Science in China Series E: Technological Sciences

www.scichina.com
tech.scichina.com

Spatial calculating analysis model research of land-use change in urban fringe districts

ZHANG XinChang†, PAN Qiong, WANG ZhongYang & CHEN XinXiang

Department of Remote Sensing and GIS Engineering, Sun Yat-sen University, Guangzhou 510275, China

The spatial calculating analysis model is based on GIS overlay. It compartmentalizes the research district land into three spatial parts: unchanged part, converted part and increased part. By this method we can evaluate the numerical model and dynamic degree model for existing calculating changing speed of land-use. Furthermore the paper raises reviving the calculating analysis model of spatial information in order to predict the dynamic changing level of all sorts of land. More concretely speaking, the model is mainly to know the changing area and changing speed (increased or decreased) of different land classifications from the microcosmic angle and to clearly show the spatial distribution and spatio-temporal law for changing urban lands. We discover why the situation has taken place by combining social and economic conditions. The result indicates that the calculating analysis model of spatial information can derive more accurate procedure of spatial transference and increase of all kinds of land from the microcosmic angle. By this model and technology, we can make the research of spatio-temporal structure evolution in land-use be more systematical and deeper. The result will benefit the planning management of urban land-use of developed districts in China in the future.

land-use, dynamic change, calculating analysis model

1 Introduction

The general analysis of the quantity, structure and environment of land-use change is useful to perceive the trend and character of land-use spatio-temporal change. The fixity and distinction of spatial position is one of the remarkable characters of land-use. In order to recognize the changing process of different kinds of land-use spatial structures, the quantitative spatial information analysis is applied to analyzing different kinds of land-use change. For instance, there are two different kinds of land-use changes in the same period: In an industrialized suburban area, an

Received November 27, 2007; accepted January 26, 2008
doi: 10.1007/s11431-008-5004-7
†Corresponding author (email: eeszxc@mail.sysu.edu.cn)
Supported by the National Natural Science Foundation of China (Grant No. 40471106) and "985 Project" of GIS and Remote Sensing for Geosciences of the Chinese Education Department

abandoned brickfield will be changed to arable land; while in another suburban area, the same acreage of arable land will be used for a newly found industrial park. In cases like this, the land-use changes counteract each other and cannot reflect the changes. The actual condition can be revealed only through quantitative spatial information analysis. As shown in Figure 1, during the research observation period, from $t1(\mathrm{LA}_{(i,t1)})$ to $t2(\mathrm{LA}_{(i,t2)})$, there are three kinds of spatial models in the changes of No. I land-used category: 1) Unchanged part ($\mathrm{ULA_i}$). No. I land-use sort and spatial position has not changed. In the research observation period, for consideration of the time-scale aspect, the process that the land-use sort changes and then switches back to the original condition is considered as invalid change and will not be discussed in this paper; 2) converted part $(\mathrm{LA}_{(i,t1)} - \mathrm{ULA}_i)$. No. I land-use sort changed into the other land-use sorts; 3) increased part $(\mathrm{LA}_{(i,t2)} - \mathrm{ULA}_i)$. The other land-use sort converted into No. I sort. $\mathrm{LA}_{(i,t1)}$ and $\mathrm{LA}_{(i,t2)}$ represent the area of this land-use sort at the beginning and end of the period respectively.

GIS spatial information analysis technology provides a strong technique of support for the spatial information analysis of land-use change. By the calculation and spatial statistic analysis of land-use graphs of different periods, we can identify the unchanged part, the converted part including what the converted part converts to, and the increased part including what the increased part comes from Figure 1.

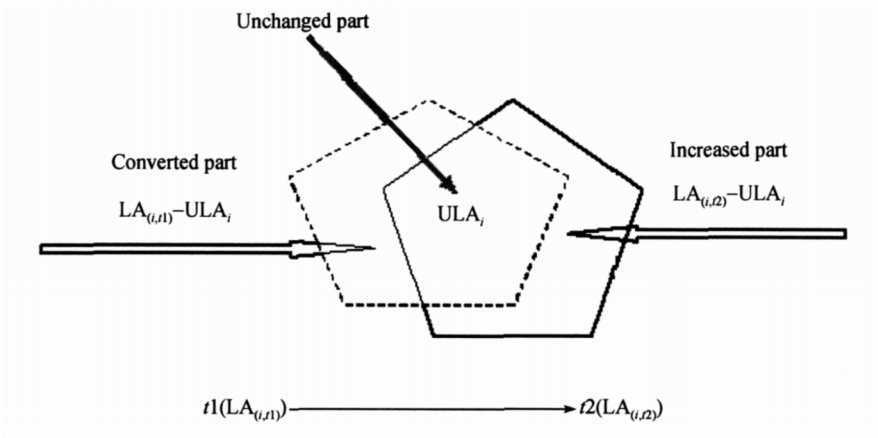

Figure 1 Spatial meaning of land-use change.

2 Research method

At present, the quantitative model calculating land-use dynamic change basically includes the traditional numerical model and dynamic model.

2.1 Numerical model

Bruce Pond and Maurice Yeates, the famous quantitative geographers, provided a traditional and ordinary analysis model in 1993. The principle of this theory is that the land-use changes during a certain period can be shown by calculating the average changing ratio of land-use model in the researched region[1]. This is called the single dynamic land-use model[2]. The mathematical expression is

$$K_i = (\mathrm{LA}_{(i,t2)} - \mathrm{LA}_{(i,t1)}) / \mathrm{LA}_{(i,t1)} / (t2 - t1) \times 100\%. \quad (1)$$

In the formula, K_i is the yearly average changing ratio of the land-use sort I, $\mathrm{LA}_{(i,t1)}$ and $\mathrm{LA}_{(i,t2)}$

represent the area of this land-use sort at the beginning and end of the period respectively.

The main advantage of the calculating model is conciseness, and we can use it without complicated professional analysis. It is used in both professional and non-professional reports and academic papers[3], but the disadvantage is obvious as well.

1) This model ignores the fixity and particularity of land-use spatial position, and cannot reflect the spatial process and interrelated attributes of changing land-use dynamic. For example, the following two changes is taking place with spatial locations and attributes different, but acreage completely the same: On one hand, barren unused land is reclaimed far from the city; on the other hand, a field of high quality is converted into land for civil construction near the city. The two changing processes counteract each other and cannot reflect the actual condition when we analyze the dynamic changing of the region.

2) This model cannot calculate and compare the active degree of land-use changes, that is to say, it cannot discern the "hot" or "sensible" district, as it has no spatial characters.

2.2 Dynamic model

The expression calculating the dynamic degree or land-use change speed of one land-use sort in the research region during the changing period is as follows[4,5]:

$$S_i = (\mathrm{LA}_{(i,t1)} - \mathrm{ULA}_i) / \mathrm{LA}_{(i,t1)} / (t2 - t1) \times 100\ \%. \tag{2}$$

In the formula, $(\mathrm{LA}_{(i,t1)} - \mathrm{ULA}_i)$ represents the area of conversion, namely the total area of the No.I category land-use which is converted into other kinds of land-use in the research period; $\mathrm{LA}_{(i,t1)}$ represents the area of No.I land-use at the beginning of the period, ULA_i represents the unchanged area of the No.I land-use during the research period (as shown in Figure 1).

The expression of land-use dynamic degree in the research district is listed below:

$$S = \frac{\sum_{i=1}^{n} \{\mathrm{LA}_{(i,t1)} - \mathrm{ULA}_i\}}{\sum_{i=1}^{n} \mathrm{LA}_{(i,t1)}} / (t2 - t1) \times 100\ \%. \tag{3}$$

Liu et al.[4] provides this spatial calculating model based upon GIS. This model considers both the amount and spatial attributes of the No. I land-use kind that is converted into other land-use kinds, and can compare the changing degree of the district land-use. Thus, obviously, it is a better model than the previous one. But the model only considers the single changing process in which the No. I kind of land-use is converted into other kinds, whereas the condition in which other kinds of land-use being converted into the No. I land-use style is neglected. Thereby, it is named the single spatial information analysis model, the limitation of which is that the land-use sort with high increasing speed and slow transformation, especially land for civil construction, is greatly undervalued. There are numerous cases which indicate that the rapid increase and spread of the land for civil construction is the most important character and impetus of land-use in developed districts[6,7]. Especially in China, given the fact that the land is highly populated and the nation is in the period of rapid urbanization, the spreading land for civil construction and its corresponding resource, environmental and ecological domino effects have brought attention from the national and international societies and the recognition of the government. It becomes a key to investigating the land-use dynamic changes in China. The calculated result for land-use dynamic degree cannot reflect the spreading trend of land-use due to its strong irreversibility; especially, it cannot agree with actual

conditions. However, the model is suitable for calculating integrated dynamic degree of land-use, since, as a whole, the inter-converting of land-use sorts is a bi-directional and equal process.

2.3 Spatial calculating model

In our opinion, while calculating the speed of land-use dynamic changes, it is necessary to consider the increased part during the research period, that is, other land-use sorts that are converted into the No. I land-use sort in other districts. In order to describe and calculate the degree of land-use change more accurately, we introduce the spatial calculating model that is modified based upon the land-use dynamic model.

$$\mathrm{TRL}_i = (\mathrm{LA}_{(i,t1)} - \mathrm{ULA}_i) / \mathrm{LA}_{(i,t1)} / (T_2 - T_1) \times 100\,\%, \tag{4}$$

$$\mathrm{IRL}_i = (\mathrm{LA}_{(i,t2)} - \mathrm{ULA}_i) / \mathrm{LA}_{(i,t1)} / (T_2 - T_1) \times 100\,\%, \tag{5}$$

$$\mathrm{CCL}_i = \{(\mathrm{LA}_{(i,t2)} - \mathrm{ULA}_i) + (\mathrm{LA}_{(i,t1)} - \mathrm{ULA}_i)\} / \mathrm{LA}_{(i,t1)} / (T_2 - T_1) \times 100\,\% = \mathrm{TRL}_i + \mathrm{IRL}_i. \tag{6}$$

In the above formulas, TRL_i represents the converting speed of the No. I land-use sort during the observation period; IRL_i represents the increasing speed of the land-use; CCL_i is the changing speed; and 'n' represents the amount of land-use sort in the research district, $i \in (1, n)$. The formula for regional land-use changing speed agrees with that of the dynamic model.

By comparing the formulas of (1) to (6), we can find that the main distinction between the spatial calculating model and numerical model as well as dynamic model is how to treat the relation between converting speed and increased speed. In the numerical model, the changing ratio (K_i) of No.I kind of land-use actually is the margin's absolute value between converting speed (TRL_i) and increased speed in the spatial calculating, considering the numerical changing of the land-use sort only. While in the dynamic model, the result of changing speed (S_i) of No.I kind of land-use is the converting speed (TRL_i) in the spatial calculating model as a result of ignoring the increased process. The spatial calculating model gives attention to both converted and increased process; the changing speed is the sum of converting speed and increased speed.

Numerical analyze model: $K_i = \left|\mathrm{TRL}_i - \mathrm{IRL}_i\right|$.

Dynamic model: $S_i = \mathrm{TRL}_i$.

Spatial calculating model: $\mathrm{CCL}_i = \mathrm{TRL}_i + \mathrm{IRL}_i$.

3 Case analyses

In China, suburban areas of the metropolis, with the fastest steps of urbanization and industrialization and the most complicated changes of land-use between city and country, are the ideal locations for research[8]. Haizhu District, which is located in the south of Guangzhou City, surrounded by the Pearl River and adjacent to Panyu District in the south, is a relatively new region of 90.4 km² with a fast developing speed. Compared with the other districts of Guangzhou City, the most part of Haizhu District is a transitional zone between the city and the countryside. In the city, land for agriculture takes up a relatively great percentage. With continuous urbanization and regional economic development, land-use changes frequently in this district. Because of this, it can serve as a perfect case for land-use dynamic changes and developing trend research[9−11].

According to the existing spatial data, this paper studies the land-use changing of Haizhu District from 2001 to 2005 with the help of spatial calculating model. The actuality graphs of 2 years

can be overlaid with the help of GeoMedia 4.0 GIS software so the unchanged area can be calculated. Here we calculate it with spatial calculating model, and the result is listed in Table 1. We can see from the result that in the cultivated land of the first land-use sort, the largest acreage of converted part is garden land, the next are the other kinds of cultivated land and infield, accounting for 46%, 32% and 18% of the total area respectively. For the land for civil construction of the first land-use sort, the largest acreages of increased part are transportation land and land for civil construction, with the percentages of 65% and 15% of the total increased area of land for civil construction respectively. It indicates that the second land-use sort above acts an important role in the land-use changes of the research observation region. We can take infield, garden land and the other lands in cultivated land, land for town and transportation land in constructed land for example and use the covered map of land-use in Haizhu District of Guangzhou in 2001 and 2005, and the changed map of main land-use sorts which is obtained by spatial overlaying and calculating analysis (Figures 2—4) to represent the evolvement of increasing sort and spatio-temporal converting about land-use in Haizhu District from 2001 to 2005.

Table 1 Change rate of land-use in Haizhu District (2001—2005) (area unit: ha)

Land classification	Unchanged area	Converting part			Increased part			Changing rate
		Area	Total area (%)	Converting area	Area	Total area (%)	Increasing rate	
Cultivated land	2098.46	588.90	6.52	5.48	103.10	1.14	0.96	21.56
Infield	560.34	109.93	1.22	4.10	32.18	0.36	1.20	5.30
Garden land	1460.44	275.25	3.05	3.96	52.46	0.58	0.76	4.72
Woodland	41.01	3.92	0.04	2.18	1.25	0.01	0.70	2.88
Grassland	2.08	8.03	0.09	19.86	5.37	0.06	13.28	33.14
The others	34.59	191.77	2.12	21.18	11.84	0.13	1.31	22.49
Constructed land	5730.96	186.50	2.06	0.79	686.27	7.60	2.90	3.50
Land for town	4648.27	30.44	0.34	0.16	451.84	5.00	2.41	2.57
Industrial land	333.84	33.93	0.38	2.31	43.62	0.49	2.97	5.28
Community land	356.75	31.89	0.35	2.05	61.88	0.68	3.98	6.03
Transportation land	315.35	68.14	0.75	4.44	106.13	1.17	6.92	11.36
Water conservancy land	20.26	22.10	0.24	13.04	22.80	0.26	13.46	26.50
Special land	56.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Unused land	129.12	315.88	1.43	17.51	286.59	3.17	16.62	33.13
Unused field	10.30	9.89	0.11	12.25	7.96	0.09	9.86	22.11
The others	118.82	305.99	1.32	18.62	278.63	3.08	16.95	35.57

As far as agricultural land is concerned, from 2001 to 2005, the unchanged area is 560.34 ha, 94.579% of the total area in 2005; converted area is 109.93 ha, 18.55% of the total area accordingly; the increased area is 32.18 ha, 5.43% of the total area. The converted area is 13.12% more than the increased area, which indicates obviously that the net area of agricultural land is decreasing continuously in Haizhu District. As for garden land, the unchanged area is 1460.44 ha, 96.53% of the total area; the increasing area is 52.46 ha, 3.47% of the total area; converted area is 275.55 ha, 18.21% of the total area correspondingly; the converting area is 14.74% larger than the increased area, indicating that the net area of garden land is decreasing in the same way. When it turns to land for the city or town, the unchanged area is 4648.27 ha, 91.14% of the total area of land for civil construction in 2005; the converting area is 30.44 ha, 0.65% of the total area; the increased area is 451.84 ha, 8.86% of the total area. Contrary to agricultural land and garden land, the con-

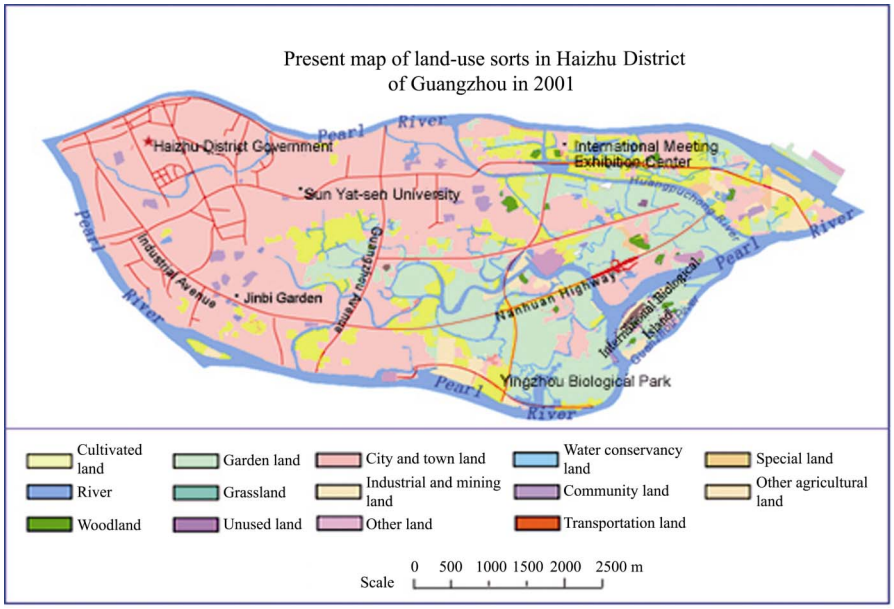

Figure 2 Present map of land-use in Haizhu district of Guangzhou in 2001.

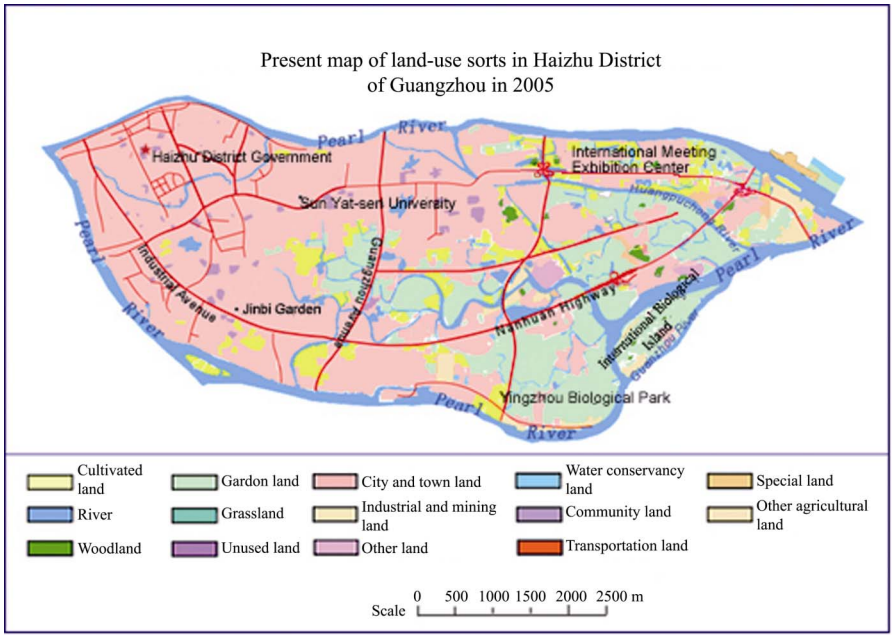

Figure 3 Present map of land-use in Haizhu district of Guangzhou in 2005.

verting area is 8.21% smaller than the increased area, showing that the land for town is again increasing. Furthermore, we can draw the conclusion from Table 1 and Figure 2: In the stream area in the east, as a result of government regulation, a large part of civil-used land will be changed to biology garden. It mostly derives from the land for town in the east of the research observation region. For the land used for civil construction, the second largest portion is used for communica-

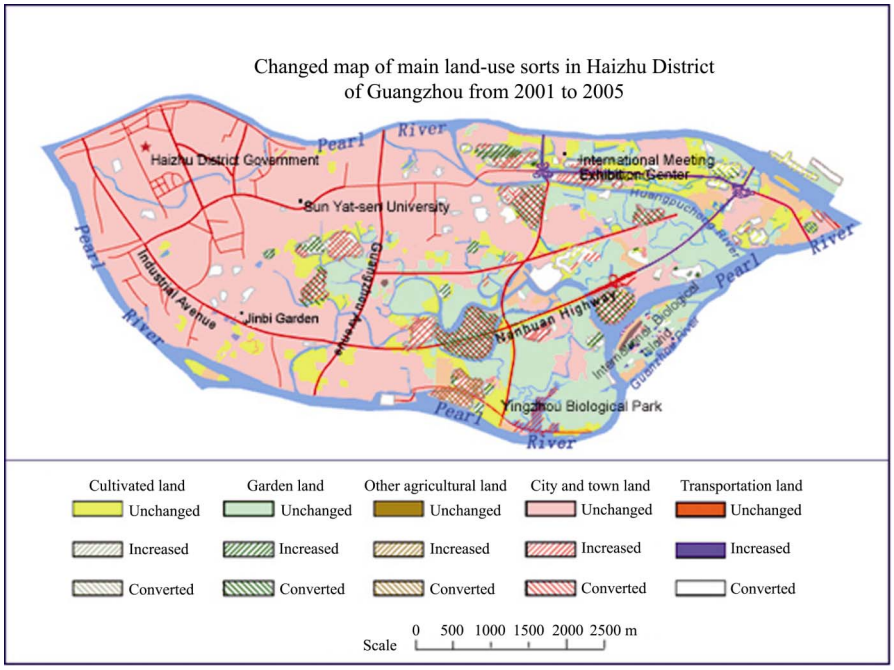

Figure 4 Changed map of main land-use sorts in Haizhu district from 2001 to 2005.

tions, and this indicates the importance of infrastructure of communications for the rapid urbanization. At the same time, we may notice that the percentages of both increased and unchanged parts of infield and garden land are over 82%, which ensures the main infield unchanged. How to make sure that the primary cultivated land won't be taken up optionally, how to improve the efficiency of urban land-use by regulating and altering the land-use spatio-temporal structure and how to control the scope of land for town should be paid more attention to. The government should consider the demand of land-use more rationally, which will have active effort on the land-use condition. Of course, some parts of the rivers, lakes and ponds were filled up and used for civil construction, shortening or cutting some streams as they were blocked, which makes the scarce water source become worse[12−14].

4 Conclusion and discussion

The spatial calculating model can analyze land-use changes from the microcosmic aspect, taking the converting and increased parts of land-use changes into account as well, which can actually reflect the land-use changing degree, especially the land-use category that is increased and converted actively (i.e. the infield and garden land)[15]. At the same time, the model can calculate the dynamic changing degree of all kinds of land-use categories. By analyzing the spatial calculating model, combining with the regional characters and the perfection of economic policies and land laws in our country in the past ten years, we can draw the conclusions.

1) The spatial-temporal changing of land-use and urbanization are a synchronous process, and the urbanization agrees with the principle of the spatial diffusion. According to the location changing character, the land-use diffusing sort of observation area can be considered as a sort with continuous diffusion to the regions around the active land-use spot. The Pearl River surrounds the

western border of Haizhu District, which makes it impossible for the urban land-use to diffuse toward the western area. Therefore, the urban land-use area expands along the river channels network to the center of the region; while in the downtown area, it expands along the transportation artery. The two processes interact with each other, but the expanding speed of the former is faster than the latter. As for the present condition of land-use, we can divide the research observation area into three region sorts from the point of land-use changing rule: The stable area in the west, developed region in the middle of the area and developing region in the eastern area[16].

2) Cities, towns and residential areas with inactive changing trend are the primary land-use sorts in the western area. Here the land-use changes are primarily rapid changes of small pieces. The land in the area is almost all for commerce and habitation. The marginal land changing spreads forward the central region at the drive of the center, because of the dense population, fast increment of land and saturated spatial capacity. The land changing in the central region is more active, and the land for town sprawls at an especially high speed, for it is a transitional zone between the city and the countryside. That the single soil cell breaks into other sorts is the primary change in the area along the Pearl River and transportation artery. It spreads around the center, and the infield is mainly converted into urban land at this case. The land in the east is primarily used for agriculture or even unused. In this area, the cultivated land needs to be protected and the spatial capacity has not been made best use of. The area is becoming smaller and smaller as a result of the spreading of the west steady area and the mid developing area as well as to the limitation of the Pearl River. The land changes will be active and variable, so the government needs to protect and manage the developing of the land in this area.

3) As far as the land-use spatial distributing is concerned, the land-use condition of the urban edges is the most complex and unstable. It has the great trend to be changed into land for civil construction. Without effective controls, the city will be extended to a large scale, which will lead to the sharp decrease of infield. In addition, some parts of the rivers, lakes and ponds were filled up and used for civil construction, which shortens or cuts some streams, causing "dead streams" and "dead lakes" as they were blocked. Some rivers across the city were polluted by the wastewater. At the same time, the soil erosion caused by vegetation destruction leads to the increase of the sand in the rivers. In short, the spread of land for civil construction and the decrease of the infield in the suburb will arise numerous ecological and environmental problems. Therefore it is important to reinforce the regulation of land-use control[17].

According to the analysis, different actions should be taken to manage different land-use areas during the planning and management of the land in the future. In districts where land-use is stable, the main objective is to adjust land-use structure and enhance land-use efficiency to make best use of the land when land-use development, sustainable development, ecologic and environmental protection are considered[18]. In developing districts, based on the principle of "strategic planning, comprehensive developing, systematic construction, infrastructure in the first step", the main objective is to carry out comprehensive development plans step by step and to achieve planned benefits after construction and planning. In new districts, the main objective is to improve the protection of land resource, tap the latent power of urban reserved land resource and make a good general planning of urban land-use so as to make management a standard and scientific process. As for the management of land resource, the limited urban land resource must be properly planned and the urban constructions must be carefully coordinated. In order to maintain the cultivated land and vegetable land, it may be necessary to transform and utilize hilly land and wasteland and develop

them into residential, industrial land or parkland.

1 Bruce P, Maurice Y. Rural/urban land conversion I: Estimating the direct and indirect impacts. Urban Geogr, 1993, 14(4): 323－347
2 Wang X L, Bao Y H. Study on the methods of land use dynamic change research. Progr Geogr (in Chinese), 1999, 18(1): 81－87
3 Zhao J, Wei C J, Huang L F, et al. Research methods of land use changes and their applications in Hainan Island. Geogr Res (in Chinese), 2001, 20(6): 723－730
4 Liu J Y, Liu M L, Zhuang D F, et al. Study on spatial pattern of land-use change in China during 1995－2000. Sci China Ser D-Earth Sci, 2003, 46(4): 373－384
5 Wang S Y, Liu J Y, Zhang Z X. Analysis on spatial-temporal features of land use in China. Acta Geogr Sin (in Chinese), 2001, 56(6): 631－639
6 He C Y, Shi P J, Chen J. A study on land use/cover change in Beijing area. Geogr Res (in Chinese), 2001, 20(6): 667－687
7 Zhu H Y, Li X B, He S J. Spatio-temporal change of land use in bohai rim. Acta Geogr Sin (in Chinese), 2001, 56(3): 253－260
8 Luo Y, Zhou C S. The review and outlook on urban-rural fringe studies in China. Urban Stud (in Chinese), 2005, 12(1): 25－30
9 Zhang X C, Yang D Y, Pan Q, et al. Study on developing and predicting analysis of cultivated land in urban edge districts. Acta Sci Nat U Suny (in Chinese), 2002, 41(3): 104－108
10 He C Y, Shi P J, Chen J. Developing land use scenario dynamics model by the integration of system dynamics model and cellular automata model. Sci China Ser D-Earth Sci, 2005, 48(11): 1979－1989
11 Zhou T, Lv P. On spatial heterogeneity of residential land in urban fringes: Patterns, calculating and low entropy transmuting. Geogr Geo-Inf Sci (in Chinese), 2007, 23(2): 70－74
12 Zhu Z G, Xu G, Yao S M. Analysis on the urbanization process in the fringe of the metropolis－a case study on Ji-angning district of Nanjing. Geogr Geo-Inf Sci (in Chinese), 2003,19(3): 76－86
13 Lambin E F, Baulies X, Bockstael N. Land use and land cover change. Implementation Strategy. IGBP report 2004, No. 48, IHDP report No. 10
14 Ralph E, William D A. Development at the urban fringe and beyond-impacts on agriculture and rural land. Econ Res Ser, 2001, 803: 11－14
15 Jim H. Land use conflicts on the urban fringe: Causes and potential resolution. http://www.strom.clemson.edu/publications/hite/landuse-hite.pdf
16 Rodney L C. Issues at the rural-urban fringe: The land use debate-situational background. http://edis.ifas.ufl.edu
17 Lawrence W L, Jeff S S. Land-use compatibility, change and policy at the rural-urban fringe: Insights from social capital. Am J Agr Econ, 2003, 85: 1194－1200
18 Turker M, Asik O. Land use change detection at the rural-urban fringe using multi-sensor data in Ankara. Int J Geogr Inf Sci, 2005, 1(3): 27－36