Quantifying the Speed, Landscape Pattern Changes and Its Driving Factors of Shenzhen China

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Abstract. Urban expansion has always been a topic of great concern. The purpose of this study is to explore land use change and the types of urban expansion in Shenzhen from 1995 to 2015, and to indicate the driving factors of this change, so as to provide a paradigm for other similar studies. By analysing the landscape expansion index and the correlation coefficient between urban area and various factors in Shenzhen, the following conclusions are obtained: 1) The main changes of land use types are the decrease of cultivated land and the increase of urban land. The land cover type changed most dramatically from 2000 to 2005, and the urban land transformed from cultivated land and grassland occupied most of the area. 2) Analysis shows that during the 20 years from 1995 to 2015, the main expansion type is edge-expansion. In detail, during the period from 1995 to 2010, the proportion of infilling has been increasing, while that of the outlying has been decreasing. After 2010, the urban area of Shenzhen increased slightly. Besides, according to the landscape expansion index, Shenzhen experienced dramatic urban expansion from 2000 to 2005. 3) Education and population growth are the main factors of urban growth in Shenzhen, which is reflected in the strongest correlation between university enrolment rate and urban area.

1 Introduction

Land resources are very limited and play a critical role in the functioning of the Earth system [1]. According to the statistic of United Nations, half of the population in the world are living in urban land area. The study of urbanization has become one of the hottest topics. Although urbanization is a worldwide phenomenon, it is exceptionally active in China [2]. After the reform and opening-up policy was enacted, China's urbanization progressed rapidly [3]. In the 21st century, China is promoting the construction of a new type of urbanization [4]. Using remote sensing imageries can possibly help us to do the land use classification and study urban expansion [5]. Shenzhen, as the first special economic zone in China, its development study has implications for the development of China's coastal cities.

Despite there is much research on China's urban sprawl, relatively speaking, little research has been done on the drivers of its urban expansion. Most of the studies focus on the pattern of urban growth, or its influence on social-ecological effect. For Shenzhen, its fractal dimension curves are similar to those of European and American cities [6]. As a city in a developing country, this is a testament to the advanced development model of Shenzhen. Compared with other cities in China, the drivers of Shenzhen's expansion are considered as GDP (Growth Domestic Product), GDP pre capita, a series of economic policies, and its national portals [7]. The study of urban sprawl in Shenzhen also has important implications for sustainable development [8]. Besides, most of the traditional indices that study urban expansion ignore outlying growth but only focus on the infilling and edge-expansion, which leads to the birth of the Land Expansion Index (LEI) [9].

Existing studies on urban expansion in Shenzhen ignore education, demographic drivers, and also the rate of urban expansion in Shenzhen. So, in our study, we consider the following main components: (a) to calculate infilling, edge, outlying urban expansion of Shenzhen based on LEI; (b) to calculate the average annual growth rate of construction land area based on Urbanization Growth Index (UGI); (c) to increase population, education, and other factors in the study of Shenzhen's expansion drivers, and by comparing the correlation between different factors and urban expansion based on the correlation coefficient in statistics, derive the most significant driving factors. Similar research methods and processes can be applied to most urban expansion and its driver studies, and the results can guide future urban expansion policies and sustainable development goals for coastal cities in southeastern China.

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2 Research area and data

2.1 Study Area

As an important costal city in China, Shenzhen is located in the south-central part of Guangdong Province, southeast China, as shown in Figure 1. It covers 113°46′E - 114°37′E, 22°27′N - 22°52′N, belonging to subtropical maritime climate. Its total administrative area is 1997.47 km^2. Shenzhen, which has the title of "China's Silicon Valley" and "China's Smartest City", respectively, has grown from a small fishing village to an international metropolis during the last 40 years [10]. Shenzhen is the portal city with the largest number of ports, the largest number of people entering and leaving China, and the largest traffic flow.

After the establishment of Shenzhen Special Economic Zone in 1979, "The Five-Year Plan" in China guided the development of Shenzhen. Shenzhen has completed the historical tasks of the foundation stage of modernization, and made new breakthroughs in urban construction and management. According to the Statistic Bureau of Shenzhen 2015, the population of Shenzhen is a huge reserve. Until 2015, Shenzhen had already hold 1,137.87 billion persons. Besides, Shenzhen had a domestic economic growth. After three "Five-Year Plans" (the 9th, the 10th, the 11th), the GDP (Gross Domestic Product) of Shenzhen had grown to 1.84 trillion in 2015. The Gross Domestic Product Per Capita had increased from 19,558 yuan in 1995 to 166,415 yuan in 2015.

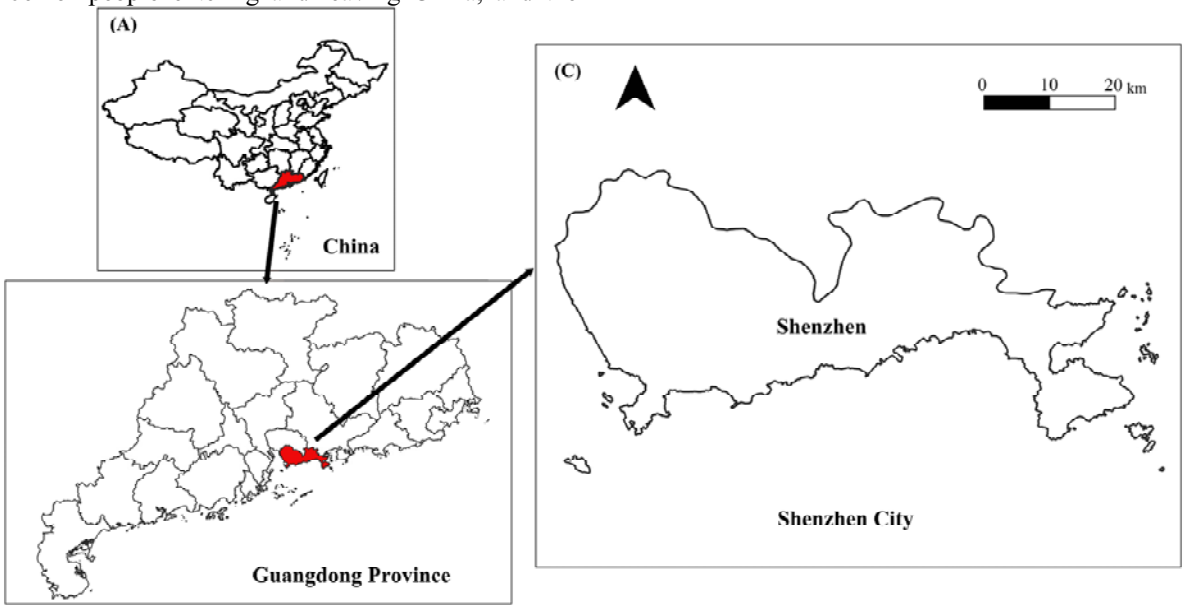

Figure 1. The geographic location of Shenzhen: (A)the location of Shenzhen in China; (B) the location of Shenzhen in Guangdong Province; (C)Shenzhen administrative area map

2.2 Data acquisition and processing

Several CCI-LC products land cover maps for Shenzhen, including five time periods (1995, 2000, 2005, 2010, 2015), was obtained from ESA CCI Land Cover project (mailto:contact@esa-landcover-cci.org), which delivers a time series of 24 consistent global LC maps on an annual basis from 1992 to 2015. They were used to provide the inputs to the analysis. The land cover maps were then clipped by shapefile (commonly used format that can be directly used in ArcGIS software) of Shenzhen, obtained from GADM data(https://gadm.org/data.html). The study area consists of 52,812 pixels, with a spatial resolution of 300 m.

Five general land use types were reclassified: urban, water, forest, grass land, and crop land. More detailed land use categories within each type are listed in Table 1. The reclassification was carried out by using the Spatial Analyst Toolbox of ArcMap10.4.1 software. The land use types were further converted to only two classes: urban and non-urban to better study the urban expansion. Further study on driving factors on the rate of urban expansion was carried out thanks to Shenzhen Statistical Yearbook 2020(http://tjj.sz.gov.cn/attachment/0/736/736628/8386382.pdf), containing comprehensive statistics of Shenzhen's social and economic development in 2019 and selected data of some important years and the period after the establishment of the city.

Table 1. Land use types and their constituents

Reclassification land use	Original land cover
Urban	Urban areas
Water	Water bodies
Forest	Tree cover
	Sparse vegetation
	Shrubland
	Shrubland evergreen
	Mosaic tree and shrub(>50%)
Grass land	Grassland
	Herbaceous cover
	Mosaic herbaceous cover (>50%)
Crop land	Cropland
	Mosaic cropland (>50%)

3 Research methods

3.1 Landscape Expansion Index

The Landscape Expansion Index (LEI) proposed by Liu Xiaoping can quantitatively describe the scale of landscape expansion and identify the pattern of landscape expansion [11]. LEI is defined by buffer, and its formula is:

$$\mathrm{LEI}=100\times\frac{A_o}{A_o+A_v} \tag{1}$$

In this formula, A_o is the overlapping area between the buffer zone and the occupied patch, A_v is the intersection between the buffer and the vacant patch.

The range of LEI varies from 0 to 100. In addition, when $50<LEI\leq100$, the expansion pattern is infilling; if $5\leq LEI\leq50$, the expansion pattern is edge-expansion; and if $0\leq LEI<5$, it belongs to outlying type.

3.2 Urbanization Growth Index

In order to quantitatively study the expansion intensity of urban land in Shenzhen, we calculated some indices of growth quantity and area widely used in the previous study of urban expansion [12]:

$$\Delta U=\Delta U_{t+1}-\Delta U_t \tag{2}$$

In this formula, ΔU represents the increase of the urban area, while ΔU_{t+1} and ΔU_t represent the urban area at time t+1 and t, respectively.

More importantly, Urbanization Growth Index (UGI) is used to represent the annual average Growth rate of urban area, and its formula as follows:

$$UGI=\frac{\Delta U_{t+1}-\Delta U_t}{\Delta T} \tag{3}$$

In the formula, ΔT is the time interval in years. According to previous studies and data distribution characteristics, UGI is divided into five levels, as shown in table1:

Based on these indices, UGI in Shenzhen in different time periods are analyzed, which is detailed as follows (Table 2):

Table 2. UGI rating

Expansion Rate Level	UGI (km^2/a)
Super-low speed	<2
Low speed	2-5
Moderate speed	5-7
High speed	7-10
Super-high speed	>10

3.3 Pearson product-moment correlation coefficient

Pearson product-moment correlation coefficient was used to identify the correlation between urban area and different impact factors. The formula is:

$$r(X,Y)=\frac{Cov(X,Y)}{\sqrt{Var(X)Var(Y)}} \tag{4}$$

where, $Cov(X,Y)$ is the covariance of X and Y, $r(X,Y)$ is the correlation coefficient of X and Y variables, $Var(X)Var(Y)$ is the variance of two variables. In detail, Y is defined as City Area, X is the driving force factor (Table 3).

Table 3. Driving variables of urban expansion in Shenzhen

Independent variable	Meaning
X1	Gross Domestic Product (10,000 yuan)
X2	Population (billion persons)
X3	Investment in Fixed Assets (10,000 yuan)
X4	Gross Domestic Product Per Capita (yuan)
X5	Freight Traffic Volume (10,000 tons)
X6	Total Imports and Exports (USD 10,000)
X7	Students Enrollment in Institution (person)

4 Results and discussion

4.1 Land use change

We first describe the changing landscape pattern during urbanization at the whole landscape level. Figure 2 is the distribution map of land use types in Shenzhen every five years from 1995 to 2015. It is indicated that the main land use type in Shenzhen was crop land in 1995 and 2000, while in 2005, changed to urban land. Since then, urban land has always accounted for the largest proportion of all land use types, which also illustrates the intense urban expansion of Shenzhen from 2000 to 2005.

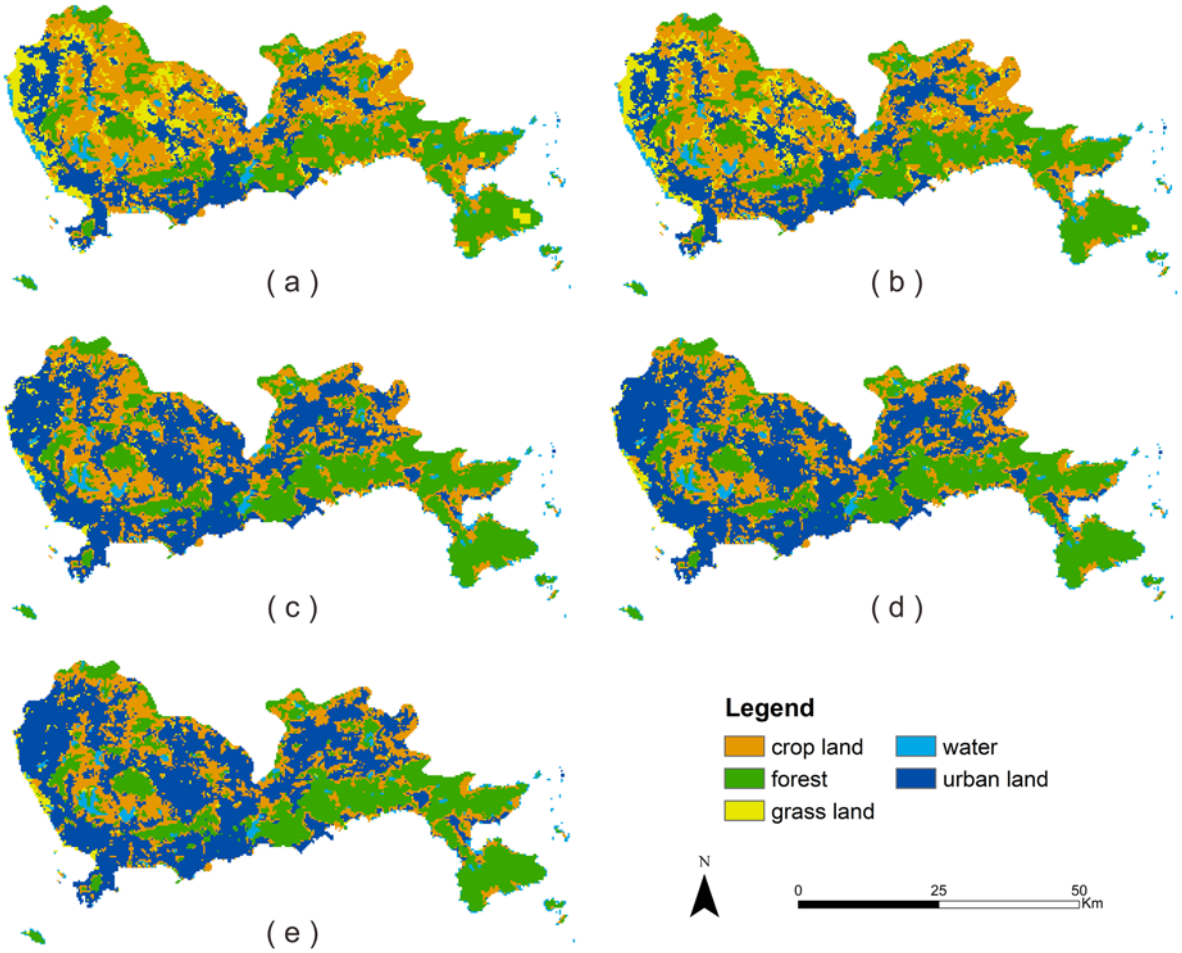

Figure 2. Distribution of land use types in Shenzhen every 5 years in different periods(1995(a), 2000(b), 2005(c), 2010(d) and 2015(e))

Based on the results of the area data in ArcMap statistics for 2010, Fig. 5 is carried out for further study in the change of land use types in Shenzhen from 1995 to 2015. As can be seen from the line chart (figure 3), the main land use types in Shenzhen in the past 20 years were crop land, forest, and urban land, while grass land area and water area were small. The main change is the decrease of crop land (700 km² in 1995 and 480 km² in 2015) and the increase of urban land (420 km² in 1995 and 850 km² in 2015). The most dramatic change occurred between 2000 and 2005, when the total area of urban land reached 800 km². The bar chart (figure 4) shows the proportion of each land use type in Shenzhen in different periods. The five bars represent the proportion of each land use type in the area of all land use types in 1995, 2000, 2005, 2010, and 2015 respectively.

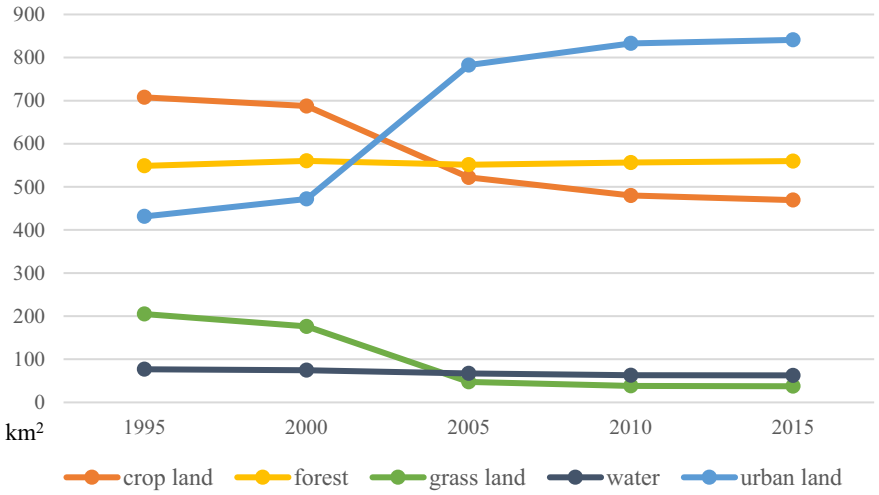

Figure 3. Area of each land type in Shenzhen during period 1995-2015

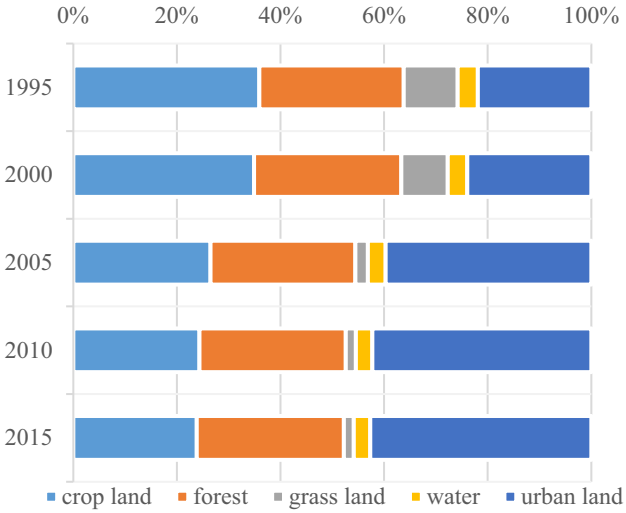

Figure 4. Proportion of each land type in Shenzhen during period 1995-2015

The land change maps of every five years from 1995 to 2015 were illustrated in figure 5, which can demonstrate the interconversion among different land use types more clearly. Among them, the number of crop land patches that turned into urban patches is the largest, followed by grassland, which mainly occurred during the period 2000-2005. As a result, the number of land use change patches between 2000 and 2005 was the highest. By contrast, from 2010 to 2015, the number of land use change patches was the least, and each land use type was relatively stable.

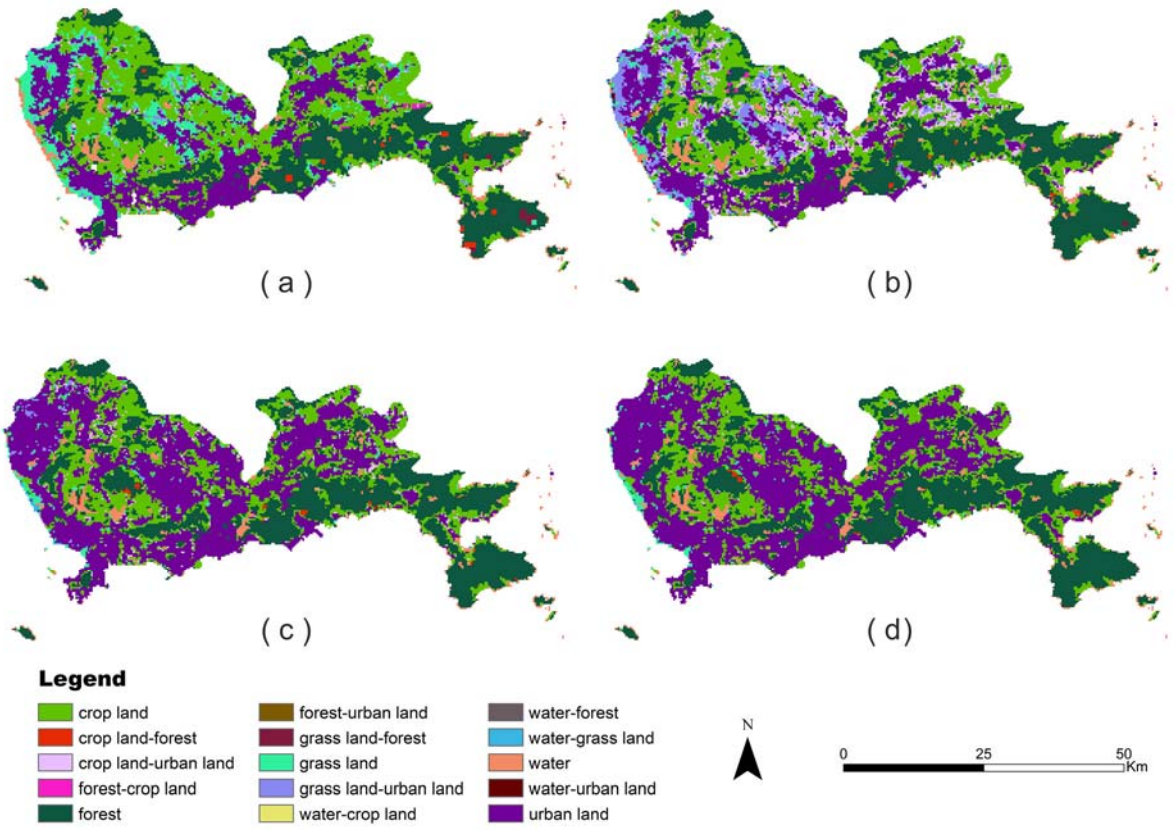

Figure 5. Changes of land use types in Shenzhen every 5 years during different periods(1995-2000(a), 2000-2005(b), 2005-2010(c) and 2010-2015(d))

We quantified land use change based on the area data in ArcMap statistics. According to figure 6, during the period 1995–2015, the main source of urban land transfer in Shenzhen was crop land, which increased year by year from 46% to 84%, while the proportion of grassland that changed into urban land decreased from 49% to 7%. Besides, the contributions of forests and water bodies to urban growth have been modest, at less than 5% each.

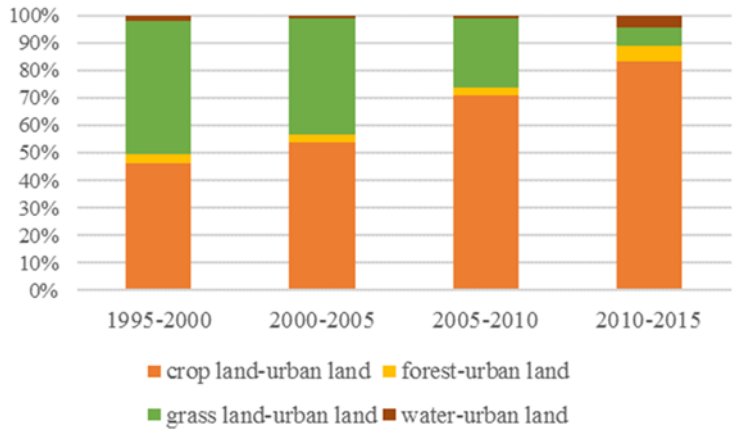

Figure 6. Proportion of land types and sources of urban expansion in Shenzhen every five years during different periods

4.2 Landscape expansion analysis

With the reform and opening up accelerating the process of urbanization in China, scholars are also conducting more and more studies in this field [13], [14]. As one of the earliest special economic zones in China, Shenzhen plays the role of a leader in socialist modernization, attracting a large number of foreign technologies and scientific management models [15]. Therefore, Shenzhen is a fast-expanding city in China. According to figure 7, the graph demonstrates three different ways of urban expansion in Shenzhen, which are classified according to the formula (1). From figure 7a, Shenzhen expanded smoothly from 1995 to 2000, and edge-expansion was the main urban expansion mode. It can be seen from figure 7b that from 2000 to 2005, the expansion type of Shenzhen was still mainly in the form of edge-expansion. Meanwhile, the expansion type of Shenzhen still dominated by edge-expansion from 2000 to 2005, and during this period, the area occupied by various urban

landscape expansion types increased. Besides, the urban expansion was relatively uniform, and more outlying-type appeared in the northern part of Shenzhen. However, the speed of urban expansion in Shenzhen slowed down sharply in 2005-2010, though the main urban expansion pattern was still edge-expansion, which concentrated in the northern region, and the urban structure became more compact (figure 7c). In 2010-2015(figure 7d), edge-expansion was still the main way of urban expansion, and the urban area of Shenzhen increased slightly during this period.

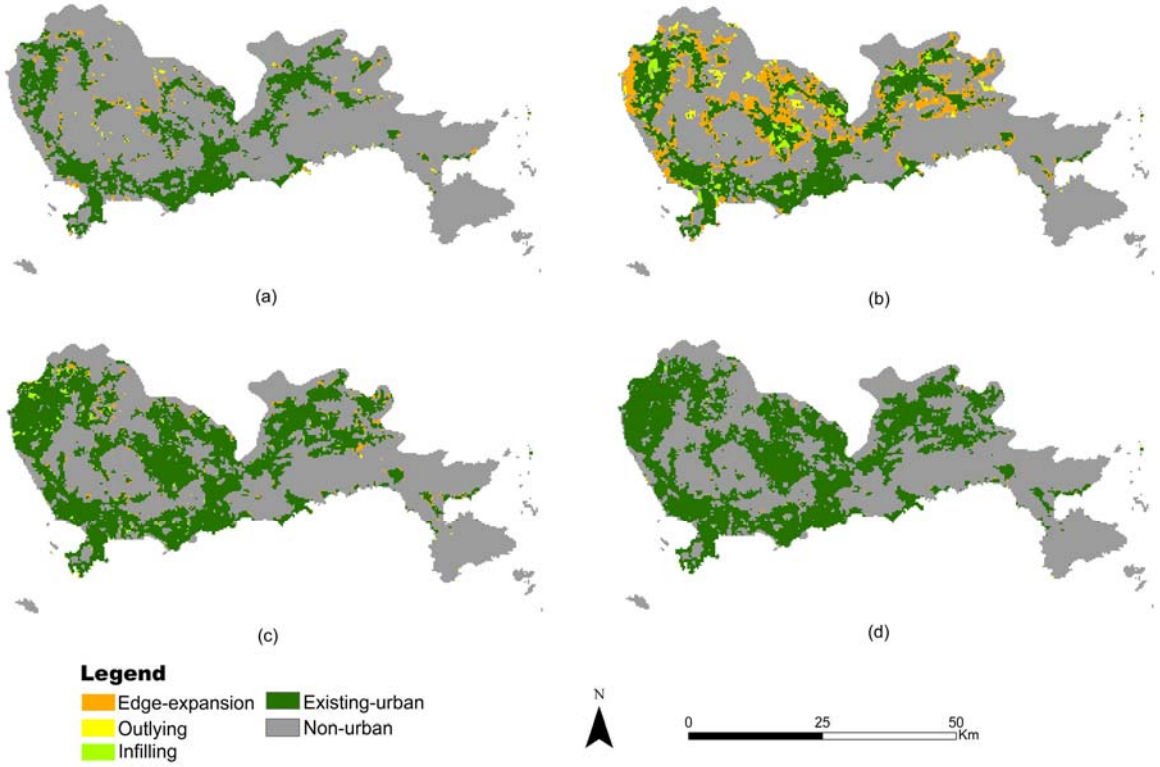

Figure 7. This figure illustrates the spatial distribution of 3 urban expansion types of Shenzhen during 4 periods respectively(1995-2000(a), 2000-2005(b), 2005-2010(c) and 2010-2015(d))

According to figure 7, figure 8 and figure 9 are obtained by data statistics. Figure 8 shows the proportion of urban expansion types in Shenzhen from 1995 to 2015. We could learn that edge-expansion has always been the chief way of urban expansion in the past 20 years (figure 8), the proportion of infilling had been rising during 1995-2010 while the outlying's had been falling. Besides, the drastic urban expansion occurred in Shenzhen in 2000-2005, and the urban landscape expansion speed in Shenzhen dropped rapidly in 2005-2010 (figure 9).

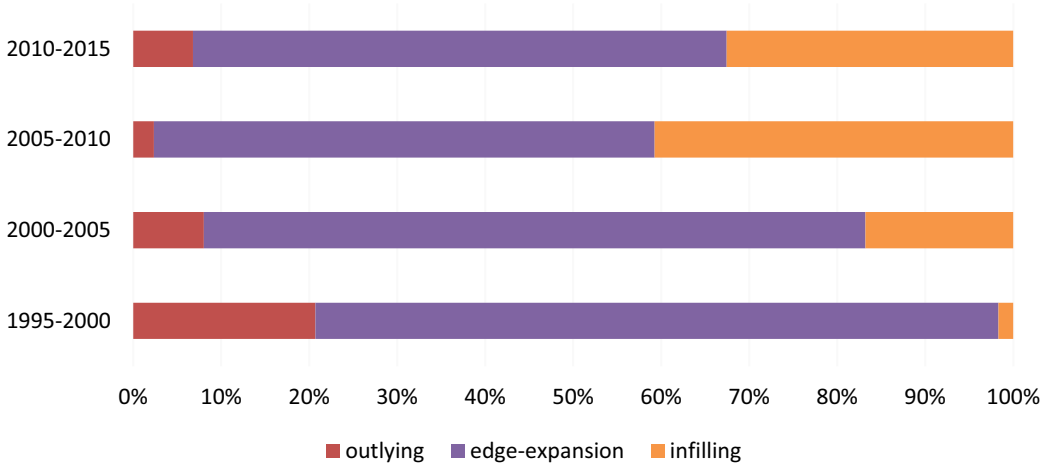

Figure 8. The proportion of Urban Expansion Types in Shenzhen from 1995 to 2015

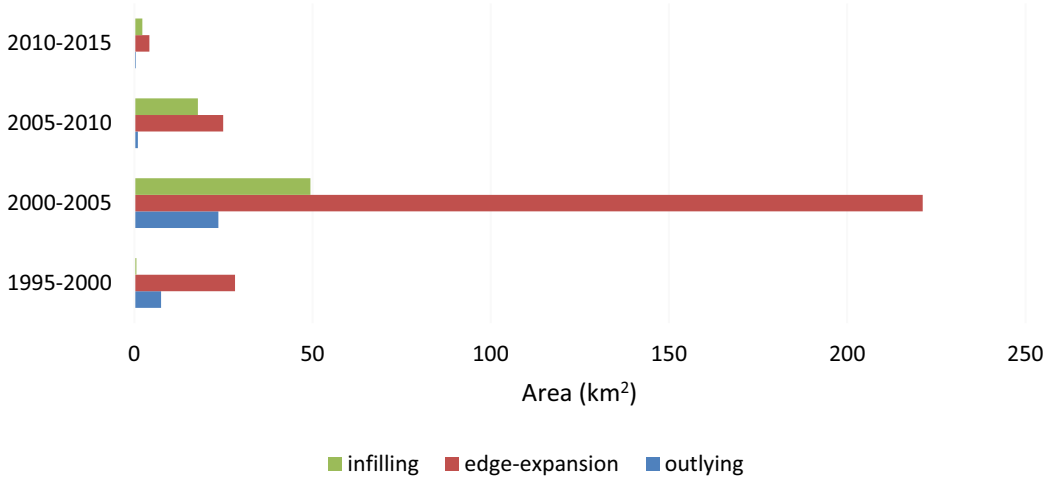

Figure 9. Area of Urban Expansion Types in Shenzhen from 1995 to 2015

4.3 Urbanization Growth analysis

According to formula (2) and formula (3), the results are shown in Table 4. We can see intuitively that during 2005-2010, the urban expansion of Shenzhen reached the highest speed in 20 years, with a UGI of 58.84 (km²/a), which also supports the previous conclusion we drew from the change detection. After this period, the expansion rate of Shenzhen decreased to 8.77 (km²/a) during 2005-2010, which is similar to the UGI of the period from 1995 to 2000. However, the UGI of Shenzhen plummeted down to only 1.40, representing a super-low speed of urban expansion after 2010, mainly due to a shortage of urban land resources [16].

Table 4. Urbanization growth index of four periods in Shenzhen

Period	ΔU(km²)	UGI(km²/a)	Expansion Rate Level
1995-2000	40.14	7.28	High speed
2000-2005	310.77	58.84	Super-high speed
2005-2010	50.31	8.77	High speed
2010-2015	8.19	1.40	Super-low speed

4.4 Quantitative analysis of driving factors

As shown in Table 5, through the calculation of the correlation coefficient between the potential driving factors and the city area, it can be seen that Students Enrollment in Institution has the strongest correlation with city area, with a correlation coefficient of 0.934. And it is closely followed by the Population, with a correlation coefficient of 0.912. Compared to the population and education factors, the correlation coefficients of economic factors are lower. The factors ranked 3-6 are GDP (Gross Domestic Product Per Capita), Investment in Fixed Assets, Freight Traffic Volume, and Gross Domestic Product, with the correlation coefficient of 0.827, 0.825, 0.814, and 0.801, respectively. The correlation between Total Imports and Exports and city area is the smallest, with the coefficient of 0.559, ranking 7.

We believe that the drivers of urban expansion are different in different regions. Cui el al found the main driving force of Guangzhou expansion includes economic growth, urban population, and transportation development [17]. Thapa et al think that the core factor of urban expansion is economic opportunities in the Kathmandu valley, Nepal, while the population growth is the fringe [18]. However, our results show that the education and population growth is the main factor of urban growth in Shenzhen. Students Enrollment in Institution offers talents, for the reason that most of the college students in Shenzhen prefer to stay local to make contributions. As the population grew exponentially, urban sprawl became necessary to accommodate such a large population, and the city area increased.

Socio-economic is one of the dimensions to examine the drivers of urban expansion [16]. GDP (Gross Domestic Product), external trade, and other kinds of indicators are the driving forces in Chinese cities growth [19]. In a general view, economic development mainly leads to urban expansion. We think that traditional economic indicators have many limitations when they are used to describe economic development which influences the urban expansion. For example, GDP (Gross Domestic Product) has its main limitations rather than OECD Better Life Index [20]. However, similar indices like OECD Better Life Index are only available in some countries and are only calculated on a country-wide basis rather than a city-wide basis. We hope that there will be future studies on the drivers of urban expansion based on these new indices calculated on a city-wide basis.

Table 5. Correlation of potential factors with land area

Variable	Correlation coefficient	Ranking
Students Enrollment in Institution (person)	0.934	1
Population (billion persons)	0.912	2
Gross Domestic Product Per Capita (yuan)	0.827	3
Investment in Fixed Assets (10,000 yuan)	0.825	4
Freight Traffic Volume (10,000 tons)	0.814	5
Gross Domestic Product (10,000 yuan)	0.801	6
Total Imports and Exports (USD 10,000)	0.559	7

5 Conclusion

Since the establishment of the Chinese Special Economic Zone, Shenzhen has made remarkable achievements in the rapid construction of new urban areas and the promotion of industrialization and technological innovation during the 20 years between 1995 and 2015, providing valuable experience for China's urbanization. In this study, information of the dynamic change process of landscape pattern in Shenzhen during 1995-2015 was obtained through spatial analysis, with the help of GIS and remote sensing. It is concluded that the main change of land use types is the decrease of crop land and the increase of urban land. With the most dramatic change period from 2000 to 2005, urban land became the largest land use type, mainly converted from crop land and grass land.

By using the proposed landscape expansion index (LEI), which can identify various urban growth types, i.e., infilling, edge-expansion, and outlying, our study has investigated the urban growth processes in Shenzhen for four periods, i.e.,1995–2000, 2000–2005, 2005–2010 and 2010–2015. The analysis has demonstrated that the main type of expansion during the 20 years between 1995 and 2015 is edge-expansion, with a total area of 278.7 km^2. Most conspicuously, the proportion of infilling had been rising during 1995-2010 while the outlying's had been falling. After 2010, the urban area of Shenzhen increased slightly. Therefore, although the infilling remains the dominant type of urban expansion, there are only 4.2 km^2 to be detected.

In order to further quantify the urban expansion research, the average annual growth rate of urban land area was calculated based on Urbanization Growth Index (UGI). It supports the previous conclusion that urban area of Shenzhen expanded at the highest speed from 2000 to 2005, with a UGI of 58.84 (km^2/a). Our study of urban expansion in Shenzhen also considers the influence of driving factors on the rate of urban expansion. The results show that the education and population growth are the main factors of urban growth in Shenzhen, which is reflected in the strongest correlation between university enrollment and urban area, with a correlation coefficient of 0.93.

Ultimately, this study has a basic grasp of the urban growth types and their changes in Shenzhen during 1995-2015 by using LEI, increasing understanding of the spatial structure of urban growth in Shenzhen. Future research could include deeper discussion of land use planning and its implementation to further optimize the selection of indicators affecting urban sprawl and determine their weight, so as to provide in-depth theoretical experience for urban development in China.

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