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Study on the Dynamic of Urban Sprawl in Zhanjiang City Using RS and GIS

BY

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Abstract

This study aims to realize the dynamics of Zhanjiang's built-up area sprawl from 2013 to 2021. The method applies Landsat8 OLI remote sensing imagery data from December 2013 and Phase II of December 2021, combined with Remote Sensing (RS) and Geographic Information System (GIS) technology for analyzing the spatiotemporal characteristics and driving factors by combining the urban sprawl index, sprawl model and location conditions, socio-economic development, policy factors and other relevant data. The results show that the sprawl trend of Zhanjiang City during this period is slow, and the sprawl model is mainly "pie spreading". The spatiotemporal characteristics of its urban built-up area sprawl are related to the overall urban planning, regional advantages and social and economic factors.

Keywords: Remote Sensing (RS), Geographical Information System (GIS), Urban Sprawl, Urbanization growth index (UGI) , Land Use Transfer Matrix

1. INTRODUCTION

From a geographical perspective, urbanization refers to the transversion of transforming rural or natural areas into urban land. The connotation of urbanization mainly includes population urbanization, economic urbanization, geographical space urbanization, and social civilization urbanization, among which geographical space urbanization is manifested as the sprawl of urban construction land in space, so is also a critical interpretation and measurement standard. Meanwhile, urbanization becomes a significant reference to measure the economic condition of a country or region, that is, the spatial volume is the connection to the economic volume.

With the development of industrialization in western countries, urbanization forms are driven, and problems such as the contradiction between human and land relations and environmental pollution caused by urban sprawl need to be solved urgently. At this time, western countries took the lead in studying urban space sprawl (Sang and Li, 2019). After the 1960s, the concept of human-land relationships changed and the sustainable development concept deepened. The research begins to focus on urban sprawl control and evaluation (Lu, et al., 2010). With the development of Remote Sensing (RS) and Geographic Information System (GIS) technology, the research is combining computer technology to monitor sprawl scope and the urban construction land rate more efficiently and conveniently. In general, the research on urban land use change in foreign countries is becoming more and more comprehensive and cross-cutting (Yang et al., 2020).

China's industrialization started late, and the research on urbanization-related issues began in the middle of the 20th century. Chinese scholars' research on urban sprawl mainly reflected the following aspects: the content research, including the scale and direction of urban sprawl, the spatial evolution characteristics (Wei et al., 2021), the form of urban land sprawl (Wang and Zhou, 2014), the conversion of agricultural land to agriculture, the internal differentiation of urban land use (Yehua and Reid, 2014) and the coupling study of urban sprawl and economy (Li, 2015), the impact of urban sprawl on the environment, etc. The research method is primarily a combination of qualitative analysis and quantitative analysis (Wang et al., 2021). In terms of the study area, there are national (Liu and Liu, 2020), provincial (Ai et al., 2020), and prefecture-level cities or counties (Mei et al., 2009) as the study areas, which are concentrated in first-tier cities or some cities or regions with regional characteristics, such as Shenzhen

(Lin et al., 2020; Wang et al., 2021), Beijing-Tianjin-Hebei (Li et al., 2007; Li and Kuang, 2019), Guangdong-Hong Kong-Macao Greater Bay Area (Zhang et al., 2020) and other regions.

The degree of urbanization is the economy's developing reflection, while economic development is the driving force to promote the urbanization process. Since the implementation of reform and opening up in 1978, China's economy has experienced rapid growth, and the urbanization process has also been advancing (Tian and Wang, 2020). As the carrier of economic activities and production and living activities of the urban population, urban construction land has also expanded rapidly (Fu et al., 2016). Rural residential land, cultivated land, forest land, undeveloped areas, or water areas around cities and towns are increasingly occupied as urban construction land. However, the cities and towns' sprawl will inevitably change the types of land covered around them, which may impact the ecological environment and food security (Hasan et al., 2020).

With the construction of the Guangxi Beibu Gulf Economic Zone and the Hainan Pilot Free Trades Zone, Zhanjiang's regional advantages have become more and more increase, and its policy support has also become more important. Thus, it is necessary to analyze and study the dynamics of urban sprawl in Zhanjiang City in recent years to fill the gap of the lack of research on the sprawl of urban construction land in economic depressions in China. This study intends to start with the urban sprawl index, combine RS and GIS technology to extract the urban construction land information of Zhanjiang, analyze the urban sprawl dynamics in recent years, and analyze the relevant driving mechanism. By analyzing the space-time characteristics and driving factors of urban sprawl, this paper summarizes the current situation and its impact on the environment, intending to provide reasonable information for land use planning, proposed suggestions for the coordinated development of urban sprawl, ecological environment, and economy, and realizing the harmonious development of social economy and environment.

2. STUDY AREA

Zhanjiang, a prefecture-level city in the southwest of Guangdong Province, is the southernmost city in Mainland China, with geographical coordinates of 109 ° 40 ′ E~110 ° 58 ′ E, 20 ° 13 ′ N~21 ° 57 ′ N. The land area is composed of the Leizhou Peninsula, Donghai Island, Nansan Island, and other islands. It is adjacent to the South China Sea in the east, the Beibu Gulf in the west, Hainan Province across the Qiongzhou Strait, Guangxi Zhuang Autonomous Region, and Maoming City in the northwest and northeast. Located at the junction of Guangdong, Guangxi, and Hainan, it is an important port city on the south coast of China and the first batch of maritime cooperation hubs of the "the Belt and Road". As far as China's marine geographical location is concerned, Zhanjiang is the shortest distance between inland China and Southeast Asia, Europe, Africa, and Oceania. In terms of transportation, it includes Zhanjiang Port, Zhanjiang Wuchuan International Airport, Zhanjiang Station, Zhanjiang West Station, Wuchuan Station, and other transportation nodes.

The total area of the city is 13263 km^2. By the end of 2021, the permanent population will be 7.0309 million, the urbanization rate of the permanent population will reach 46.46%, and the gross regional product will reach 355.993 billion yuan. It has jurisdiction over 4 municipal districts and 2 counties, and three county-level cities including Wuchuan, Lianjiang, and Leizhou, with a total of 82 towns, 2 townships, and 37 streets. Zhanjiang is a beautiful coastal city with a monsoon climate at the northern edge of the tropics and is influenced by the marine climate all year round (Shown in Figure 1).

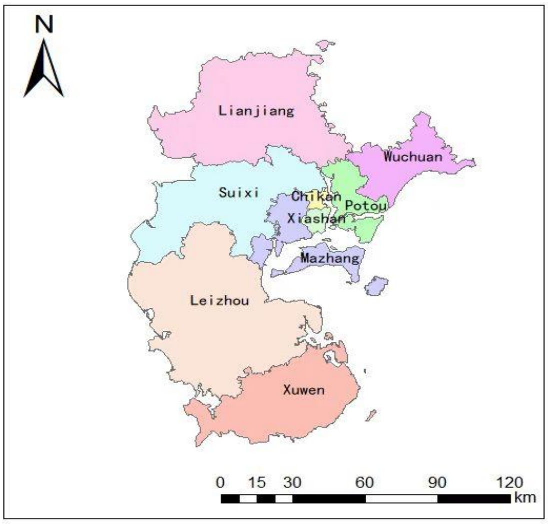


Figure 1 map of administrative division of Zhanjiang City

3. METHODOLOGY

3.1 Data collection

The data in this study include RS data and non-RS data. RS imagery data adopt Geospatial Data Cloud (https://www.gscloud.cn/) Landsat8 satellite imagery, the OLI image of Zhanjiang in 2013 and 2021 is selected, and the acquisition time is December. RS technology is used to process and interpret RS images of different periods in the study area to obtain construction land information. Non-RS data is including the administrative division vector map, the socio-economic data of Zhanjiang City, and relevant policies. The local gross domestic product, permanent resident population, and other data are from the Zhanjiang Statistical Information Network or the 2021 Zhanjiang Statistical Yearbook, the 2021 Statistical Bulletin of National Economic and Social Development of Guangdong Province, and other statistical data provided by the Guangdong Provincial Bureau of Statistics. Socio-economic data combined with the urban sprawl index is used to analyze the driving factors of urban sprawl.

3.2 Methods

First, after the RS image is downloaded, ENVI5.3.1 is used to preprocess the RS imagery of Zhanjiang in 2013 and 2021, such as radiometric calibration, atmospheric correction, mosaic, and clipping according to the administrative zoning map of Zhanjiang. Then the Support Vector Machine (SVM) is used to supervise and classify the RS imagery after preprocessing, and the accuracy evaluation is made, and then the classification results are imported into ArcMap to extract the urban built-up area information, including the statistics of the area of each land use type. Finally, overlay the built-up areas of the two periods and make thematic maps. See Figure 2 for the specific technical route.

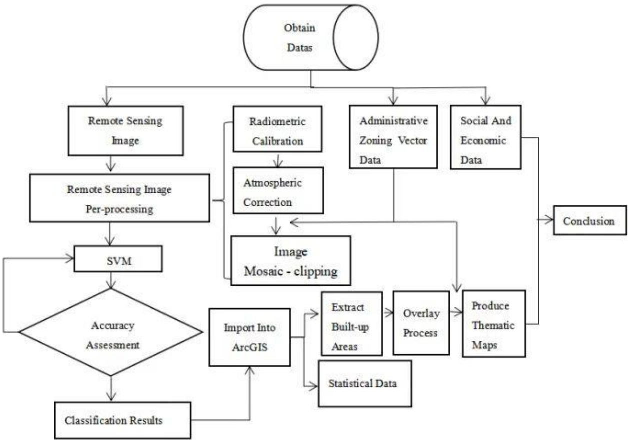


Figure 2 Flowchart of the study schema

3.3 Urban land sprawl index

The three indexes such as urban area growth index, urban sprawl intensity index, and urban sprawl dynamic degree are significant indicators to reflect the sprawl dynamics of urban land in the study area within a certain period. The sprawling area, sprawl rate, and sprawl intensity of the built-up area of urban land are analyzed qualitatively and quantitatively from the time dimension, and the sprawl speed of cities and towns is evaluated accordingly.

■ ***Urbanization growth index***

Urbanization growth index (UGI) (Chen et al., 2016) refers to the increase of urban construction land area in the study region during the study period compared with the time interval, which means the annual growth rate of urban construction land, which can reflect the annual average sprawl rate of cities and towns during the period, and is a reference factor for evaluating urban land sprawl (Sang and Li, 2019). The calculation formula of UGI is as follows:

$$UGI = \frac{S'-S}{\Delta T} \text{ ………(1)}$$

Among them, S refers to the area of urban construction land in the study area at the beginning of the period, S' refers to the area of urban construction land in the study area at the end of the period, Δ T is the time interval between the beginning and the end of the study, and the unit is a.

■ ***Urban sprawl intensity index***

Urbanization intensity index (UII), which can reflect the intensity of urban sprawl in a specific period, refers to the ratio between the increment of urban built-up area sprawl in the study area and the total land area multiplied by time, that is, the annual average of the growth rate of urban built-up area sprawl (Wang et al., 2015). The mathematical expression of UII is as follows:

$$UII = \frac{S'-S}{TLA} \times \frac{1}{\Delta T} \times 100\% \text{ -----------(2)}$$

Where: UII refers to the urban sprawl intensity, S refers to the urban built-up area of the study area in the beginning year of the study period, S' refers to the urban built-up area of the study area in the last year of the study, and TLA refers to the total land area, Δ T represents the time interval from the start year to the end year, and the unit is a.

■ ***Dynamic analysis of urban sprawl***

The dynamic degree of urban sprawl refers to the dynamic trend of the quantitative change of a certain land cover type in the study area in a specific research period, which can be used to explain the rate of land cover change in the area. Its mathematical formula is as follows:

$$K = \frac{S'-S}{S} \times \frac{1}{T} \times 100\% \text{……………(3)}$$

Where: K is the dynamic degree of urban built-up area sprawl, S is the urban built-up area in the beginning year of the study period, and S' is the urban built-up area in the last year of the study period, Δ T represents the time interval between the start year and the end year of the study (Sang and Li, 2019).

3.4 Supervised Classification

Supervised classification, also known as the training ground method or training classification is the process of classifying unknown pixels with known pixels. That is, select a certain number of training area samples from various defined land cover types, train them to identify, determine the pixels of the category determined, and classify them into the identified category, to achieve the purpose of land feature classification. At present, the commonly used supervised classification methods in ENVI5.3 include the SVM, neural network, maximum likelihood, Markov distance, minimum distance, and parallelepiped method (Li and Song, 2020).

In this study, we use SVM as the supervised classification method for RS information interpretation. SVM is the application of statistical learning theory in machine learning. It is a classifier model with interval maximization. It can automatically find the support vector with a powerful classification function and construct the corresponding classifier. It can maximize the interval of classification categories, and it has good classification accuracy.

Evaluate the results after supervision classification. The Kappa coefficient is an index to evaluate classification accuracy. The value is usually within 0-1. If the obtained Kappa value is between 0-0.2, it means that the classification result is very consistent with the real pixel. If the Kappa value is 0.21-0.40, it means that the consistency of classification results is in general. Similarly, if the Kappa value is between 0.41-0.60, the consistency of classification results is medium. When Kappa is at 0.61-0.8, the classification results are highly consistent; When the Kappa value is between 0.81-1, the classification results obtained are almost identical to the reality (Tang et al., 2015).

3.5 Land use transfer matrix

The establishment of the land use transfer matrix is derived from the practice of system analysis to quantitatively describe the system status and the transformation of the system status. It is the practical application of the introduction of the land use type transformation into the Markov model. This matrix can show the migration and transformation between the surface cover types, and reveal the rate of their mutual transfer (Liu and Zhu, 2010). The land use transfer matrix is shown in Table 1.

There are two time points T1 and T2 in the table, which are located in the row and column respectively. The row and column respectively represent the land cover status of the study area at time points T1 and T2. Pij refers to the area of land use type from i to j during T1-T2; Pi indicates that the area of land of type i has not been converted to other land use types during the study period. Pi+represents the total area of type i land at the start time of the study T1; P+j represents the total area of land of type j at the end of the study time T2. Pi+- Pi refers to the area or area percentage of land type i decreased during the study period T1-T2; Similarly, P+j-Pjj refers to the increased area or area percentage of j-type land in the study period T1-T2 (Liu and Zhu, 2010). The transfer matrix of land use visually shows the mutual transfer of land use types, and we can obtain the transfer rate of land use types during this period through calculation.

Table 1 Land use transfer table

		T_2				P_{i+}	decrease
		A_1	A_2	...	A_n		
T_1	A_1	P_{11}	P_{12}	...	P_{1n}	P_{1+}	P_{1+}-P_{11}
	A_2	P_{21}	P_{22}	...	P_{2n}	P_{2+}	P_{2+}-P_{22}
	...	...	...	...	...	...	...
	A_n	P_{n1}	P_{n2}	...	P_{nn}	P_{n+}	P_{n+}-P_{nn}
P_{+j}		P_{+1}	P_{+2}	...	P_{+n}	1	
increase		P_{+1}-P_{11}	P_{+2}-P_{22}	...	P_{+n}-P_{nn}		

4. DYNAMIC ANALYSIS OF URBAN SPRAWL

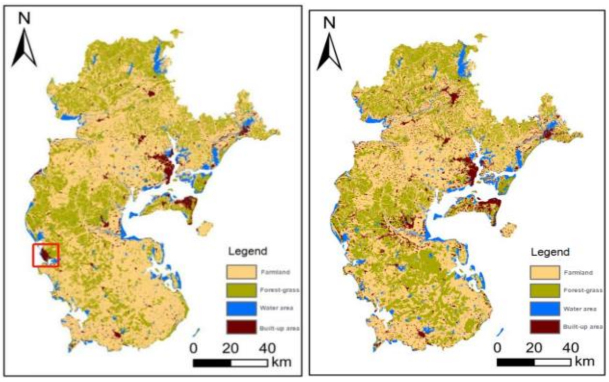
4.1 Urban land information extraction

The spatial resolution of Landsat 8 imagery used in this study is 30m, and it has been processed by terrain and geometric correction by the platform at the time of acquisition. Image interpretation classification is to use the learning and logical analysis ability of the computer to analyze the spectral information and implicit spatial information held by various ground object pixels in the image according to specific classification rules, and divide each pixel in the image into different ground object categories, to achieve the purpose of classification. According to the area of the study and the characteristics of the land cover types, the land use of Zhanjiang City is divided into four types for improving the classification accuracy of the built-up area. The specific classification is shown in Table 2.

Table 2 Classification of Land Use Types

Category	**Description**
Cultivated land	Paddy field and dry land
Forest and grass	Forest land, orchard, and grassland
Water area	Fishpond, river, lake, reservoir, sea
Construction land	Urban land, factory construction land, rural residential areas

In this study, we use the SVM method of supervised classification for classification. Then evaluate the accuracy of the confusion matrix, and the classification results of the study area in 2013 and 2021 were evaluated respectively. Trying to ensure that the total accuracy of the classification results was more than 85% and the Kappa coefficient was greater than 0.8 (Lin et al., 2020). The results of supervision classification and precision evaluation are shown in Figure 3 and Table 3 respectively. After the accuracy of the classification results meets the requirements, import the classification data into ArcGIS, and then use the overlay analysis to count the changing area. Finally, extract the built-up area according to the attribute and make a thematic map, as shown in Figure 4.

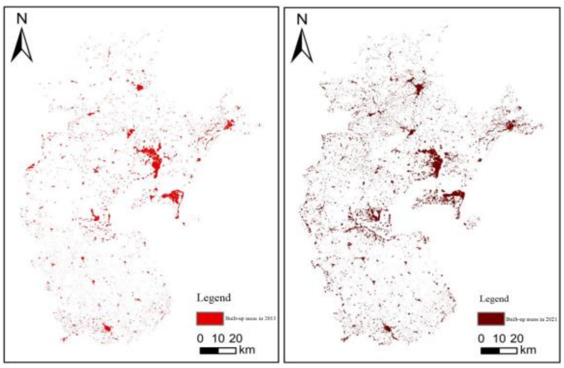


(a) Land use classification map in 2013 (b) Land use classification map in 2021

Figure 3 Map of Land Use Classification in Zhanjiang City

Table 3 Precision Verification Table

Year	Accuracy	Kappa value
2013	91.4145%	0.8546
2021	89.4747%	0.8171



（a）Built up area map in 2013 （b）Built up area map in 2021

Figure 4 Map of built areas in Zhanjiang in 2013 and 2021

4.2 Dynamic characteristics of urban sprawl

The spatial overlay analysis function of ArcGIS is used to process the image surveillance classification results of Zhanjiang City in 2013 and 2021, then the data of image overlay in the two periods are analyzed with a pivot table to obtain the land use transfer matrix from 2013 to 2021. It is used to explain the temporal and spatial changes in land use between cultivated land, forest and grassland, water body, and construction land in the eight years. Meanwhile, it is used to assess and master the changes and implications of land use in Zhanjiang City, as shown in Table 4.

Table 4 Land use transfer matrix from 2013 to 2021 (km^2)

		2021				
		Cultivated land	Forest and grass	Water area	Construction land	2013 total
2013	Cultivated land	6429.501	**797.52**	42.553	**146.983**	7416.557
	Forest and grass	265.356	3372.053	34.922	**169.726**	3842.057
	Water area	32.019	18.347	645.985	6.877	703.228
	Construction land	15.785	8.918	0.816	482.565	**508.084**
	2021 total	6742.661	4196.838	724.276	**806.151**	

As shown in Table 4, the total land area of Zhanjiang City has reached 12469.926 km^2. During the period from 2013 to 2021, the construction land of Zhanjiang City has increased from 508.084 km^2 to 806.151 km^2, with an increase of 298.067 km^2, mainly from cultivated land (146.983 km^2), forest and grassland (169.726 km^2), and a few from water bodies to construction land. The total transfer area of the water body has little change. Compared with other land types, the total area of cultivated land decreased significantly, and the reduced area was mainly transferred to construction land and forest and grassland (797.52 km^2), and a small part was converted into water. The area of forest and grassland increased by 354.781 km^2 after 169.726 km^2 was converted into construction land.

The built-up area of Zhanjiang City in 2013 is 508.084 km^2, and the built-up area in 2021 is 806.15 km^2. The interval between the first year and the last year of the study area is 8 years. By substituting formula (1), it is calculated that UGI=37.26 km^2/a that is, during 2013-2021, the construction area of Zhanjiang City has expanded by 298.067 km^2, with an annual sprawl rate of 37.26 km^2/a

The built-up area of Zhanjiang in 2013 and 2021 is 508.084 km^2 and 806.151 km^2 respectively. Through simple calculation, the total land area of the study area in this experiment is 12469.926 km^2, and the research interval is 8 years. Using the above data to calculate in formula (2), the sprawl intensity index of Zhanjiang from 2013 to 2021 is 0.3.

According to the evaluation criteria of the urban sprawl intensity index, when the urban sprawl intensity index is between 0~0.28, the sprawl intensity means slow sprawl. At 0.28~0.59, it is a low-speed sprawl. At 1.05~1.92, it is rapid sprawl. When it is greater than 1.92, it is high-speed sprawl. The intensity index obtained from this study is 0.3. According to the evaluation criteria, the sprawl intensity of Zhanjiang City from 2013 to 2021 belongs to low-speed sprawl.

Similarly, according to the data and formula (3) in Table 3, it can be seen that S'=806.151 km^2, S=508.084 km^2, T=8. According to the above data on built-up areas from 2013 to 2021, the dynamic degree of urban sprawl in Zhanjiang City during this period is calculated as K=7.33%. According to the rating reference of the dynamic degree of urban sprawl, when the K value of a town is less than 8%, the dynamic sprawl of the town is slow, when the K value is between 8% ~14%, it is medium speed sprawl, and when the K value is greater than 20%, it is high-speed sprawl. The results of this study show that the sprawl of Zhanjiang City is slow.

Combined with the evaluation indicators of urban sprawl in Zhanjiang City in Table 5, the analysis shows that the area of built-up areas has increased significantly in the past 8 years, with an added value of 258 km^2. However, the original level of urbanization in Zhanjiang City is low, so the sprawl of built-up areas from 2013 to 2021 belongs to the type of slow sprawl or low-speed sprawl.

Table 5 The sprawl area and sprawl intensity index of the built-up area from 2013 to 2021

Project/Year	*2013-2021*
Sprawl area （km^2）	*298.067*
Sprawl speed （km^2/a）	*37.26*
Sprawl intensity index /%	*0.3*
Sprawl of dynamic degree/%	*7.33*

From 2013 to 2021, Zhanjiang's built-up area showed a sprawl pattern. In 2013, the built-up areas were mainly distributed in the urban area of Zhanjiang City, the counties, cities, and districts under the jurisdiction of Zhanjiang City, and the urban areas of the Economic and Technological Development Zone. Except for Chikan District and Xiashan District, the urban areas were not closely connected and there were many "blank areas". The patches in the built-up areas of surrounding towns and townships are not obvious and are small and scattered. (Shown in Figure 5)

In general, during the period from 2013 to 2021, the built-up areas of various urban areas, towns, and villages in Zhanjiang City have slowly expanded to the surrounding areas on the original basis. Lianjiang City, Leizhou City, Potou District, Wuchuan City and

Zhanjiang Economic and Technological Development Zone have a good sprawl momentum. Suixi County and Xuwen County have no obvious urban sprawl. The sprawl phenomenon of surrounding towns is relatively prominent. The built-up areas and sprawl scope are mostly along railways, highways, rivers, and coastal areas. Chikan District, Xiashan District, and Mazhang District are gradually connected, and the continuity of construction land is further improved. Compared with 2013, the connection between surrounding towns and streets will be closer in 2021. The intuitive change is that the patches in the built-up area will expand from small spots to more obvious small patches.

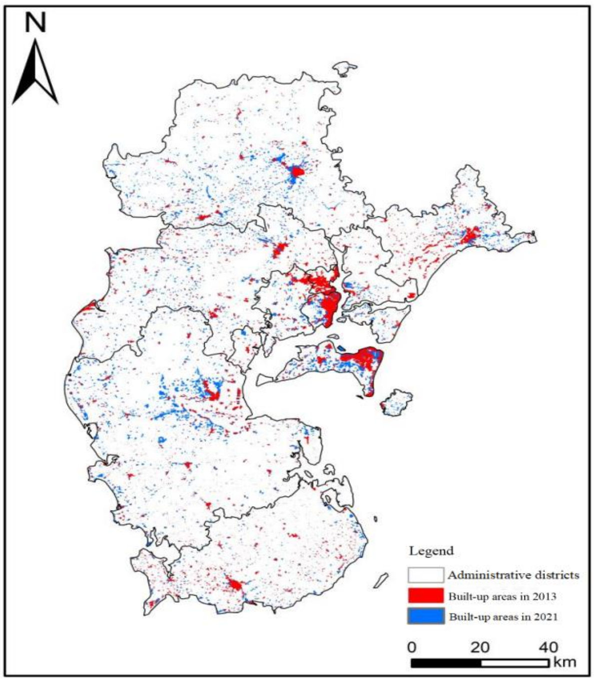


Figure 5 Overlay map of built-up areas in Zhanjiang from 2013 to 2021

4.3 Evolution characteristics of urban sprawl space

The characteristics of urban sprawl are analyzed from time and space dimensions. The previous text analyzes the sprawl characteristics of the study area from the time dimension, and now analyzes the spatial evolution characteristics of urban sprawl from the space dimension. There are three modes of urban space sprawl. One is the "old city reconstruction" mode, that is, redevelopment in the original urban construction space. The second is the "pie spreading" mode (unplanned development), which means continuous development based on the original urban construction space. The third is the model of "building new cities", that is, the model of jumping to the new areas developing instead of the original urban construction space. However, from the practical point of view of urban sprawl, each city's spatial sprawl mode is mixed with the above three modes. In the process of urban sprawl, the spatial sprawl of urban construction land primarily focuses on internal filling and external sprawl and interacts to form the spatial evolution characteristics of urban construction land sprawl (Lu et al., 2010).

According to visual interpretation, from 2013 to 2021, Zhanjiang's sprawl mode is to expand to the surrounding areas based on the original urban built-up areas in the form of "pie spreading" and fan-shaped sprawl. For example, Wuchuan City, Leizhou City, Xiashan District, and the Economic and Technological Development Zone are restricted by the natural geographical environment (e.g. rivers, lakes, and coastline), and the sprawl mode is to expand to the suburbs in a fan-shaped pattern against rivers, lakes or coasts. The sprawl of Lianjiang City and Potou District is carried out in a leaping mode combined with the "pie spreading" mode. The sprawl of the Chikan District in the old city is not obvious. Xuwen County and Suixi County are slowly expanding to the surrounding areas in the form of "pie spreading" based on the original urban construction land. The expansion of towns and townships in all counties and cities is relatively obvious, which is based on the expansion of the original construction land to the surrounding areas in a circular way, and the intuitive performance is the expansion of small spots as the center into large spots.

In space, the continuity of construction land in Chikan District, Xiashan District, Mazhang District, and Potou District has been further strengthened. The spatial connection between the urban areas of other counties and cities is still a relatively far way. The communication between the urban areas of the city is mainly by bus or minibus, with the urban area as the center to radiate the urban areas of the counties. There is no direct public transport between some counties, but the spatial continuity between the urban areas and the surrounding towns in the region is getting better and better.

5 ANALYSIS ON THE DRIVING FORCE OF URBAN SPRAWL

The essence of urban sprawl is to meet the needs of human survival and economic activities, and constantly change the land use type, so that more natural areas, rural land to urban land conversion process. It is reported that the driving forces of urban sprawl include location factors, natural geographical environment, social economy, and policy factors (Li et al., 2007; Wang et al., 2019). Unique location factors, suitable natural environment, climate, developed economic conditions and support of economic policies are all conducive to promoting the sprawl of cities and towns.

5.1 Natural environmental factors

Zhanjiang's regional advantages: First, it is surrounded by the sea on three sides, east and south, facing the South China Sea on the east and south, separated from Hainan Free Trade Port only by the Qiongzhou Strait, and navigable to Vietnam's Beibu Gulf on the west, with obvious marine advantages. Second, Located in the center of "Guangdong, Guangxi and Hainan", it is the fortress of the ditch through the Great Bay Area of Guangdong, Hong Kong, and Macao, the Beibu Gulf Economic Zone, and the Hainan Free Trade Zone, with great development opportunities. Third, with the construction of the Hainan Free Trade Port, the neighboring city of Zhanjiang will enjoy the dividends brought by Hainan's development.

Disadvantages: First, it is located in the westernmost part of Guangdong Province, far away from the Pearl River Delta region, which has a strong economy in Guangdong, and fails to share the economic benefits of the Great Bay Region. Second, the self-building industry is inadequate in innate conditions. Third, although close to Hainan Free Trade Zone, it has not directly promoted Zhanjiang's economy. Therefore, although Zhanjiang has good geographical advantages, it has not been fully displayed, which is commensurate with the current urban sprawl dynamics of Zhanjiang.

5.2 Social and economic development

■ ***Demographic factors：***

The population is an essential component of urban production and consumption activities. Population growth will promote the sprawl of urban construction land. The permanent resident population of the city increased from 6.9942 million in 2013 to 7.0309 million in 2021, an increase of 36700, and the urbanization rate of the permanent resident population increased from 37.32% to 46.46%; The non-agricultural population with registered residence in Zhanjiang increased from 2.9162 million in 2012 to 3.2431 million in 2020, an increase of 0.3269 million, or 10.08%. According to the data, although the permanent population in Zhanjiang City has grown slowly, the population type has continuously changed from rural to urban. The growth dynamics of the urban population in Zhanjiang City are consistent with the sprawl trend of urban construction land (Shown in Figure 6).

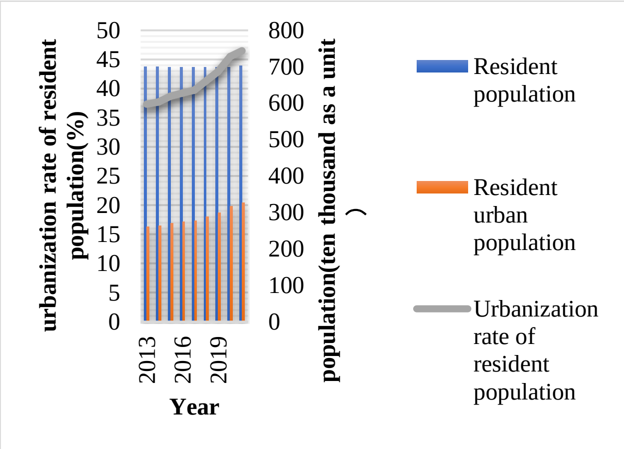


Figure 6 The statistical map of resident population of Zhanjiang City

■ ***Economic development***

Based on the research on urban sprawl at home and abroad, it is found that economic development plays a decisive role in urban sprawl, and per capita, disposable income is an indicator reflecting the regional economic level. In 2013, the gross regional product of Zhanjiang City was 203.18 billion yuan, increasing to 355.993 billion yuan in 2021, an increase of 42.29%. GDP and annual disposable income of residents have been increasing for 9 consecutive years. While GDP continues to grow, the annual disposable income of urban and rural residents is also slowly widening the gap.

On the one hand, the growth rate of regional GDP from 2013 to 2020 is weak, and the growth rate in 2021 is obvious; On the other hand, the annual disposable income growth trend of urban and rural residents is also more obvious in 2020-2021. Throughout the province, in 2021, Zhanjiang's GDP ranked 10th among the 21 cities in Guangdong Province, and the per capita disposable income of urban residents/rural residents ranked 14th in the province, both of which were below the average level of the province. Therefore, although the economic level of Zhanjiang has developed, it still belongs to a relatively backward echelon. The slow economic development of Zhanjiang is also consistent with its urban sprawl dynamics (Shown in Figure 7).

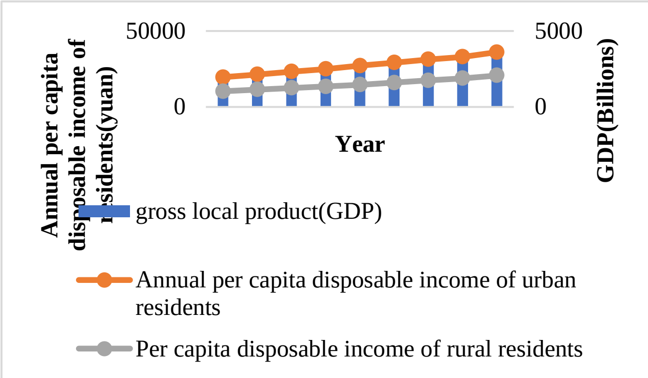


Figure 7 Map of regional GDP and disposable income of urban and rural residents of Zhanjiang City

■ ***Industrial structure***

First, the growth trend of Zhanjiang's secondary and tertiary industries is more obvious than that of the primary industry. Second, the proportion of industrial structure in 2013 and 2021 was 19:39.5:41.5 and 18:38.6:43.4, respectively. The proportion of the primary and secondary industries decreased slightly, and the proportion of the tertiary industry increased slightly, but the overall change was not significant. Third, with 2020 as the turning point, the development trend of the secondary and tertiary industries is rising. Overall, Zhanjiang's primary industry still accounts for a large proportion of its GDP, while the secondary and tertiary industries are the main contributors to GDP growth. The evolution of industrial structure is reflected in the change in urban land use type, and the weak change of industrial structure can also reflect the sprawl of urban construction land in Zhanjiang (shown in Figure 8).

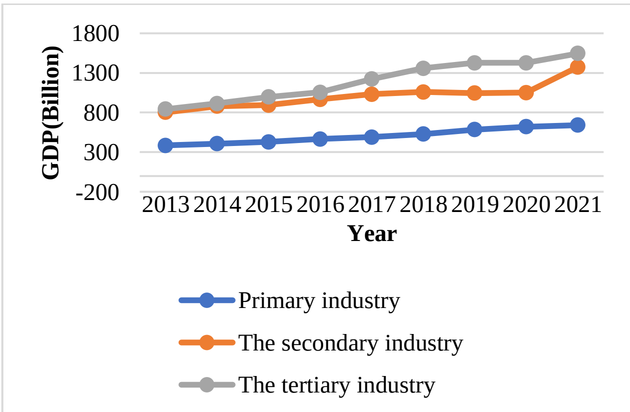
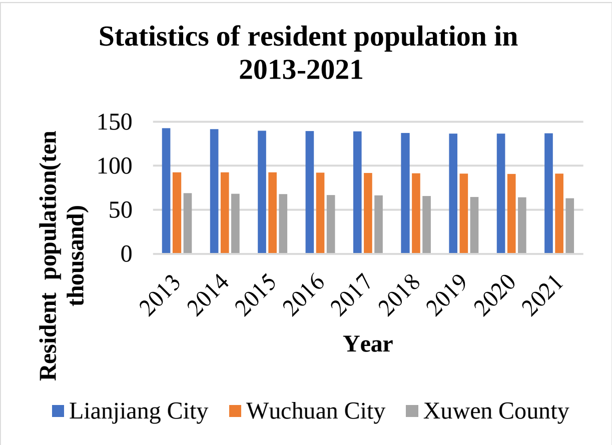


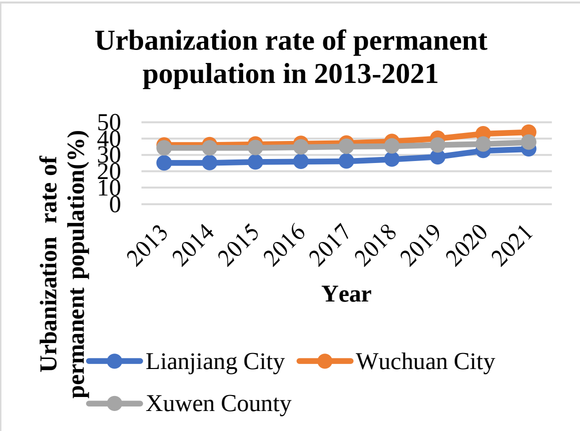
Figure 8 The gross product chart of GDP of three industries in Zhanjiang City

- ***Relationship between sprawl of built-up areas and social economy***

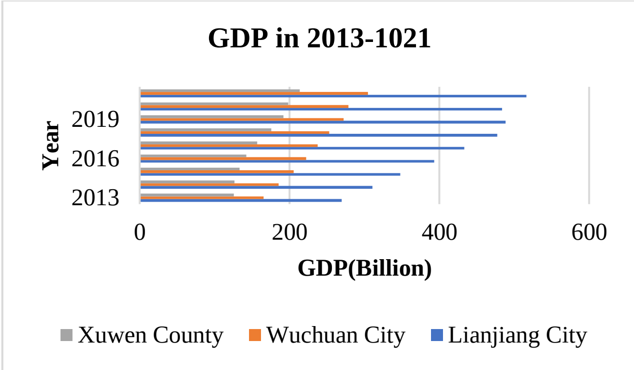
The analysis shows that the built-up area of Lianjiang City expanded most obviously from 2013 to 2021, in the form of "pie spreading". The expansion of Xuwen County was not obvious. The expansion of Wuchuan City was in the form of a fan-shaped sprawl, with obvious sprawl results. Taking the three cities as examples, this paper analyzes the relationship between the expansion of built-up areas and social economy from three factors: a permanent population, urbanization rate of the permanent population, and GDP. The permanent population and GDP have been Lianjiang City>Wuchuan City>Xuwen County. The urbanization rate of permanent residents is Wuchuan City>Xuwen County>Lianjiang City; From 2013 to 2021, the GDP increment of Lianjiang City, Wuchuan City, and Xuwen County was 246.66, 139.32, and 8.785 billion yuan respectively. The increase in population urbanization rate is 8.5%, 7.83%, and 3.43% respectively. It is shown that the main factors affecting the expansion of urban built-up areas are the number of permanent residents, economic development, and the increase in urban population (shown in Figure 9).



a. The statistical map of resident population



b. The map of the urbanization rate of resident population



C. The map of gross regional product of Zhanjiang City

Figure 9 Comparison of social and economic data of Lianjiang City, Wuchuan City, and Xuwen County

5.3 Policy factors

The development of cities cannot be separated from the guidance of policies, which has long been said as "urban development, policy first". The urban master plan undoubtedly points out the way for the construction scale and development direction of the city and provides a strong guarantee for urban economic development and urban sprawl. According to the Overall Urban Planning of Zhanjiang City (2011-2020), it is clear to expand the scope of the central urban area and the urban planning area, with a planned area of 225.79 km^2 and 2216.92 km^2 respectively. The central urban area is planned to expand from the southeast to the northwest, gradually integrate with Suixi County, Mazhang District, Potou District, and other districts and counties with the urban area, and carry out the renewal of the old city and the development of the new area simultaneously to expand the scope of the central urban area. In terms of urban spatial planning, it is planned to build a city-wide urban spatial structure of "one main and four auxiliary, two districts and two axes". Clear urban planning will also guide the sprawl of urban built-up areas.

6. CONCLUSION

This paper takes the Landsat8 images of Zhanjiang in 2013 and 2021 as the data source, thus obtaining the information on the built-up area from RS imagery, calculates the urban sprawl index, quantitatively analyzes the time characteristics of urban sprawl, and then analyzes the spatial evolution characteristics of urban sprawl through the superposition of the two time-phased built-up areas in 2013 and 2021. Finally, from the aspects of location conditions, natural geographical environment, social and economic development, and policy support, this paper discusses the role of various influencing factors on urban sprawl, and obtains the following results:

During 2013-2021, the urban sprawl trend of Zhanjiang was between slow sprawl and low seed sprawl. From 2013 to 2021, the area of Zhanjiang's built-up area expanded by 298.067km^2, 1.5 times. The urban sprawl intensity index is 0.3, and the dynamic degree of urban sprawl is 7.33%.

From the perspective of spatial evolution, the sprawl mode of the built-up area is mainly "pie spreading+ fan-shaped sprawl +

internal filling", which stimulates the built-up area to expand to the surrounding areas in the form of "pie spreading" or fan-shaped sprawl on the original basis, and gradually forms the urban spatial structure of "one main and four auxiliary". Among them, the built-up areas of the Zhanjiang urban area (including Chikan District, Xiashan District, Economic and Technological Development Zone, Mazhang District, and Potou District, which are close to the urban area) are more closely connected in space. The spatial evolution of Xiashan District and Wuchuan City is characterized by fan-shaped sprawl, and the sprawl of built-up areas in Lianjiang City and the surrounding towns of counties and cities are in the form of "pie spreading". Compared with the construction goal of the Zhanjiang Urban Master Plan (2011-2020), the sprawl of construction land in Zhanjiang from 2013 to 2021 lagged or was related to the global COVID-19 epidemic.

The unique geographical conditions, suitable natural and geographical environment, economic development, population growth, and government policy support are the main driving factors for the sprawl of construction land in Zhanjiang. The spatiotemporal characteristics of urban sprawl in Zhanjiang City are consistent with the development direction of the social economy and urban master plan, which is the joint action result of economic development, urban master plan, policy factors, etc.

According to the overall sprawl trend of the built-up areas in Zhanjiang and the analysis of the land transfer matrix in 2013-2021, the impact of the slow sprawl trend of the built-up areas on the current ecology is not obvious. However, with the increasingly obvious geographical advantages and the increasing policy support, the sprawl dynamics of Zhanjiang's built-up area after 2020 and its impact on the ecological environment deserve further attention.

Overall, in the future, more reasonable arrangements should be made for the spatial layout and construction efficiency of the built-up areas, closely focusing on the goal and task of "fully constructing provincial sub-central cities and accelerating the construction of an important development pole of the modern coastal economic belt", seize the opportunity and give full play to the location advantages. As far as the analysis results of this paper are concerned, efforts should be made to promote the coordinated development of population, economy, and land, optimize the existing population layout, industrial structure, and urban spatial structure, focus on the strategic positioning of the central urban area and counties, plan and construct the new region with higher efficiency, and guide the orderly and good sprawl of towns in Zhanjiang.

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