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Spatial and temporal land use change and occupation over the last half century in a peri-urban area

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A B S T R A C T

Understanding the reorganisation of land in order to adapt its use and spatial structure to social demands has become crucial to management and represents a major challenge to land use planning and public policies. This study explores the temporal and spatial land use change transitions in a peri-urban area of a medium-sized city located in the central Portugal and characterised by profound changes in the last half century. The study is supported by a collection of seven years/moments of image analysis (the 1958, 1973, 1979, 1995, 2002 and 2007 maps). Cross-referencing the successive sets of images defines the percentage of land transition and provides the stability grade (SG), which expresses the total proportion of the landscape that has not experienced any transition to a different category of land use. In order to evaluate the intensity of urban expansion, an annual rate of artificialisation of surfaces (AS) indicator was used. The seven cartographic outputs highlight a decrease in the area occupied by permanent crops, an increase in urban areas, especially the continuous urban fabric, a large forest occupation involving different typologies and paths, and an increase in base soil areas. The data also shows a general increase in the number of patches recognised and in pattern complexity. The results show that land use changes are created by systematic transitions, with or without gross variations, and also by casuistic processes associated with an increase in artificialised areas and the growth of the continuous urban fabric. Land use transition reflects the internal and external inputs associated with the approval of Municipal Master Plans and the land regulatory regime, and also the consolidation of the road infrastructure network. The analysis indicates that the transfer takes place in a set of small sequential steps marking the evolution from rural characteristics to a process of peri-urbanisation, ending in urban consolidation.

Introduction

The analysis of changes in land use highlights processes and interactions involving socio-economic driving forces and biophysical conditions, and explores the dynamics and self-organising characteristics of land use. Evaluating these strengths enables complex relationships and emerging spatial/temporal changes to be isolated, frequently representing knowledge of lengthy processes or the identification of local forces (Lambin & Geist, 2006; Sherestha, York, Boone, & Zhang, 2011; Turner et al., 1990).

Understanding the relevance of the gradual reorganisation of the land in order to adapt its use and spatial structure to social demands has become crucial to management and represents a major challenge to land use planning and management (Antrop, 2005; Hasse & Lathrop, 2003).

Land use spatial variability and urban spread have become important requirements (Hietel, Waldhardt, & Otte, 2004; Su, Jiang, Zhang, & Zhang, 2011) which can be monitored by transition patterns as the dynamic spatial configuration of land use, reflecting decisions made by different land managers. These changes in land use can be classified into random and systematic transitions (Braimoh, 2006), with random transitions representing those influenced by casuistic or abrupt processes of change and systematic transitions those marked by consistency and common processes.

Transitions in land use can be detected by an evaluation of traditional causal factors or a statistical evaluation of the land cover transition matrix (Pontius, Shusas, & McEachern, 2004). The transition matrix, comparing different temporal pattern maps, is the method commonly used to assess changes in land use (Long, Tangc,

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Lia, & Heilig, 2007; Pontius & Petrova, 2010; Xiao et al., 2006). However, an in-depth analysis of the transition matrix should identify not only overall gains and losses, but also random and systematic transitions (Pontius et al., 2004), enabling the most important transitions to be identified, followed by research into the generation processes.

Evaluation of the ongoing processes of transition in urban areas, from compact to dispersed forms, has produced different outcomes (Kasanko et al., 2006; Zhang et al., 2004) which stress new models and changes in land use (Andersson, Ahrné, Pyykönen, & Elmqvist, 2009; Serra, Pons, & Saurí, 2008; Yin et al., 2011) in which peri-urban areas reflect the evolution of different dispersed patterns.

Peri-urban areas are the areas in which land use transitions are more subject to systematic processes of change, but also where random changes can suddenly occur. Analysis of the stability grade, which expresses the total proportion of the landscape that has not experienced a transition to any different category of land use, may explain both processes and driving forces.

Several case studies have pointed out the importance of these evaluations of peripheral areas or mixed urban–rural land use in planning processes and territorial management (Hara, Thaitakoo, & Takeuchi, 2008; Su et al., 2011; Zhang, Hong, & Yang, 2008). In these peripheral areas the planning initiatives have unduly defined the territory, and the land use changes are either a reflection of the plan framework or illustrate the encroachment of the master plans.

Land use change is frequently studied using different models and documented sources (Aspinall, 2004; Braimoh, 2006; Hasse & Lathrop, 2003; Orenstein, Bradley, Albert, Mustard, & Hamburg, 2011; Pontius et al., 2004; Stefanov, Ramsey, & Christensen, 2001). Photo-interpretation techniques, using aerial photographs or satellite images, have been applied in different studies to investigate a series of images of land cover changes (Hara, Takeuchi, & Okubo, 2005; Pôças, Cunha, & Pereira, 2011; Wentz, Stefanov, Gries, & Hope, 2006). The current possibility of obtaining time-stamped data from satellite imagery, aerial photography and ground observations has made accurate mapping of land use/land cover possible, thus enabling the process of urbanisation evaluation (Pan & Zhao, 2007; Wentz et al., 2006). The detection of time intervals in land use changes can be divided into two main categories of processes: pre-classification (image to image comparison) and post-classification (map to map comparison), generating a transition matrix consisting of two-dimensional tables (Manandhar, Odeh, & Pontius, 2010).

This study adds to the understanding of land use dynamics and, in particular, the extent of urban sprawl or fragmented land use, which is a challenging task in Europe (Engelen, Lavalle, Barredo, van der Meulen, & White, 2007; Kasanko et al., 2006), particularly in Portugal, which has been marked by urban development and population densification in recent decades (EEA, 2006, p. 56; Freire, Santos, & Tenedório, 2009), supported by changes in public policies (Jones, de Graaff, Rodrigo, & Duarte, 2011).

The analysis presented here updates the different land use change evaluations that have been carried out for Portugal (Castanheira & Aranha, 2004; Freire et al., 2009; Jones et al., 2011; Petrov, Lavalle, & Kasanko, 2009; Pôças et al., 2011) using different focuses and scales of analysis, none of which refer to peri-urban areas.

Given the wide coverage of land use classes, both systematic and random processes of change and their relation to land management can be studied. These resources are available for seven spatial/temporal sets of data in the peri-urban area of Coimbra, which is considered a medium-sized European city (EU, 2005). Analysis of land use change and occupation provides additional information on peri-urban areas and is reproducible in similar contexts. The specific driving forces emerging and controlling peri-urban change can be understood from the results and discussion, allowing us to anticipate future plan frameworks and plan public policies.

The objective of this paper is to carry out an in-depth analysis of systematic spatial and temporal land use changes during the last half century, based on the data period 1958 to 2007, in a peri-urban area of a medium-sized city, by attempting to answer the following questions:

What are the spatial and temporal random and systematic transitions in land use and occupation in the area?

Which stability grade dynamics are associated with changes in land use?

What is the rate of artificialisation of surfaces, representing the speed of urbanisation in the peri-urban area?

What are the driving factors behind land use change and urban occupation in the area?

Description of the study area

The study area is located in the Central Region of Portugal, on the left bank of the River Mondego. It is a part of the municipal area of Coimbra, a historic city with an important cultural heritage centre and educational and health facilities that are of national importance.

In morphological terms, the urban area is surrounded by an uplift area in the east, with incised valleys defined by the River Mondego, which flows in a wide meander from an upstream-incised valley to a large downstream valley floor. These morphological constraints and its proximity to flood-prone areas have resulted in urban occupation and sprawl for centuries.

The city of Coimbra has a population of around 102,000 (2001 National Census). It has a high rate of urban occupation and is surrounded by outer urban areas and other areas with rural characteristics. In recent decades, large-scale radial urbanisation has taken place, together with the construction of important road infrastructures and facilities. A comparative analysis of past decades shows that the municipal urban area has doubled (from 42 km^2 to 95 km^2), and this correlates with peri-urbanisation and rurbanisation processes (Tavares, 2004).

The study area is approximately 6 km away from the historic city on the opposite side of the River Mondego and is linked to it by important major roads/bridges and public transport facilities (Fig. 1). It is represented by a small-scale hydrological basin of approximately 7 km^2, with a S-N orientation and contrasting biophysical characteristics. The area shows a sharply widening valley with hypsometry values ranging from 9 m to 200 m, draining into the large floodplain of the River Mondego (Fig. 2). The valley presents slope classes with average values ranging from 10% to 30%, is deeply incised and defined by contrasting lithological factors (carbonate and sandstone subtracts) and tectonic lineaments, with a concentration of classes under 10% in the upstream areas and the downstream valley framing an intermittent or ephemeral water stream.

The area has moist Mediterranean climate characteristics, with over 60% of the precipitation falling in the November–March period, affecting land suitability classes. In the downstream area the soils present some waterlogging restrictions during the winter season (Bh) and the dominant soil classes C and D present limitations which adversely affect agriculture due to the extreme shallowness of the soil.

The basin has been characterised by profound changes in land use and occupation during the last half century. In the mid 20th century it was a rural, natural area with some dispersed urban areas or buildings along the major roads. The former Master Plan, dating from the 1950s, considered the area a rural zone which supplied fresh air and agricultural produce.

The lack of space for low-cost building in the city of Coimbra justified successive transgressions within the framework of the plan, involving an increase in the discontinuous fabric, especially