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Analysis on spatial structure of landuse change based on remote sensing and geographical information system

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ABSTRACT

Analyzing spatio-temporal characteristics of landuse cover change is essential for understanding the pattern of urbanization. More importantly, such analysis can provide much information for decision-making. Landuse changed rapidly in Guangzhou in the last several years, so that it is necessary to study the spatial structure of landuse change. DOM (Digital Orthophoto Map) of Guangzhou in 2003, 2005 are acquired for this study. Accurate landuse information was first extracted by Definiens Developer. Secondly, we applied the landuse transfer model to analyze the mutual conversions among different landuse classes. Thirdly, a landuse spatial position conversion and quantity change model was established to analyze the position conversion of landuse classes from a quantitative perspective. Finally, Landuse dynamicity model is applied to study Guangzhou's landuse change level and the reasons of the change are analyzed. The results showed that farmland diminished relatively fast and adjustable landuse areas increased substantially. The main reason for farmland reduction lies in that part of the original farmland has been turned into other cultivated lands. The absolute quantity of landuse change is enormous, dominated by the internal conversion among landuse categories, such as farmland converted into garden and other types of cultivated lands.

1. Introduction

Since 1995, the International Geosphere-Biosphere Program (IGBP) and the Global Environmental Change in the Humanities Program (IHDP) put forward the "landuse and land cover change" (LUCC) research project. Since then LUCC has rapidly become the frontier global change research and hot topics, in which the investigation and description of the landuse and land cover dynamics in spatio-temporal distribution are identified as the fundamental goals. Technologies and methods have been developed to use geo-spatial information technology investigate issues of LUCC such as change detection (Coppin et al., 2004; Lu et al., 2004), change trajectory analysis (Mertens and Lambin, 2000; Yang and Lo, 2002; Zhou et al., 2008a), spatio-temporal modeling (Pereira et al., 2002; Zhou et al., 2008b) and result evaluation (Morisette and Khorram, 2000; Liu and Zhou, 2004; van Oort, 2007; Li and Zhou, 2009).

With the world's most active economic growth and dynamic change in the past decades, China has been the focus of scientific research on landuse change. Ge et al. (2003) have systematically collected, collated and calibrated a variety of landuse surveys, censuses and remotely sensed data tracing back to the historical period since early 20th century. Based on this they were able to derive statistics and undertake comparative analysis of the general view of landuse change, including the change of arable land, woodland, grassland and built-up areas, and revealed history of landuse change over entire China in the 20th century and early 2000s. He et al. (2000) and Zhang et al. (2002) used multi-temporal remote sensing images to analyse LUCC in the metropolitan region of Beijing since the implementation of China's economic reform and open-door policy in 1978. The results showed that rapid urban expansion has taken place with significant regional variation. Liu and Zhou (2005) reported a study on the analysis of spatial pattern of urbanization and made a prediction on future urban expansion in the eastern districts of Beijing. Zhao et al. (2005) analyzed landuse structure using information entropy and balanced degrees in Shanghai downtown area in the past 50 years and modeled the urban spatial morphology of the fractal structure using the fractal theory. Zhu et al. (2001) analyzed the arable land flow in Bohai Sea region and its relationship with demographic changes as well as the agriculture economic development. They reported that the main drivers of landuse change in this region are land management policies, the per capita growth of residential land, restructuring of agricultural production and urban expansion.

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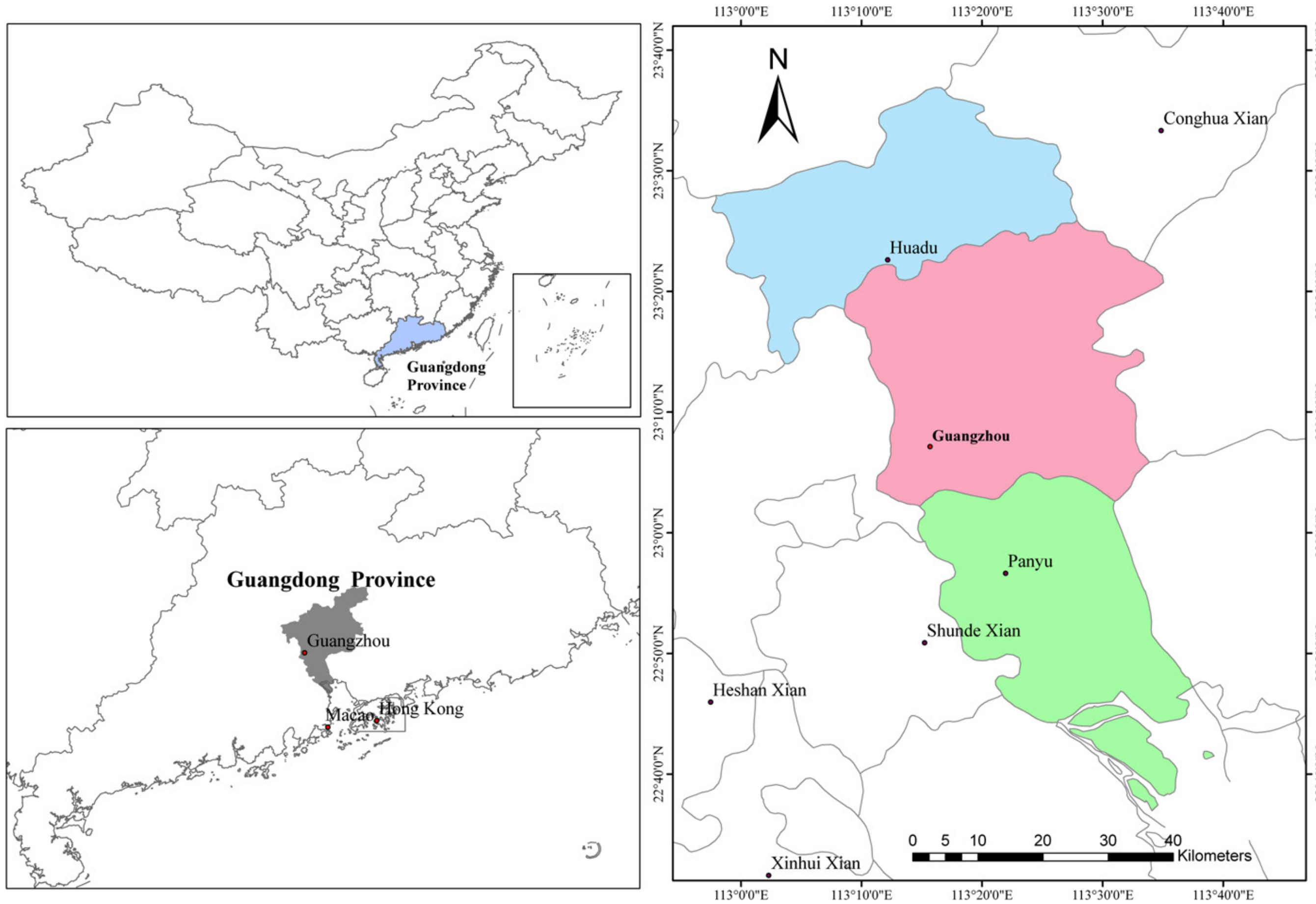

Fig. 1. Location of study area.

In southern China, the Pearl River Delta (PRD) region has widely been recognized as the "factory of the world" in the past two decades. The region has experienced over 100 times growth since the implementation of China's economic reform and open-door policy in 1980s. As the consequence of this, the region has shown dramatic conversion from original agricultural landuse to urban built-up areas at an averaged annual rate of about 10% (Zhou and Hou, 2009). Chen et al. (2009) used 1979, 1990, 2002 and 2006 TM images to establish landuse databases and revealed the spatio-temporal characteristics of land cover changes of Guangzhou City of China. Research projects have also been reported by numerous researchers on the urbanization and landuse change in the PRD region (e.g. Yeh and Li, 1999; Weng, 2001; Li and Yeh, 2002; Seto and Kaufmann, 2003; Enright et al., 2005).

Remote sensing and GIS technologies have been widely used in landuse change and urbanization studies. Using multi-temporal satellite images to detect landuse/cover change and its spatio-temporal pattern has been proven an efficient approach (e.g. Masek et al., 2000; Herold et al., 2003; Dietzel et al., 2005; Maktav and Erbek, 2005).

This paper reports a case study in Guangzhou City, the largest metropolis in southern China. DOM has been utilized as the main data source to explore the spatio-temporal dynamics and conversion of landuse. By integrating remote sensing and GIS, this study focuses on the analysis of spatio-temporal pattern of landuse change from macroscopic and microcosmic points of view and making preliminary exploration of the influence of urban development on these changes. The overall objective is to improve the understanding of the effects of urbanization on landuse change in the region.

2. Study area and image processing

2.1. Study area and data

The study area (Fig. 1), Guangzhou Metropolis, is the capital city of Guangdong Province in southern China. Located at 112°57′E to 114°3′E and 22°26′N to 23°56′N and 120 km northwest of Hong Kong, Guangzhou is characterized as an important seaport in southern China and a sub-provincial city with direct jurisdiction over 10 districts and 2 county-level cities. In this study, we have selected the 10 districts of Guangzhou as the study area, namely, Baiyun, Tianhe, Haizhu, Huangpu, Liwan, Yuexiu, Panyu, Luogang, Huadu and Nansha.

For urban applications, it is necessary to use high-resolution remotely sensed data to ensure the quality of change detection. In this study, we selected DOM for September 1, 2003 and August 25, 2005 at the scale of 1:2000. The DOM was produced from original film of aerial survey and geo-coded into Xi'an 1980 coordinate system complying with the 1985 National Height Datum of China. The spatial resolution of the DOM is 0.2 m, the typical DOM pictures of study area (Tianhe district) are given (Figs. 2 and 3).

2.2. Image processing

ERDAS Imagine 9.2 has been used for the process of image radiometric enhancement and geometric rectification. We processed the DOM in order to acquire sufficient landuse information required for the Change Vector Analysis (CVA) model, which was used to detect extent, distribution and landscape features of urban landuse change from a macro perspective (Tian et al., 2002). The images were clas-

Fig. 2. The typical DOM picture of study area of 2003.

sified using Definiens Developer, with the accuracy exceeding the minimum requirement of 85% stipulated by the USGS classification scheme (Anderson et al., 1976). The classification result was then integrated with GIS for spatial analysis and landuse change modeling and quantitative and positioning analysis of different types of landuse change from a micro perspective were then conducted.

The national landuse classification system is used as the basis for the classification system in this study, which comprises 3 level-one classes, namely, agricultural, constructional and unused land, and 10 sub-classes, the classification system are shown as Fig. 4.

3. Analytical methods

3.1. Change vector analysis

Change vector analysis (Guo and Zhen, 2003; Chen et al., 2001) is one of the direct spectral comparison methods in remote sensing image processing. Using CVA, a "change vector" is retrieved from multispectral images to describe the pixel spectral change both in extent and direction.

Let $G_i = (g_{i1}, g_{i2}, \ldots, g_{ik})^T$ and $H_i = (h_{i1}, h_{i2}, \ldots, h_{ik})^T$ denote the grey-level vectors of pixel i at phase t_1, t_2 images, respectively, where k represents image band 1, 2, ..., m. The changing vector of spectral change of the pixel is therefore defined as (Chen et al., 2001):

Fig. 3. The typical DOM picture of study area of 2005.

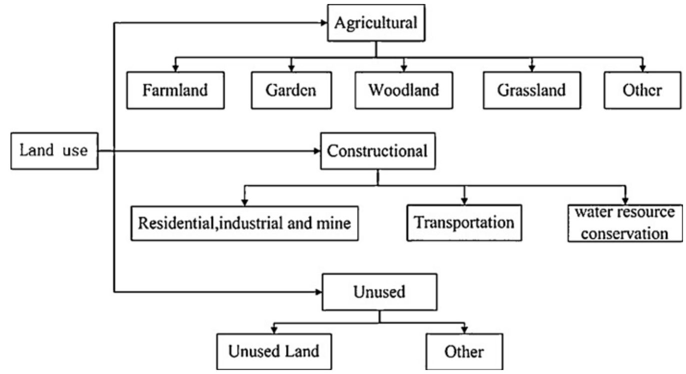

Fig. 4. Classification system.

$$\Delta T_i = G_i - H_i = \begin{Bmatrix} \Delta t_{i1} \\ \Delta t_{i2} \\ \ldots \\ \Delta t_{ik} \end{Bmatrix} = \begin{Bmatrix} g_{i1} - h_{i1} \\ g_{i2} - h_{i2} \\ \ldots \\ g_{ik} - h_{ik} \end{Bmatrix} \quad (i = 1, 2, 3 \ldots, n) \tag{1}$$

where ΔT_i denotes the change information of the two corresponding images, while the change intensity is determined by $||\Delta G||$ (Chen et al., 2001):

$$||\Delta G|| = \sqrt{(g_1 - h_1)^2 + (g_2 - h_2)^2 + \cdots + (g_k - h_k)^2} \tag{2}$$

The definition of change intensity indicates that the greater change intensity is, the greater the difference of the two images. Therefore, changing and non-changing pixels could be detected by setting thresholds, according to the degrees of the change intensity. That is to say, if a pixel's change intensity exceeds a certain threshold, it could be judged as a landuse change pixel. The selection of the threshold is a key step for the CVA. In this study we adopt the double-windows flexible pace searching method (Chen et al., 2001) to define the threshold. The change information extracted by this method contains errors, so that manual intervention, such as visual interpretation and ancillary data, is required during the extraction of the change information. As a result, we can derive the extent, distribution and landscape features of the urban landuse change from a macro perspective, in order to show, e.g. which area has the larger area of landuse change, and whether the spatial distribution of the landuse change is balanced.

3.2. Landuse dynamic change analysis

Landuse dynamic change analysis is required to gain better understanding about the complexity of landuse change. It is also an effective approach to study the process, extent and trend of landuse change. For better understanding the dynamic change processes of different landuse classes, in this study we have conducted a quantitative and positioning spatial information analysis of different classes of landuse change from a micro perspective.

3.2.1. Landuse transfer analysis

Landuse transfer analysis has been applied to obtain the transition among different landuse classes with the aid of GIS, which provides more detailed landuse information, as well as some basic geographical data for analysis.

This study adopts the calculation model in which the attribute database of intersected layers is used to reach the balance in an iterative process (Gao and Wang, 2004). The specific procedure is:

Table 1
Attribute table of intersected layers.

No.	AREA	C_ID	A^k	A^k_ID	Landuse type	A^{k+1}	A^{k+1}_ID	Landuse type
1		1	1	11	Farmland	2	12	Garden
2		2	3	13	Woodland	5	12	Garden
3		3	5	12	Garden	7	11	Farmland
...		...	...	...	...	...	...	...

Table 2
Landuse transfer model in Guangzhou (unit: hm^2).

Before class	After class									
	Agricultural land					Constructional land			Unused land	
	11	12	13	14	15	21	22	23	31	32
11	0	16310.70	4820.31	3.71	13627.72	2870.98	480.76	431.50	30.00	66.63
12	561.59	0	1158.24	75.12	2682.55	2358.90	250.70	288.25	87.45	102.66
13	121.05	3049.37	0	14.46	5118.07	1034.83	82.05	97.79	275.44	87.02
14	55.84	12.91	8.05	0	54.13	53.22	2.44	0	10.29	0.34
15	890.02	3726.22	1285.25	5.33	0	473.82	237.16	204.65	120.65	314.64
21	328.19	290.42	1130.91	2.78	1613.22	0	1442.78	321.82	684.91	1535.18
22	67.54	122.98	179.56	0	355.16	779.95	0	6.25	268.00	28.65
23	15.11	14.41	92.79	0	217.22	106.64	0	0	1.91	83.04
31	495.39	730.39	2360.28	0	1311.75	404.46	120.39	307.79	0	481.75
32	435.97	386.94	107.81	0	2847.80	1003.38	479.83	298.96	345.11	0

(1) Perform a spatial intersection computation on the previous map with a table that can be represented by a matrix named $A^k{}_{i\times j}$, and the changed map with a matrix $A^{k+1}{}_{i\times j}$.
(2) The intersection of all the curves within the resultant intersection layer (matrix) $C_{i\times j}$ generates nodes, from which a new polygon is created.

In the attribute table of the intersected layers, both the attribute fields of the previous map and the changed map are included, as well as all the records of the two maps. Table 1 shows an ergodic iterative computation on the attribute table of the intersection layer $C_{i\times j}$ and then an accumulation according to the permutations of the two-dimensional matrix. A transfer matrix of landuse change can then be obtained. For example: to find out the transferred area that from period k, class i into period $k+1$, class j, denoted as A_{ij}, one only needs to search the records within $C_{i\times j}$ containing i in the A^k_ID field and j in the A^{k+1}_ID field, and then sum up the area as the value of A_{ij}.

3.2.2. Landuse spatial position conversion and quantity change model

The landuse change in a specific region includes the spatial position conversion and quantitative change of different landuse classes. Spatial position conversion is the conversion in which the position of the landuse classes has changed in the study area. For instance a small unit of farmland may return to forest while a small unit of forest could be converted into farmland. The overall area of corresponding landuse classes, however, might not change (Fu et al., 2006). The position conversion can be modeled as (Fu et al., 2006):

$$S_j = 2 \times \min(P_{j+} - P_{jj}, P_{+j} - P_{jj}) \tag{3}$$

where S_j represents the area of category j to which spatial position conversion happens. P_{j+} and P_{+j} denote the areas of category j before and after the change, respectively. P_{jj} stands for the area with no change.

Quantitative change refers to the increase and decrease of the balance of areas of different landuse classes after the position conversion (Wang et al., 2000). It can be calculates as (Wang et al., 2000):

$$Q_j = \max(P_{j+} - P_{jj}, P_{+j} - P_{jj}) - \min(P_{j+} - P_{jj}, P_{+j} - P_{jj}) \tag{4}$$

where Q_j stands for quantitative change of area of category j. The total change of category j can thus be calculated as (Wang et al., 2000):

$$C_j = S_j + Q_j \tag{5}$$

where C_j stands for the total change of category j.

3.2.3. Landuse dynamicity model

The quantitative change of landuse can be represented by landuse dynamicity, including single landuse dynamicity and comprehensive landuse dynamicity. The former refers to the quantitative change of one single landuse class in a particular region at a certain period of time, and the latter refers to the quantitative change of several landuse classes in a particular region at a certain period of time (Sun et al., 2005). The single landuse dynamicity can be calculated as (Zhu et al., 2001):

$$K = \frac{(U_b - U_a)}{U_a} \times \frac{1}{T} \times 100\% \tag{6}$$

where K denotes the dynamicity of one landuse type over the given period, U_a and U_b denote the areas of one landuse class at the beginning (moment a) and at the end (moment b) of the study period, respectively, and T stands for the time span from moment a to moment b. If T is set to be multiple years, the value of K will be the annual changing rate of the landuse class during the given period.

4. Results and discussions

4.1. Result of landuse transfer model

The result of the landuse transfer model for all the landuse classes are shown in Table 2.

From Table 2, we can find the general trend of the spatial structure of landuse change in Guangzhou, especially the changes in farmland. As a major type of agricultural land in Guangzhou, farmland has shown a great change, largely due to the implementation of structural readjustment policy of agriculture in Guangzhou.

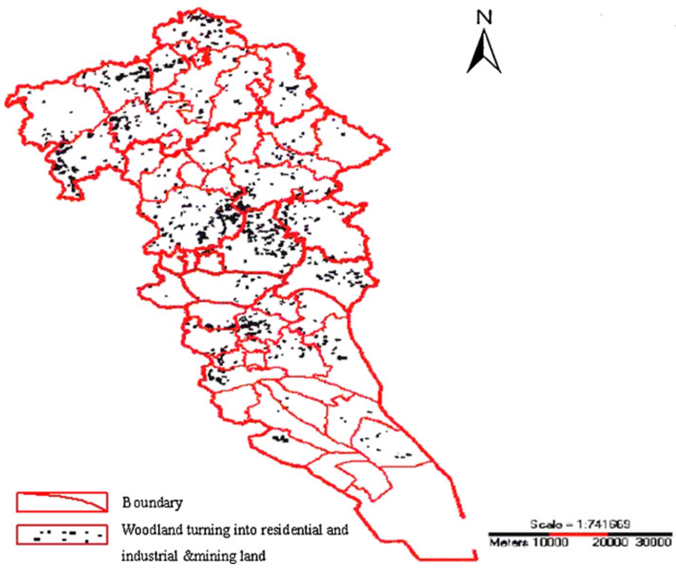

Fig. 5. Spatial distribution map of woodland turning into residential and industrial and mining lands in Guangzhou City.

Farmers, who used to grow cereal crops have now switched to high-return economic crops and fruit orchards, thus converted large area of farmland into garden and other agricultural land. The total area of this kind of conversion accounts for 34,762 hm^2, or 90% of the total decreased area of farmland, where conversions from farmland to garden and to other agricultural land account for 47% (16,311 hm^2) and 39% (13,628 hm^2), respectively. Meanwhile, 378,324 hm^2 of farmland has been converted into constructional land.

As the landuse interpretation standards of urban areas and scenic areas have changed and part of the idle land has now been reclaimed, 3365 hm^2 of residential, industrial and mining lands has been converted into agricultural land, accounting for 46% of the diminishing constructional land. For example, a piece of 17 hm^2 independent industrial and mining land in Qiangang Village of Baiyun District has now been reused for plantation of litchi thus its landuse type was reclassified as garden.

Using overlay analysis, we derive spatial distribution of landuse class conversions. For example, in order to attain the spatial distribution of woodland that was converted into residential, industrial and mining, we conduct spatial overlay on the previous map with the matrix $A^k{}_{i\times j}$ and the changed map with matrix $A^{k+1}{}_{i\times j}$ to obtain the intersection layer with a matrix $C_{i\times j}$. The GIS "Select By Attributes" function is then used to select spatial elements that meet the requirements (Target Layer set to $C_{i\times j}$, Method set to "Create a new selection", SQL Statement set to A^k_ID = 11 AND A^{k+1}_ID = 21). Finally the selected elements are stored as a separate layer that shows the spatial distribution of woodland turning into residential, industrial and mining lands (Fig. 5).

Table 4
Area and dynamicity of initial and last stage of landuse class in Guangzhou (unit: hm^2).

Land class	Area of 2003	Area of 2005	Dynamicity
11	86005.54	50333.91	−20.70%
12	32375.75	49454.62	26.40%
13	68790.04	70053.18	0.92%
14	199.17	103.37	−24.10%
15	29022.16	49592.04	35.40%
21	85704.17	87440.10	1.00%
22	9189.03	10477.03	7.00%
23	3274.55	4700.45	21.80%
31	6329.24	1940.81	−34.67%
32	35016.07	37547.79	3.62%

4.2. Result of landuse spatial position conversion and quantity change model

The spatial position conversion and quantity change of landuse can be obtained by the calculation of Eqs. (3)–(5). The result is shown in Table 3, where we rank the sequence of different landuse classes in terms of their change extents as farmland > other agricultural lands > garden > unused lands > other lands > residential, industrial and mining > water resource conservation > transportation > woodland > grassland. Considering forms of change, garden, woodland, grassland, transportation and other lands have greater areas of the position conversion than their quantitative change, while the position conversions of other classes are, in various degrees, less than their quantitative change. For example, the landuse class garden shows a large position conversion that can be interpreted by following basic conditions:

(1) Guangzhou is located in subtropical coastal areas with various terrain conditions, where the soil, climate and hydrology are suitable for the plantation of banana, sugarcane, papaya and other economic fruit trees. This helps the growth of garden plantation industry. Especially since 1990s, as a result of an agricultural restructuring project, the areas of fruit plantation, nurseries and other high-return plants increased significantly.
(2) Farmers may freely opt to grow cereal crops, fruit or flowers according to the needs of market, production and their own lives, thus some orchards or gardens may also be converted into farmland. In addition, part of the garden has been turned into constructional lands as the consequence of the rapid urbanization in the region. These scenarios are reflected by the amount of gardens that were converted to other landuse types.

4.3. Result of landuse dynamicity model

Table 4 shows the result of the Landuse dynamicity model of the initial (2003) and last (2005) stage of landuse class of Guangzhou by Eq. (6).

Natural factors may have some impact on the landuse change in Guangzhou, but the socio-economic factors apply the primary

Table 3
Spatial position conversion and quantity change of landuse in Guangzhou (unit: hm^2).

Class	Converted into	Converted from	Total change	Spatial position conversion	Quantitative change
11	2970.68	38642.31	41612.99	5941.36	35671.63
12	24644.32	7565.45	32209.77	15130.89	17078.88
13	11143.20	9880.06	21023.26	19760.12	1263.14
14	101.40	197.21	298.61	202.81	95.80
15	27827.62	7257.74	35085.36	14515.48	20569.88
21	9086.17	7350.21	16436.38	14700.42	1735.96
22	3096.09	1808.09	4904.18	3616.18	1288.00
23	1957.01	531.11	2488.12	1062.22	1425.90
31	1823.77	6212.20	8035.97	3647.53	4388.43
32	2699.90	5905.80	8605.70	5399.80	3205.90

force. For example, due to landslides and other natural disasters as well as some human-impacts, the land conditions may be deteriorated for agricultural use so that original woodland may be converted into unused land. Such changes are noticeable in the southeast of Baiyun District, the downtown of Panyu District, the Nansha Economic and Technological Development Zone, Huangge Town, and the northern part of Huadu District. Furthermore, improper use of land and industrial pollution may also cause the harsh growing condition and damage to the soil, resulting in the conversion from agricultural to unused land.

According to “Guangzhou City Master Plan”, the urban area of Guangzhou City has expanded and will expand constantly to the surrounding region. The recent move of revoking cities of Panyu and Huadu into districts of Guangzhou has stimulated rapid expansion of urban areas in the city fringe. The implementation of the national urbanization policy that encourages the development of small and medium towns and migration of rural population into cities will also accelerate the expansion of urban built-up areas.

5. Conclusions

In this study we have adopt models (mentioned in Section 3) by analyzing landuse changes from the microcosmic aspect, taking into account the type and extent of landuse conversion. This method has shown its advantage to model the landuse categorical change in frequent succession. The models can be used to compute the extent of dynamic change of various landuse categories. By analyzing the results of models, with the consideration of the regional characteristics, the perfection of economic polices and land laws of China in the past decades; we may draw the following conclusions:

(1) The decrease of farmland area is significant. The main reason for farmland reduction is that substantial proportion of the original farmland has now been converted into other agricultural lands.
(2) The absolute quantity of landuse change has been great, with the internal conversion among agricultural landuse dominating.
(3) The rapid socio-economic development of Guangzhou is the main driving force for landuse change. Due to the readjustment of the agricultural structure and other reasons, a large area of farmland has been converted into other types of agricultural lands. Meanwhile, the rapid urban expansion has also caused the significant change of agricultural into constructional lands.

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