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Identification of interconnections between landscape pattern and urban dynamics—Case study Bratislava, Slovakia

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ABSTRACT

The change of land use in urban and suburban areas is an on-going process. The aim of this paper is to study and statistically model landscape patterns changes in the Bratislava region (Slovakia) between 2002 and 2011. In the study, we perform the classic landscape-ecological method of land use mapping, and several spatial analytical tools provided by the GIS environment with statistical modeling using obtained spatial data. In order to explicitly study the determinants of landscape patterns changes between 2002 and 2011, firstly an exploratory principal component analysis (PCA) is performed with variables obtained from GIS modeling. Secondly, the results from PCA are used in the logistic regression model. The landscape patterns changes were defined as transition areas in which the change of function has been performed in the study time period. The proposed regression model estimates the threshold probability of the landscape patterns' changes of transition areas under the effect of the adjacent areas. In order to accurately capture land use changes, high resolution aerial photographs of the Bratislava area including the city and surrounding villages from 2002 to 2011 were analyzed. The spatial buffers mapping of the transition areas in the GIS environment was based on data from ortophotos in the precise scale of 1:2000. Key methodology findings are regularities about the process of urban dynamics, focused on the change of urban boundaries in the urban system contact area. Various behavior rules have been defined such as embedded distance, spatial pattern and transition probabilities, which are essential in the proposed logistic regression model. In order to pragmatically incorporate the regression model as a software model tool, it needs to generate effective urban simulations consistent with GIS data inputs, outputs and related functionality. This enables utilizing the software model, which might be incorporated as a plugin in the GIS environment. Both GIS and statistical regression modeling might be used as predictive tools in an urban policy decision making, with a better understanding of discrete non-linear urban dynamics and to ensure the sustainable use of land and the protection of biodiversity in urban ecosystems.

1. Introduction

Although urban areas make up a small proportion of land surface area (EEA, 2010), they cannot be ignored due to the fact that urban growth causes more dramatic changes in environmental conditions than other land-use changes (Lambin et al., 2001; EEA, 2006; Kong et al., 2012). Persistent rapid urbanization is associated with the loss of biodiversity (Meffert and Dziock, 2013), landscape fragmentation (Shrestha et al., 2012), depletion of natural resources (Shen et al., 2005), increasing demands on transportation infrastructure, and general increase of system entanglement (Madlener and Sunak, 2011). Especially with presents of protected areas in the proximate surroundings of the city, like in Bratislava region (The Slovak Nature Conservancy, 2005), detailed management of urban growth is necessary. Looking at these huge scale urban systems and their environmental problems arising from urban development, we have started to consider them as a complex system (Batty, 2005) and realized their spatio-temporal dynamics. Analyzing the urban development process, and then using appropriate management strategies that aid sustainable urban development, is one of the most important ways to address the environment problems arising from urban growth (Fang et al., 2005; Haase and Schwarz, 2009; Jaeger et al., 2010). Monitoring urban change implies taking account of the extent and location of current and future changes. Remote sensing represents a major, though still under-used, source of current and historical urban

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information by providing spatially consistent coverage of large areas with high spatial detail and temporal frequency (Cowen and Jensen, 1998; Donnay et al., 2001). With increased availability and improved quality of multi-spatial and multi-temporal remote sensing data, as well as new analytical techniques, it is now possible to monitor and analyze urban expansion and land use change in a timely and cost-effective way (Yang et al., 2003). Remote sensing is relevant for the identification of the volume of land use changes, as well as the location of such changes (Weber, 2003). Precise remote sensing data could be used to quantify spatial landscape properties by using a set of metrics (McGarigal et al., 2002; Li and Wu, 2004; Martinuzzi et al., 2007), as well as for the modeling approach (Weber, 2003; Batty, 2005; Crooks and Castle, 2012). Spatial metrics characterize quantitative and qualitative attributes of urban elements (Herold et al., 2003). In this context, spatial metrics can be a very valuable tool for planners who need to better understand and more accurately characterize urban processes and the consequences thereof (Weber, 2003; Herold et al., 2005; Kim and Ellis, 2009). In fact, in the last ten years it has been increasingly used to study the spatial characteristics of urban processes (Herold et al., 2003, 2005; Berling-Wolf and Wu, 2004), namely the spatial characteristics of urban patches, including their size, shape, and spatial distribution.

The association between the spatial characteristics of urban landscape and urban growth has been confirmed by several pieces of research (e.g. Berry and Minser, 1997; Alberti and Waddell, 2000; Berling-Wolf and Wu, 2004; Alberti and Marzluff, 2004). Spatial metrics as a tool for the quantification of the spatial characteristics of urban landscape could be used for territorial planning regarding urban growth in metropolitan areas in Central Europe. These metrics allowed us to determine the spatial patterns and characteristics generated by the urban processes using remote sensing and GIS tools. Interpretations of data obtained by this quantification procedure enable the description of the processes that drive the change of spatial patterns. Statistical approaches can readily identify the influence of independent variables, and also provide a degree of confidence regarding their contribution. The interpretation and understanding of spatial-temporal processes of urban dynamics that is provided by statistical analysis is essential for defining urban growth's driving forces and predicting future urban patterns. This is knowledge that could be used in the spatial planning process for building models that provide an optimal arrangement of landscape elements in the available space (Briassoulis, 2000; EPA, 2000; Weber, 2003). In spatial planning practice in Slovakia, such models are not used, except for the models of transportation network optimalization. The creation of urban management tools is a complicated process, involving a huge amount of data with a high number of participants throughout the process. The result of this process is a spatially determined restriction of future land use, including regulation limits. Due this fact, the spatial model intended for urban management improvement must fulfill the basic requirements: (1) the model has to be built on data currently available during the planning process; (2) model outputs have to be simple, due to the involvement and participation of citizens; (3) the model has to produce spatially allocated forecasts. A good model examines the whole landscape, has spatially accurate data, is broadly available for usage in regional or city planning, assesses urban growth in all areas, is based on historical data, and is consistent over time (Theobald, 2001).

The current shape of the city of Bratislava is clearly driven by a variety of factors, including topography, configuration of transportation networks, planning decisions, and natural elements such as the River Danube. These factors interact in complex ways to form the current urban boundary. Thus, the first requirement of an urban regression model is to quantify how the current spatial pattern of a city influences future development. The second requirement is to predict these changes in urban boundaries.

Fig. 1. Location of the study area within the Slovak Republic.

The global purpose of this study is to understand the relations between the spatial pattern of the landscape and urban dynamics trends. This paper describes how the proximate surrounding of transition areas affects their shifting process, and how these formulas could be used in the development of a regression model. We operated with the hypothesis that the proximate surrounding of a particular area in the landscape affects (or indicates) the probability of its change.

2. Materials and methods

2.1. Study area

Bratislava is the capital city of the Slovak Republic. Its area is 367.59 km^2 and the number of inhabitants is 428 672 (Statistical Office of Slovak republic, 2012). The town is situated on both sides of the Danube. The relief of the town is quite dissected. The northern part extends to slopes of the Malé Karpaty hills (altitude 162–559 m). The southern sector is of lowland character; it is a part of the geographical unit of the Podunajská nížina lowland, with an altitude reaching 200 m above sea level. The city in its present form is the result of the linking of its historic center with the surrounding villages. The studied area (Fig. 1) was selected according to the administrative division and consisted of 36 cadastres (cadastre = basic territorial unit) including the city of Bratislava (19 cadastres) and surrounding villages (17 cadastres).

2.2. First mapping level

Current aerial ortophotomaps (1 m/pxl) of two periods – 2002 and 2011 – were processed (source: Eurosense Slovakia). These data were used to capture the land use information and its change over time. Data processing was executed in ESRI ArcMap 9.3 environment. The process resulted in the creation of two vector polygon layers on the scale of 1:10 000, thus capturing the land use of the landscape (Fig. 2).

The land use categories were created by the manual interpretation of orthophotomaps in the ArcMap environment. In these maps, three thematic land-use and land-cover categories were obtained:

1. Built-up area (housing, industry, commerce, transport including city parks, unused spaces between buildings, etc.).
2. Natural area (forests, shrub areas, grasslands, water bodies, bare soil, rocks, etc.).
3. Agricultural land (croplands, including cereal crops, vegetable crops, vineyards and fruit orchards, etc.).

The interpretation of the 2011 data was made by taking the interpreted vector data of 2002 as the baseline. The identification