

DETECTION AND PREDICTION OF LAND USE CHANGE IN BEIJING BASED ON REMOTE SENSING AND GIS

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ABSTRACT:

With the development of global changes, researchers from all over the world attach attention to land use changes increasingly, and large scale land use changes which have resulted from urban expansion catch people's eyes. In this paper, urban expansion and their spatial and temporal variability of the Beijing city has been studied over a period of 21 years (1984–2005) via statistical classification approaches based on the remotely sensed images obtained from sensors both Landsat TM5 and SPOT4. The research method includes three parts: First, using multi-temporal images, land use/land cover change is detected by means of remote sensing. Then, based on result of classification images, the process of land use/land cover change and the model of urban expansion are analyzed by GIS technologies. It includes markov and transfer matrix, trajectories analysis, the spatial distribution rules of urban land and the spatial distribution rules of urban expansion intensity. Concretely, these include Markov and transitional probabilities matrix and the spatial distribution rules of urban land and urban expansion intensity. Finally, the relationship of population, GDP and urban land area are built up through a linear regression analysis. Research shows that: 1) Land use/land cover change detection using multi-temporal images by means of remote sensing and ration research of model of urban expansion by GIS are good means of research of urban expansion. 2) Research of time sequence land use/ land cover change through analysis of urban expansion trajectories and index reveals of urban distribution rules in terms of spatial-temporal. 3) Combined the analysis of social economic data, the simulation of expansion urban land is given in amount.

1. INTRODUCTION

The land use change in large city area is a complicated process; several factors have influences on this process, including both physical aspects and human aspects. On the one hand, accelerated urban expansion is usually associated with and driven by the social-economic factors; on the other hand, the process of urbanization has a considerable impact on the economics of the society in that area (He, 2006; Mahesh, 2008). For substantial development, municipal authorities need tools to monitor how the land is currently used, assess future demand, and take steps to assure adequacy of future supply; for a better planning of future urban development, municipal authorities need to know situation of urban expansion and in what way it is likely to move in the years to come (Mahesh, 2008). So the detection of urban land change is important for officials and planner in the local government.

Recent years, urbanization is a major trend in big city all around the world (Weber, 2003). The main change of landuse in these areas can be described as other type of landuse converting into urban land. Unfortunately, the conventional survey and mapping techniques are expensive and time consuming for the estimation of urban expansion and such information is not available for most of the urban centers, especially in developing countries. As a result, increased research interest is being directed to the monitoring of urban growth using GIS and

remote sensing techniques (Epstein et al., 2002). Remote sensing is increasingly used for detection and analysis of urban expansion since it is cost effective and technologically efficient. The detection of landuse change using either an image-to-image comparison or a post-classification comparison (Liu, 1999). During the past ten years, extensive study efforts has been made for urban change detection using remotely sensed images (Yeh and Li, 2001; Liu and Zhou, 2004; Li et al., 2005; He et al., 2005; Mahesh, 2008). Despite these efforts, further research is needed in order to reinforce the absolute and comparative relationship between the type and intensity of urban land use change and their causative factors (Mahesh, 2008).

Many models for urban growth prediction, such as the cellular automata (CA) model and land conversion in the urban fringe area, have been developed (Wu, 1998; Li and Yeh, 2002; He et al., 2008). Among these models, Geographical Information System (GIS) based urban models have been widely used (Yeh and Li, 1998; He et al., 2005). In practice, however, the use of these models has been limited in urban growth analysis because of the difficulty in obtaining all of the required factors or enough data for the model.

Therefore, in this paper, we take plain region of Beijing City as an example, based on remotely sensed data (Landsat TM and SPOT images) in seven years (1984, 1988, 1991, 1994, 1997, 2001 and 2005), detecting Beijing's land use/land cover change

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from 1984 to 2005 (six periods: 1984~1988, 1988~91, 1991~1994, 1994~1997, 1997~2001 and 2001~2005) by means of remote sensing. Then, we study and predict the phases of urban expansion in Beijing with assistant socioeconomic statistical data by GIS and statistical method.

2. STUDY AREA AND DATA USED

2.1 Study area

We selected Beijing as the study area, which is one of the most typical urban expansion cities. And our research mainly focus on the plain region of the city(study area about longitudes 115° 50' -116° 59' E, latitudes 39° 35' - 40° 23' N), which is mainly the rural fragment and has an intensive urban expansion. The whole administrative area governed by Beijing Municipality is 16,808 km². And our study scope, with a land area of 4902.9 Km² (29% of the whole city) and a population of 10,559,000 (79% of the whole city) is basic to include the main town district of Beijing and to express the most obvious urban expansion model (Jiang, 2004). Presenting the obvious change from center to downtown, from the city edge area to far suburban area county on the space, this area can express mostly the characteristic of the downtown.

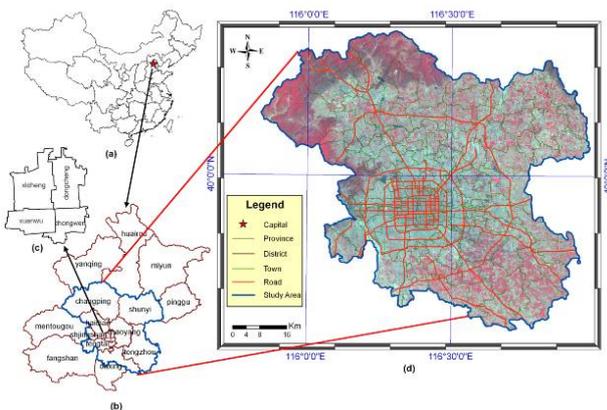


Figure 1. Location of study area

(a) Administrative region map of China; (b) Administrative region map of Beijing; (c) Four center city districts of Beijing; (d) The study area.

Located on the northern edge of the North China Plain, the administrative area of Beijing Municipality is composed of four city districts (Dongcheng, Xicheng, Xuanwu and Chongwen;), four suburban districts (Chaoyang, Haidian, Fengtai and Shijingshan), eight outer suburban districts (Mengtougou, Fangshan, Daxing, Tongxian, Shunyi, Changping, Pinggu, Huairou), as well as two rural counties (Yangqing, Miyun). Traditionally, the four city districts(Figure 1(c)) plus the four suburban districts are viewed as the central city with about 300 km² in area. Beijing is in the temperate climatic zone with a mean annual temperature of 12°1 C and an average annual precipitation of 640mm (He et al., 2008). The mountains are located in the northwest, which account for 62% of the surface area with an average elevation about 1000m above sea level. The so-called Beijing Plain is in the southeast where the elevation is below 100m above sea level. As the most intensively developed area of Beijing, the plain covers 38% of

the administrative area, and is the main focus of urban expansion (Li et al., 2005).

The road system in Beijing can be briefly described as a ring network, with ring roads and radial roads as its arteries (He et al., 2008). The road around the Forbidden City is named the First Ring Road (actually can not seen in the map), and the ring roads beyond are the Second, Third, Fourth, Fifth and the Sixth Ring Roads in the order of the radial distance from the center of the city (Figure 1). Before 1949, Beijing's development was confined within the old city, now marked by the Second Ring Road. The implementation of Reform and Open Policy since 1978 brought a phase of rapid urbanization and further encroachment into the surrounding countryside (Li et al., 2005).

2.2 Data used

The main spatial data sources used in this study has been list in the table (Table 1Table 1). For detecting Beijing's land use/land cover change from 1984 to 2005 by means of remote sensing, six Landsat-5 Thematic Mapper (TM) images (1984, 1988, 1991, 1994, 1997 and 2001) and seven SPOT4 High Resolution Visible Infrared (HRVIR) images (1998, 1999 and 2005) are collected for the case study. In addition, essential ancillary data including 1: 100,000 Ward Map and Road Network Map are also obtained from the local government. Furthermore, population and other social statistical data of the Beijing city are obtained from the demographic data (Beijing Statistics of 2005), i.e. 1978 – 2005. All the spatial data layers were registered to the same Universal Transverse Mercator (UTM) coordinate system and sampled to the same pixel resolution of 30 m.

No	Information		
	Type of data/Sensor	Scale/Resolution	Year/Time
1	Landsat5 TM	30 m	02/10/1984
2	Landsat5 TM	30 m	21/04/1988
3	Landsat5 TM	30 m	06/05/1991
4	Landsat5 TM	30 m	28/08/1994
5	Landsat5 TM	30 m	16/05/1997
6	Landsat5 TM	30 m	19/05/2001
7	SPOT4 HRV	10 m	10/10/1998
8	SPOT4 HRV	10 m	27/09/1999
9	SPOT4 HRV	10 m	15/03/2005
10	SPOT4 HRV	10 m	04/07/2005
12	SPOT4 HRV	10m	25/08/2005
13	SPOT4 HRV	10 m	31/10/2005
14	Ward Map	1:10,000	2000
15	Road network map	1:10,000	2000

Table 1. Different type of spatial data

3. METHODOLOGY

3.1 Detection of Land use/land cover change

A time series of remotely sensed images (Landsat TM5 and SPOT4), covering 21 years, were used to obtain landuse change information, using the post-classification comparison technique (Lillesand and Kiefer, 2000).

3.1.1 Image pre-processing

All information extracted from remotely sensed data is obtained in the consistent technical flow: the geometric rectification, image registration and images matching with each other. The

classification schemes include: urban land, cultivated land, vegetable land, grass and forest, unused land and water (rivers, lakes, ponds and reservoirs). The maximum likelihood method was used for the land use classification in ERDAS IMAGINE 9.1 software. Then, post-classification process method includes sub-region classification method are used in the work flow (Jiang, 2004).

The overall accuracy of the land use maps for 1984, 1988, 1991, 1994, 1997, 2001 and 2005 was determined to be 89.01%, 86.45%, 86.73%, 87.32%, 85.23%, 88.14% and 87.51%, respectively. The Kappa indices for each map were 0.86, 0.82, 0.84, 0.85, 0.83, 0.85 and 0.87, respectively (Jiang, 2004). All these steps above ensure the accuracy of land use pattern for further spatial analysis. And the distribution maps of land use maps in the study area from 1984 to 2005 are shown as followed (Figure 4Figure 4).

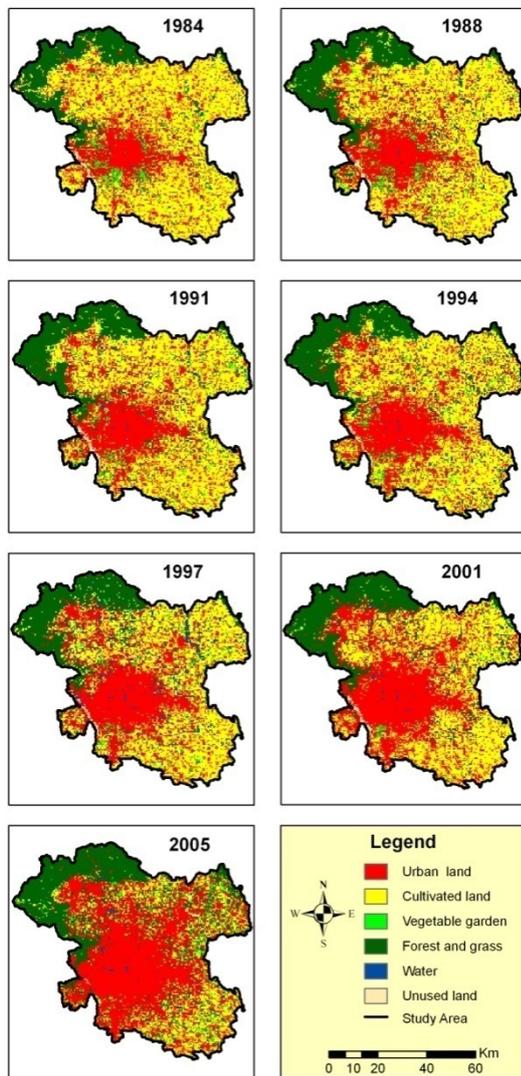


Figure 2. Land use of study area from 1984 to 2005

3.1.2 Extraction of urban information

First, we recode the map of land use to obtain the distribution of urban land. Then, to make the comparison possible, we calculate the urban land ratio in a window of 5×5 neighbourhood. Then, we reclassify the ratio of urban land from

high to low into four grades: highest ($\geq 80\%$), higher (60%-80%), medium (40%-60%), lower (20%-40%) and lowest ($\leq 20\%$), respectively. The spatio-temporal distribution of proportion of urban is show as followed (Figure 3Figure 3).

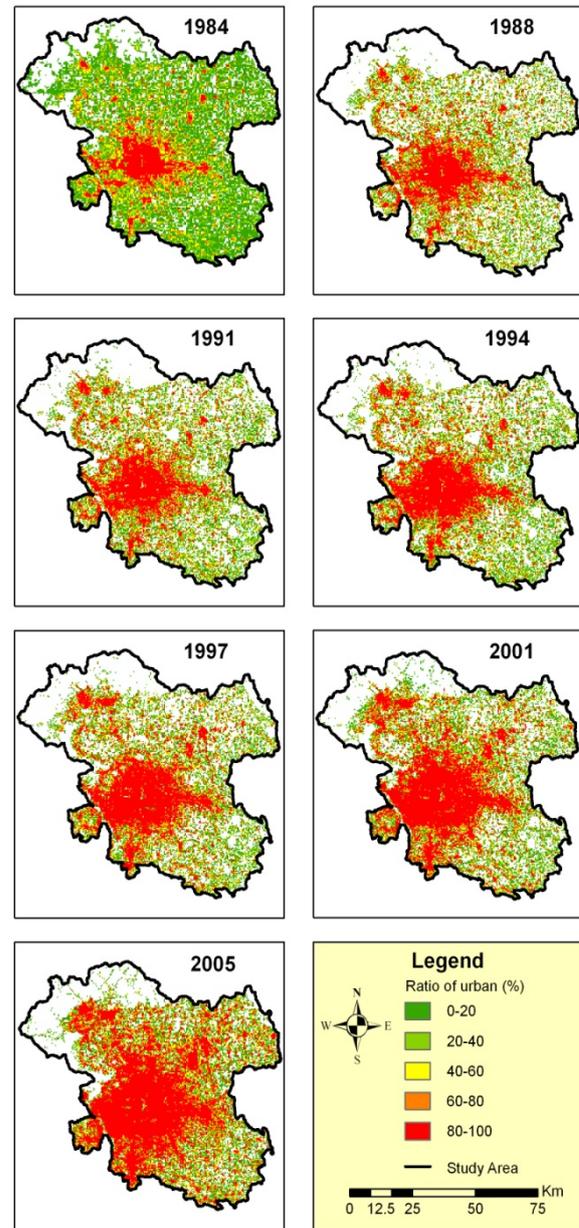


Figure 3. Spatio-temporal distribution maps in study area on ratio of urban land

3.2 Analysis of land change

3.2.1 Markov chains and transitional probabilities matrix

Markov chains have been widely used to model land use changes including both urban and nonurban areas at large spatial scales (Jahan, 1986; Muller and Middleton, 1994; Wu, 2006). Markov chains were used to gain the percentage and probability for each type of land use convert to urban land. A time-stationary Markov chain is completely determined by the Markov transition matrix P:

$$P = (p_{ij}) = \begin{pmatrix} P_{11} & P_{12} & \dots & P_{1n} \\ P_{21} & P_{22} & \dots & P_{2n} \\ \dots & \dots & \dots & \dots \\ P_{n1} & P_{n2} & \dots & P_{nn} \end{pmatrix}, \quad \sum_{j=1}^n p_{ij} = 1 \quad (1)$$

where P = the Markov transition matrix P
 i, j = the land type of the first and second time period
 P_{ij} = the probability from land type i to land type j

In the transition matrix it request that each rate is a non-minus quantity, and each line factors plus to 1.

The estimate of Markov chain is the relative frequency of transitions observed over the entire time period. And the result of the estimation would used for prediction. In practice, based on the map algebra principle, the class of land type we use the equation followed to calculate the transfer map of land use change under the ERDAS Modeler module.

$$C_{ij} = A_{ij}^t \times 10 + A_{ij}^{t+1} \quad (2)$$

Where A_{ij}^t, A_{ij}^{t+1} = the land use map of the first and second time period, respectively
 t, t + 1 = the first and the second time period
 i, j = the land type of the first and second time period
 C_{ij} = the class of land type i to land type j

When the observation time series becomes long, the primarily two-time comparison methods by Markov matrix are not applicable. The Markov chain in way of trajectory reflected land-cover change refers to successions of land-cover types for a given sampling unit over more than two observations (Liu and Zhou, 2005). To establish the trajectory of landuse change, we have selected numerous sample points over the study area and recorded for each sample point the landuse category at every period using GIS functions (sample tool in ArcInfo Tool box).

3.2.2 Urban expansion intensity

Currently, the concept of urban expansion has many different comprehensions and understanding (Xu et al., 1997). In this research, the concept mainly points the conversion from non-urban to urban. For the sake of better evaluation, we import the urban expansion index into the study. For the same reason, we a set a neighbourhood window of 5×5, then the urban expansion index E_{ij} for pixel (i, j) can be described as followed equation:

$$E_{ij} = \frac{\sum_{i=1}^N \sum_{j=1}^N g(i, j)}{N * N} \times \frac{1}{\Delta T} \quad (3)$$

Where N = the window size, i.e. 5 for this study
 i, j = the row and column number of expansion maps
 g(i, j) = the value of pixel, i.e. 1 for urban expansion
 ΔT = the time period, by year

3.3 Statistical analysis

The regression analysis was used to find the relationship between urban land areas and associated socio-economic factors. Data of socio-economic were from the Beijing’s Statistical Yearbook from 1978 to 2005.

3.3.1 Data of socio-economic

According to economic theory, GDP is divided into nominal GDP and real GDP. Nominal GDP calculated all end-products at the prices of the production of goods and services in the market value, which is not considered the price changes each year. And real GDP used a certain year as the base period refer, then calculated the prices of all end-products from the market value, which is taking into account price changes each year.

Usually, the economic data derived from Statistical Yearbook of the socio-economic statistics is the nominal GDP. The GDP_n for the real GDP of year n then can be derived from:

$$GDP_n = GDP_0' \times I_n / 100 \quad (4)$$

where n = the year
 GDP₀' = the nominal GDP in year n
 I_n = the index of GDP in year n, i.e. set 1978=100, from Statistical Yearbook 2007

3.3.2 Regression analysis

With the support of historic statistical data in Beijing (BMSB, 2007), population and GDP were related to time by means of a linear regression. The year of 1978 was used as the starting point because it was when China made the transition to the Reform and Open Policy and the economy started a fast growth (He et al, 2008). Then, the data of population and GDP in predicted year were added to the dataset for further calculating. And then the relationship between population, GDP and urban area was established by regression analysis using area measurements from satellite images and population, GDP from statistical data. Finally, we can get predict of urban land area in Beijing till year 2020 from the estimated population and GDP.

4. RESULT AND DISCUSSIONS

4.1 Land use/land cover change analysis

The work flow of multi-temporal land use/land cover change detection proved to be efficiency. The outcomes were maps of land use pattern (Figure 2Figure 2) in seven years and maps of urban expansion(Figure 3Figure 3) during the six periods and whole period from 1984 to 2005. And through the maps of urban ration in 5×5 window, it represents a strong expansion in urbanization during the 21 years.

Year	Proportion (%)					
	UB	CL	GF	VE	WA	UN
1984	25.32	51.24	15.66	4.88	1.30	1.56
1988	27.49	46.15	18.56	4.72	1.81	1.24
1991	28.63	43.93	19.04	4.66	1.95	1.76
1994	30.58	42.80	18.74	4.48	2.70	0.68
1997	33.50	37.67	19.32	3.66	4.53	1.30
2001	38.72	36.20	19.94	1.82	2.25	1.04
2005	47.75	14.12	25.87	3.07	1.21	0.98

Table 2. The proportion of every land use type in period of detection

UR: urban land; CL: cultivated land; GF: grass and forest land; VE: vegetable garden; WA: water; UN: unused land.

From the table (Table 2Table 2), we can find that during the entire study period from 1984 to 2005, the urban land area proportion expanded from 25.32% to 47.75% of the study area, nearly a double in 21 years, showing a strong trending of expansion. And also, we can find a growing in grass and forest land area, since the government has taken a policy so-called returning farmland to forestry or grass.

4.1.1 Type of land transferred

Transfer proportion of land use types was obtained by means of Markov model and the principle of algebra in map. The main type of land transferred to urban land was cultivated land; while other types, for example, water to urban land and gardens to urban land are nearly none.

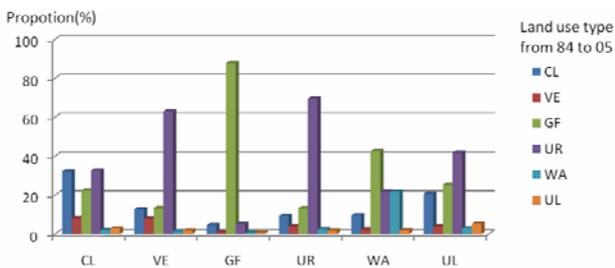


Figure 4. Land use type change from 1984 to 2005

UR: urban land; CL: cultivated land; GF: grass and forest land; VE: vegetable garden; WA: water; UN: unused land.

4.1.2 Markov chains and transitional probabilities matrix

To make trajectory analysis, we need to take random sample of a certain number of points in seven classification maps, respectively. Then, we examine these samples in six phases on the types of land-use changes. According to Liu’s point stability of the test results (Liu and Zhou, 2004), when the number of random sample reached 1,000 points, its stability will not change. So in this study 1,000 randomly were selected sample points used for trajectory analysis. And there are 29 types of trajectories as followed (Table 3).

Through analysis of 1000 randomly selected sample, the trajectory of urban expansion in the land use change tracked by 29 series, the proportion of each track as shown in Table (Table 4Table 4). According to the arrow indicates, the expansion of urban in the study area of the track can be divided into three groups the following:

- (1) From cultivated land to urban land. Track series of 1 to 17 belong to this type, as a whole taken for the largest proportion of 77.7 percent. For the majority of this type of cultivated land to urban land, very small portion from other types into cultivated land, and then to urban land.
- (2) From vegetable land to urban land. Track series of 18 to 21 belong to this type, as a whole taken for the largest proportion of 8.8 percent.
- (3) From others to urban land. Track series of 21 to 29 belong to this type, as a whole taken for the largest proportion of 10.1 percent.

NO	84	88	91	94	97	01	05	(%)
1	1	→4	4	4	4	4	4	6.9
2	1	1	→4	4	4	4	4	1.3
3	1	1	1	→4	4	4	4	27.0
4	1	1	1	1	→4	4	4	4.5
5	1	1	1	1	1	→4	4	1.7
6	1	1	1	1	1	1	→4	10.2
7	1	1	3	1	1	1	→4	3.6
8	1	3	1	1	1	1	→4	3.2
9	1	2	1	1	1	1	→4	3.0
10	1	5	5	5	5	1	→4	2.1
11	1	1	1	5	1	1	→4	2.2
12	2	2	1	→4	4	4	4	3.8
13	2	2	2	1	→4	4	4	1.2
14	3	1	1	1	1	1	→4	2.1
15	5	1	1	1	→4	4	4	1.4
16	6	1	1	1	1	1	→4	2.0
17	1	1	1	2	1	1	→4	1.5
18	2	→4	4	4	4	4	4	4.1
19	2	2	→4	4	4	4	4	1.5
20	2	2	2	2	→4	4	4	2.3
21	1	1	2	→4	4	4	4	0.9
22	3	→4	4	4	4	4	4	1.7
23	1	1	1	1	1	3	→4	0.6
24	1	1	1	2	1	3	→4	1.0
25	2	2	3	→4	4	4	4	0.9
26	1	1	1	1	1	5	→4	1.9
27	1	1	1	3	1	5	→4	0.6
28	1	6	→4	4	4	4	4	0.8
29	1	1	6	→4	4	4	4	2.6

1: cultivated land; 2: vegetable garden; 3: grass and forest land; 4: urban land; 5: water; 6: unused land; arrow (→): other types of land convert to urban land use.

Table 3. The trajectories of landuse change from 1984 to 2005

4.2 Spatio-temporal analysis

From central city to suburb, the land use variation takes on strong spatio-temporal change. The extent of urban expansion of east is higher than west’s as a whole. The model of urban expansion is analyzed by the spatial distribution rules of the proportion of urban land and the spatial distribution rules of urban expansion. Round-sprawl is the main model of urban expansion. The urban expansion models include isolated growth and corridor’s growth. Urban expansion cores and traffic are two urban expansion spatial influence factors (Figure 5).

4.2.1 Analysis of maps

As shown in the expansion map (Figure 5), we can easily find that there are one main city-expansion core and four sub-expansion cores, which is center of Changping, Shunyi & Airport, Tongzhou and Daxing, respectively.

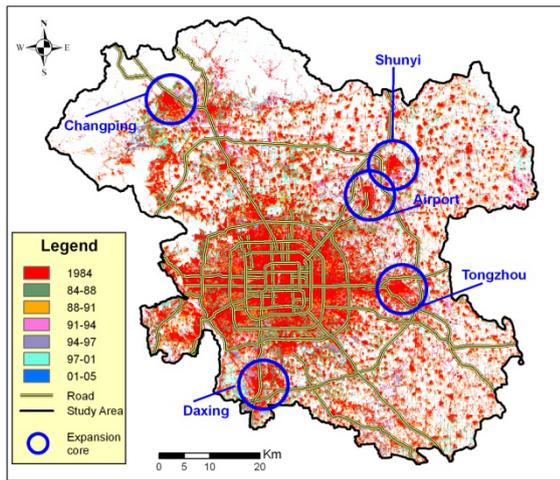


Figure 5. Urban expansion map and expansion cores in study area, from 1984 to 2005

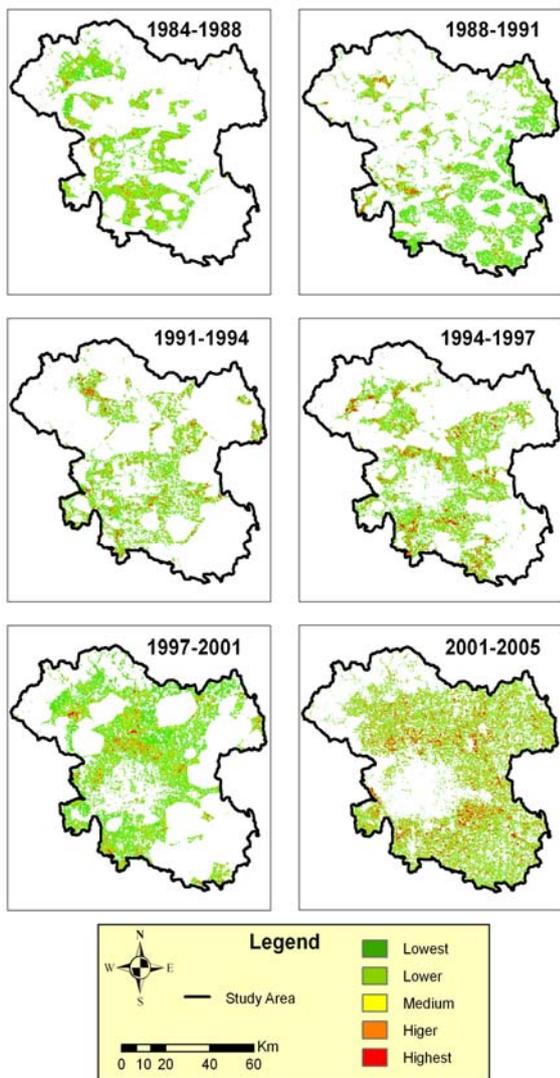


Figure 6. Spatio-temporal distribution maps of urban Expansion intensity in study area from 1984 to 2005

4.2.2 Urban expansion intensity

First, we recode the map of land use transition in period (from the start year to the end year (i.e. 1984-1988) to obtain the distribution of expansion urban land during the period. Then, to make the comparison possible, we calculate the expansion urban land ratio in a window of 5×5 neighbourhood. Then, we reclassify the index of urban expansion from high to low into four grades: highest (>=20), higher (15-20), medium (10-15), lower (5-10) and lowest (<=5), respectively. The spatio-temporal distribution of proportion of urban is show as followed (Figure 5). For the six period of detection, there is a strong trend of expansion from original four urban districts to the suburb districts. From central city to suburb, the land use/land cover variation information takes on strong spatio-temporal change. The extent of urban expansion of east is higher than west's as a whole. The urban fringe is the main region of urban expansion.

4.3 Analysis of socio-economic data

4.3.1 Data of socio-economic

The GDP index (i.e. 1978=100) in corresponding years from 1978 to 2005 is derived from Beijing Statistical Yearbook 2007, with 1978 as the base period, in terms of real GDP.

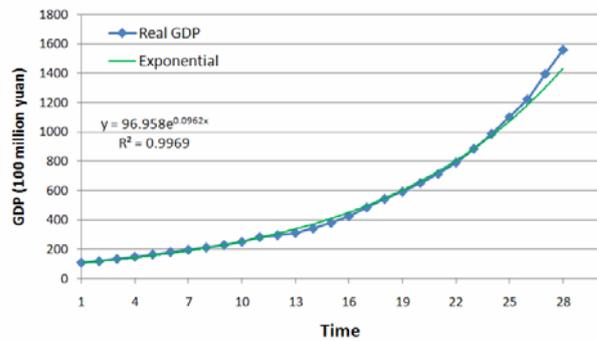


Figure 7. Scatter-plot of real GDP and time, exponential fitting where y stands for GDP and x stand for time (with 1 being the year of 1978 and 28 being the year of 2005)

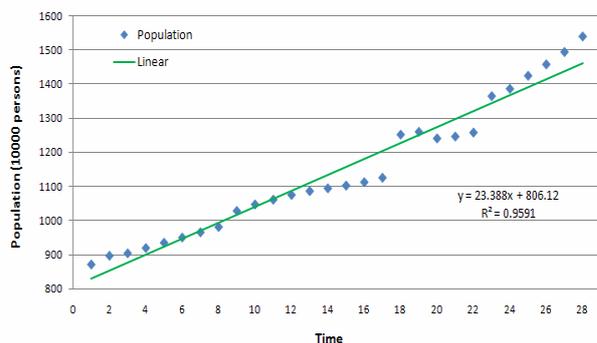


Figure 8. Scatter-plot of population and time, linear fitting

where y stands for population and x stands for time (with 1 being the year of 1978 and 28 being the year of 2005).

4.3.2 Regression analysis

The result of regression analysis between urban land area and Population, GDP is as followed:

$$Y_n = 792.225 + 0.647x_{1n} + 0.346x_{2n} \quad (5)$$

where Y_n = the urban area in year n
 x_{1n} = the real GDP in year n
 x_{2n} = the population in year n

It is estimated (Table 4) that the urban land for 2010, 2015 and 2020 would be 2895.06Km², 3393.91 Km² and 4198.89 Km², respectively. This implies that by year 2020, the urban area in the study area would rise to a high ratio, which may be nearly 179.37% of the 2005 in 15 years. Thus, the pressure on land would further grow and the farm land areas, open grounds and region around the highways are likely to become prime targets for urban expansion.

Year	Item		
	Real GDP (100 Million Yuan)	Population (10000 Persons)	Urban Area (Km ²)
1984	196.14	965.66	1241.63
1988	282.77	1061.00	1348.11
1991	341.41	1094.00	1404.14
1994	485.14	1125.00	1499.07
1997	652.04	1240.00	1642.24
2001	988.77	1385.10	1898.73
2005	1561.17	1538.00	2340.94
2010	2318.97	1577.92	2895.06
2015	3751.38	1694.86	3393.91
2020	6068.57	1811.80	4198.89

Table 4. Population, GDP and Urban area from 1984 to 2020

where data for 1984-2005 are from BMSB (2007) and data for 2010-2025 are from the regression analysis result.

5. CONCLUSION

(1) Land use/land cover change detection using multi-temporal images by means of remote sensing and ration research of model of urban expansion by GIS are good means of research of urban expansion. Through this process, we obtain the seven temporal distribution maps of land use in the study area from 1984 to 2005 (Figure 4). And the spatio-temporal distribution maps of ratio of urban land represent a strong expansion in urbanization.

(2) Research of time sequence land use/ land cover change through analysis of urban expansion trajectories and index reveals of urban distribution rules in terms of spatial-temporal. According to analysis of 1000 randomly selected sample, the trajectory of urban expansion in the land use change tracked by 29 series (Table 3); and track series from cultivated land to urban land, taken for the largest proportion of 77.7 percent. The maps of urban expansion intensity (Figure 6) show that the expansion of urban land in study area experiences a transition from center city to suburb.

(3) Combined the analysis of social economic data, the simulation of expansion urban land is given in amount. With the analysis of socio-economic data, population and real GDP in this study, we obtain the result of prediction urban land area through a linear regression. It is estimated (Table 4) that the urban land for 2020 would be 4198.89 Km². Thus, the pressure on land would further grow and the farm land areas and other type of land nearby the highways are likely to become prime targets for urban expansion.

Future studies will investigate the impacts and interactions of spatial variables on urban expansion patterns and suitable method to quantify other socio-economic factors that may also play important roles in urban expansion. Appropriate and practical methodologies for expansion simulation in terms of spatial should also be further studied.

REFERENCES

- Beijing Municipal Statistical Bureau, 2007. Beijing Statistical Yearbook. Beijing: China Statistical Press.
- Epstein, J., Payne, K., Kramer, E., 2002. Techniques for mapping suburban sprawl. *Photographer Engineering Remote Sensing*. 63 (9), pp. 913-918.
- He, C., Okada, N., Zhang, Q., Shi, P., Zhang, J., 2006. Modeling urban expansion scenarios by coupling cellular automata model and system dynamic model in Beijing, China. *Appl. Geogr.* 26(2006), pp. 323-345
- He, C., Okada, N., Zhang, Q., Shi, P., Li, J., 2008. Modelling dynamic urban expansion processes incorporating a potential model with cellular automata, *Landscape Urban Plan.*(2008), ARTICLE IN PRESS.
- Jiang, Q., 2004. Monitoring and change analyzing of the temporal and spatial urban expansion pattern based on remote sensing. Beijing: Beijing Normal University.
- Xu, X., Zhou, Y., Ling, Y., 1997. Urban Geography. Beijing: Higher Education Press.
- Li, X., Yeh A., 2000. Modelling sustainable urban development by the integration of constrained cellular automata and GIS. *Int. J. Geographical Information Science*. 14(2), pp. 131-152.
- Li, X., Yeh, A., 2001. Calibration of cellular automata by using neural networks for the simulation of complex urban systems. *Environ. Plan. A*. 33, pp.1445-1462.
- Li, X., Yeh A., 2002. Neural-Network-Based Cellular Automata for Simulating Multiple Land Use Change Using GIS. *International Journal of Geographical Information Science*. 16(4), pp. 323-343.
- Liu, H., Zhu, Q., 1999. Studies of methodologies and their development on land use/ cover change detection by using high spatial resolution remote sensing data. *Resources Science*. 21 (3), pp. 23-27.
- Liu, H., Zhou, Q., 2004. Accuracy analysis of remote sensing change detection by rule-based rationality evaluation with post-classification comparison. *Int. J. Remote Sens.* 25(5), pp. 1037-1050.
- Liu H., Zhou Q., 2005. Developing urban growth predictions from spatial indicators based on multi-temporal images. *Comput., Environ. and Urban Systems* 29 (2005) , pp. 580-594.
- Mundia, C.N., Aniya, M., 2005. Analysis of land use/cover changes and urban expansion of Nairobi city using remote sensing and GIS. *Int. J. Remote Sens.* 26(13), pp. 2831-2849.
- Mills, H., Cutler, M. E. J. and Fairbairn, D., 2006. Artificial neural networks for mapping regional-scale upland vegetation from high spatial resolution imagery. *Int. J. Remote Sens.* 27(11), pp. 2177-2195.

Weber, C., 2003. Interaction model application for urban planning. *Landscape Urban Plan.* 63, pp. 49-60.

Weber, C., Puissant, A., 2003. Urbanization pressure and modeling of urban growth: example of the Tunis Metropolitan Area. *Remote Sens. Environ.* 86, pp. 341-352.

Wu, F., 1998. Simland: a prototype to simulate land conversion through the integrated GIS and CA with AHP-derived transition rules. *International Journal of Geographical Information Science.* 12, pp. 63-82.

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