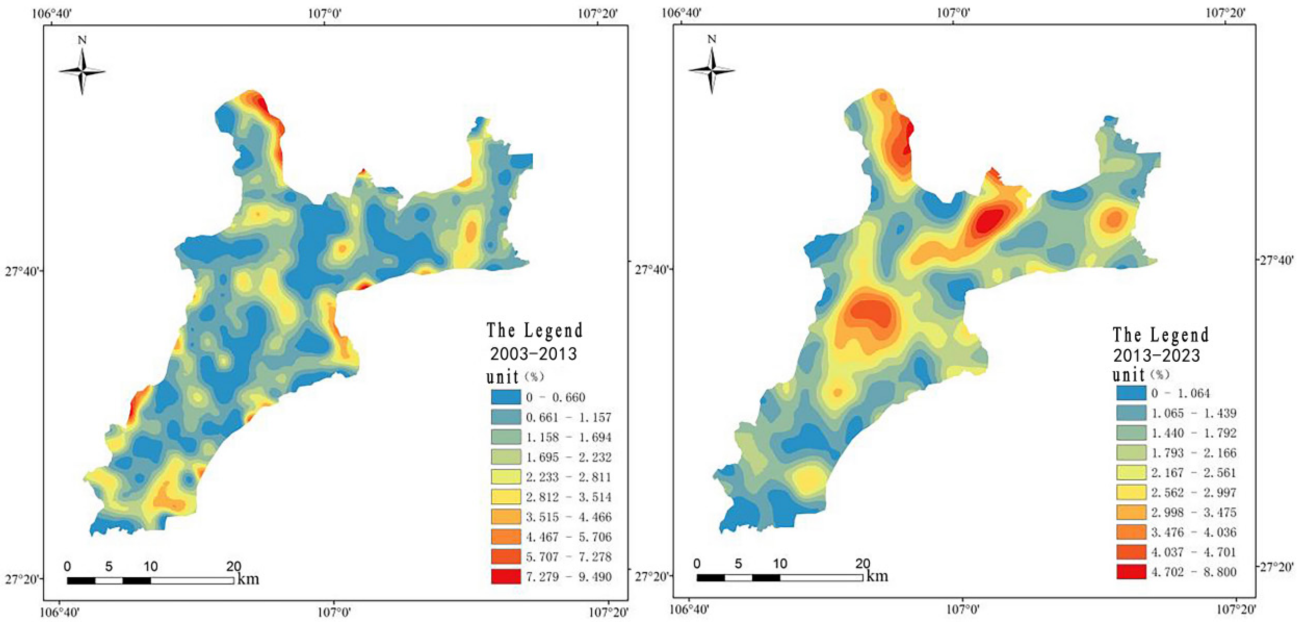

Figure 3. Spatial distribution of comprehensive dynamic changes in land use in the central urban area of Zunyi City Center, 2003 to 2023

4.4. Analysis of the driving forces influencing the dynamics of green spaces

4.4.1. Natural environmental factors are binding for the evolution of green space

Zunyi, as a typical mountainous city characterized by “eight mountains, one water, and one field,” has a mountainous area accounting for 64.3% of the land, a hilly area accounting for 29.4%, and flat dams and river basins comprising only 6.3% of the land area [15]. The undulating topography and complex geomorphology are the main constraints on the city’s development. Urban construction initially utilizes gently sloping areas and gradually transforms the complex terrain. Steep slopes and highlands with high construction costs have become restrictive areas, inhibiting uncontrolled growth. Consequently, urban expansion exhibits a pattern of clustered development, contrasting with the “sprawling” development typical of flat cities. Over time, urban construction has increasingly filled in valley basins and spread into hilly areas, causing trends in the hilly areas to align more closely with those in the valley basins. This indicates that urban construction efforts intensifying and the relationship between urban construction and green space shifting from benign interaction to competitive conflict.

4.4.2. Economic and technological factors as enablers of green space evolution

In just over 20 years since its withdrawal as a city, Zunyi has rapidly transitioned from early industrialization to the middle to last stages of development. This catch-up development mode has driven high-speed economic growth. However, as the level of urbanization exceeds 50%, the environmental crisis caused by incremental city development at the expense of green space has become increasingly prominent. Entering the post-industrial development stage, the city’s outward expansion trend slows, shifting focus to the adjustment and optimization of internal functions. This shift encourages a deceleration in crude development, leading Zunyi to gradually prioritize improving the city’s overall quality rather than solely pursuing economic growth.

4.4.3. Policy regulatory factors as a pulling force in the evolution of green space

In recent years, high-quality development under the leadership of ecological civilization has gained national consensus, and Zunyi has recognized the crucial role of the ecological environment in industrial growth. To reduce the high dependence on urban expansion and natural resource consumption, effective policy regulation is key to the city’s transformation [16,17]. In 2019, Zunyi City established the Bureau of Natural Resources to implement the central, provincial, and municipal guidelines and policies on natural resource management. This marked a new stage in Zunyi’s governance of its “mountains, water, forests, fields, lakes and grass” community life system. However, Zunyi faces challenges due to a lack of traditional ecological planning, ineffective implementation and monitoring mechanisms, and prominent multi-sectoral management conflicts. Local exploration is just beginning, and the city must also address the central government’s changing regulations and market-oriented adjustments. Consequently, planning will encounter more problems and challenges in allocating green space, increasing efficiency, improving quality, and coordinating rights and interests.

5. Conclusion and discussion

(1) Based on multi-temporal remote sensing data, we extracted quantitative information on green space in Zunyi City Center for three periods by using Remote Sensing (RS) and GIS technology and conducted a comparative analysis of two time periods from 2003 to 2023 in terms of the scale of land use, transfer of land use, and utilization of land use. The results show that the total scale of green space has been decreasing significantly along with the expansion of the built-up area of Zunyi City in the past two decades after it was established. In particular, the intensity of urban expansion in the last decade has increased by 5.16 times compared with that of 10 years ago. Arable land has been transferred to construction land in large quantities, resulting in a sudden decrease in the area of arable land. There are frequent transitions between categories in green space, and the rate of increase and growth of construction land is the most significant.

(2) From the analysis of the green space evolution process in Zunyi City Center in the past 20 years, it can be seen that the green space is a complex territorial system coupled with nature and various socio-economic elements, and the natural environment, economic technology, and policy regulation are the main driving forces affecting the evolution.

Disclosure statement

The author declares no conflict of interest.

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