Applied Geography 31 (2011) 292–302

Contents lists available at ScienceDirect

Applied Geography

journal homepage: www.elsevier.com/locate/apgeog

# Detecting spatially non-stationary and scale-dependent relationships between urban landscape fragmentation and related factors using Geographically Weighted Regression

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*Keywords:*
Geographically Weighted Regression
Landscape fragmentation
Spatial non-stationarity
Scale-dependence
Shenzhen City
China

ABSTRACT

Landscape fragmentation is usually caused by many different anthropogenic influences and landscape elements. Scientifically revealing the spatial relationships between landscape fragmentation and related factors is highly significant for land management and urban planning. The former studies on statistical relationships between landscape fragmentation and related factors were almost global and single-scaled. In fact, landscape fragmentations and their causal factors are usually location-dependent and scale-dependent. Therefore, we used geographically Weighted Regression (GWR), with a case study in Shenzhen City, Guangdong Province, China, to examine spatially varying and scale-dependent relationships between *effective mesh size*, an indicator of landscape fragmentation, and related factors. We employed the distance to main roads as a direct influencing factor, and slope and the distance to district centers as indirect influencing factors, which affect landscape fragmentation through their impacts on land use and urbanization, respectively. The results show that these relationships are spatially non-stationary and scale-dependent, indicated by clear spatial patterns of parameter estimates obtained from GWR models, and the curves with a characteristic scale of 12 km for three explanatory variables, respectively. Moreover, GWR models have better model performance than OLS models with the same independent variable, as is indicated by lower AICc values, higher Adjusted $R^2$ values from GWR and the reduction of the spatial autocorrelation of residuals. GWR models can reveal detailed site information on the different roles of related factors in different parts of the study area. Therefore, this finding can provide a scientific basis for policy-making to mitigate the negative effects of landscape fragmentation.


## Introduction

Landscape fragmentation due to road construction, urbanization, land use/land cover change (LUCC) and other anthropogenic factors leads to more and smaller habitat patches, increased isolation among habitat patches, decreased complexity of patch shape, and higher proportions of edge habitat (Saunders, Mislivets, Chen, & Cleland, 2002). It is considered as one of the most serious threats to the conservation of natural ecosystems as well as the health of agricultural and urbanized ecosystems (Zeng & Wu, 2005). Therefore, the phenomenon of landscape fragmentation has recently attracted more and more attention due to growing applications in biological conservation and ecosystem management (Velázquez, Bocco, & Romero, 2003; Velázquez et al., 2009). However, most studies on landscape fragmentation focus on the depiction of landscape pattern characteristics (Feranec, Jaffrain, Soukup, & Hazeu, 2010; Long, Nelson, & Wulder, 2010) and the indication of its impacts on wildlife habitats (Liu, Li, & Li, 2007), biodiversity (Trombulak & Frissell, 2000), ecological processes and functions (Givertz, Thorne, Berry, & Jaeger, 2008), but few of these studies indicate the causes of landscape fragmentation (Munroe, Croissant, & York, 2005), which is highly significant for land management and urban planning.

Landscape fragmentation is usually caused by many different human activities such as urbanization and LUCC, and landscape elements such as roads, railways and rivers, whereas a merely qualitative description of the causes is not convincing. Therefore, the quantitative indication of the relationships between landscape fragmentation and its impact factors should be strengthened.

In order to effectively characterize the process of landscape fragmentation and its impact factors, the measure of landscape fragmentation should be done firstly. Many landscape fragmentation metrics were proposed to quantify spatial segregation (Li, Chang, Peng, & Wang, 2009). One such metric used in this study

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0143-6228/$ – see front matter 
doi:10.1016/j.apgeog.2010.06.003

is the *effective mesh size* ($m_{eff}$), which explicitly incorporates the ecological process of animal dispersal into its definition. *Effective mesh size* is an expression of the probability that any two randomly chosen locations in the landscape are connected, i.e. not separated by barriers such as transportation infrastructure or urban areas (Jaeger, 2000).

Spatial data exhibit two properties, i.e. spatial autocorrelation and non-stationarity, which makes it difficult to meet the assumptions and requirements of conventional regression techniques such as Ordinary Least Squares (OLS). Traditional statistical methods can only produce "average" and "global" parameter estimates (Bacha, 2003; Batisani & Yarnal, 2009; Geri, Amici, & Rocchini, 2010), and thus they are unable to deal with spatial autocorrelation existing in the variables. In recent years, a relatively simple, but effective, new technique for exploring spatially varying relationships, called Geographically Weighted Regression (GWR), has been developed (Brunsdon, McClatchey, & Unwin, 2001; Fotheringham, Charlton, & Brunsdon, 2001). GWR allows different relationships to exist at different points in the study area and improves the modeling performance by reducing spatial autocorrelations. In addition, these relationships also greatly depend on scale, which is inherent in natural and man-made processes and patterns (Lü & Fu, 2001). Therefore, local rather than global parameters can be estimated, and spatial non-stationarity can be detected at multi-scales by changing bandwidth of GWR.

The objective of this paper, with a case study in Shenzhen City, Guangdong Province, China, was to investigate the applicability of GWR in modeling the relationships between *effective mesh size* and related factors, and then examine their spatial non-stationarity and the scale-dependence. In this study, *effective mesh size* calculated using FRAGSTATS software is used as dependent variable, and three impact factors of urban landscape fragmentation are employed as explanatory variables in the regression.

## Study area

We used Shenzhen City as our case study, which lies in the south of Guangdong Province in southern China (Fig. 1), at 22°26′–22°51′N and 113°45′–114°37′E, and is the passageway from mainland China to Hong Kong Special Administrative Region. It has a total terrestrial area of 1952.84 $km^2$ (including all islands) with a North–South span longer than its East–West. Vegetation covers 50–80% of the land area. Its topography is relatively higher in the southeast part and lower in the northwest part with elevation ranging from −1 m (coastal zone) to 935 m (Fig. 1). The primary landscape type is hill, with dotted patches of plain. With a southern subtropical monsoon climate, the average annual rainfall is 1938 mm, and the mean annual temperature is 22.4 °C. The main soil types are yellow soil, red soil and lateritic red soil according to soil horizontal zonality.

Shenzhen Municipality was established in 1979 and was designated a Special Economic Zone in 1980 to attract domestic and foreign investment with tax relief, favorable land development policies, and a skillful and cheap labor force. For only 30 years, Shenzhen City has conglomerated nearby small rural towns and numerous fishing villages with less than 20,000 people into one of the largest cities in China with a population of 8.46 million. Although the opening up of other cities and regions for investment in China in the late 1980s has reduced its comparative advantage, the city has still become one of the most vigorous economies with a gross domestic product (GDP) of 7807 billion RMB in 2008, because of the connections with foreign investors that have been established for three decades (Yeh & Xu, 1996), and the geographical proximity to Hong Kong, which is unrivaled by other Chinese coastal cities (Sui & Zeng, 2001). Owing to the rapid industrialization and urbanization, large areas of natural ecosystems have been converted into construction land use types since 1979, resulting in severe urban landscape fragmentation.

## Materials and methods

The pattern, process and spatial relationships are fundamental issues in geography (Li & Cai, 2005). Landscape patterns interact intensively with ecological processes (Gustafson, 1998) and are usually considered as the results of various ecological processes at multi-scales. Based on sufficient consideration of ecological processes and their key influencing factors that can have important impacts on landscape fragmentation, this paper is intended to indicate spatially varying and scale-dependent relationships between landscape fragmentation and its related factors in Shenzhen City using GWR.

### *Dependent variable: effective mesh size*

*Effective mesh size* quantifies landscape fragmentation based on the probability that any two randomly chosen points in the landscape are located in the same non-fragmented patch. It can also be interpreted as the average size of the area that an animal placed randomly in the landscape will be able to access without crossing barriers. The more barriers in the landscape, the lower probability that two points will be connected, and the lower the *effective mesh size* (Givertz et al., 2008; Jaeger, 2000). Compared with previous landscape metrics such as edge density, which is a function of the length of edge at landscape level regardless of any patch affiliation, *effective mesh size* is more comprehensive due to the incorporation of ecological process, landscape composition, landscape spatial configuration, and landscape shape into its definition and computation.

The spatial pattern analysis program FRAGSTATS (McGarigal & Marks, 1995), developed by Dr. Kevin McGarigal with programming by Eduard Ene and additional programming assistance by Chris Holme, was used to quantify the landscape fragmentation, because it facilitates the spatial analysis of landscape patches and the modeling of the associated attributes. In this study, Landsat Enhanced Thematic Mapper Plus (Landsat/ETM+) images of Shenzhen (path/row 121-44 and 122-44), acquired on 2nd January 2000, were rectified to match other georeferenced data layers. They were then classified to two different land use types (i.e. build environment and greenspace) (Fig. 2) by supervised classification in ERDAS 8.5. The results of land classification were used to further calculate *effective mesh size* of land use in FRAGSTATS with a moving window of 60 m radius. The formula is as follows:

$$m_{efff}(j) = A_j \cdot \sum_{i=1}^{n} \left( \frac{A_{ij}}{A_j} \right)^2 = \frac{1}{A_j} \sum_{i=1}^{n} A_{ij}^2 \tag{1}$$

where $n$ equals the number of unfragmented patches in landscape $j$, $A_{ij}$ is the size of patch $i$ within landscape $j$, and $A_j$ is the total area of landscape $j$. The values of $m_{eff}$ range from the cell size when the landscape is maximally subdivided (i.e. every cell is a separate patch), to total landscape area when the landscape consists of a single patch. Fig. 3 is the spatial pattern of *effective mesh size* retrieved with above-mentioned algorithm and data.

### *Explanatory variables*

#### *Distance to main roads*

Road construction, which was intensified in the past 30 years to improve the transportation accessibility in Shenzhen City, has important impacts on ecosystem and landscape fragmentation. Roads directly caused landscape fragmentation as one of several