Journal of Geographical Sciences

© 2007 Science in China Press Springer-Verlag

DOI: 10.1007/s11442-007-0469-z

Measuring urban sprawl in Beijing with geo-spatial indices

JIANG Fang[1,2], LIU Shenghe[1], YUAN Hong[1,2], ZHANG Qing[1,2]

1. Institute of Geographic Sciences and Natural Resources Research, CAS, Beijing 100101, China;
2. Graduate University of Chinese Academy of Sciences, Beijing 100039, China

Abstract: Concerning about the rapid urban growth in recent China, this study takes Beijing as a case and puts forward that urban sprawl can be measured from spatial configuration, urban growth efficiency and external impacts, and then develops a geo-spatial indices system for measuring sprawl, a total of 13 indicators. In order to calculate these indices, different sources data are selected, including land use maps, former land use planning, land price and floor-area-ratio samples, digitized map of the highways and city centers, population and GDP statistical data, etc. Various GIS spatial analysis methods are used to spatialize these indices into 100m×100m cells. Besides, an integrated urban sprawl index is calculated by weight sum of these 13 indices. The application result indicates that geo-spatial indices system can capture most of the typical features and interior differentia of urban sprawl. Construction land in Beijing has kept fast growing with large amount, low efficiency and disordered spatial configuration, indicating a typical sprawling tendency. The following specific sprawl features are identified by each indicator: (1) typical spatial configuration of sprawling: obvious fragmentation and irregularity of landscape due to unsuccessful enforcement of land use planning, unadvisable pattern of typical discontinuous development, strip development and leapfrog development; (2) low efficiency of sprawl: low development density, low population density and economic output in newly developed area; and (3) negative impacts on agriculture, environment and city life. According to the integrated sprawl index, the sprawling amount in the northern part is larger than that in the southern, but the sprawling extent is in converse case; most sprawling area include the marginal area of the near suburbs and the area between highways, etc. Four sprawling patterns are identified: randomly expansion at urban fringe, strip development along or between highways, scattered development of industrial land, leapfrog development of urban residence and industrial area.

Keywords: urban sprawl; measurement; geo-spatial indices; Beijing

1 Introduction

In the late 1950s, urbanized areas in USA have extended outside rapidly during the subur-

Received: 2007-01-20 **Accepted**: 2007-04-15

Foundation: National Natural Science Foundation of China, No.40571056; Sustentation Fund on Doctoral Thesis from Beijing Science and Technology Committee, No.ZZ0608

Author: Jiang Fang (1979–), Ph.D, specialized in the study on regional and urban sustainable development, land use planning and urban agriculture. E-mail: jiangfang1979@hotmail.com

banization process of residence, industry and commerce, which encroach large amount of farmland and forest, brought negative effects to environment and cause more traffic problems. This pattern of urban development out of control has been regarded as "urban sprawl" (Zhang, 2004). Urban sprawl has aroused wide social focus because it is possible to impede regional sustainable development. Related studies have come out consequently which mainly cover the features, the cause, impacts of sprawl and countermeasures as well.

Urban sprawl also has emerged in some regions of China during the rapid urbanization period. Land development has been out of control and the construction land has kept expanding blindly, especially in the marginal areas of some metropolises. Some experts pointed out: the urban sprawl phenomenon in the past decade is extremely severe, and the tendency of scattered development and sprawling growth has been formed, which will seriously impede the modernization process of China if the rash urbanization could not be kept under control (Lu, 2006). Recently, the negative impacts of urban sprawl have got more awareness, and then the related departments of government have started to seek solutions for urban sprawl. Many scholars also have proposed policy suggestions on growth management (Liu, 2002; Sun, 2003; Yan, 2000).

As for seeking solutions for urban sprawl, the first step is to analyze sprawl features so as to explore the cause of sprawl with which it is possible to put forward practicable countermeasures. However, the understanding on urban sprawl in China still rest on qualitative discussion instead of quantitative analysis. There is no clear answer on how to identify sprawl, evaluate the extent of sprawl or estimate the policy effect. The existing methods for measuring urban sprawl are mainly put forward within the context of Western developed countries. So those methods are not exactly developed for analyzing the spatial features and unique mechanism of urban sprawl within Chinese context.

Beijing is a typical case of urban sprawl because the built-up area has increased very fast and gradually formed a situation of extensive development via various spatial patterns including circularity expanding, sector growth, corridor radiation, leapfrog and in-filling development (Liu, 2000; Zong, 2002; Xu, 2002; He, 2003). Thus, based on the conclusion of previous studies, this paper takes Beijing as a study area to put forward geo-spatial indices for measuring sprawl so as to contribute to decision-making on regulating sprawl.

2 Geo-spatial methods for measuring urban sprawl in Beijing

2.1 A review of measuring urban sprawl

According to overseas literatures on measuring sprawl, various indices are widely used as the primary method. Some research organizations have put forward their indices for measuring sprawl, among which the most influential ones are raised by Sierra Club, USA Today and Smart Growth America. Sierra Club (1998) ranked major metropolitans in USA by four sprawl indices, including: population moving from inner city to suburbs; comparison of land-use and population growth; time cost on traffic; and decrease of open space. USA Today (2001) put forward the share of population beyond SMSA (Standard Metropolitan Statistical Area) as an indicator for measuring sprawl. Smart Growth America (2002) carried out a research to study the impacts of sprawl on life quality in which four indices were used to measure urban sprawl: residential density; mixture of residence, employment and service facilities; vitalization of inner city; and accessibility of road network.

Besides, some overseas scholars also have contributed to measuring sprawl (Nelson, 1999; Kline J D, 2000; Paul M Torrens, 2000; George Galster, 2000; Edward Glaeser, 2001; Carlo Lavalle, 2002; John E Hasse, 2003; F Patrick Holmes, 2005; Gerald Shoultz, 2005; Marjo Kasanko, 2006) by establishing multi-indices by GIS analysis or descriptive statistical analysis. Those indices cover various aspects including population, employment, traffic, resources consumption, architecture aesthetics and living quality etc. Commonly used indices include: growth rate, such as growth rate of population or built-up area; density, such as population density, residential density, employment density; and spatial configuration, such as fragmentation, accessibility and proximity.

Generally speaking, most of the overseas studies took whole city as the analysis unit to calculate these indices, which could exactly reflect the sprawling situation of a whole city or region, but the interior differentia of sprawl in a given city could not be well depicted. Moreover, some indices are raised based on the context of Western urbanization; therefore, they are not so suitable for measuring sprawl in China, such as the share of detached house. Besides, some necessary statistic data are not successive enough to calculate certain indicator, such as the density of employment.

As for China, some indices developed for measuring urban expansion could be used for reference. Those indices include: those reflecting spatial features, such as density of built-up area (Huang, 2006), intensity of annual growth (Liu, 2000; Xiao, 2003; Chen, 2004); those reflecting growth scale, such as the area or share of urban growth (Fan, 1997); those reflecting growth speed, such as annual growth rate (Liu, 2002), elasticity of urban growth to population (Chen, 2005); and those reflecting landscape configuration, such as shape index, fractural dimension, isolation index, etc. (Zhang, 2004; Zhu, 2005; Yang, 2005). The latter three types of indices are suitable for analyzing general situation of sprawl, but not fit in illustrating interior differentia. The density of built-up area and intensity of annual growth could efficiently depict the sprawl features of low density and strong change, but they are still weak in capturing the particular spatial patterns of urban sprawl.

To sum up, the overseas sprawl indices could not be directly applied to the Chinese context. The existing indices on urban expansion in the Chinese context could not be simply used to measure urban sprawl either. So this paper proposes a series of geo-spatial indices for measuring sprawl based on the case of Beijing in China.

2.2 Geo-spatial indices for measuring sprawl in Beijing

Generally speaking, urban sprawl is an urban growth pattern with the features of low density, dispersion, automobile-dependent and other environmental and social effects (Richard Moe, 1993; Ewing, 1997; Downs, 1998; Burchell and Shad, 1999). Sprawl in China refers to rapid, low-efficient and disorderly growth of non-agricultural land towards peripheral areas.

According to this working definition, 13 geo-spatial indices are selected from various aspects of spatial configuration, growth efficiency and external impacts in order to measure sprawl (Figure 1). Six indices including size and shape of land use patches, consistency with planning and three typical growth patterns are adopted to reflect spatial configuration of urban growth. Four indices including horizontal and vertical building density, population den-

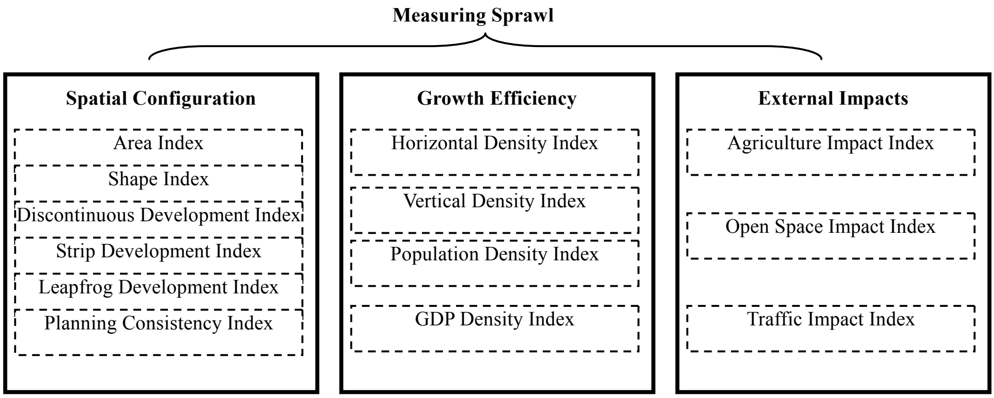


Figure 1 Geo-spatial indices for measuring urban sprawl in Beijing

sity and GDP density are used to demonstrate the efficiency of urban growth. Another three indices including arable land loss, open space loss and traffic burden are applied to indicate the impacts on agriculture, environment and city life.

3 Measuring urban sprawl in Beijing

3.1 Study area

Beijing is located in the northwestern edge of North China Plain. The total area of Beijing is 16,410 km^2, among which mountainous areas account for 61.4%, and plain areas account for 38.6%. By the end of 2005, the total population of Beijing had come to 15.38 million, with 83.6% being urban population. During the period of the Tenth Five-Year Plan (2000–2005), the GDP increased 11.9% annually, reaching 681.45 billion RMB yuan by 2005. With rapid economic development, the area of non-agricultural land increased very fast but with low efficiency. From 1996 to 2004, non-agricultural land increased by 965 km^2, with an annual growth rate of 4.6%, which is twice as that of population. Each increment of 100 million yuan in GDP consumes 36 hm^2 of land for construction accordingly.

3.2 Data sources and methodology

Basic data source includes population at town level of Beijing from the fifth national census in 2000, population at county level by 1% sample survey in 2005, GDP at county level of Beijing in 2005 from Beijing Yearbook, land use maps in 1996 and 2004 from land use update surveys, the existing land-use master planning (1997–2010), the map of floor-area ratio derived from land transactions cases from 1998 to 2003 and the vector maps of highways and city centers digitized from the hardcopy of Beijing geographical base map (Table 1).

3.3 Results of measuring sprawl in Beijing

(1) Sprawl features on spatial configuration: fragmentation and irregularity of land use patches, strong evidence for discontinuous, strip and leapfrog development, and noticeable planning inconsistency.

Table 1 Definition of geo-spatial indices for measuring sprawl in Beijing

Index		Data source	Calculation methods
AI	Area index	Land use maps	Overlay analysis, vector converting to grid; AI= patch area of newly developed
SI	Shape index	Land use maps	Overlay analysis, vector converting to grid; SI= 0.25×Perimeter/SQRT (area)
DDI	Discontinuous development index	Land use maps	Distance analysis, vector converting to grid; DDI=distance between newly developed and previously developed land
SDI	Strip development index	Land use maps; map of highways	Distance analysis, vector converting to grid; SDI=distance between newly developed patches and highways
LDI	Leapfrog development index	Land use maps; map of centers (point)	Distance analysis, vector converting to grid; LDI=distance between newly developed patches and county centers
PCI	Planning consistency index	Land use maps; map of planning	Overlay analysis, vector converting to grid; PCI={1, 0}, 1 stands for inconsistency with plan
HDI	Horizontal density index	Land use map in 2004	Neighborhood analysis; HDI=The share of non-agricultural land area within neighborhood of 1 km^2
VDI	Vertical density index	Map of floor-area ratio	Kriging Interpolation Analysis (samples Num: 2226); VDI=ratio of floor area to land area
PDI	Population density index	Population at town level; land use map in 2004	Kriging Interpolation Analysis (samples Num: 200); PDI=ratio of population to land area
GDI	GDP density index	GDP at county level in 2005	Vector converting to grid; GDI=ratio of GDP to land area
AII	Agriculture impact index	Land use maps	Overlay analysis; AII={1, 0}, 1 stands for arable land loss
OII	Open space impact index	Land use maps	Overlay analysis; OII={1, 0}, 1 stands for open space loss
TII	Traffic impact index	PDI; map of centers (polygon)	Spatial modeling; TII=simulated population×distance to centers

Methods for calculating indices are as follows: 1) data preparation by which to process various data so as to establish practicable database for each index; 2) spatialization processing for each index by spatial analysis or modeling so as to integrate all indices into the same grid platform of 100m×100m; 3) standardization processing by which to normalize these indices with different dimensions; and 4) weighting these indices by paired comparison method and then sum up all standardized indices into one integrated sprawl index (Table 1). The formula is given below:

$$USI=-0.02[AI]+0.02[SI]+0.08[DDI]-0.09[SDI]+0.10[LDI]+0.14[PCI]-0.05[HDI]-0.05[VDI]-0.05[PDI] -0.05[GDI]+0.12[AII]+0.12[OII]+0.12[TII] \quad (1)$$

where USI stands for integrated urban sprawl index. Each sum term stands for one of 13 indices respectively, operator reflects the correlation with urban sprawl.

As AI indicates, land use patches are of obvious fragmentation tendency. From 1996 to 2004, the patch number of non-agricultural land increased by 31%; meanwhile the average patch size only increased by 13%. The average patch size of the newly developed land (NDL) is only 1.52 km^2, and 64% of them are less than 1 km^2 (Figure 2a).

As SI indicates, land use patches become more irregular. The average shape index of the NDL patch is 1.7, and the shape index is relatively wide, ranging from 0.97 to 4.33. About 65% of them are over 1.7 (Figure 2b).

As PCI indicates, land development is lacking of effective planning management. Much NDL is inconsistency with the previous land use planning. Taking urban land for instance, there are two types of inconsistency with planning. One is “developed but not planned”: Some 35% of the urban NDL is beyond the planning area. The other is “planned but not developed”: 7% of the planning areas have not been developed yet (Figure 2c).

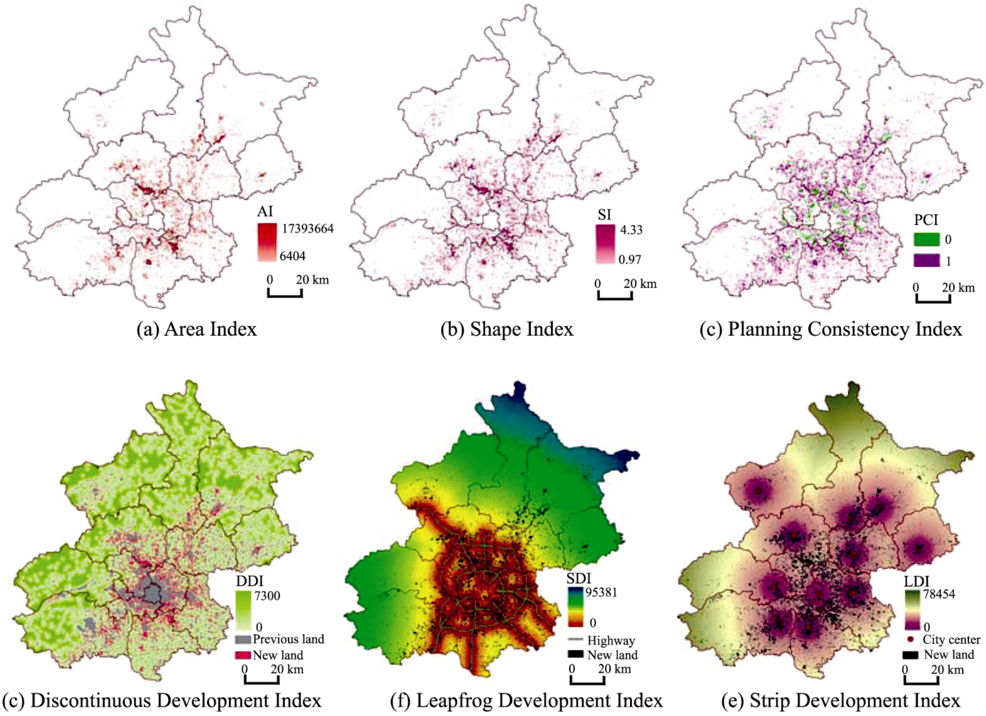


Figure 2 The spatialization results of six indices on spatial configuration

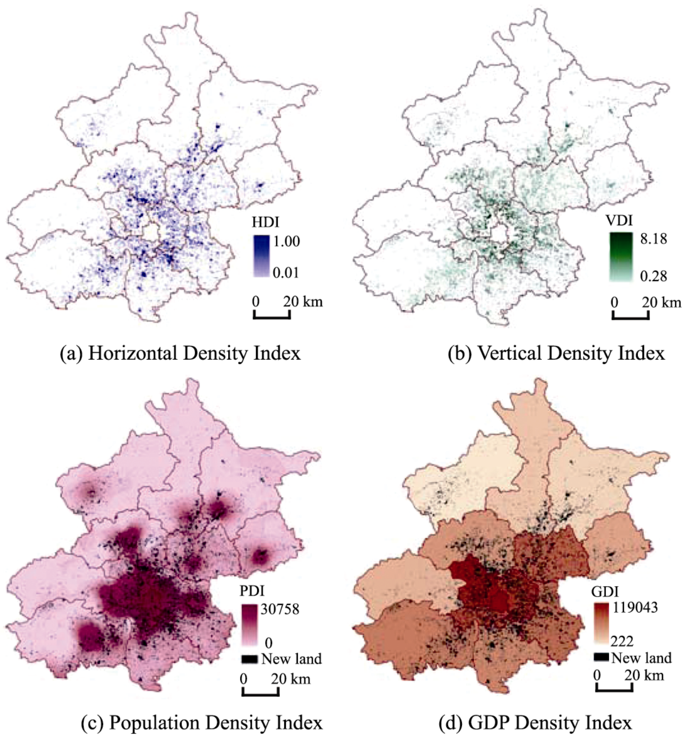


Figure 3 The spatialization result of four indices on growth efficiency

According to the result of DDI, SDI and LDI, non-agricultural land is of strong evidence for discontinuous development, strip development and leapfrog development. As DDI indicates, 63% of the NDL is not adjacent to the previously developed lands. The average distance between the NDL to the previously developed lands is 0.26 km (Figure 2d). As SDI indicates, the NDL has a typical feature of strip development, especially urban land. The average distance between the urban NDL and highways is 4.79 km, and nearly 55% of the urban NDL is located in the 2-km buffer of the highways (Figure 2e). As LDI indicates, the NDL has a typical feature of leapfrog development. The average distance between the NDL and city centers is about 12 km, and 55% of the NDL has a distance over 10 km to city centers (Figure 2f).

(2) Sprawl features on growth efficiency: low density and low efficiency of the NDL.

As HDI indicates, the horizontal density of the NDL is lower than before. The average density of the NDL from 1996 to 2004 is 0.35, while the average density in 1996 is 0.52. Moreover, there is distinct spatial difference. For instance, the density in the outer suburb is less than 1/5 of that in the central area or 1/3 of that in the near suburbs (Figure 3a).

As VDI indicates, the vertical density of the NDL is still lower. The floor area ratio ranges from 0.28 to 8.18 with an average of 1.26, and about 90% of the NDL with a floor area ratio of less than 2. What's more, the floor area ratio in outer suburbs is much lower (Figure 3b).

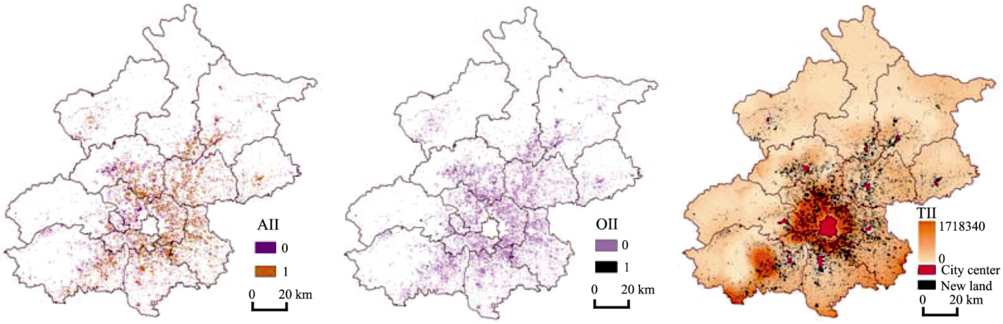
According to the result of PDI and GDI, the efficiency of the NDL still needs to be further improved. As PDI indicates, the population capacity of the NDL is relatively low. The average population density of the NDL is 2020 persons/km^2, much lower than that of the previously developed lands in 1996 (4091 person/km^2) (Figure 3c). As GDI indicates, the economic output of the NDL is not high as expected. The average GDP density of the NDL is 54 million yuan/km^2, lower than that of the previously developed lands in 1996 (113 million yuan/km^2). Besides, only 30% of the NDL is located in the area with GDP density exceeding 100 million yuan/km^2 (Figure 3d).

(3) Sprawl features on external impacts: negative effects on agriculture, environment and city life.

According to the result of AII, OII and TII, urban sprawl has brought significant effects on agriculture, environment and city life. Firstly, urban sprawl has led to huge loss of high quality arable lands in the suburbs. Some 870 km^2 of the NDL were transferred from arable land from 1996 to 2004 (Figure 4a). Secondly, urban sprawl has encroached upon limited open space, such as forests, grassland and water area. 156 km^2 of the NDL were transferred from open space from 1996 to 2004 (Figure 4b). Thirdly, the urban sprawl caused traffic burden increases the distance between the NDL and city centers where job opportunities concentrate upon. The average distance increased 21% from 1996 to 2004 (Figure 4c).

(4) Interior differentia of sprawl: more sprawling in the northern part, severer sprawling at the marginal area of the near suburbs and the area between highways, four typical sprawling patterns including randomly expansion at urban fringe, strip development along highways, scattered development of industrial land and leapfrog development of urban residence and industrial area.

According to the integrated urban sprawl index, the NDL could be classified into four categories: rational growth, low sprawling, moderate sprawling and high sprawling by natural break method (Figure 5). The result shows that sprawling amount in the northern part is larger than that of the southern, but the sprawling extent is in converse case. Rational growth accounts for over 20% in the northern part, while high sprawling accounts for 40% in the southern. Besides, severer sprawling mainly concentrates in the marginal area of the near suburbs and the area between highways. Four typical sprawling patterns could be identified: randomly expansion at urban fringe, strip development along highways, scattered development of industrial land and leapfrog development of urban residence and industrial area.



(a) Agriculture Impact Index (b) Open Space Impact Index (c) Traffic Impact Index

Figure 4 The spatialization results of three indices on external impacts

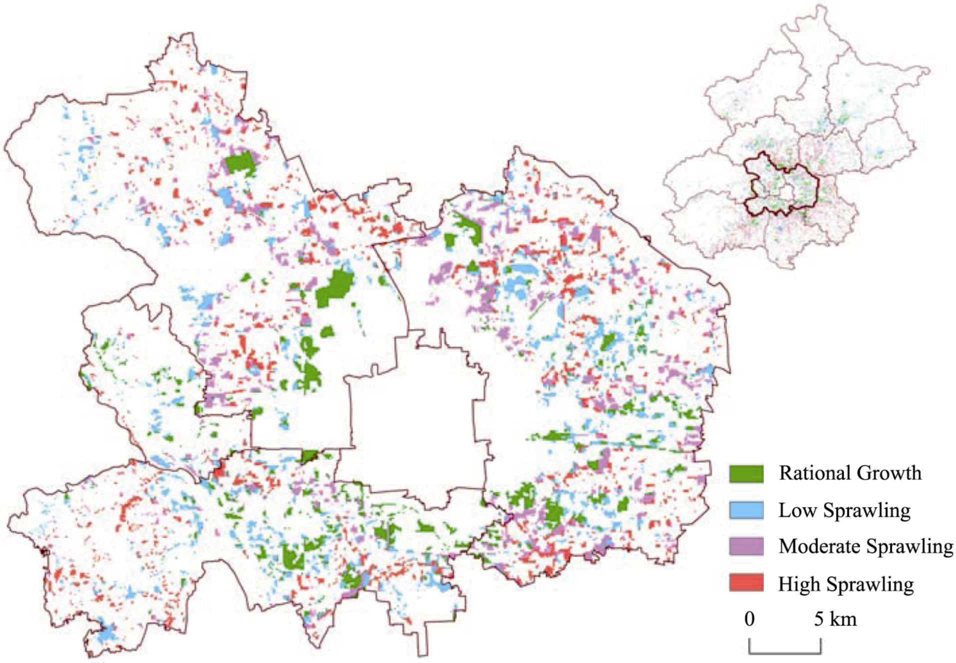


Figure 5 Measuring result by Integrated Urban Sprawl Index

4 Conclusion and discussion

This paper proposes a method for measuring sprawl. The analysis result shows that non-agricultural land in Beijing has kept fast growing with large amount, low efficiency and disordered spatial configuration, indicating a typical sprawling tendency. The following specific sprawl features are identified: obvious fragmentation and irregularity of landscape due to unsuccessful enforcement of land use planning; unadvisable pattern of land use growth with typical discontinuous development, strip development and leapfrog development; low density of land use growth, low population density and economic output in the NDL; and other negative impacts on agriculture, environment and city life. According to the integrated sprawl index, sprawling amount in the north part is larger than that in the southern, but the sprawling extent is in converse case; severer sprawling areas include the marginal area of the near suburbs and the area between highways, etc. Four sprawling patterns are identified: randomly expansion at urban fringe, strip development along highways, scattered development of industrial land and leapfrog development of urban residence and industrial area.

The application result indicates that the geo-spatial indices system can capture most of the sprawl features and interior differentia as well. Specifically, six indices on spatial configuration are most effective. Patch Area and Shape Index could directly depict the microcosmic features; Discontinuous Development Index, Strip Development Index and Leapfrog Development Index could indicate the growth pattern; and Planning Consistency Index examines the enforcement of planning. Four indices on growth efficiency are more dependant on the precision of spatializing process, especially the GDP Density Index. Due to the limitation of statistic data, the depiction on spatial differentia of economic output is not sufficient yet. Three indices on external impacts could comparatively quantify the impacts on arable land loss, opens space loss and traffic burden, but there are still other impacts of sprawl, such as energy consumption, not being included in the indices system due to data limitation.

References

Beijing Statistics Bureau, Survey Office of the National Bureau of Statistics in Beijing. 1% Sample Population Survey Report in 2005. http://www.bjstats.gov.cn/

Beijing Statistics Bureau, Survey Office of the National Bureau of Statistics in Beijing. Beijing National Economic and Social Development Report in 2005 and Tenth Five-Year Plan. http://www.bjstats.gov.cn

Burchell R W, Shad N A, 1999. The evolution of the sprawl debate in the United States. *West Northwest*, 5(2): 137–160.

Carlo Lavalle, N McCormick, Kasanko M *et al.*, 2002. Monitoring, planning and forecasting dynamics in European areas: The territorial approach as key to implement European policies. Technical Report of MOLAND Program, 1–8. http://moland.jrc.it/

Chen Benqing, Xu Hanqiu, 2005. Urban expansion and its driving force analysis using romote sensed data: A case of Xiamen City. *Economic Geography*, 25(1): 79–83. (in Chinese)

Chen Longqian, Guo Dazhi, Hu Zhaoling, 2004. Research on spatial differentiation of urban growth using multi-temporal landsat thematic mapper satellite remote sensing images. *Journal of China Coal Society*, 29(3): 308–312. (in Chinese)

Downs A, 1998. How America's cities are growing: The Big Picture. Brookings Review, 16(4): 8–12.

Edward Glaeser, Matthew Kahn, Chenghuan Chu, 2001. Job Sprawl: Employment Location in U.S. Metropolitan Areas, Survey Series of Center for Urban & Metropolitan Policy, The Brookings Institution, 1–8.

Ewing R, 1997. Is Los Angeles-style sprawl desirable? *Journal of the American Planning Association*, 63(1): 107–126.

Fan Zuojiang, Cheng Jicheng, Li Qi, 1997. Study on urban growth by using RS and GIS analysis. *Remote Sensing Information*, (3): 12–16. (in Chinese)

George Galster, Royce Hanson, Hal Wolman *et al.*, 2000. Wrestling sprawl to the ground: Defining and measuring an elusive concept. Working Paper of Fannie Mae, 1–38.

Gerald Shoultz, 2005. ASPH/CDC Fellow, National Center for Health Statistics, Measures of Sprawl Applied to Urban and Rural Areas, and Cardiovascular Disease Mortality: A Bayesian Spatial Analysis. Population Association of America Annual Meeting Report, 1–3.

He Chunyang, Chen Ji, Shi Peijun, 2003. City expansion model of metropolitan area in China: A case study of Beijing. *Acta Geographica Sinica*, 58(2): 294–304. (in Chinese)

Holmes F Patrick. Rockies Sprawl Index, Annual Research Report of the Rockies Project, 2005. 61–70. http://www.coloradocollege.edu/.

Huang Yue, Chen Xi, Bao Anming *et al*., 2006. Urban sprawl pattern and spatial features of Urümqi City during the last 15 years. *Journal of Glaciology and Geocryology*, 28(3): 364–370. (in Chinese)

John E Hasse, Richard G Lathrop, 2003. Land resource impact indicators of urban sprawl. *Applied Geography*, 23: 159–175.

Kline J D, 2000. Comparing states with and without growth management analysis based on indicators with policy implications comment. *Land Use Policy*, 17: 349–355.

Liu Shenghe, Wu Chuanjun, Shen Hongquan, 2000. Beijing urban land growth pattern based on GIS analysis. *Acta Geographica Sinica*, 55(4): 407–416. (in Chinese)

Liu Shenghe, 2002. Spatial pattern and dynamic mechanism of urban land use growth. *Progress in Geography*, 21(1): 43–50. (in Chinese)

Lu Datao. Rash urbanization process will lead to endless negative impacts. December 31, 2006. (in Chinese). http://www.cas.ac.cn/html/Dir/2006/12/30/14/65/68.htm

Marjo Kasanko *et al*., 2006. Are European cities becoming dispersed? A comparative analysis of 15 European urban areas. *Landscape and Urban Planning*, 77: 111–130.

Nelson A C, 1999. Comparing states with and without growth management: Analysis based on indicators with policy implications. *Land Use Policy*, 16: 121–127.

Paul M Torrens, Marina Alberti, 2000. Measuring Sprawl. Working Paper Series of Centre for Advanced Spatial Analysis, 1–43.

Reid Ewing, Rolf Pendall, Don Chen. Measuring Sprawl and Its Impacts, 2002. 1–42. http://www. smartgrowthamerica.org.

Richard Moe, 1993. National trust for historic preservation, from communities at risk: The consequences of Sprawl.

Sierra Club, 1998. The Dark Side of the American Dream. Research Report. http://www.sierraclub. org/sprawl/report98/report.asp.

Sun Chengren. Smart growth, the future of Chinese cities. Ministers and Governors Forum, 2003-11-29. (in Chinese)

USA Today. A Comprehensive Look at Sprawl in America, 2001. http://www.usatoday.com/news/sprawl/main.htm.

Xiao Jieying, Ge Jingfeng, Shen Yanjun, 2003. Analysis on urban land use sprawl by using GIS: The case of Shijiazhuang City, China. *Geographical Research*, 22(6): 789–798. (in Chinese)

XinHua Net. Beijing Channel, Beijing Introduction. http://www.bj.xinhuanet.com/bjpd-whsd/sq.htm

Xu Xiaoli, Shi Peijun, He Chunyang, 2002. The urbanization process comparison of Beijing and Shenzhen. *Advance in Earth Sciences*, 17(2): 221–229. (in Chinese)

Yan Jinming, 2005. Land Resource Management Calls for Rational Notion. *People Forum*, (6): 40–41. (in Chinese)

Yang Yingbao, Jiang Nan, Su Weizhong, 2005. Dynamics of landscape ecology in Nanjing city revealed by RS and GIS. *Resources and Environment in the Yangtze Basin*, 14(1): 34–39. (in Chinese)

Zhang Bo, 2004. Study on Urban Growth Management in China. Beijing: Xinhua Press. 56–57. (in Chinese)

Zhang Liqua, Wu Jiaping, Zhen Yu, 2004. A GIS-based gradient analysis of the urban landscape pattern of Shanghai Metropolitan Region. *Acta Phytoecologica Sinica*, 28(1): 78–85. (in Chinese)

Zhu Ning, Wang Jiandi, 2005. Spatial configuration change of urban growth in Hangzhou. *Zhejiang Economy*, (16): 59. (in Chinese)

Zong Yueguang, Zhou Shangyi, Zhang Zhenshi, 2002. Spatial characteristics of suburbanization and its developing strategies in Beijing. *Acta Geographica Sinica*, 57(2): 135–142. (in Chinese)