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Original Research

Landscape Pattern Analysis Based on Optimal Grain Size in the Core of the Zhengzhou and Kaifeng Integration Area

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Abstract

Landscape pattern analysis is a popular topic in global change research, and appropriate grain size is the basis for accurate landscape pattern analyses. In this study, methods based on landscape metrics and spatial autocorrelation are used to determine the optimal grain size of the study area. Based on a grain size of 20 m, the landscape pattern of the core of the Zhengzhou and Kaifeng integration area was analyzed at class and landscape levels from 2005-15. The results show that over the study period, the landscape fragmentation of the study area increased by approximately 32.38%, the distribution of landscape types was homogenized gradually, and human impact was the main reason for the changes in landscape pattern. Additionally, cultivated land was the predominant landscape type, and the area percentage of cultivated land decreased from 79.01% to 60.01%. The patch number and total area of forests increased, the percentage of construction land increased by approximately 1.5 times, and the area and patch number of unused land gradually decreased. This research provides useful information for land use policy-making.

Keywords: grain size, landscape pattern, landscape metrics, core area of Zhengzhou and Kaifeng integration

Introduction

Landscapes are the carrier of most ecosystem services that provide the foundation for human well-being [1]. For centuries, large-scale changes in landscape patterns have occurred worldwide and reduced the provision of most ecosystem services [2]. Historical change in landscape patterns must be quantified to understand the consequences of landscape changes [3]. Because of the scale dependency of landscapes, optimal grain size is the basis for accurate landscape patterns analyses [4].

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In previous studies, landscape metrics methods have been used to quantify landscape patterns and provide objective descriptions of landscape patterns [5-6]. When addressing landscape patterns, the first task is to determine the landscape scale. The landscape pattern index values vary at different scales [7-8], and the landscape scale is generally studied in terms of the grain size and extent [9]. At present, a mature method of selecting the optimal grain size is not available [10]. Many studies have determined optimal grain size by analyzing the trends in landscape metrics for different grain sizes, and studying the internal relationships among landscape metrics for different grain size backgrounds [11-17]. Studies have shown that a linear or power function relationship occurs between certain landscape indices and grain size, although most landscape indices do not have clear mathematical relationships with grain size [18-19]. Landscape pattern studies based on optimal grain size have been performed for forests, grasslands, cultivated land, cities, wetlands, suburbs, deserts, watersheds, etc. [12, 20-24]. However, some research has been performed on planning regions that do not apply administrative units or watersheds as a boundary. Landscape pattern analyses of planning regions is important for monitoring the effectiveness of planning and providing useful information for environmental policies [3].

In China, many planning regions do not have boundaries defined by administrative units or watersheds. Additionally, this issue affects landscape pattern analyses in many counties. In this study, the core area of Zhengzhou and Kaifeng integration region is chosen as the study area, and landscape metrics methods and spatial autocorrelation analyses are used to determine the optimal grain size. The main objective of this study is to quantify changes in the landscape pattern at landscape and class levels from 2005 to 2015 at the optimal grain size, and the results will provide useful information for local land policies.

Materials and Methods

Study Area

The study area is the core of the Zhengzhou and Kaifeng integration area, which is the area between the two cities. It is located east of Zhengzhou and west of Kaifeng. The study area extends east to Jinming Road in Kaifeng, west to the Jing-Gang-Ao Highway in Zhengzhou, north to Lian-Huo Highway, and south to the 310 National Road. The study area is approximately 47,314 hm^2. It is located between longitudes 34°72′ and 34°85′E, and latitudes 113°81′ and 114°30′N (Fig. 1).

The study area belongs to a traditional agricultural landscape. Cultivated land is the main landscape type. In the past 10 years, considerable changes have occurred in the landscape pattern of the study area, because of the “Central Henan Urban Agglomeration,” “Zheng and Bian New District Planning,” and “Zheng and Bian Industrial Belt Planning.” Currently, the local government has

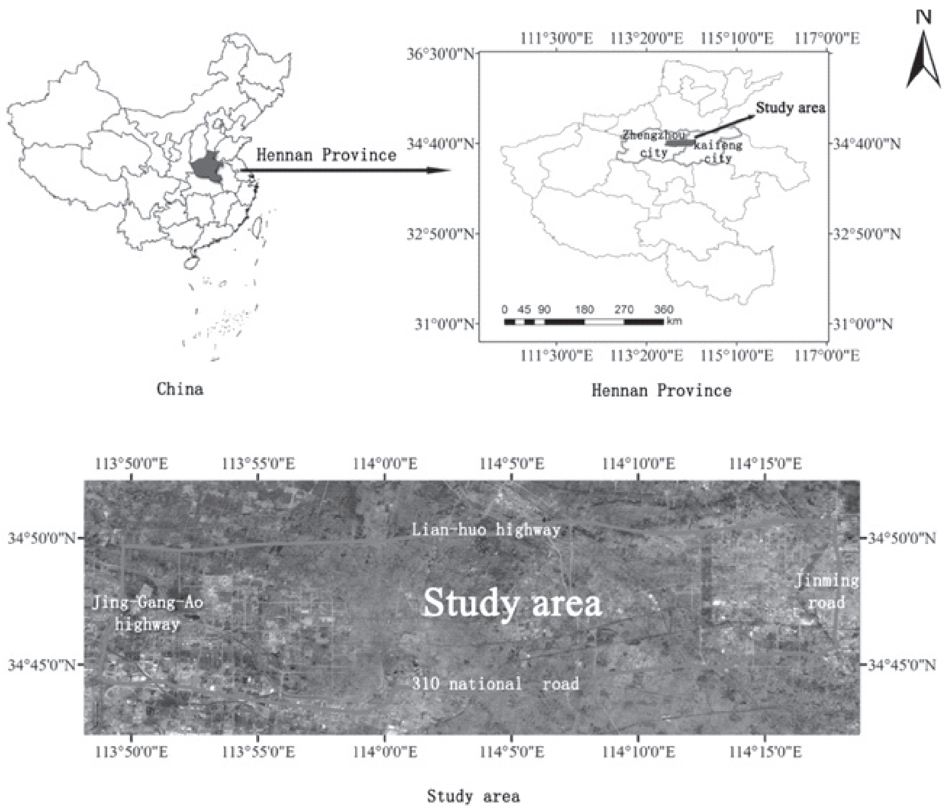

Fig. 1. Study area location.

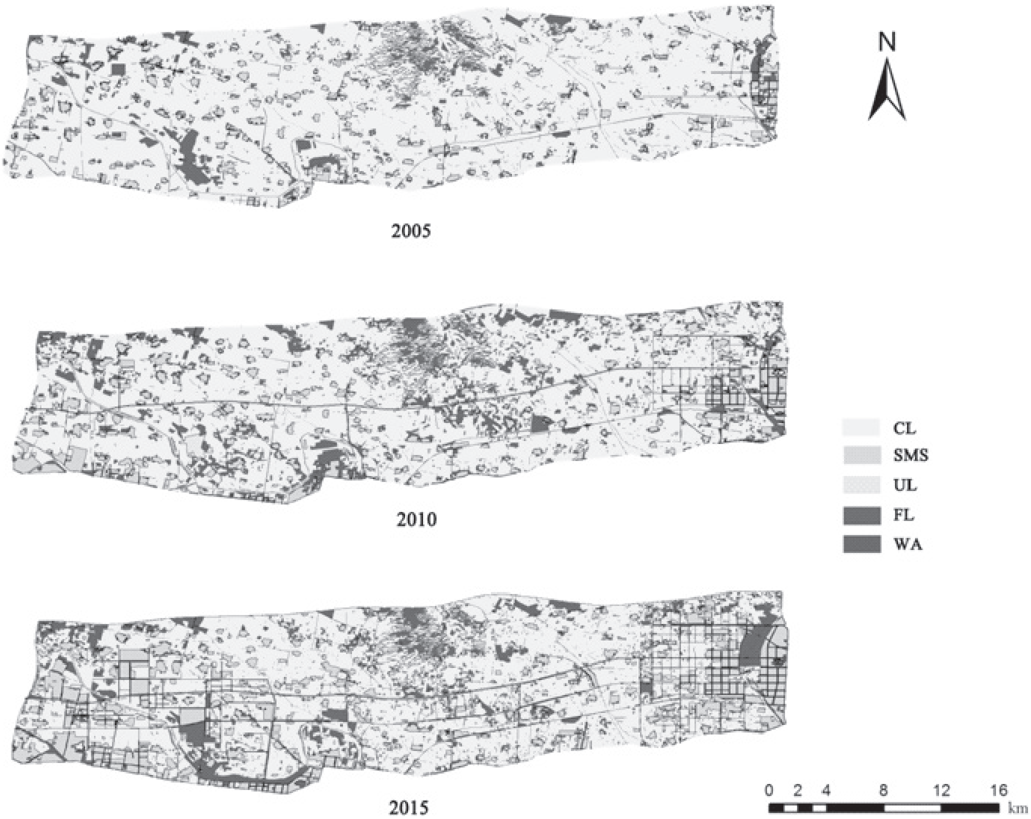

Fig. 2. Landscape pattern of the study area in 2005, 2010, and 2015.

Table 1. Fourteen landscape metrics.

Abbreviation	Landscape metric	Definition or formula
SHDI	Shannon's diversity index	Proportional abundance of each patch type
SHEI	Shannon's evenness index	Observed Shannon's diversity index divided by the maximum Shannon's diversity index
CONTAG	Contagion	Considers all patch types present in a landscape affected by both the dispersion and interspersion of patch types
LSI	Landscape shape index	Standardized measure of patch compactness that adjusts for the size of the patch; as LSI increases, the patches become increasingly disaggregated
LPI	Largest patch index	Area of the largest patch in the landscape divided by total landscape area
DIVISION	Landscape division index	Probability that two randomly chosen pixels in the landscape are not situated in the same patch
COHESION	Landscape cohesion index	Physical connectedness of the corresponding landscape type
SPLIT	Splitting index	Effective mesh number
NP	Patch number	Number of landscape patches
PD	Patch density	Number of landscape patches per unit area
MPS	Mean patch size	Average patch size
MPI	Mean proximity index	Measure of the degree of isolation and fragmentation
TE	Edge density	Sum of the lengths of all edge segments in the landscape
PAFRAC	Perimeter-area fractal dimension	Perimeter-area fractal dimension reflects shape complexity across a range of spatial scales (patch sizes)

sought to determine the distribution of changes in the landscape pattern and quantify these changes. This information can be used to monitor the progress of the planning activities and will provide a necessary reference for future land policies.

Data Preparation

Datasets of the study area in 2005, 2010, and 2015 were downloaded from Google Maps. The pixel size of each Google image was approximately 5×5 m. To ensure the accuracy of the results, 1:5,000 topographical maps and a land use map were used to register the image. The topographical maps and digital maps were obtained from Henan Province Resources Department of China. Image data preprocessing was performed using Arc GIS 10.0. According to the National Standard of Land Use Classification of China (2007), the research region was divided into cultivated land (CL), which includes irrigated lands and paddy fields; forest land (FL); water areas (WA), which includes rivers, ditches, and pools; settlements and mining sites (SMS); and unused land (UL) (Fig. 2). We optimized the quality of the images by field sampling. The results showed that the kappa values for the 2005, 2010, and 2015 datasets were all greater than 0.83.

Methods

Selection of Landscape Metrics

More than 100 landscape metrics were used in the landscape pattern analysis [25]. Certain landscape patterns have similar meanings, such as patch number and patch density [26]. In this study, 14 landscape metrics (Table 1) were selected because of their widespread use and well-documented effectiveness in landscape pattern studies [27-29]. To avoid redundancies, a principal component analysis was used to identify independent metrics. The specific methods are listed below.

The study area was divided into 10 equal parts. Then, FRAGSTATS 4.2 was used to calculate the 14 landscape metrics in each part. Finally, landscape metrics that were independent of one another were selected accoraccording to the results of the principal component analysis.

Determining Optimal Grain Size

The selected landscape metrics of different grain sizes and a spatial autocorrelation analysis of different grain sizes were used to determine optimal grain size. The study area landscape in 2005 was used as an example. First, the grain size of the land use/cover map of 2005 was resampled to 10×40 m, 20×20 m, 40×40 m, 60×60 m, 80×80 m, 100×100 m, 120×120 m, 140×140 m, 160×160 m, 180×180 m, and 200×200 m in Arc GIS 10.0. Then the selected landscape metrics were calculated at various grain sizes in FRAGSTATS 4.2 at the landscape level.

Table 2. Principal component analysis of the 14 landscape metrics.

Principal components	Landscape metrics			
1	SHDI	SHEI	CONTAG	
2	LPI	DIVISION	COHESION	SPLIT
3	NP	MPS	MPI	PD
4	TE	LSI		
5	PAFRAC			

Finally, Moran's I was calculated using the following formula:

$$I = \frac{n\sum_{i=1}^{n}\sum_{j=1}^{n} wij(x_i - \bar{x})(x_j - \bar{x})}{\sum_{i=1}^{n}\sum_{j=1}^{n} wij(x_i - \bar{x})^2}$$

…where i≠j; n is the number of the spatial unit; x_i and x_j are the observed values of spatial unit i and spatial unit j, respectively; $\bar{x}$ is the mean value of x; and w_{ij} is the spatial weight matrix. Commonly, w_{ij} is defined by the adjacency of spatial units: $w_{ij} = 1$ if regions i and j are adjacent (neighbors) and $w_{ij} = 0$ otherwise.

Analysis of Landscape Patterns

After determining optimal grain size, the selected landscape metrics were used to analyze the landscape pattern of study area at the landscape and class levels for 2005, 2010, and 2015 based on optimal grain size. The landscape metrics are calculated by FRAGSTATS 4.2.

Results

Selection of Landscape Metrics

Five principal components from 14 landscape metrics were selected via principal component analysis (Table 2).

To avoid redundancies in the landscape metrics, one landscape metric was selected from each of the five components. Therefore, SHDI, LPI, NP, TE, and PAFRAC were selected to determine the optimal grain size and analyze the landscape pattern of the study area.

Determining Optimal Grain Size

Grain Size Analysis of Five Landscape Metrics

In 2005 the five landscape metrics (SHDI, LPI, NP, TE, and PAFRAC) for the study area were calculated for various grain sizes (Fig. 3).

As grain size increases, adjacent patches merge to form larger patches, which leads to changes in the landscape metrics [30].

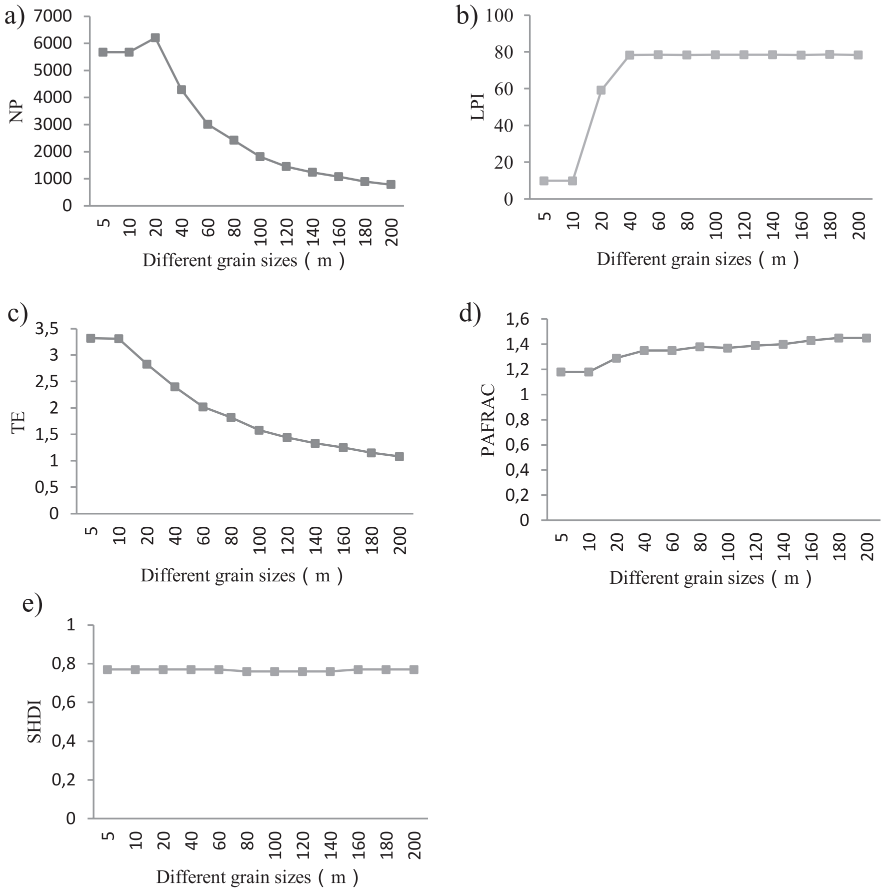

Fig. 3. Five landscape metrics for various grain sizes.

As shown in Fig. 3a, a significant scale effect is not observed for NP at grain sizes of 5~10 m. As grain size increases, NP increases. From grain sizes of 20 to 200 m, NP is sensitive to the increase of grain size and decreases gradually and regularly. Therefore, a grain size of 20 to 200 m is selected for NP.

Fig. 3b) shows that a significant scale effect does not occur for LPI at grain sizes of 5~10 m and 40~200 m. At 10~40 m, LPI is sensitive to increases in grain size and it increases gradually. Therefore, a grain size of 10~40 m is selected for LPI.

Fig. 3c) shows that a significant scale effect does not occur for TE at grain size of 5~10 m. At 20~200 m, TE is sensitive to increases in grain size, and it decreases gradually and regularly. Therefore, a grain size of 10~200 m is selected for TE.

Fig. 3d) shows that a scale effect does not occur for PAFRAC at grain size of 5~10 m, 40~60 m, 80~100 m, and 180~200 m. PAFRAC presents a significant increasing trend as the grain size increases from 10~40 m, and slight increasing trends are observed for 60~80 m and 100~180 m. Generally, the first grain size interval is the most appropriate selection (Zhao et al., 2003, Xu et al., 2007) [31-32]. Therefore, a grain size of 10~200 m is selected for PAFRAC.

Fig. 3e) shows that a scale effect does not occur for SHDI at all grain sizes (5~200 m).

In summary, the characteristic scale of NP is 20~200 m, LPI is 10~40 m, TE is 10~200 m, and PAFRAC is 10~200 m. SHDI does not present a scale effect for all grain sizes. Therefore, 20~40 m is used as the common characteristic scale of the five landscape metrics.

Spatial Autocorrelation Analysis

Using the land use/cover map from 2005 as an example, Moran's I was calculated for all grain sizes (Fig. 4).

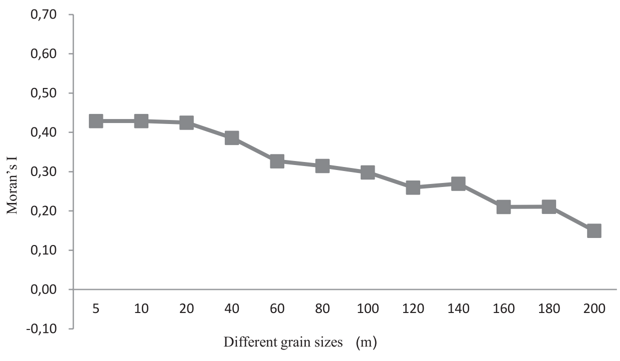

Fig. 4. Spatial autocorrelation analysis of different grain sizes.

Moran's I was constant at 5~20 m and declined continually at grain size of 20~200 m. This result suggests that the landscape gradually became less spatially auto correlated as the grain size increased to more than 20 m. Therefore, a grain size of 5~20 m is the spatial autocorrelation scale of the study area.

From the combination of the above analyses, a grain size of 20~40 m is the common scale of five landscape metrics, and a grain size of 5~20 m is the spatial autocorrelation scale. Therefore, a 20 m grain size is determined to be the optimal grain size.

Analysis of the Landscape Pattern

Landscape Level

At the landscape level, the five landscape metrics are used to analyze the landscape pattern at a gain size of 20 m (20×20 m) in 2005, 2010, and 2015 (Fig. 5).

Fig. 5a) shows that NP exhibits an overall increase from 2005 to 2015, and a small fluctuation was observed in 2010. As the area of study is unchanged, NP represents the landscape fragmentation of the study area. Thus, under the implemented planning policies, the landscape fragmentation of the study area increased by 32.3% from 2005 to 2015.

Fig. 5b) shows that LPI of the study area decreased gradually from 2005 to 2015, which indicates that the area of the predominant landscape type decreased. In the study area, CL is the dominant landscape. Therefore, Fig. 5b) reveals that the largest area of CL decreased gradually from 2005 to 2015.

Fig. 5c) shows that the TE of the study area increased from 2005 to 2015, which indicates that the landscape fragmentation increased or the landscape patch shape became more complex. Combined with the above analysis of Fig. 5a) (NP decreased from 2005 to 2010 and increased from 2010~15), the TE increased from 2005 to 2010 mainly because the patch shape became increasingly complex from 2010 to 2015, which was mainly because of an increase in landscape fragmentation.

Fig. 5d)shows that the PAFRAC of the study area varied between 1.28 and 1.30 from 2005 to 2015. A PAFRAC value near 1 suggests that the landscape patch shape is relatively regular. In this case, the landscape pattern is mainly influenced by human activity. The PAFRAC value decreased from 2005 to 2010 and increased from 2010 to 2015, which indicates that the influence of human activities was greater from 2005 to 2010 than from 2010 to 2015.

Fig. 5e) shows that the SHDI of the study area increased gradually from 2005 to 2015, which indicates that the distribution of landscapes became increasingly homogeneous because no new patch types appeared in the study area.

Class Level

Because the SHDI value is meaningless at the class level, the percentage of landscape metric (PLAND) is used instead (at class level, PLAND is the percentage of the total landscape composed of a certain class). Then, five landscape metrics were analyzed at the class level as follows:

WA

1) WA is not the predominant landscape type in the study area because its area percentage varied between 3.68% and 5.37% in 2005~15.
2) From 2005~15 the total area and average area increased gradually, but the patch number decreased. A combination of field surveys and policy research

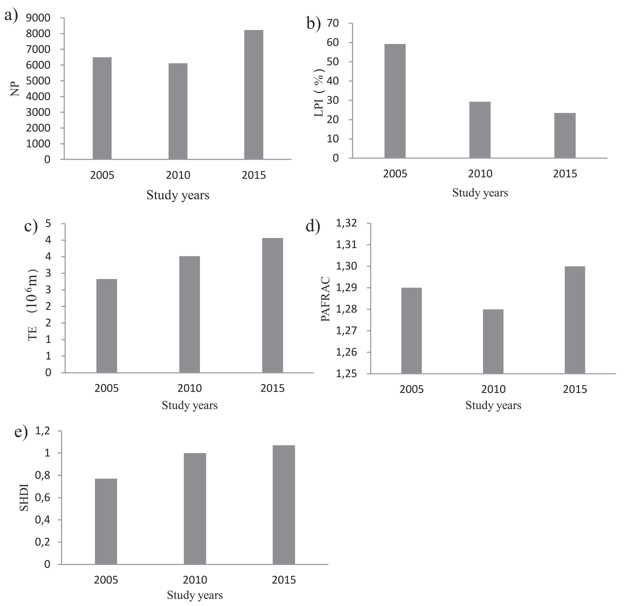

Fig. 5. Five landscape metrics in 2005, 2010, and 2015 at the landscape level.

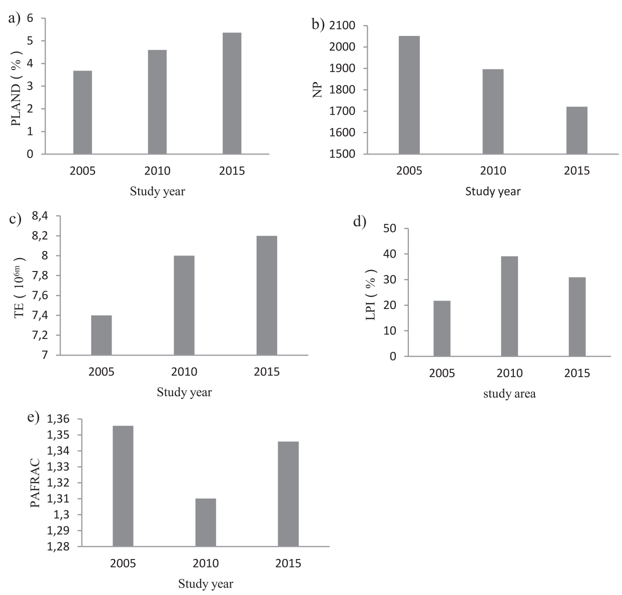

Fig. 6. WA

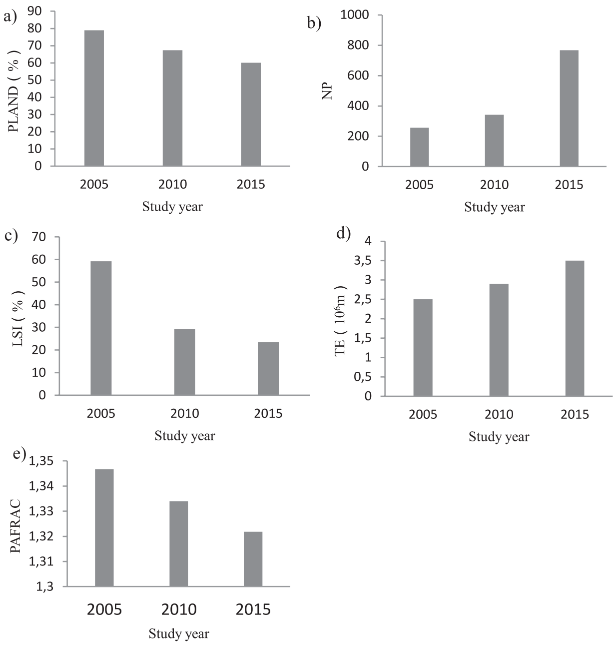

Fig. 7. CL

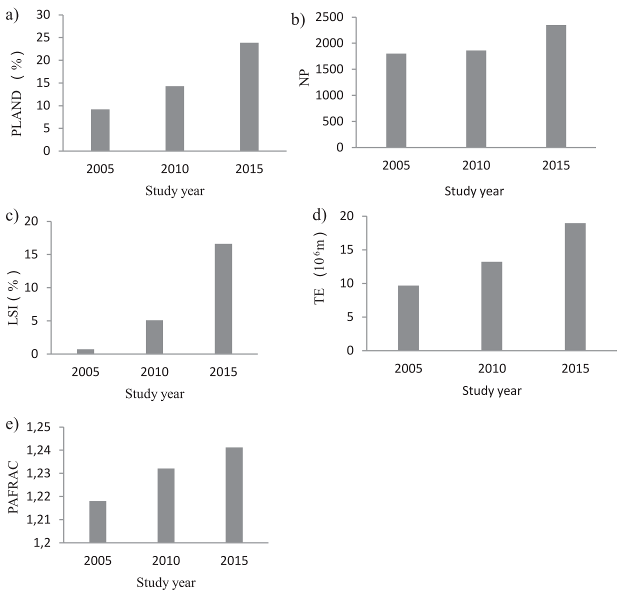

Fig. 9. SMS

identified two main reasons for these changes: an increase in the number of artificial water bodies and the disappearance of randomly distributed country ponds, and the implementation of the River System Connectivity Project in the study area.

3) From 2005~15 the WA landscape pattern was mainly influenced by human factors, especially from 2005~10. Edge length increased gradually, and edge complexity was higher from 2005~10 than from 2010~15.

CL

1) CL was the predominant landscape type, although the area percentage decreased from 79.01~60.01% from 2005 to 2015.
2) From 2005~15, the NP number of CL type increased as the CL area decreased, which indicates that CL experienced severe fragmentation. Notably, the largest patch of CL was subject to fragmentation, which led to a decrease in the largest patch area. The fragmentation was more serious from 2010~15, and the edge complexity decreased during this period.
3) During 2005~15 the landscape pattern of CL was mainly changed by human activities, which gradually had a more prevalent effect.

FL

1) FL was not the predominant landscape type. The FL area increased from 6.86% to 12.59% from 2005~10 but decreased to 10.06% from 2010~15.

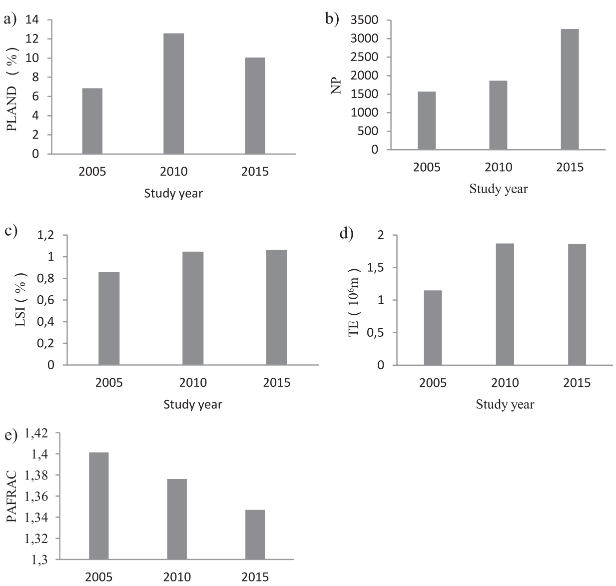

Fig. 8. FL

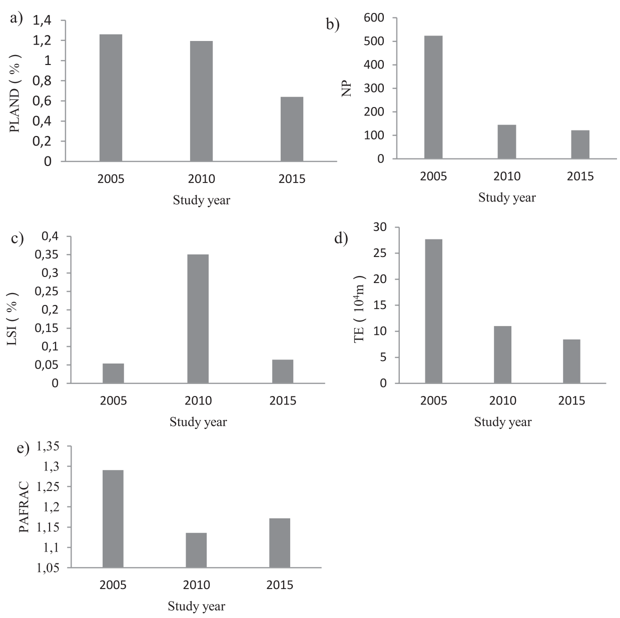

Fig. 10. UL

2) From 2005~15 the patch number increased gradually. Additionally, from 2010 to 2015 the fragmentation of FL was relatively significant, edge complexity decreased, and the largest patch was less influenced by fragmentation.
3) The FL shape was relatively regular, which indicated that human influence was the main driving force of the landscape pattern. The field survey and policy research result showed that new parks were built and small country green areas disappeared.

SMS

1) From 2005~15 SMS was the second most abundant landscape element in the study area, and gradually increased from 9.20 to 23.84% over this period. The average patch area and largest patch area also gradually increased from 2005~15, indicating that landscape fragmentation had no effect on SMS.
2) Compared with the previously analyzed landscape elements, SMS showed a greater influence associated with human activities because its shape was more regular.

UL

From 2005~15 the increase in land use intensity corresponded to a decrease in the area of UL, and the landscape pattern map indicates that most UL areas converted to SMS areas.

Discussion and Conclusions

Grain size is a fundamental parameter underlying landscape pattern analyses, and it corresponds to the resolution of a remote sensing image [33]. Landscape metrics must be calculated based on a remote sensing image that contains resolution information. Most landscape metrics are highly dependent on the grain size of the study area [34]. Therefore, when analyzing the landscape pattern via landscape metrics, the optimal grain size should be confirmed firstly.

Numerous case studies have been performed based on watershed and administrative regions, whereas limited research has focused on planning regions. However, planning regions are relatively important because they directly reflect the influence of policies.

Because a number of landscape metrics are available, determining the most appropriate metrics for analyzing landscape pattern becomes an issue. Previous studies have illustrated a number of methods for selecting landscape metrics. For example, Ahmadi Mozhgan et al. 2015 [34] selected landscape metrics that have been commonly used in landscape pattern studies, whereas other researchers have selected landscape metrics according to study-specific definitions [35-36]. In addition, some researchers have used correlation analyses [37] and conversion accuracy loss evaluation [38] to determine the most appropriate landscape metrics. Here, a principal component analysis was used to determine the optimal grain size of the study area because this method can ensure the independence of each landscape metric. Every method has advantages in determining optimal grain size. Therefore, method integration or comparative analyses should be further performed.

In this paper, the land use/cover map of 2005 was used as an example for determining optimal grain size. After this was determined, the landscape patterns in three periods (2005, 2010, and 2015) were analyzed based on five landscape metrics. This model has been widely used in previous studies of landscape pattern analysis. If each period in the study area has a unique optimal grain size, sizable errors will be introduced into the landscape pattern analysis over multiple periods. If the optimal grain size does not vary, then the grain size is not related to changes in the landscape pattern in a certain area. In the future, multiple study areas and multiple periods should be investigate to address this problem.

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