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RESEARCH ARTICLE

Driving factors of urban land growth in Guangzhou and its implications for sustainable development

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Abstract Since 2000, China's urban land has expanded at a dramatic speed because of the country's rapid urbanization. The country has been experiencing unbalanced development between rural and urban areas, causing serious challenges such as agricultural security and land resources waste. Effectively evaluating the driving factors of urban land growth is essential for improving efficient land use management and sustainable urban development. This study established a principal component regression model based on eight indicators to identify their influences on urban land growth in Guangzhou. The results provided a grouping analysis of the driving factors, and found that economic growth, urban population, and transportation development are the driving forces of urban land growth of Guangzhou, while the tertiary industry has an opposite effect. The findings led to further suggestions and recommendations for urban sustainable development. Hence, local governments should design relevant policies for achieving the rational development of urban land use and strategic planning on urban sustainable development.

Keywords driving factors, urban land growth, principal component regression, land management policy, sustainable development, Guangzhou

1 Introduction

With the rapid economic development of China in the late 1980s, the rising economy has accelerated the urbanization process and led to an increase in the number of people moving from rural to urban areas. More agricultural land areas have been transformed into urban areas to supply the urban population with adequate shelter and settlements. This trend is expected to continue in the coming decades, especially for large cities, possibly resulting in a larger loss of agricultural land and greater degradation of the environment[1)].

Urbanization and its synergy effect have significantly influenced urban land use, including land demand-supply, land use structure, land use function, and land ownership. Some scholars have argued that urbanization was the most immediate driving force on land use change in the developing countries (Xiao et al., 2006; Chen et al., 2008). This situation is more apparent in big cities such as Guangzhou, which the third largest city in China. As an important economic and cultural hub of China, Guangzhou has been in a period of rapid urbanization. Rapid economic development (ranking third among the cities in China for 25 years) has made Guangzhou an economy-developed city, featuring a crowded city center, scattered edges, and increasing land price. This imbalance of land supply and demand (Bao et al., 2014), irrational land use, and its destructive effect on resources and the environment (Guo et al., 2008), have made future rapid development difficult for Guangzhou. Thus, new requirements are necessary for more sustainable development (Ma et al., 2010). Effective and sustainable utilization of urban land resource could be one of the most important issues in the future urbanization process. Hence, policy makers must identify the specific problems of, and optimize the use of, urban land. Urban land use management should be exerted on the basis of rational urban land growth to benefit sustainable urban development.

This paper aims to evaluate the driving factors of urban land growth by establishing an indicator frame work and to explore the driving forces of urban growth in Guangzhou by using a regression model. This study is organized as

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1) United Nations. World urbanization prospects, the 2007 revision.

follows: First, a review of existing studies on urban land growth and its driving forces is introduced. This review is followed by a brief outline of the research hypothesis and method. Guangzhou city and its urban land use situation are chosen as the subject of this study. Data collection and processing are clarified, and the regression results lead to a detailed analysis of the effects of these indicators. Finally, appropriate policies and strategies for promoting urban land use efficiency and driving urban sustainable development are suggested on the basis of the findings of the study.

2 Literature review

Most scholars have argued that urbanization is the most direct driving factor of urban land growth and urban land use change (Liu et al., 2003; Li et al., 2006; Liu et al., 2014b; Long et al., 2014). Urbanization has also been studied widely in farmland conversion studies (Pribadi and Pauleit, 2015). As one of the main sources of human food, farmland has been an important part of human society development, but its conversion to urban land is an inevitable trend because of urbanization and industrialization (Pandey and Seto, 2015; Yang et al., 2015; Li et al., 2017; Liu et al., 2017). Understanding the driving factors of urban land growth and protecting farmland are important issues in the urbanization process all over the world. Studies that focus on related content have proposed their points on urbanization. Chen et al. (2014) have compared urban land expansion in Shenzhen and Dongguan, two adjacent cities in South China. The driving factors of urbanization in these cities include 1) development of capital- and technology-intensive industries; 2) total GDP and per capita GDP; 3) government policies; 4) transportation facilities; and 5) immigrants. The expanding mechanism in these cities differ from that of each other. Because Shenzhen has benefitted from government policies, the city has much more favorable conditions to attract population and develop high-tech industries that support its urban development and land expansion. In contrast, Dongguan has continued to rely on export-oriented manufacturing and processing, resulting in land use change. Liu et al. (2013) studied the rural-urban development patterns using data from 31 Chinese provinces (autonomous regions and municipalities), and concluded that institutional structure and its corresponding policies, economic growth and urbanization, were the main driving factors causing urban expansion. Taking 288 cities in China as the research object, Zhou et al. (2017) estimated the effect of land use planning on urban land growth. The effect of land use planning presented significant differences among cities. Mega and large cities experienced weaker effects, while medium-small cities experienced stronger effects. Liu et al. (2015) explored the urban–rural construction land use change and its anthropogenic driving forces in Wuhan from 1996 to 2009. They pointed out that societal and economic factors, including demographic change, economic growth, living standards, and policies were related closely to the urban–rural construction land use pattern. Gao et al. (2014) used land use survey data in Jiangsu province at the county level to shed light on the effects of economic transition on land use change and urban land expansion in China. They found that urban land expansion has a temporal dimension and is driven mainly by local governments. Foreign scholars in Indonesia have identified the land use change in Banda Aceh from 2005 to 2009 and examined the driving factors that influence urban land growth. Their results showed that socio-economic factors including population density and distance to the central business district had positive influence on the growth of urban area. In contrast, the biophysical factors, including distances to green open spaces, historical areas, rivers, and highways had negative effects (Achmad et al., 2015). On the basis of Landsat remote sensing data, Ma and Xu (2010) studied the driving force of urban expansion in Guangzhou city and concluded that GDP, total population, urban resident income, and urban traffic were the dominating driving factors for urban built-up area expansion. These studies on driving factors have become useful for research on the mechanisms of urban land growth. Several assessment tools have been proposed to help achieve specific needs and goals.

First, models for simulating land use change were used to provide alternatives for policy making (Liu et al., 2014a). Zheng et al. (2015) used the CLUE-S model and the Markov Chain prediction for land use change in the urban renewal of Hong Kong. Through this method, a scenario analysis was applied to show the different policy directions of land use in the future. A methodology based on GIS and spatial multi-criteria analysis was used to map land use competition in Meknès, Morocco (Debolini et al., 2015). The map can be considered as a preliminary tool for improving new planning strategies to manage land resource competition in rural–urban fringe zones. Scholars usually adopted cellular automata (CA) as an important method to simulate the land use change. Sun et al. (2012) took CA and a geographical information system to study the relationship between trip generation and urban land use, which could also help in understanding the evolution of urban land use in Florida. CA has also been used in assessing factors for urban land growth because of its capability to reproduce characteristics of urban evolution processes and explore future scenarios (Pablo et al., 2015). A partial validation based on CA was applied in their study, which took Madrid, Spain as an example. Several simulations were computed by different combinations of the factors to enable the testing of the spatial variability of given factors and the detection of the more robust areas. Some Chinese scholars have used a GIS-based CA model to simulate the vertical urban growth in Guangzhou from 2001–2010 (Lin et al., 2014). By displaying the buildings'

spatio-temporal changing process on urban landscapes, the important feature of smart urban growth was provided. Kong et al. (2012) developed and applied an urban growth model to ensure that sustainable cities incorporated spatial metrics. They predicted the urban growth trend and examined the effects of urban development on natural resources in Jinan, China.

Second, studies on urban land use change have also been connected with sustainable development. Tian (2015) examined the land use change in Jiangyin city and Shunde city from 2001 to 2010 and found that land revenue contributed large quotas for the industrial sector. Moreover, the expansion of industrial land played a dominant role on urban sprawl, which had negative effects on sustainable development. Musakwa and Niekerk (2013) used decision consequence analysis to study urban sustainable development. Their findings showed that land use change affects sustainable development, and planners can use land use change indicators to support land use policy decisions. Wang et al. (2015) examined urban land use and land planning in Hong Kong from the perspective of sustainability. Their study used an urban renewal case and discussed problems in the planning system of Hong Kong. Cui and Wang (2014) studied the urban land use change in Shanghai. Their study proved that urban land management could lead to sustainable development by balancing the social metabolism flow, which was used to measure its contribution to sustainable development (Conke and Ferreira, 2015). From the perspective of land use change and land use efficiency, Chinese scholars used the data on 336 cities in China from 2005 to 2012 and found that the National General Land Use Plan had failed to control the expansion of built-up area and was useless in promoting intensive land use (Chen et al., 2016a).

3 Research hypothesis and method

3.1 Hypothesis

This study was based on the following hypotheses from the scope of the study, types of driving forces, and methods:

1) Research scale is important in urban land growth studies, because the evolutionary processes may have different influences on land use change depending on their scales. These scales include spatial boundary, time span, and quantitative or analytic dimensions (Gibson et al., 2000). Defining the specific scale for choosing the exogenous variables, or the so-called driving forces, is necessary. The scale of this study is on the local level. The urban area is influenced by economic and social resources, and other changes in its city center and the surrounding suburbs or countryside managed by the municipal government. From this perspective, the driving factors of urban land growth can be understood through social science theory and methodology.

2) Land use change is often considered and modeled as a function of the selected socioeconomic or biophysical driving forces. Among the three groups of driving forces, including socio-economic, biophysical, and land management drivers (Turner II et al., 1995), socio-economic and land management drivers were chosen in this study to explore the mechanism of urban land growth. Although the biophysical factors could also influence land use decisions, these factors cause land cover change more directly through climate change and soil quality in the long term (Verburg et al., 2004). In this case, socio-economic factors should be more important in the urban land use study.

3) From the socio-economic perspective, the driving factors are considered exogenous to the urban land use system to establish a quantitative model in this study. Based on statistical techniques, an econometric model could be established to identify the socio-economic factors that cause the urban land use change, and to quantify the relations between urban land growth and their driving forces.

3.2 Method

For model implementation, two steps of the driving factors chosen were of importance: variable selection and the quantification of the relationship between urban land growth and their driving forces.

3.2.1 Variable selection

According to related literature, urban land use is usually measured by the total urban area. According to the Ministry of Housing and Urban-Rural Construction of the People's Republic of China (GBJ137-90), urban land use can be classified into ten types: residential, commercial and public facility, industrial and warehouse land, intercity transportation land, road, street and square, municipal utilities, green space, specially designed land, water bodies, and other non-urban development land. Based on this classification, the total urban area is called an "urban build-up area" determined by the total area of these ten land use types, and set as index Y in the regression model. The dependent variable facilitates the regression model and explores the driving force of the urban land growth.

The dependent variables were chosen on the basis of China's economic development and urbanization process. These eight factors were considered as follows: macro-economic factors, foreign investment factors, secondary industry factors, tertiary industry factors, population factors, fixed investment factors, transportation factors, and government regulation factors. These factors are defined in Table 1.

Focusing on China's economic transition on land use change, local officials have been pushed to increase their revenue by transforming rural land into urban areas.

Table 1 Indexes of urban land use and its influencing factors

Variables	Symbols	Definitions/calculate method
Urban land use	Y	A measurement of urban construction land area that represents the urban land use scale and its growth, it is defined by the city build-up area (Zhang et al., 2011; Zhu et al., 2014)
Macro-economic development	X_1	A measurement of the economic development of a city, it is usually quantified as GDP. The relationship between economic growth (GDP) and urban land use has been proven to exist (Cui, 2007)
Strength of foreign direct investment (FDI)	X_2	A measurement of the strength of FDI, it can be calculated by the proportion of the absolute values of FDI account to GDP (Gao et al., 2014)
Secondary industry development	X_3	One of the measurements of industry structure change in particular time intervals. It can be calculated by the proportion of the second industry as a share of GDP (Gu et al., 2009; Meng et al., 2011)
Tertiary industry development	X_4	One of the measurements of the industry structure change in particular time intervals. It can be calculated by the proportion of the tertiary industry as a share of GDP (Gu et al., 2009; Meng et al., 2011)
Population	X_5	A measurement of the urban population that reflects urban land demand during the urbanization process. Rural inhabitants choose to move to urban areas, causing an increase in the demand for urban land (Yuan, 2005)
Strength of fixed asset investment	X_6	A measurement of the fixed asset investment, it is one of the influencing factors that improves urban infrastructure and attracts population (Xu et al., 2006)
Urban rail transit development	X_7	A measurement of the public traffic in large cities, it is calculated by rail transit capacity. It can be considered an influencing factor that affects urban growth (Li and Yan, 2002; Aljoufie, 2014)
Government regulation on urban land use	X_8	A measurement of the government's regulation on urban land use, it is calculated by the sales area of urban land (Cui et al., 2012; Bai et al., 2014)

Officials are driven mainly to do this because of the decentralized fiscal responsibilities of local governments and powerful economic incentives. These land finance and political tournaments among local government officials have become the incentives of urban expansion (Gao et al., 2014). Thus, local factors, such as the local socioeconomic situation, are important in the process of urban expansion. Cui (2007) suggested that the GDP increase affected the macro-economic environment and caused further demand for urban land. Because of globalization, foreign investment has influenced regional land use through operations establishment. In this study, we tested the influence of economic globalization on regional land use change as indicated by regional foreign direct investment (FDI) as shown in Table 1. The industry structure is usually thought to be an important aspect that affects urban land use because of its industrial productivity (Gu et al., 2009). The structure leads to regional specialization and influences the local land use structure (Meng et al., 2011). From this point of view, land use change is related closely to industrial structure, which was measured in this study through secondary and tertiary industry development. With the shift from arable land to construction land, accompanied by the flow of population and active investment (Yuan, 2005; Xu et al., 2006), we took the variables of population and fixed asset investment to measure the demand for increasing inhabitants. As decentralization has become one of the most important transition processes, public transportation has affected changes in regional land use. Urban land growth has been affected by a more convenient public transportation service (Li and Yan, 2002; Aljoufie, 2014), and we used the effect of urban rail transit development to measure its function on urban expansion. Aside from the eight factors enumerated above, local urban land supply is another key in increasing budgetary revenue and promoting urban land growth (Cui et al., 2012; Bai et al., 2014). In this study, the sales area of urban land was taken to measure the government's regulations on urban land use.

3.2.2 Relationship quantification

Different methods have been used by scholars all over the world to quantify the relations between urban land growth and its driving forces. Studies based on the economic input-output analysis cannot be implemented without empirical data (Waddell, 2000; Fischer and Sun, 2001), and this method has been found to be difficult to use in qualifying the driving factors and their influence on land use change. Econometric models, which usually rely on statistical techniques, have thus been developed. Regression analysis has been commonly used in land use change studies as a kind of multivariate statistical method. The regression model uses empirical methods to quantify the relationship between land use and driving forces. Regres-

sion builds the multivariate linear function by collecting and sorting sample data, and uses statistical methods (often least square method) to estimate the parameters. This method has been proven to be one of the most common approaches to quantify the relations between land use change and its driving forces. Econometric models usually rely on statistical techniques, mainly regression, to quantify the defined models based on historic data of land use change. These models describe historic land use change as a function of the changes in driving forces. By using the statistical data of land use change and its driving factors, the regression model establishment can be applied to check their supposed relations (Turner et al., 1996; Mertens and Lambin, 1997; Wear and Bolstad, 1998; Mertens and Lambin, 2000; Pontius and Schneider, 2001; Pontius et al., 2001; Serneels and Lambin, 2001; Zhang et al., 2005; Liu et al., 2009; Zhang, 2009).

In this study, the regression model was put forward by the supposed relations according to the simplification and the theoretical and behavioral assumptions of the land use system. This model can explore the driving forces of urban growth. The model will result in a stable explanation of land use change because the relation between land use change and driving forces has already been proven. The relationship can be expressed as an equation with independent variables X_1, X_2, ..., X_8, and dependent variable Y.

$$\begin{aligned} Y_1 &= b_0 + b_1X_{11} + b_2X_{12} + \ldots + b_pX_{1p} + \varepsilon_1, \\ Y_2 &= b_0 + b_1X_{21} + b_2X_{22} + \ldots + b_pX_{2p} + \varepsilon_2, \\ &\cdots \\ Y_n &= b_0 + b_1X_{n1} + b_2X_{n2} + \ldots + b_pX_{np} + \varepsilon_n. \end{aligned}$$

Generally, for data in a given spatial and temporal scale, this mathematic term expresses the influence of each driving factor through the estimation of these parameters (b_0, b_1, b_2,..., b_p) in the above equations, where ε_i shows the effects of the random factors. The estimation was based on the premise that independent variables do not exhibit multi-collinearity.

We avoid multi-collinearity between these variables by using principal component analysis (PCA) to test and reduce the dimensionality of the independent variables before regression model establishment. PCA relies on the variation and covariation of the data matrix, and constructs weights among the indices, which are then used to produce a small number of new variables to replace the original ones. Through PCA, the principal components can be extracted to simplify the data structure and minimize the original data information loss. The principal component regression model is expressed as the following:

$$Z_m = \sum_{i=1}^{n} \beta_{mi} \cdot X_i,$$

$$Y = \alpha_0 + \alpha_1 Z_1 + \alpha_2 Z_2 + \ldots + \alpha_m Z_m,$$

$$\alpha_i = (\mathrm{Z'_m} \cdot \mathrm{Z_m})^{-1} \mathrm{Z'_m Y^*}$$

$$= \begin{bmatrix} \lambda_1 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & \lambda_m \end{bmatrix}^{-1} \begin{bmatrix} Z_1 \\ \vdots \\ Z_m \end{bmatrix} \begin{bmatrix} y_1^* \\ \vdots \\ y_n^* \end{bmatrix}$$

$$= \begin{bmatrix} \lambda_1 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & \lambda_m \end{bmatrix} \begin{bmatrix} \sum_{i=1}^{n} Z_{i1} y_1^* \\ y_1^* \\ \sum_{i=1}^{n} Z_{im} y_i^* \end{bmatrix} = \begin{bmatrix} \sum_{i=1}^{n} Z_{i1} y_1^* / \lambda_1 \\ y_1^* \\ \sum_{i=1}^{n} Z_{im} y_i^* / \lambda_m \end{bmatrix}.$$

In this PCA regression model, Z_1,Z_2, …, Z_m are the principal components that are transformed from the original variables X_1,X_2, …, X_n through linear combinations. These principal components represent the main information of the driving factors of urban land growth and avoid multi-collinearity to ensure accuracy of the estimated results. The coefficients a_0,a_1,a_2, …, α_m show the influence of each principle component on the dependent variable. In this perspective, the effects of the original variables can be expressed as the following:

$$\begin{aligned} Y &= \alpha_0 + \alpha_1 Z_1 + \alpha_2 Z_2 + \cdots + \alpha_m Z_m \\ &= \alpha_0 + \alpha_1 \sum_{i=1}^{n} \beta_{1i} \cdot X_i + \alpha_2 \sum_{i=1}^{n} \beta_{2i} \cdot X_i + \cdots + \alpha_m \sum_{i=1}^{n} \beta_{mi} \cdot X_i \\ &= \alpha_0 + \sum_{i=1}^{n} \alpha_1 \beta_{1i} X_i + \sum_{i=1}^{n} \alpha_2 \beta_{2i} X_i + \cdots + \sum_{i=1}^{n} \alpha_m \beta_{mi} \\ &\triangleq b_0 + b_1 X_1 + b_2 X_2 + \cdots + b_i X_i. \end{aligned}$$

4 Empirical study

As reviewed in Section 2, a number of land use change studies took multiple levels into account. The driving forces have been found to change the demand for different land use types at aggregate levels, whereas the actual allocation of change was determined by regional or local conditions. Different hierarchical levels were used, and at each scale, different processes have a dominant influence on land use. These studies were bound by the extent and resolution of measurement, thus each result provided only a partial description of the entire multi-scale land use system. This study aimed to evaluate the driving factors of urban land growth of Guangzhou from 1991–2014 by establishing an indicator framework to explore the driving forces of urban growth during Guangzhou's rapid urbanization process.

4.1 Study area and its urban land growth

Guangzhou city was chosen as the subject of this empirical

study to explore the relationship between urban land growth and its driving factors. As the third largest Chinese city, Guangzhou has experienced rapid economic development and urbanization. During this process, economic growth and population migration accelerated the urban sprawl, and more urban land was needed to satisfy urban development. Under this situation, some problems emerged, such as an overcrowded city center, scattered city edge, and supply-demand contradiction. Because Guangzhou city has already adjusted its administration divisions several times, clarifying the specific study area and its variation is important.

Guangzhou changed its municipal boundaries in 2000, which made former towns Huadu and Panyu into two districts of Guangzhou. The second adjustment in 2005 adopted the area of Nansha and Luogang as two additional municipal districts of Guangzhou, causing the urban area of Guangzhou to increase rapidly. At present, Guangzhou city has 10 municipal districts (Yuexiu, Tianhe, Haizhu, Baiyun, Liwan, Huangpu, Huadu, Panyu, Luogang, and Nansha) and two county-level cities (Zengcheng and Conghua), as shown in Fig. 1. The 10 municipal districts listed above were chosen as the study area because their urban characteristics best represent the urban land use features of Guangzhou.

Because of the quantitative growth of urban land use in Guangzhou, the build-up area was 182 km^2 in 1990, and increased to 284 km^2 by 2000. After the administrative adjustment of the district divisions in 2000, the area increased to 431 km^2 in 2001, and expanded to 1024 km^2 in 2013 (Fig. 2). This dramatic land growth peaked twice, in 1996 (changing rate was 119.8%) and in 2001 (changing rate was 151.8%). After 2001, the changing rate was comparatively stable. Xu et al. (2016) observed the rapid urbanization in Guangzhou from 2000 to 2012, during which the built-up land increased by 118.91%. This expansion took the form of concentric circles extending around the old Yuexiu district. For their central districts

Fig. 1 Administrative district divisions of Guangzhou.

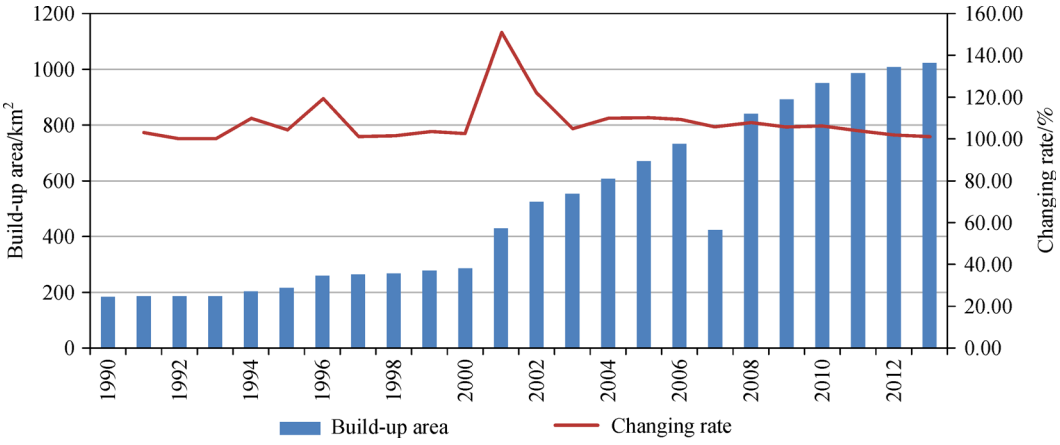

Fig. 2 The urban build-up area and its changing rate in Guangzhou (1990−2013). Data source: China City Statistical Yearbook 1991−2014.

study, Chen et al. (2016b) found that the urban land price in Guangzhou's central districts doubled from 1980 to 2010, and that road density and proximity to transportation services, banks, and hotels were the most important spatial determinants. The intensity change of urban land use in Guangzhou has been studied by Gong et al. (2014), who found that the rapid industrialization and urbanization have improved land-use intensity in Guangzhou. The per capita urban road area and per capita GDP show a strong relationship when compared with land-use intensity. Guangzhou might have experienced its great urban land growth during the rapid urban development.

According to the urban land expansion of Guangzhou from the map of aviation image data (Fig. 3), the build-up area has shown a continuous growth trend towards the north and the east, as in Tianhe and Haizhu districts. Figure 3 also shows a scattered sprawl situation by the administrative divisions change on Panyu and Huadu districts. Along with the economic development and mass transportation railway development, the new construction area in Guangzhou has become much larger since 1990. The quantitative relationship between urban land growth and its influencing factors should be understood to explain this dramatic growth.

4.2 Data collection and multi-collinearity analysis

Data for urban land use in Guangzhou was obtained from the Statistical Yearbook. The indicator of the build-up area of Guangzhou city was obtained from the National Urban Statistical Yearbook 1991–2014. Data for the influencing factors shown in Table 1 were included in the Guangdong Statistical Yearbook 1991–2014. Among these indicators, GDP was used by its constant price, and FDI and fixed asset investment were also handled by the GDP deflator.

After data collection, a correlation analysis was used to check the multi-collinearity among these driving factors. Their bivariate correlations were calculated by SPSS© 13.0. The correlation matrix can be found in Table 2, which shows significant multi-collinearities between some of the variables.

The new components and their eigenvalues contribution rate were calculated and are given in Table 3. Contributing 93.415% of the original information, the first two eigenvalues were satisfied of their cumulative variability (cumulative contribution rate > 90%) and were designated as Com-1 and Com-2, which were linearly combined by X_1, X_2, ..., and X_8 on the basis of their eigenvector's value.

The first component named Com-1 was predominantly loaded with X_1, X_2,..., and X_7. This component contained nearly 82.5% variance of the original data, including seven parts: 1) GDP, 2) FDI, 3) the proportion of the second industry as a share of GDP, 4) the proportion of the tertiary industry as a share of GDP, 5) total urban population, 6) fixed asset investment, and 7) rail transit capacity. This demonstrated that Com-1 was composed of the social-economic aspects. In this combination, X_1, X_2, X_3, X_4, and X_6 had high loads on economy development, and X_5, X_7 had high loads on social development. The second component, Com-2, reflected the other parts of the original information not described by Com-1. The second component provided a high positive weight on X_8 (0.921), which reflected the effect of government regulation.

In this context, these two components can be used as the independents to establish a regression model. Their driving mechanism on the dependent variable was found as expected.

5 Results

The PCA optimal regression model with two independents (Com-1 and Com-2) was finalized by ordinary least square (OLS) estimation. The results of the coefficients estimation passed the *t*-test, as shown in Table 4. Results presented significant relations between urban land growth and socio-economic development by the coefficient of Com-1. The effects of the government policy on urban land growth are

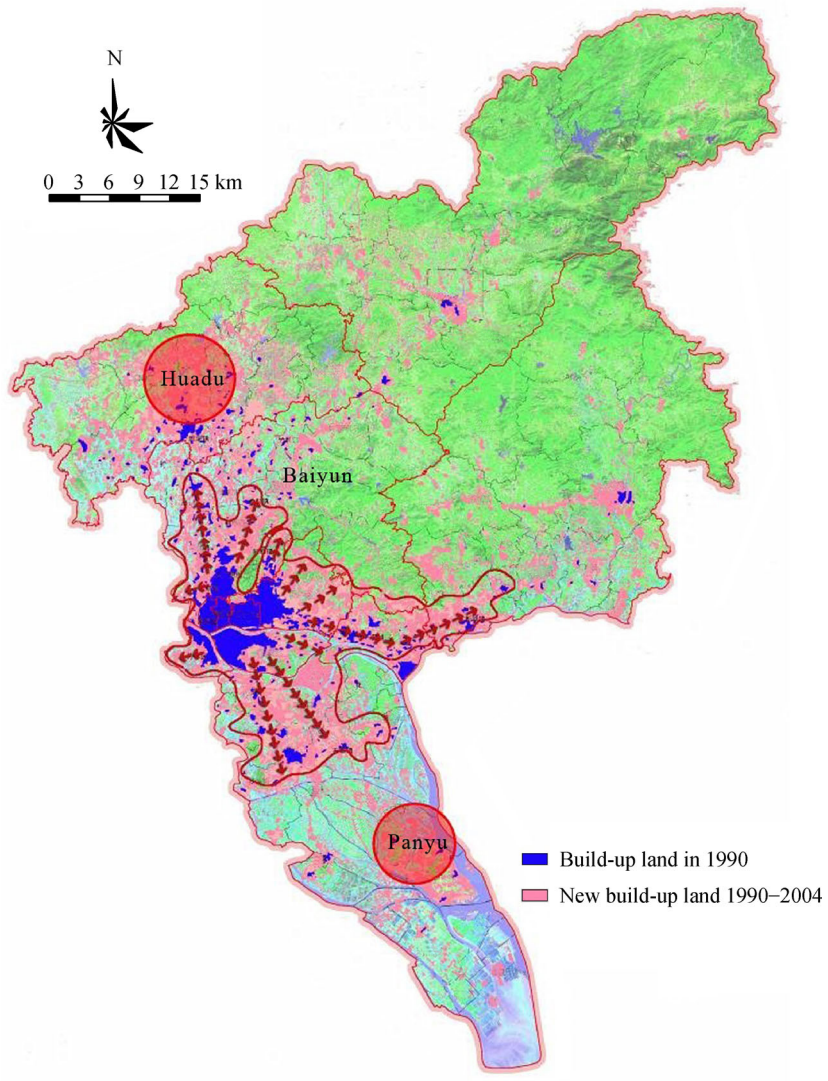

Fig. 3 Spatial expansion of urban build-up land in Guangzhou 1990–2004. Data source: Aviation image data 1990–2004.

Table 2 Correlation matrix of the influencing factors

	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8
X_1	1	0.931	−0.914	0.909	0.964	0.994	0.971	−0.316
X_2		1	−0.766	0.754	0.844	0.939	0.945	−0.295
X_3			1	−0.997	−0.964	−0.902	−0.842	0.331
X_4				1	0.973	0.892	0.824	−0.335
X_5					1	0.944	0.884	−0.344
X_6						1	0.978	−0.319
X_7							1	−0.315
X_8								1

also presented by the coefficient of Com-2.

The PCA regression equation is shown using the *B* value in Table 4. This equation could be shifted based on the component score coefficients. In the later formation, clarifying the effect of each variable on urban land growth was much easier.

$$Y = 653.45 + 265.27\text{Com-}1 + 8.42\text{Com-}2$$

$$Y = 653.45 + 40.53X_1 + 30.66X_2 - 38.43X_3 + 28.08X_4$$

$$+40.23X_5 + 23.25X_6 + 35.2X_7 + 16.53X_8$$

First, as expressed by the equation, the industrial structure adjustment in Guangzhou has played a significant role on its urban land growth. The tertiary industry had positive relationships with urban land growth in Guangzhou during the study period, while secondary industry was negatively related to urban land growth (the secondary industry was at –38.43, while the tertiary industry was at 28.08). This could be due mainly to industry relocation and the suburban industry park establishment. These changes have made the secondary industry development reach a scale agglomeration, as three

Table 3 Component matrix of the original variables

Variable	Component	
	Com-1	Com-2
X_1	0.991	0.076
X_2	0.916	0.082
X_3	−0.949	−0.023
X_4	0.943	0.016
X_5	0.977	0.028
X_6	0.986	0.073
X_7	0.956	0.072
X_8	−0.387	0.921
% of Variance	82.503	10.912
Cumulative %	82.503	93.415

Table 4 Results of the PCA regression model with Com-1 and Com-2

Model	Unstandardized Coefficients		Standardized Coefficients	*t*	sig
	B	Std.error	B		
	653.446	22.136		29.52	0.000**
Com-1	265.265	22.817	0.951	11.626	0.000**
Com-2	8.416	21.998	0.03	0.369	0.039*

main industry centers have already been distributed separately in the northwest, east, and south of Guangzhou (Fig. 4). Most auto industries, economic-technology centers, and port industries have gathered in these zones, causing an increase in economic output while negatively affecting urban land growth by using less land area. This combination of the industry groups and their intensive location pattern has benefitted urban land utilization. Generally, the adjustment of industry land use has affected urban land growth and has been consistent with the differential rent of urban land. Meanwhile, the tertiary industry has positively affected urban land growth during its development. As the third largest city in China, Guangzhou has dramatically developed its tertiary industries, resulting in more employment opportunities and larger living demands. These factors have become an important driver for urban land growth in Guangzhou. We should also put forward the problem of balancing residence and employment through urban land use planning and management.

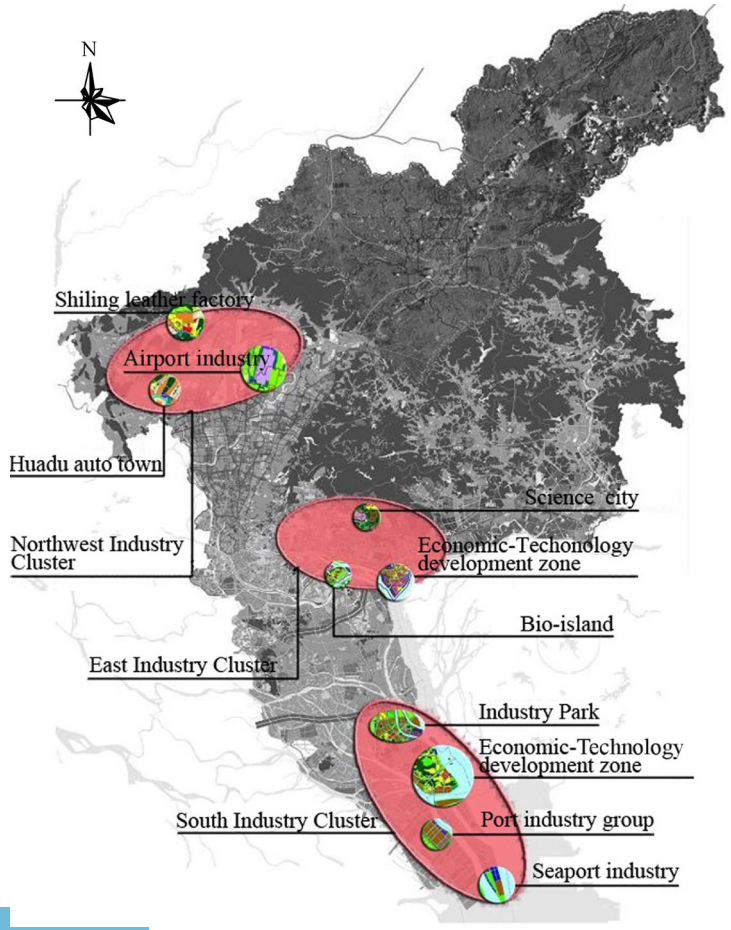

Fig. 4 Industry land use distribution in Guangzhou. Data source: Urban master planning of Guangzhou 2011−2020.

Second, gross economy was another driving factor of urban land growth in Guangzhou. Rapid economic development has stimulated the urban land demand and provided sufficient financial support for the urban renewal and urban new zone development. Accompanied by continuous economic development, the limited land resource cannot satisfy the increasing urban land use demand and urbanized advancement. Future economic growth in Guangzhou should be along the lesser land use demand and more economic output per unit area path.

Third, FDI positively influenced urban land growth in this equation. Since the 1990s, Guangzhou has exerted considerable efforts to improve its investment environment and invite foreign businesses. The foreign business share of the total industrial production was 44.2% in 1999, which increased to 62.3% in 2010. This improvement has considerably accelerated economic development, and at the same time, played an important role on urban land use by bringing in more foreign businesses. Guangzhou's manufacturing industry, especially the auto ones, accounted for a large percent of FDI, and had great demand on urban land use. As shown in Fig. 5, automobile enterprises, specifically the Toyota car plant, Honda automobile factory, and Dongfeng Nissan car manufacturer located on Guangzhou's outskirts, are the three major automobile giants that use foreign investments. All three companies chose the suburban areas, which were on the urban expanding orientations: the south route for Toyota, the eastward line for Honda, and the north axis for Nissan. The establishment of these factories has provided employment opportunities, which highlights the positive effects of FDI on urban land growth, and has also accelerated the expansion of the urban area through the increase in suburban employment and settlement.

Fourth, population was another factor that influenced urban land growth in Guangzhou. Population had a considerable effect as shown by the coefficient 40.23. Population increase usually results in an increased demand for housing and urban residential land growth. According to the Guangzhou Planning Committee, the population in Guangzhou will reach 20 million in a few years, and its urban planning must aim to house around 20 million people. This finding implies that an increasing amount of land areas should be transformed into residential areas to satisfy the demand. According to the circular population distribution in Guangzhou, the peripheral area with the labor-intensive industries have attracted many immigrant employees and contributed to the increase of land use demand. As a result, these industries have stimulated urban land expansion. In future urbanization, Guangzhou will face a higher proportion of immigrant population (Li, 2014), which will be a more important influencing factor

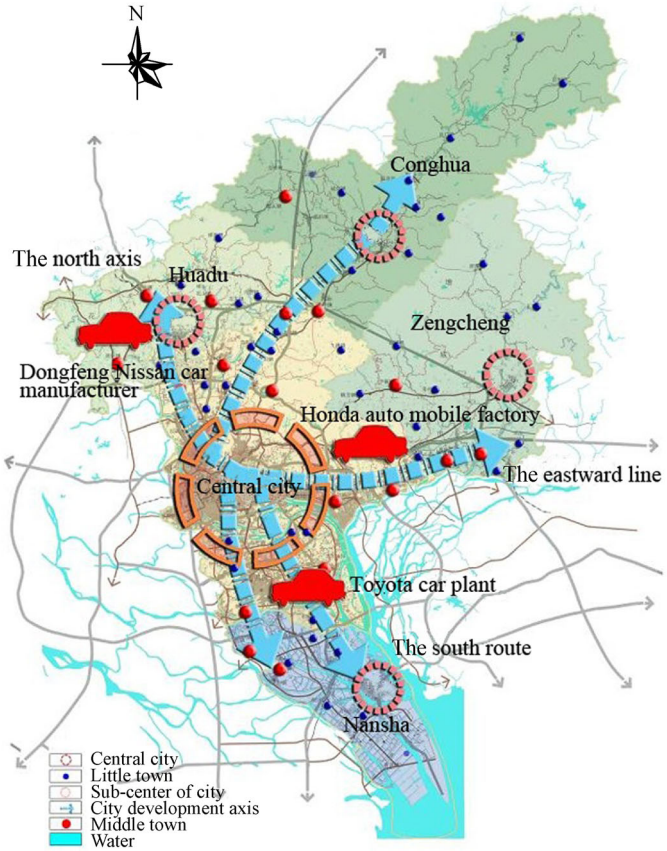

Fig. 5 Foreign auto makers distribution in Guangzhou. Data source: Urban master planning of Guangzhou 2011–2020.

on urban land use, especially in peripheral areas, such as west Tianhe, northeast Fangcun, northwest Haizhu, and south Baiyun.

Fifth, the fixed asset investment also influenced urban land growth at a coefficient of 23.25. Along with the rapid development of the urban economy, massive investment has been put into the urban construction. The well-developed public facilities have facilitated urban evolution and took effect on the expansion of urban land use. Guangzhou has experienced the construction of a new airport, a new port, and other large infrastructures like the road traffic infrastructure and rail transit projects.

Sixth, the subway transit capacity boost in Guangzhou was one of the factors that accelerated urban land growth with a coefficient of 35.2. The score implies that the expansion of urban land is closely related to the developing subway lines and its increasing capacity. The subway has provided a convenient transportation system, making it possible to redistribute the city layout during expansion. The sub-central areas are forming, and the polycentric city structure is facing a challenge. From this point, subway development in Guangzhou has driven the expansion of the area for social activity and has led to its urban land growth as a result.

Lastly, the annual sales area of urban land has had a direct influence on urban land growth, reflecting the government's attitude on urban land supply. Because the urban land in China belongs to the country, most of the urban land transfer should be carried out under auction or bidding as it has been since 1993. According to the equation, urban land sales area played a role on urban land growth as shown by its influencing coefficient (16.53). This finding implied that the governments' land supply has affected the real estate market, which ultimately influenced urban land expansion. Thus, local governments should guide and arrange the functional land use through land supply, by which the urban land could be used more rationally and efficiently.

6 Implications for urban sustainable development

Sustainable urban development is a policy issue for all levels of government and a shared responsibility for the entire population. Urban land use is one of the crucial aspects of sustainable development (Zhang et al., 2011), and thus, the driving factors of urban land growth must be understood. These factors have implications on urban sustainable development strategies, including intensive economy, industry development, public transportation mode, and city layout.

6.1 Intensive economy and its land use

Land use change is considered as the interaction between nature and human society, and urban growth has been viewed as the phenomenon concerning urbanization. In the last several years, China has been undergoing considerable non-agricultural economic development, particularly in coastal cities such as Guangzhou. In this study, the GDP increase in Guangzhou was one of the main driving forces that stimulated its urban land growth. Compared with the extensive modes, an intensive economic development should have a positive effect on controlling urban land growth, such as smart land use and reduced pressure on urban outward expansion. This point could be a contribution to urban sustainable development and provides implications for land use policy. Urban land distribution and utilization during the mid- and long-term urban development has to be coordinated with the economic development policy. Hence, local governments must carry out a series of integrated land use plannings to guide urban land use change and assist intensive economy. Rational land use strategies, such as adjusting the industry land utilization, establishing tridimensional transportation networks, protecting open spaces, and conserving prime agricultural land resources, will be helpful in achieving the goal of economic transition in Guangzhou and benefit its urban sustainable land use.

6.2 Industrial development

Accompanied by the administrative districts re-divisions, which enabled the increase of the build-up areas and spatial expansion in a short time, industry land use change and adjustment in Guangzhou was nearly carried out at the same time. The manufacturing layout went outward, while the service industry agglomerated in the city center. The spatial distribution changes of the three industries showed that the second industries, most of which are located in Luogang, Huangpu, Panyu, Baiyun, and Huadu districts, sprawled towards the outside circle of the city. In contrast, the tertiary industries, especially commercial, financial business, and information and consulting services, became more and more centralized in the downtown area, and have also led directly to the residential, commercial, service and related supporting facilities transfer. The urban service-industry-agriculture layer structure has been gradually formed as a part of urbanization and industrialization. According to the results of the above studies (Liu et al., 2013; Chen et al., 2014), industry development has a significant effect on urban land growth. In this sense, industrial land use adjustment and its further development should exert efforts to curb the dramatic growth of urban land aiming at a sustainable way. For further industrial development, land use transition between the second industries and the tertiary industries should be continued for industrial layout optimization. More importantly, the tertiary industries should aim for intensive development on land use. Land use policies on industrial land replacement, industry agglomeration, and service upgrade should hence

provide planners with the possibility of rational land growth during the industrialization process to achieve urban sustainable development.

6.3 Public transportation mode

The influence of the rail transit system on urban land growth in Guangzhou was significant, thereby implying that public transportation development was responsible for the urban sprawl in Guangzhou. Land intensive use and mixed land use development should hence be encouraged for public transportation planning and land use planning. As expected, TOD was put forward primarily to improve public transportation and benefit urban intensive land use. But it has failed to achieve these goals, however, and is at present facing the dilemma of urban expansion in Guangzhou. According to this study, the public transportation based on TOD has to be further improved to lead to the compact land use around TOD stations and sites, which could also improve public transportation capacity and effectively reduce the residents relying on cars. By increasing the share of public transportation, TOD with its high-intensity land use mode could effectively slow down the total transportation demand of Guangzhou during its further urbanization. Hence, the TOD should be further improved and combined with the consideration of urban expansion, which could eventually lead to an intensive urban land use structure and rational growth of urban land for sustainable development.

6.4 Mono-centric city layout

With its good location and developed traffic network, the Guangzhou city center has maintained its prosperity over the past decades. The driving factors of urban land growth in Guangzhou are the characteristics of a mono-centric city (Liu and Wang, 2016), which have led to an axial expanding trend over the years. Along with the urbanization process and its urban land growth, problems such as inward commuters and traffic jams have drawn the attention of scholars and the government. Driving factors have implied that the city layout has to be changed through better planning on its population distribution, industrial development, transportation, foreign business, and some other elements according to their effects on urban land use expansion. To change the mono-centric city layout with its overcrowded city center and long axial expanding urban area, Guangzhou has made efforts to form a polycentric city layout by establishing functional groups along the Pearl River or on the transportation network. However, there is still much to do to change the existing axial growth and urban inward long commute. Results show that the population, transportation, and the second industries have influenced urban land growth significantly. Thus, the construction of urban deputy centers and satellite cities should be put forward to ease the pressure of a mono-centric city layout. The polycentric feature of Guangzhou should be strengthened through appropriate urban land use planning, which will be better for industry structure optimization, population redistribution, and rational urban land growth.

Generally, policymakers in urban land use management need to gauge the influence of the driving factors on urban land growth in order to identify the problems and carry out effective strategies. In this context, the drivers of urban land growth are essential not only for urban land use management in Guangzhou, but also for the sustainable development of the city in a long run.

7 Conclusions

Identifying the driving force of urban growth is essential to understanding the process of urbanization in China, which is currently a rudimentary issue in most of China's developed cities. This study constructed a framework for impact factors on urban land growth based on China's economic transition. This study takes Guangzhou as the study area to provide countermeasures for sustainable development.

First, the framework of the driving force study provides support for the quantifiable methods describing the urban land growth by identifying their influence. The problems of urban areas caused by land expansion are also revealed.

Second, the empirical study of Guangzhou can be used as a basal urban land growth study under the background of rapid economic development in China. Since Guangzhou partly represents the developed areas of China, its driving forces and characteristics found in this article can be used as a reference, which may not be directly applicable to other cities with a similar economic status. This study can be generalized to some extent and used as a reference for further empirical studies on urban land growth.

Third, the driving force of urban land growth of Guangzhou is depicted in this study with the principal components regression approach and empirical analysis. Guangzhou is a developed city that has extensive urban land growth, which was significantly influenced by the eight driving factors. These proposed driving forces and their effects can not only help the government better plan for urban land use, but also benefit the relevant policy changes on urban sustainable development. As mentioned in this paper, robust policy makings can be generalized as the intensive economy development based on land management, the reasonable program of industry structure adjustment according to urban land use change, the transit-oriented development, and the polycentric city layout planning under the land use intensification.

The findings in this study can also share experiences

with other cities or regions, which can be of interest to the audience of land use management and planners. This study supports sustainable development for cities in China

For future research, comparison studies of different cities in China could establish basic profiles for different urban development contexts, especially for cities in transition. Different indicators and impacts comparison can be used to define benchmarks to identify the requirements of good quality urban development for different cities.

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