【Article】

Changes of Urban Green Spaces and Their Driving Forces: a Case Study of Jinan City, China

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Abstract

Urban green spaces are looked upon as the last remnant of nature in urbanized areas. They play a pivotal role in environmental and ecological changes, and furthermore can decide whether we can have a sustainable development in the urban area. With the urban growth, green spaces varied in the area, type and spatial pattern. To optimize urban green space in the future, it is necessary to understand the driving forces on the processes of urban green space changes. In this study we chose Jinan City as a case study. We analyzed the process of urban green spaces dynamic from 1996 to 2004. During this period, a significant increase of the total area of urban green spaces took place. However, the growth rate of different green space types was not the same. To better link the spatial pattern change with the process, a gradient analysis was conducted in 4 directions combined with landscape metrics. Based on the spatiotemporal change of urban green spaces, it could be concluded that urban greening policies and urban sprawl were the main driving forces.

Key Words: GIS, spatiotemporal change, urban green policies, urban sprawl

1. Introduction

Urban green spaces are looked upon as the last remnant of nature in urban areas (Beatley, 2000). They play a pivotal role in environmental and ecological changes and furthermore can decide whether we can have a sustainable development in the urban. At the same time, rapid urbanization and increased leisure time make people pay more attention to urban green spaces. People realize that it is difficult to live without some contact with nature. Even though they become more urban in ways of living, the desire for contact with nature will continually increase rather than decrease (Miller, 1997). However, with urbanization, more and more people swarm into cities. In China, the urban population was 37.7% of the total population in 2001, and is projected to reach 75% by 2050 (The Chinese Mayor's Association, 2002; Zhang et al., 2004). Urbanization was a landscape changing process (Breuste, 2004). Increased population triggered the rapid growth of urban centers, which inevitably has profound environmental and social-economic consequences. Among them, a fundamental consequence is the increasing alienation between mankind and the natural world (Gordon, 1990). Facing with this urgent situation, the Chinese government has increasingly paid attention to planning green spaces which will adapt to urban development. Eco-urban construction was taken into consideration with the urban development agenda. This has been done since the 1980s, but most of the cities have implemented green planning in the 1990s. As a result, most of the cities have changed significantly and the urban environment has greatly improved. However, urbanization has had and continues to have a negative impact on the green space within cities (Miller, 1997). So, the understanding of natural and social factors that influence urban green space changes seems very important for the future urban planning.

Landscape ecological theory has opened doors to innovation in landscape planning and design (Nassauer, 1999). The surge in interest in landscape ecology also has become manifested in a wave of recent efforts to incorporate a landscape perspective into policies and guidelines for managing public lands (McGarigal and Cushman, 2002). In particular, it is well suited to studying urban green spaces because man-made, as well as remnant natural areas, are all considered (Design center for American urban landscape, design brief, 2003), and it offers insights on optimization of space use vis-a-vis environmental conservation and improvement (Forman and Godron, 1986; Dramstad et al., 1996; Jim et al., 2003). Landscape ecology deals fundamentally with how, when, and where the spatial and temporal patterns influence the ecological process, and how feedback from ecological processes influences ecological patterns (Turner, 1989; Urban et al., 1991; McGarigal and Cushman, 2002).

Gradient analysis, developed in the context of vegetation analysis (Whittaker, 1967, 1975), has been used to investigate the effects of urbanization on plant distribution (Kowarik, 1990; Sukopp, 1998) and ecosystem properties (Pouyat and McDonnell 1991; Pouyat et al. 1995; Zhu and Carreiro, 1999). In some recent researches, Luck and Wu (2002) and Zhang et al. (2004) used gradient analysis to study urban landscape patterns and the ecological consequences of urbanization process using a split window along chosen transects.

In this paper, Jinan City was chosen as a study area to analyze the process of urban green space dynamic based on landscape metrics combined with gradient analysis. This method seemed very well to give an insight in the spatial pattern change of urban green space and its driving forces. Based on this method, pattern and process at the landscape level were better linked. The objectives of this study were to: (1) identify the urban green spaces change process in Jinan City within the past 8 years; and (2) analyze the main socio-economic driving forces of the urban green space changes.

2. Study Area

Jinan City is located at 36° 32′ -36° 51′ N and 116° 49′ -117° 14′ E, and nearby to the south is Taishan and to the north is Yellow River (Figure 1). With a typical warm-temperate-semi-humid continental monsoon climate and well-defined seasons, Jinan has a mean annual temperature of 14℃ and an average mean precipitation of 650-700 mm. Jinan also has a special geological structure. Underground streams from Taishan flow along the limestone strata to Jinan, but in the north they are halted by igneous rocks and spurt out in the form of numerous springs. There are at least seventy-two famous springs, and so it is known as the “City of Springs.” The zonal natural vegetation is deciduous broadleaf and evergreen coniferous forest. Due to human influence, most of the original natural vegetation, has decreased or disappeared, such as Salix babylonica. So now the scene where “springs and willows are

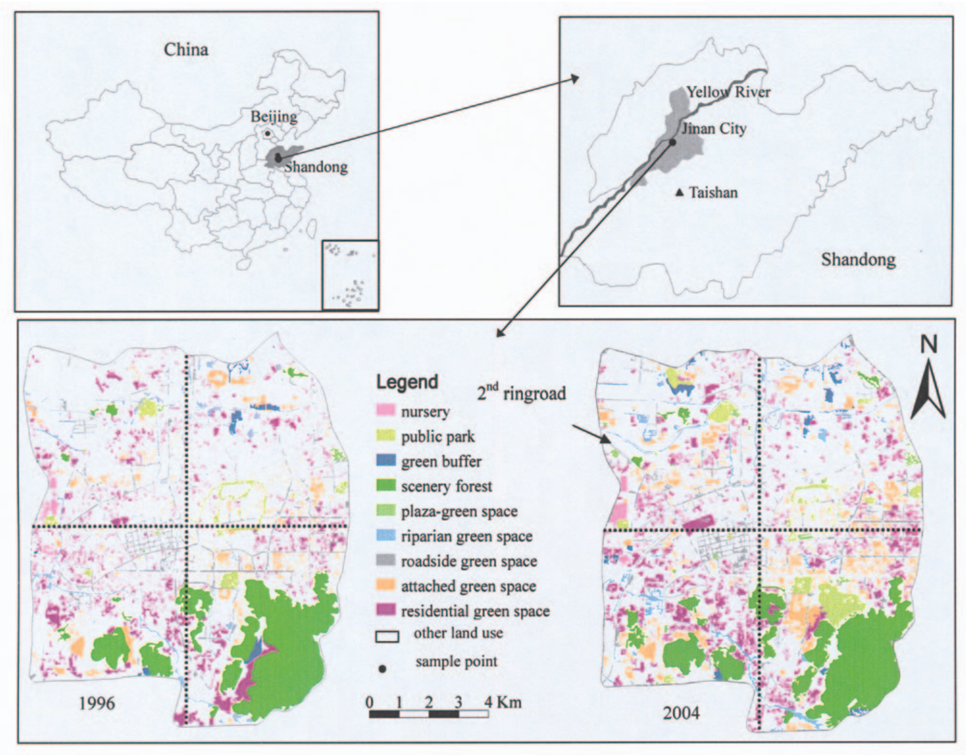

Figure 1. Location of the study area, urban green space maps and sample points.

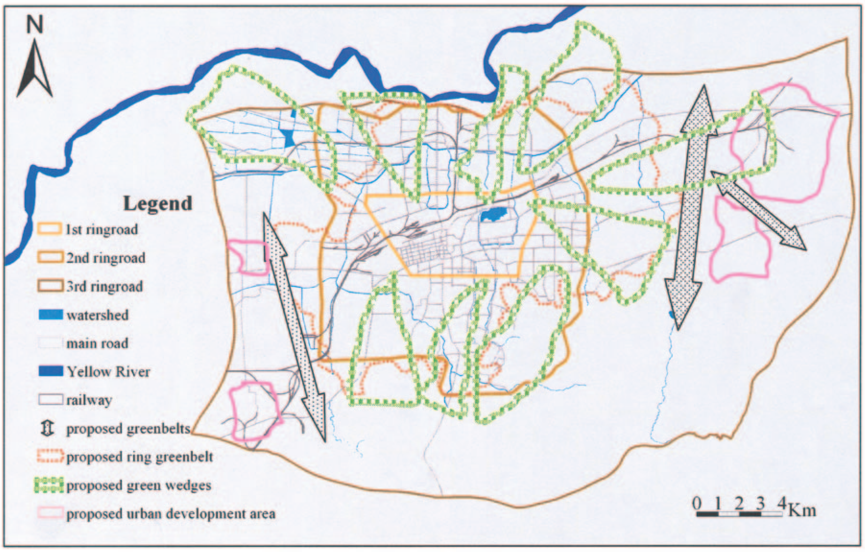

Figure 2. Urban green network system in "Great Changes in Five Years" Policy.

found in every courtyard" is almost gone. The present dominant species are *Platanus orientalis*, *Sophora japonica*, *Populus tomentosa* and *Platycladus orientalis*, and bush-grass communities (Jinan Landscape Bureau, 2001).

Jinan City is the capital of Shandong province with the history of more than 2,600 years since the rise of Xihe culture. It has experienced dramatic population growth and has sprawled greatly in the last 50 years, with a population increase from 3.19 million in 1952 to 5.75 million in 2002 and the built-up areas from 24.6km^2 in 1949 to more than 190 km^2 in 2003 (Jinan Statistics Bureau, 2003). The Jinan Planning Bureau's Master Plan 2005-2020 has proposed to build new towns, mainly east of the city, creating urban area of 400km^2. The study area contains the whole inner part of the Second-Ring Road and covers 149.2 km^2, which is the core area in the "past" and the "future" Master Plans. In the 1996-2010 Master Plan and the "Great Changes in Five Years" policy, the Jinan People's Government proposed a "One Ring, Three Greenbelts and Nine Wedges" green network system and aimed to build a "National Garden City" (Figure 2). In the Second-Ring Road area, "Inserting Green Wedges, Connecting Green Network, Vertical Greening" policy was implemented.

3. Material and Methods

The data were collected from both primary and secondary data sources. The primary data sources used in this study included 1996 Spot (SIRIUS, France) Images (resolution 10m, 1band and resolution 20m, 4 bands), 2004 Spot Image (resolution 10m, 4 bands) and a topographic map of 1:10,000 scale created in the year 2000. The secondary data included the demographic data and urban planning data obtained from the Jinan Planning Bureau and the Statistics Bureau.

To obtain urban green space information for the two years, Spot images were rectified and georeferenced to the Universal Transverse Mercator (UTM) coordinate system using the ERDAS Image System (Version 8.5, ESRI, Atlanta, Georgia 30329-2137, USA). A resolution merge of data of 1996 was conducted using ERDAS Images system to get vegetation information due to their different resolutions. The urban green space categorical maps were created by manual interpretation based on the ARC/INFO (Version 8.2, ESRI, Redlands, CA 92373-8100, USA) platform, combined with necessary field surveys and validations. The urban green space data set was reclassified into 9 types (public park, plaza-green space, nursery, green buffer, attached green space, residential green space, roadside green space, riparian green space, scenery forest) from the Standard for classification of urban green space in China (CJJ/T85-2002), based on urban green space functions, land use type and ownership (Table 1). Then, these vector data were converted to raster format with a pixel size of 10m × 10m using ARC/MAP Spatial analysis (Version 8.2, ESRI). In order to describe the overall urban green space changes over time and measure the rate of change, CA (Class area) and NP (Number of patch) landscape metrics were calculated using FRAGSTATS (version 3.3) (McGarigal et al., 2002).

To clearly link patter and process, and detect the gradient change and the driving forces of urban green spaces, we conducted a moving window analysis supported by FRAGSTATS at landscape level. The landscape metrics were computed using a 500m-radius window size. According to the grid maps, 129 samples were then selected at a distance of 200m in 4 directions from the urban center (Figures 1 and 3). In this research 6 landscape metrics (CA, NP, PD, LPI, LSI and MPS) were used to quantify the urban green space pattern (Table 2).

Table 1. Reclassification of urban green spaces.

Original urban green space type (according to CJJ/T85-2002)	Reclassified patch type	Abbreviation	Description
Public park	Public park	PU	Opening to the public (including the community park), providing education, pleasure and recreation, with natural and planted vegetation
	Plaza-green space	PL	Opening to the public, providing open space, recreational opportunities, with planted vegetation, seldom trees, most of shorter shrub and grassland, and low diversity
Nursery	Nursery	NU	Propagating and cultivating vegetation, supplying breeds and saplings for urban greening
Green buffer	Green buffer	GR	Liner corridors, protecting high-voltage transmission line, screening wind and cleansing pollutants, with planted vegetation
Attached green space	Attached green space	AT	Attached with industrial, commercial, utility land et al., with planted vegetation, and low diversity
	Residential green space	RE	All the green spaces in a residential area except the community park, providing aesthetic, amenity-recreation venues, with planted vegetation, and limited plant diversity
	Roadside green space	RO	Linear corridors between the sidewalk and curb or island patch in the crossroad, buffering people from traffic, screening noise and solar radiation et al., with planted vegetation, and limited plant diversity
Other green space	Riparian green space	RI	Linear corridors along the watershed, mostly with natural habitat type, and often high plant diversity
	Scenery forest	SC	Opening to the public, protecting and preserving the flora, fauna and providing scenic beauties, with a mosaic of remnant or naturalized habitat type

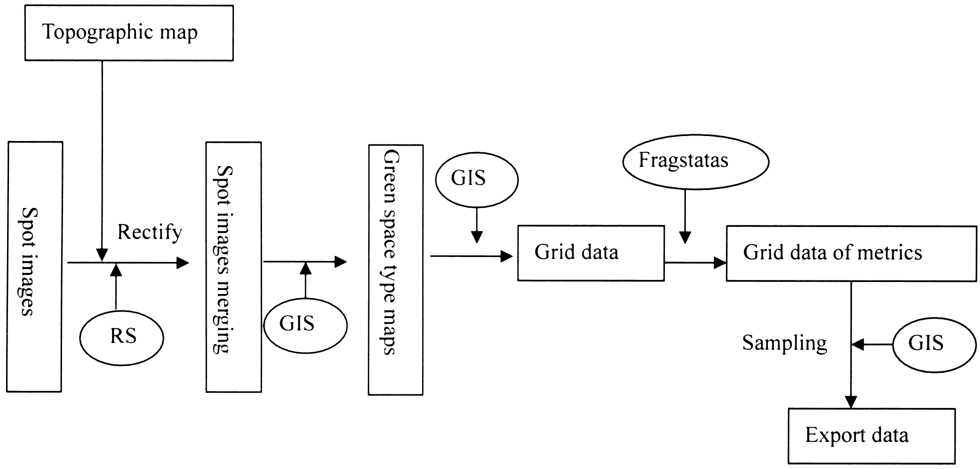

Figure 3. Flow diagram of gradient analysis procedures.

Table 2. Definitions of landscape metrics (Based on McGarigal et al., 2002).

Landscape metrics	Abbreviation	Description	Units	Range
Class area	CA	CA equals the sum of the areas (m^2) of all patches of the corresponding patch type divided by 10,000 (to convert to hectares)	Hectares	CA＞0, no limit
Number of patch	NP	NP equals the number of urban green spaces corresponding patch type	None	NP≧1, no limit
Patch density	PD	The number of patches per 100ha	Number per 100 hectares	PD＞0, constrained by cell size
Mean patch size	MPS	The area occupied by a particular patch type divided by the number of patches of that type	Hectares	MPS＞0, no limit
Largest patch index	LPI	LPI equals the area (m^2) of the largest patch of the corresponding patch type divided by total landscape area (m^2), multiplied by 100 (to convert to a percentage)	Percent	0＜LPI＜100
Landscape shape index	LSI	The total length of edge involving the corresponding class divided by the minimum length of class edge for a maximally aggregated class, a measure of class aggregation or clumpiness	None	LSI≧1, no limit

4. Results

4.1. Spatio-temporal change of urban green spaces

4.1.1. General change of urban green spaces

In comparison of the two years (Table 3), the increase of urban green space area was very obvious. The total green space area was 4,337.7ha and 5,538.6ha, respectively in 1996 and 2004, and the growth rate was 27.7%. However, the total patch number had some reduction and the decrease rate was 17.8%. This indicated the connectivity and the mean patch size of green space patches increased gradually. Thus, a green space network is evolving. Among all of the green space types, except the SC (Scenery forest), all of the other green spaces had an increase in the area, even though they had different increase rates. Especially, the PL (Plaza-green space) had the highest increase rate in the area and patch number, with 256%, and 280%, respectively. One important function of urban green spaces is that they can provide amenity-recreation venues, reduce the stress caused by working hard and offer a wide range of mental and physical health benefits (Kaplan and Kaplan, 1989). But before 1996, there were only five PLs in Jinan City. Then "urban greening project" and "Great Changes in Five Years" policy were implemented in 1997. By 2004, another 14 squares had been built or rebuilt near the hospital, at the residential district or CBD (Central Business District), which increased the area about 50ha. At the same time, several public parks were rebuilt or expanded, such as Baotu Spring Public Park. The public park area altogether increased over 227ha. Compared AT (Attached green space) and RE (Residential green space) with other green space type, they showed a larger area and patch number, indicating they had a higher degree of fragmentation. However, the SC still had the largest area but lower patch number, suggesting its dominance and high degree of agrregation. While, its change was quite different from other green spaces in the decrease of area and increase of patch number in the study period.

Table 3. Urban green spaces general change from 1996 to 2004 (CA: Class area; NP: Number of patch).

Type	Abbreviation	1996 CA (ha)	2004 CA (ha)	Change rate (%)	1996 NP	2004 NP	Change rate (%)
Nursery	NU	55.6	72.9	31.0	4	7	75.0
Public park	PU	196.1	423.5	116.0	26	39	50.0
Green buffer	BU	88.8	136.1	53.3	16	47	193.8
Scenery forest	SC	1785.1	1718.2	-3.7	16	21	31.3
Plaza-green space	PL	20.7	73.7	256.0	5	19	280.0
Attached green space	AT	478.8	927.5	93.7	546	464	-15.0
Riparian green space	RI	308.6	342.4	10.9	135	107	-20.7
Roadside green space	RO	474.0	644.1	35.9	344	373	8.4
Residential green space	RE	929.9	1200.2	29.1	1286	877	-31.8
Total urban green spaces	TG	4337.7	5538.6	27.7	2378	1954	-17.8
Other land use	LU	10587.8	9386.9	-11.3	108	274	153.7
Total area (ha)	TA	14925.5	14925.5	0.0	2486	2228	-10.4

Synoptic analysis by landscape metrics can acquire the general information of urban green space change. To link accurately changes of green space patterns in local areas with the process, in the next section, we tried to use gradient analysis and would give an explanation in detail.

4.1.2. Gradient change of urban green spaces in landscape level

In this section, four landscape metrics were presented to quantify the gradient change of urban green space pattern in the two years from the urban center to the fringe (Figure 4).

As a whole, in the south (between -3 and -2km) (Figure 3 (A-b) and (B-b)), LPI (Largest patch index) showed the peaks in the two years, combined with the lower PD (Patch density), higher MPS (Mean patch size) and LSI (Landscape shape index), reflecting the fact that these places were dominant with an almost unchanged “Green Core”, mostly being SC and PU (Public park). LPI of 2004 also showed many more peaks compared with 1996, showing the increase of urban green spaces related to the “inserting green wedges” policy, with individual green space patches closing on each other and becoming more and more connected. In comparison of the two years, from the urban center to the northward, the PD showed a lower value in the most places and a higher MPS, LPI, indicating the increase of green space area. In the north, there were lots of branches of Yellow River, and RI (Riparian green space) was the main green spaces along those rivers. However, before 1996, there was an intensive urbanization process, and lots of industries were built at that time, which made this area become the heavily polluted district. To change this situation, increase of the AT (Attached green space) and GR (Green buffer) and not less than 30% greening coverage rate were required by the government. On the other hand, to conserve springs, “controlling the mine of well” in urban area and “deriving water from the Yellow River” were introduced in 1997. This caused the restoration of some watershed in the north. However, from the urban center to the eastward (between 0 and 4km), the PD (Patch density) almost showed higher value in 2004 than in 1996, indicating a higher fragmentation in this places. This could also be evidenced by the decreasing MPS. But towards the farther east, the PD and LSI showed: 1996 > 2004, and the LPI and MPS showed: 2004 > 1996. The “eastward sprawl” made in the new Master Plan has triggered a rapid development of residential districts in recent years. The original residential district was densitified. The larger patches of green spaces were broken. However, in the new build-up area, green spaces were often designated to provide amenities to residents in the form of recreational benefits and these areas were called “Garden district”, “Eco-district” or “Green-eco-district”.

If we made a closer examination in Figure 4, it could reveal a difference dynamic of urban green spaces at different places in the two years. Near the fringe of south (in Figure 3, between -5 and -7km), LSI displayed significant peaks in 2004 and, at the same time, PD showed the rankings: 2004 > 1996, LPI and MPS showed: 1996 > 2004. This indicated a higher disaggregation over time and illustrated the urban sprawl and “leapfrog-style” urban development resulting in encompassing and encroachment on SC and PU and RI. In the west (in Figure 4, between -4 and -1km), LPI showed a significant higher value in 2004 than in 1996, with a higher LSI, MPS and a lower PD. This was related to the new PL and RO (Roadside green space) that were built. In the urban center (in Figure 4, between -1 and 1km), “rebuilding old town” policy was implemented in 1996 in the urban master plan 1996-2004. At the same time, the regulation for the urban greening in the rebuilt up area was prescribed. Not less than 25% greening coverage rate was required. The increase of the value for LPI and MPS and the decrease for LSI and PD could be a good evidence.

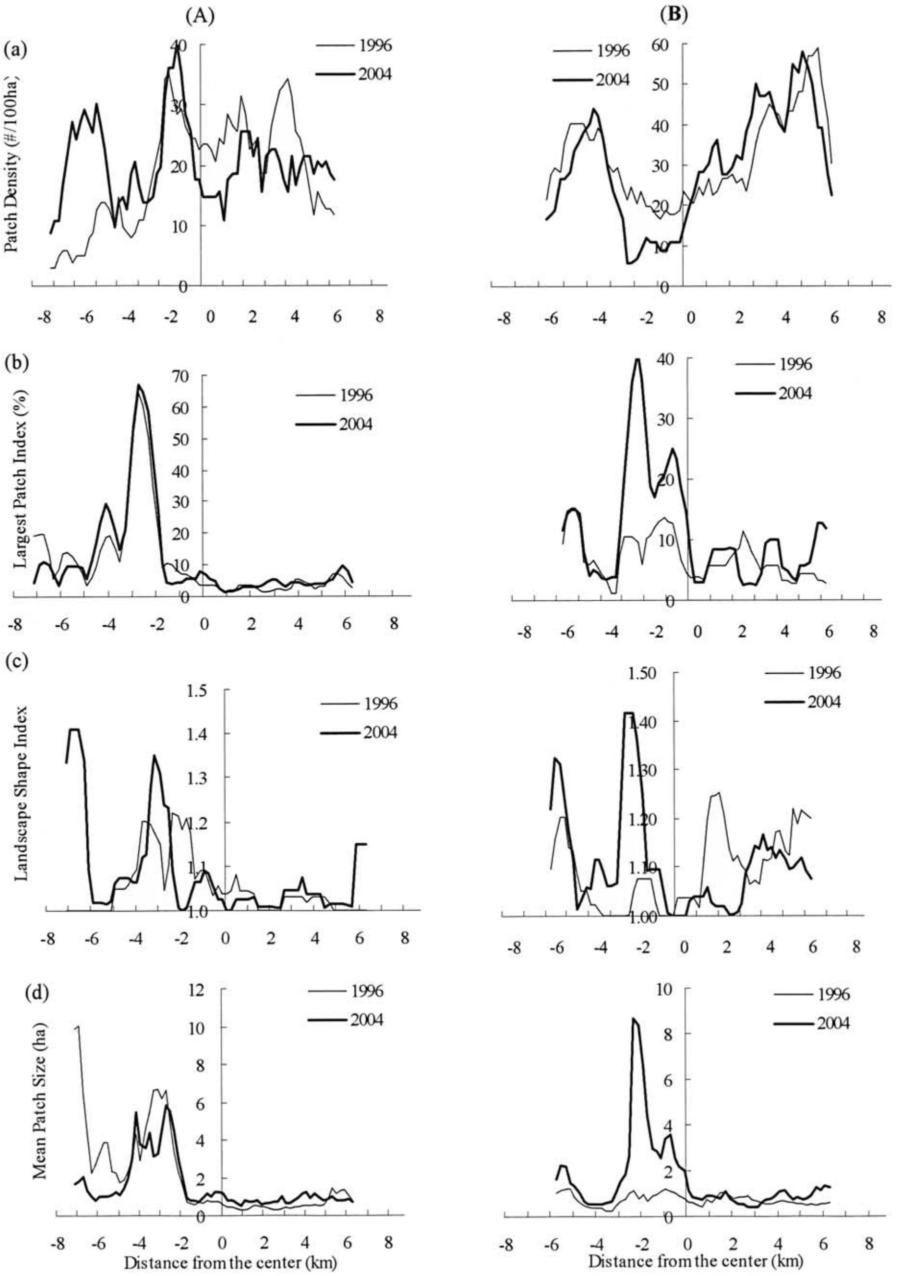

Figure 4. Gradient changes in landscape-level in four directions.
(A) South-North, (B) West-East (in columns);
(a): patch density (patch number/km2), (b): largest patch index (%),
(c): landscape shape index, (d): mean patch size (ha) (in rows).

4.2. Driving forces analysis of urban green space changes

In general, urban green spaces are mosaics of natural and human-managed patches, and the driving forces for their change are multifold. Based on the analysis of urban green space dynamic in Jinan City, we could give a conclusion for the driving forces as follows.

4.2.1. Policy affecting the development and management of urban green spaces

The policies about urban development and urban greening appeared to have a strong impact on the urban green space structure of the study area. The Master Plan1996-2010, "Great Changes in Five Years" policy in 1997, introducing "One Ring, Three Greenbelts and Nine Wedges" green network system and the "Inserting Green Wedges, Connecting Green Network, Vertical Greening" project clearly increased the urban green space area and resulted in a great alteration in the urban green space structure. The regulation of urban greening established in 1997, prescribed the level of greening coverage rate in the new built-up area and industrial district were also contributed to the spatial pattern change of urban green spaces. In response to growing concern about the undesirable impacts of sprawl on the urban green spaces, especially in the south area, a wide range of policy instruments were designed to manage urban growth and to protect them from development. The "eastward sprawl" made in the new Master Plan has triggered a rapid development in the east. It will be better to reduce the population pressure in the south.

In addition to the above, "conserving the springs" is the most important task for the urban sustainable development in Jinan City. Thus, in this regard, kinds of policies to redesign of urban green spaces including rebuilding and retrofitting the city to encourage water table replenishment were implemented by the government. For example, "regulation of conserving and management springs" was established in 1997. These measures caused the restoration of watershed in the urban area, and also kept the spring water sources in the south mountainous areas almost unchanged.

4.2.2. Urbanization often companied with urban green space pattern change

Urbanization changed urban land use pattern and caused occupation of green spaces by urban development and creation of new living conditions. Urbanization made people pay more attention to the living environment. At a certain extent, they caused the increase of residential and attached green spaces and resulted in an increase of green spaces. Urban green spaces can also influence the urban sprawl direction and then made green spaces change the spatial pattern. For example, green space amenities attract migrants, and their location, type and area often have a strong effect on the urban development, which caused the "leapfrog-style" urban development, such as in the south. In fact, rapid urbanization have magnified the effects of green space on the in-migration and associated land development (Wu and Plantinga, 2003). This was evidenced by the green spaces change near the fringe of east and south. Especially in the south, more and more people prefer to live close to green spaces, despite higher cost of living and firm measures implemented by the government to control such movements and to protect the spring water sources. The urban sprawl is beginning to consume the natural green spaces, accordingly, the RE increased gradually.

At last, natural environment was not an important factor, but it can not be overlooked. On the other hand, with mountainous area in the south and Yellow River in the north, the urban sprawl of Jinan City was limited in these two directions. This will obviously influence the urban green spaces spatial change in the future. Moreover, Jinan City has well-defined seasons. The rainfall, especially for the RI along the watershed will be an important affecting factor.

5. Discussion

In this study, the urban green space changes had been analyzed within the past 8 years. The area of urban green spaces obviously increased, but the different green space types exhibited distinctive. This was evidenced by the CA and NP landscape metrics combined with the change rate. General analysis suggested the connectivity and the mean patch size of green spaces patches increased gradually, which indicated a evolving green space network. Urban greening policies and urban master plan implemented in recent years all contributed to this result. However, the SC in the south caused by the urban sprawl had an obvious decrease in the area and increase in the patch number. Urbanization in this city had inevitably changed the urban morphology and influenced the urban green space pattern.

Gradient analysis combined landscape metrics in the landscape level provided effective tools to accurately link the patterns and processes. The different 'spatial signatures' of landscape metrics from urban center to the fringe and compared in the two years gave an perspective in the local area which were better to help us understand different underlying processes that are responsible for various forms of the urban green space pattern. The result could affirmably indicate that urbanization not only can influence the urban green spaces near urban fringe but also could act on the urban developed area. The increasing fragmentation of urban green spaces in the east should be a good evidence.

In a whole, based on our study area, the policy and urbanization were the main driving forces of urban green space dynamics. The government in Jinan City has responded to growing concern about the social and environmental costs of sprawling development patterns by creating a wide range of policies to manage urban growth and protect urban green spaces. The urban sprawl of Jinan was clearly constrained by its topography, but urban planning and policy decisions also restrict and guide the urban spatial growth and development direction, which will affect the spatiotemporal pattern change of urban green spaces. The influence for the urban development is ongoing. It seems that the policy makers and urban planners faced with managing urban growth and protecting urban green spaces could hold the balance for the future development. However, we have to mention one thing: in a long view, urban greening can not be attained through urban planning approaches or greening policies only. This centralized decision-making processes is necessary but not the only approach. Urban greening is the gateway to sustainability (Pincetl, 2003). It is something that both government and individual should act on.

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