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SPATIAL GRADIENT ANALYSIS OF URBAN GREEN SPACES COMBINED WITH LANDSCAPE METRICS IN JINAN CITY OF CHINA

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ABSTRACT: Urban green spaces have been arisen growing concern responded to the social and environmental costs of urban sprawl. A wide range of planning and policies has been and will be designed to protect urban green spaces and optimize their spatial pattern. A better design or planning of urban green space can make a major contribution to quality of environment and urban life, and furthermore can decide whether we can have a sustainable development in the urban area. Information about the status quo of urban green spaces can help planners design more effectively. However, how to quantify and capture such information will be the essential question we face. In this paper, to quantify the urban green space, a new method comprising gradient analysis, landscape metrics and GIS was developed through a case of Jinan City. The results demonstrate: 1) The gradient analysis is a valid and reliable instrument to quantify the urban green space spatial pattern precisely; 2) using moving window, explicit landscape metrics were spatially realized. Compared with quantifying metrics in the entire landscape, it would be better to link pattern with process and establish an important basis for analyzing the ecological and socioeconomic functions of green spaces.

KEY WORDS: urban green space; spatial pattern; gradient analysis; landscape metrics; GIS; Jinan City

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1 INTRODUCTION

Urban green spaces can be considered as the outdoor places in the urban covered with significant amounts of vegetation, natural or manmade, as opposed to areas that are paved or having building on them (JIM and CHEN, 2003; SHIVANAND and SUZANA, 2005). As the last remnant of nature in the urban (BEATLEY, 2000), urban green spaces perform important ecological and socioeconomic functions, including protecting the biodiversity (ATTWELL, 2000), preventing soil erosion (BINFORD BUCHENAU, 1993), absorbing pollutants (GROOT, 1994), mitigating urban heat island effect (MILLER, 1997; STANNERS and BOURDEAU, 1995), providing amenity-recreation venues (DWYER *et al.*, 1992), reducing the stress caused by working hard (KAPLAN and KAPLAN, 1989), and increasing land values (ANDERSON and CORDELL, 1988; GEOGHEGAN *et al.*, 1997).

However, with the development of urbanization, urban population increased rapidly. Concomitantly, urban green spaces were gradually consumed. Furthermore, urbanization is in an in-stoppable process, more and more people will become city dwellers (BREUSTE, 2004). It is expected about 65% world's population will live in urban by 2025 (SCHELL and ULOJASZEK, 1999). Increased population caused the growth of urban, which will inevitably have profoundly environmental and social-economic consequence. And a fundamental consequence is the increasing alienation between mankind and the natural world (GORDON, 1990). For example, the numbers of trees in US cities declined 30% over the last 15 years, while paved surfaces increased by 20% (News from American Forests, 2003). The decrease of urban green spaces will farther deteriorate the urban environment. On the other hand, rapid urbanization and increased leisure time make citizens pay much more attention to

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the living standard. People clearly wanted to enjoy and contact with nature in the place where they live. Responded to this situation, a growing concern about greening urban has been arisen. Both the governments and city dwellers are beginning to recognize it is important to heal the rift between mankind and nature. Planning and designing urban green spaces to renaturalize of urban spaces has been the first tier concerns and the critical issue. More and more policy instruments and methodologies were designed to manage urban growth and protect urban green spaces or quantify their ecological, socioeconomic functions (GORDON, 1990; MILLER, 1997; RIDDER *et al.*, 2004).

Urbanization and planning of urban green spaces are going so far, which has inevitably resulted in various effects on the structure, function, and dynamics of green space system. This issue, therefore, brings the interest to the researchers to explore the relationship between urban green space spatial pattern and their ecological process (JIM and CHEN, 2003). Thus, quantified landscape metrics combined gradient analysis and GIS will be appropriate for such studies (LUCK and WU, 2002). Landscape metrics is already commonly used to quantify the shape and pattern of quasi-natural vegetation (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 recent research, such as LUCK and WU (2002) and ZHANG *et al.* (2004), has inducted the gradient analysis to explore the urban landscape pattern and urbanization process by using the "split window" along the chosen transect. However, it is still hard to get the spatial information of each local area and better link spatial pattern and process in the whole landscape. To solve this problem, in this paper we introduced a new instruments. Instead of analyzing the whole or the part landscape pattern, gradient analysis supported by the moving window option in the Fragstats (version 3.3) (MCGARIGAL et al., 2002) can be used to quantify the local landscape pattern across space (MCGARIGAL and CUSHMAN, 2002). A sampling analysis from the urban center to the fringe in 8 directions along the surface of each landscape metrics map was conducted. The different spatial signature of each metric which fluctuated from the urban center to the fringe could be conveniently used for comprehensively studying the urban green space systems.

In this study, we chose Jinan City as the study area and integrated gradient analysis with landscape pattern metrics and GIS to quantitatively characterize the urban green space pattern in 2004. We aimed to address the following two questions: How is the urban green space spatial pattern based on general and gradient analysis? And can spatial gradient analysis of urban green spaces link pattern with process better? Identifying these will provide substantial information for the eco-city planning and will also be an important prerequisite to analyze the ecological socioeconomic functions of urban green spaces.

2 STUDY AREA

Jinan City is the capital of Shandong province, located at 36°32′–36°51′ N and 116°49′–117°14′E, and nearby to the south is Taishan Mountain and to the north is the Huanghe (Yellow) River (Fig. 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 650-700mm. Jinan also has a special geological structure. Underground streams from Taishan Mountain 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. The present dominant species are *Platanus orientalis*, *Sophora japonica*,, *Populus tomentosa* and *Platycladus orientalis*, and bush-grass communities (Jinan Landscape Bureau, 2001). The study area of this paper contains the whole inner part of the Second-Ring Road and covers 149.2km^2, which is the core area in the "past" and the "future" Master Plans.

3 DATA AND METHODS

In this research, 2004 Spot Image (resolution 10m, 4 bands) and a topographic map (1:10000) created in the year 2000 were used as the primary data. Except this, urban planning data and census data that were obtained from Jinan Planning Bureau (2003) and Statistics Bureau (2003) were used as auxiliary information.

To extract urban green space information, Spot image was rectified and georeferenced to the Universal Transverse Mercator (UTM) coordinate system by using ERDAS Imagine system. Urban green space categorical map was created by manual interpretation

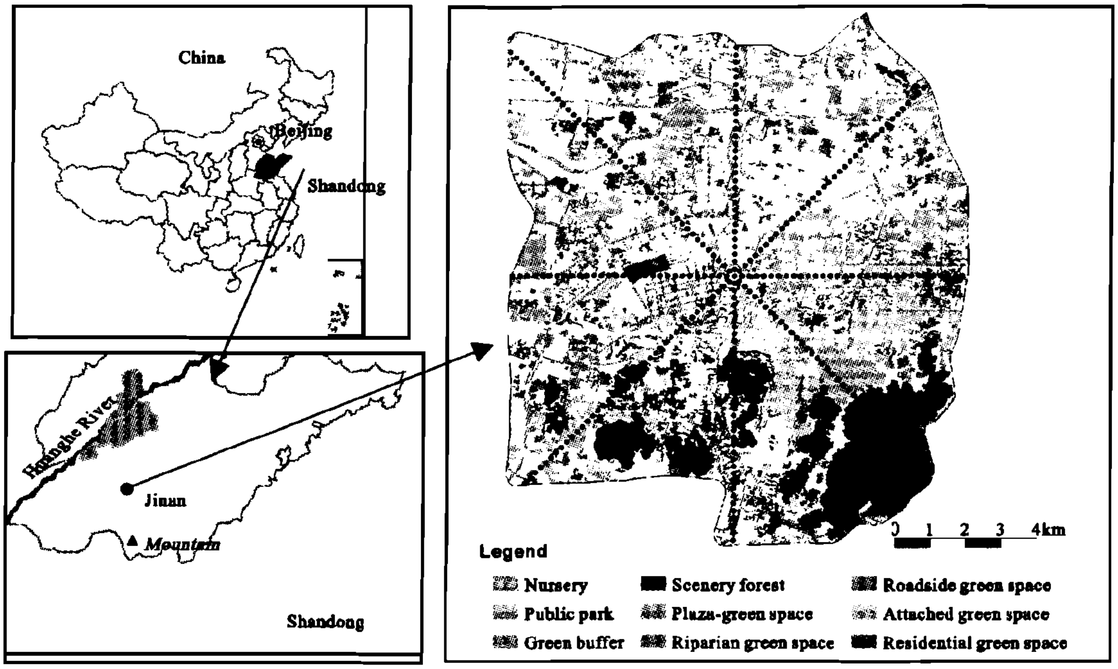


Fig. 1 Location of study area, urban green space type map and 286 sample points in 8 directions

based on the ARC/INFO platform, combined with necessary field survey and validation. Based on urban green space functions, land use type and ownership, the data set was reclassified from the Standard for Classification of Urban Green Spaces in China (China Ministry of Construction, 2002) into 9 types, which are public park (PU), plaza-green space (PL), nursery (NU), green buffer (GR), attached green space (AT), residential green space (RE), roadside green space (RO), riparian green space (RI) and scenery forest (SC) (Fig. 1) (KONG and NAKAGOSHI, 2005). Urban green space vector map was converted to raster format at the pixel size of 10m■10m using ARC/MAP Spatial analysis. To capture the synoptic feature of the landscape several landscape metrics were calculated using the Fragstats.

To detect the gradient change of the urban green space, a moving window analysis supported by the Fragstats was also conducted (Fig. 2). Before doing this, a buffer was built around outside of the vector green space type maps, with 500m distance away from the Second-Ring Road (outline of study area), the same size as the moving window radius. Then the data were converted to raster with a grid format (cell size 10m■10m). Both class and landscape level metrics were computed using a 500m-radius window size. The window moves over the landscape one cell at a time, calculating the selected metric within the window and returning that value to the center cell and output a new grid file for each selected metric (MCGARIGAL and CUSHMAN, 2002). According to the grid maps, 286 samples were then selected with the distance 200m in 8 directions from the urban center. In this research 6 metrics were used to quantify the urban green space pattern (Table 1).

4 RESULTS

4.1 General Description of Urban Green Spaces

In 2004, the total green space area in Jinan was 5538.6ha, with the forest coverage rate 37.13%, the Mean Patch Size (MPS) 2.83ha and Patch Density (PD) 13.11 patches/100ha. The Percentage of Landscape (PLAND) of SC, RE, AT, RO, PU, NU, RI, GR and PL accounted for 11.52%, 8.05%, 6.22%, 4.32%, 2.84%, 2.30%, 0.91%, 0.49% and 0.49%, respectively (Fig. 3). The PD almost has the similar rank, except the SC and PU with a lower value, indicating their higher degree of aggreation. Especially, SC occupied about 31.02% among all of the green spaces. It has highest values for Largest Patch Index (LPI) and MPS and the lower PD, all suggesting the SC is the dominant urban green space type in the study area and has a higher degree of agregation. This will be very important for preserving the spring water source and protecting biodiversity in the city. On the contrary, the RE area is inferior to SC, but it has the highest value of PD and the lowest MPS, together showing the highest degree of fragmentation(Fig. 3).

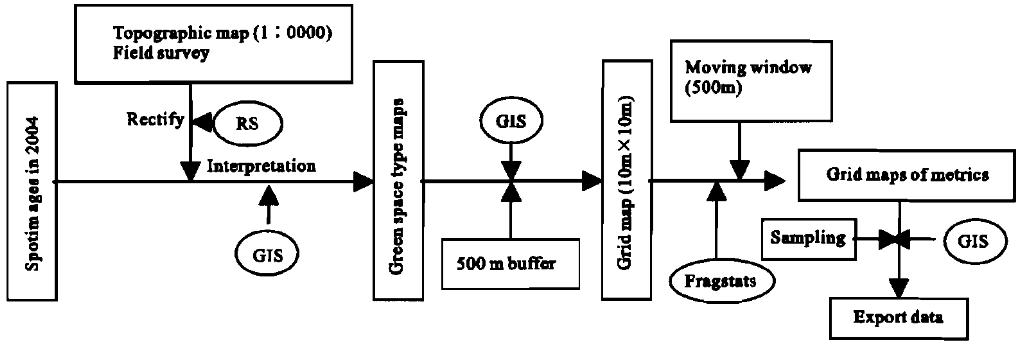


Fig.2 Flow chart of gradient analysis procedures

Table 1 Definitions of landscape metrics (MCGARIGAL et al., 2002)

Landscape metrics	Description	Unit	Range
Patch Density (PD)	Number of patches per 100ha	Patches/100ha	PD > 0, constrained by cell size
Percent of Landscape(PLAND)	Proportion of total area occupied by a particular patch type; a measure of landscape composition and dominance of patch types	%	0 < PLAND < 100
Mean Patch Size(MPS)	Area occupied by a particular patch type divided by number of patches of that type	ha	MPS > 0, no limit
Largest Patch Index(LPI)	LPI equals the area (m2) of the largest patch of corresponding patch type divided by total landscape area (m2), multiplied by 100 (to convert to a percentage)	%	0 < LPI <100
Landscape Shape Index (LSI)	Total length of edge involving 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
Patch Richness (PR)	Number of patch types in the landscape; a measure of diversity of patch types.	None	PR ≥ 1, no limit

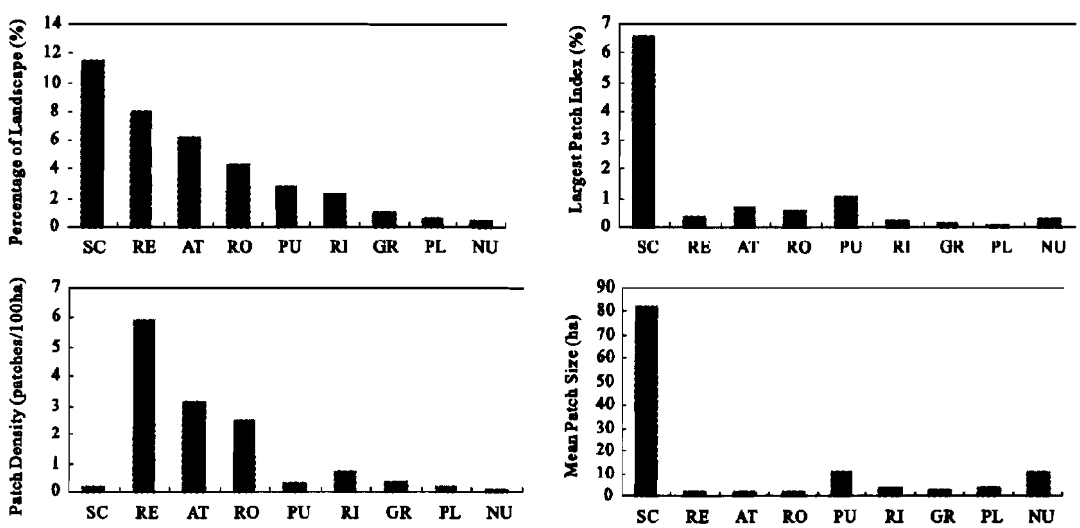


Fig.3 General landscape characteristics of urban green spaces in Jinan City

General spatial analysis by landscape metrics allowed a holistic understanding in the study area. However based only on this, it is hard for us to understand the spatial pattern in the local area and link accurately changes of green space patterns with the process. So we tried to solve this problem by gradient analysis in the next section.

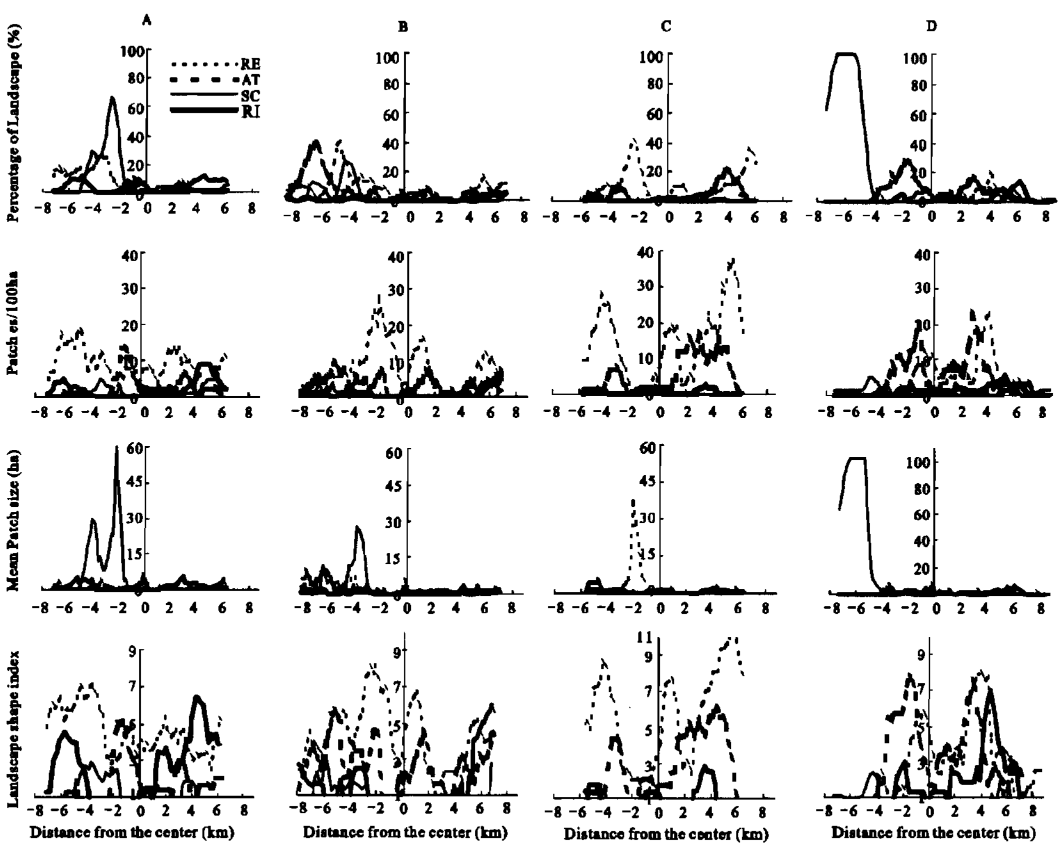
4.2 Spatial Gradient Analysis of Urban Green Spaces in Class–level

In class-level, we try to explore the spatial pattern of urban green spaces by only choosing four green space types, which are RE, AT, SC and RI. RE and AT are the green spaces built by people. On the other hand, the SC and RI are mostly natural or semi-natural. Thus, by analyzing these four green space types, it will reflect urban green space pattern simply and imply the anthropogenic influence.

In Fig. 4, the four landscape metrics in class-level varying with distance from the urban center to the fringe characterize the spatial pattern of urban green spaces. In general, the PLAND and PD take on nearly an "M" shape (except Southeast-Northwest), with a lower value around the urban center, higher value in intermediate areas and lower value at the fringe. The urban center is the place of the old city and has a higher density building. Even though rejuvenation of old urban areas has been done and not less than 25% forest coverage rate was required, it is still hard to realize the land use conversion well.

If making a close examination, we can also find that the PLAND of residential green space and attached green space showed a somewhat symmetric pattern in 8 directions if without the disturbance of scenery forest: near the urban center the PLAND of AT is higher than the RE, however, next to the center, the higher value shifting from AT to RE and then back to AT. The ring structure of land use in Jinan City (JIANG and ZHANG, 2003) was indicated. In south, southwest and southeast, for the mountainous areas, the higher PLAND, MPS and Lower PD and LSI indicating the scenery forest was dominant and least fragmentation, especially in the southeast farther than -4km, there is almost no other green space type. The RI is mostly distributed near the fringe, especially, in the north, where is the Huanghe River and lots of watersheds formed by its anabranches.

In south and southwest, PLAND of residential green space appeared peaks near the scenery forest (Fig. 4), and along the west-east transect, two peaks were shown, in west between -3 - -2 km and in east 5-7 km, respectively (Fig. 4C). All of this can indicate that different



South, southwest, west and southeast is negative and north, northeast, east and northwest are positive

(A): south-north, (B): southwest-northeast, (C): west-east, (D): southeast-northwest

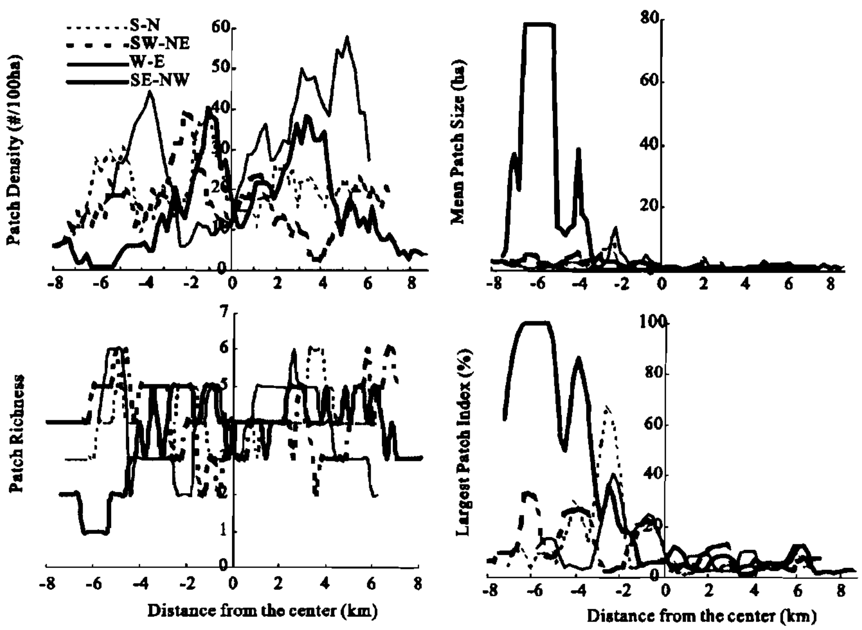
Fig.4 Gradient changes of urban green space in eight directions with class-level metrics place had different urbanized or urbanizing period and imply the urban sprawl direction. With the urbanization development, more and more residents lived outside of urban center, and much more eco-communities were built. Especially in east, a significant peak was shown. Due to urban sprawl constrained by the topography and also to protecting the spring water resource, "Sprawl in Eastward" made in the Master Plans (1996-2010 and 2004-2020) triggered a rapid development of residential districts in recent years. These places were often with designated green spaces to provide amenities to residents in the form of recreational benefits. However, near the fringes of southwest and south the peaks can be related to an encroachment of scenery forest and riparian green space, and indicated a gradual increasing process of population. Especially in south, the urban sprawl is beginning to encompass the green space. More and more people prefer to live proximity to green spaces, even though, with a higher house price and firmly measures implemented by the government to control such situation for protecting the spring water sources.

4.3 Spatial Gradient Analysis of Urban Green Spaces in Landscape–level

The lower values of the 4 landscape metrics in landscape-level at the urban center indicate a monotone and infrequent distribution of urban green spaces (Fig. 5). As explained in the class-level, even though in the old city related measures have been applied, it still failed to make a higher forest coverage rate.

The peaks of PD indicate a higher fragmentation with numerous unconnected pieces of smaller patches of green spaces. On the contrary, a smaller value means a fewer pieces and in general larger areas. On a whole, the curve of PD indicates an irregular distribution of urban green spaces in Jinan City. In the south (around -2km) and southeast (around -6km), the PD display trench combined the lower Patch Richness and higher Largest Patch Index and MPS reflecting the fact these places with obviously "Green Core" (composed primarily of "scenery forest" and "public park"). Especially, in the southeast, the PD and PR display a striking deep trench, but LPI and MPS show the highest plateaus where SC is the most dominant green space type and absolutely occupied the largest percentage. However, along the two transects towards south and southeast, the PD increases significantly. Accordingly, PR rises, and MPS and LPI decrease. It indicates a higher disaggregation near the "scenery forest" or "Public Park" and illustrates that urban sprawl is enveloping and encroaching on them.

Moreover, from west to east (W-E), the PD takes on a complete "M" shape. The striking two peaks (around -4 and 4-6km) accompanied with a stable PR indicate a higher a fragmentation of green space but slightly lower diversity. The RE contributes more to the fragmentation because they largely take place in residential areas. In the northeast (around 4km) and in the northwest (from 7 km to the fringe), PD the same as other metrics show lower. The lack of urban green space is the main reason in these areas.



S-N: South-North, SW-NE:Southwest-Northeast, W-E:West-East, SE0NW:Southeast-Northwest

Fig.5 Gradient changes of urban green spaces in 8 directions with landscape-level metrics

5 CONCLUSIONS

This study has introduced a comprehensive approach to quantify the spatial pattern of urban green spaces in the local area. The combined and integrated application of remote sensing, landscape metrics, and gradient analysis represented an innovative approach to capture the gradient change of urban green space and demonstrate that urbanization and the influence of governmental policy can be reflected by quantifying the spatial gradient of urban green space.

(1) Spatial pattern of green space in Jinan city. General analysis of urban green space provided a holistic description of green space system in the study area. To better link its spatial pattern with process, gradient analysis was conducted in class and landscape level. In class-level, the different green space type, exhibited distinctive, but not unique, the spatial signatures. For example, the SC and RE show significantly difference. In the study area, SC most located in the south and southeast is the predominant green space type with a higher aggregation, however, RE is the most frequent type with a higher fragmentation. In landscape-level, four landscape metrics provided information of urban green space spatial distribution at local area. The low value in the urban center revealed the urban spatial structure and urbanization process.

(2) Reflecting urbanization and the influence of governmental policy. Based on our study area, the urbanization is a swallowing-type expansion process. The urban sprawl of Jinan is clearly constrained by the topography, however, urban planning and policy decisions also restrict and guide the urban spatial growth and development direction, and this deeply affected the spatial pattern of urban green space. The analysis of RE and SC in the west, east, south and southeast was a good explanation. Green space amenities attract migrants and often have a strong effect on the urban development, for example, causing the encroaching and consuming of SC in south and southeast. To prevent the decrease of the remnants green space, government oriented appears very important.

(3) Importance of spatial gradient analysis of urban green space. An averaging of metrics over an entire study area may lead to incorrect interpretations of the causal dynamics in the region, e.g. the synoptic analysis reflected can not be related to specific locations or with visual a spatial interpretation (HEROLD et al., 2002). To solve this question, in our research, spatially explicit landscape metrics was realized by using Moving window method. It can provide rich quantitative information about the structure and pattern of urban green space at the local landscape area, and can effectively capture its pattern change.

More over, in this paper we focus on identifying the physical characteristics of green space. In reality, the quantified and spatially explicit urban green space pattern will be an important basic to analysis its ecological, socioeconomic functions. For example, green space amenity can affect property price which can be well valued by overlapping much more environmental or socioeconomic spatial information and based some kind of economic model, such as, hedonic price model (MORANCHO, 2003; GEOGHEGAN, 2002).

Finally, in this research, we have tried several times to choose appropriate window size and get a better smoothing effect. The result with 500m-radius window seemed well to reveal fluctuations of most metrics. This may be viewed as a good example of effects of changing scale on the landscape metrics (TURNER *et al.*, 1989; HUNSAKER et al. 1994; JELINSKI and WU 1996; WU *et al.*, 2000; LUCK and WU, 2002). How scale affects landscape metrics and how to choose window size when using gradient analysis based on categorical map is another work we will do. It also suggests further exploration and integration of different landscape metrics specifically useful in representing characteristics of spatial gradient change of urban green spaces.

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