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Research article

Conflict resolution in the zoning of eco-protected areas in fast-growing regions based on game theory

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ABSTRACT

Zoning eco-protected areas is important for ecological conservation and environmental management. Rapid and continuous urban expansion, however, may exert negative effects on the performance of practical zoning designs. Various methods have been developed for protected area zoning, but most of them failed to consider the conflicts between urban development (for the benefit of land developers) and ecological protection (local government). Some real-world zoning schemes even have to be modified occasionally after the lengthy negotiations between the government and land developers. Therefore, our study has presented a game theory-based method to deal with this problem. Future urban expansion in the study area will be predicted by a logistic regression cellular automaton, while eco-protected areas will be delimitated using multi-objective optimization algorithm. Then, two types of conflicts between them can be resolved based on game theory, a theory of decision-making. We established a two-person dynamic game for each conflict zone. The ecological compensation mechanism was taken into account by simulating the negotiation processes between the government and land developers. A final zoning scheme can be obtained when the two sides reach agreements. The proposed method is applied to the eco-protected area zoning in Guangzhou, a fast-growing city in China. The experiments indicate that the conflicts between eco-protection and urban development will inevitably arise when using only traditional zoning methods. Based on game theory, our method can effectively resolve those conflicts, and can provide a relatively reasonable zoning scheme. This method is expected to support policy-making in environmental management and urban planning.

1. Introduction

The unprecedented urban expansion in developing countries has triggered a series of environmental and ecological issues, such as arable land loss (Yeh and Li, 1999), water pollution (Zhu et al., 2002), and soil degradation (Chen, 2007). Zoning eco-protected areas is crucial for sustainable development, ecological health, environmental management (He et al., 2005; Verdiell et al., 2005; Sabatini et al., 2007; Geneletti and van Duren, 2008), and has therefore attracted great attention worldwide. The term "eco-protected area" is also known as "eco-designated line of control" in China (Li et al., 2013a), a fast-growing country during the past three decades. Most notably, Shenzhen Government took the lead in promulgating ordinance and zoning scheme for eco-protection in 2005 (The People's Government of Shenzhen Municipality (2005)). Specifically, the regions of higher ecological suitability should be marked out as eco-protected areas in order to protect limited ecological resources, support sustainable urban development, and prevent immoderate urban expansion. Later, the municipal governments of Dongguan and Wuhan issued their own schemes in 2009 and 2012 respectively.

Unfortunately, numerous reports have revealed that the land developers in some Chinese cities appealed to modify the zoning schemes because their rights and interests were being severely constrained by the protection (e.g., Liu, 2010; Huang, 2011). Local governments had to give in after lengthy negotiations with these land developers. For example, Shenzhen Government respectively issued two modified schemes in 2011 and 2013, and promised to execute ecological compensation plan as early as possible. In fact, human-environment conflict is a long-standing phenomenon throughout the world (Lewis, 1996; DeFries et al., 2004; Colyvan

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et al., 2011). Many studies have indicated that rapid urban expansion could exert negative impacts on the performance of protected areas (DeFries et al., 2007; Hansen and DeFries, 2007; McDonald et al., 2007; McDonald et al., 2008). Urban land use will change both spatially and quantitatively every year in fast-growing regions. Although urban development should be prohibited within the eco-protected areas, many land developers may still secretly break the rules due to huge economic benefits. Illegal development easily occurs in the regions with higher development suitability (Li et al., 2013a). Those zoning schemes are unable to serve the purpose of ecological protection. Therefore, from the perspective of the land developers, the great influences from continuous urban expansion should be taken into account by policy-makers during the zoning procedures.

To date, a number of techniques have been applied to land use zoning, such as linear and integer programming (Chuvieco, 1993; Hof and Joyce, 1993), intelligent algorithms (Bos, 1993; Verdiell et al., 2005; Watts et al., 2009), and multicriteria analysis (Geneletti, 2007), but most of them failed to tackle the aforementioned problem. Recently, Li et al. (2011) proposed a method to delimitate protected areas by coupling cellular automata (CA) with ant colony optimization. Undoubtedly, CA model is a successful tool for simulating and predicting urban expansion (Wu, 2002; Li et al., 2013b), and therefore shows great potential for assisting in land use zoning. In their method, however, future urban expansion predicted by CA was only considered as a negative factor for ecological suitability analysis. The conflicts between the government and land developers, as well as the ecological compensation mechanism are still neglected. These contents can be well integrated under the framework of game theory.

Game theory is a theory of decision-making that can mathematically analyze and simulate the conflicts between rational decision-makers (Myerson, 1991). It has been successfully applied in various disciplines, such as economics, politics, and biology (Osborne and Rubinstein, 1994; Basar and Olsder, 1995). Recently, game theory has also been used to deal with land use issues. For example, Liu et al. (2015) coupled game theory and genetic algorithm to solve land use spatial optimization problems; Samsura et al. (2010) presented a game theory approach to the analysis of land and property development processes; Hui and Bao (2013) established a game theory-based framework for analyzing the conflicts in land acquisitions in China. Nevertheless, the conflicts between ecological protection and urban development still remain unresolved in such a quantitative manner. Besides, the spatio-temporal dynamics of urban expansion are rarely considered in land use games. Therefore, our study aims to address these problems based on a combined use of CA and game theory. Guangzhou, a rapidly urbanizing metropolis suffering from severe ecological issues in China, is selected as the study area.

2. Methodology

The main contribution of this study is the application of game theory to protected area zoning. First, eco-protected areas will be preliminarily delimitated in a traditional way. Then, we will predict future urban expansion by using cellular automata (CA). Finally, the conflicts between urban development and ecological protection will be resolved under the framework of game theory. More details about the procedures are provided in the following subsections, and the pseudo-codes are given in Table S1 (in supplementary material).

2.1. *Zoning eco-protected areas using multi-objective optimization algorithm*

The zoning task should maximize both: (1) the average ecological suitability of the selected cells, and (2) the compactness of the protected areas (Li et al., 2011; Liu et al., 2012). Therefore, the utility (U) of the protected areas can be formulated as follows:

$$U = w_{\mathrm{E}} \cdot S_{\mathrm{E}} + w_{\mathrm{C}} \cdot C \tag{1}$$

where S_{E} denotes the average ecological suitability, C denotes the compactness metric of a protected scenario, w_{E} and w_{C} are the weights for S_{E} and C respectively ($w_{\mathrm{E}} + w_{\mathrm{C}} = 1$).

With respect to the zoning of eco-protected areas in China, S_{E} has two ecological meanings: (1) the regions that are rich in ecological resources should be protected, and (2) the regions that are unsuitable for urban development should not be developed. Some municipal governments have consequently promulgated ordinances and requirements for eco-protected area zoning. In general, vegetated areas, aquatic areas, natural habitat, vulnerable areas, and other regions of higher ecological suitability should be marked out for conservation. Therefore, in accordance with related studies (Li et al., 2011; Liu et al., 2012), S_{E} can be estimated by a number of spatial variables, all of which are introduced as follows:

(1) Normalized difference vegetation index (NDVI)

The vegetated area should be protected because it plays a key role in various aspects, such as air purification, and soil conservation (Tucker, 1979). Many vegetation indices have been developed to monitor vegetation conditions and biomass. NDVI is a widely used one that can be directly obtained from Moderate Resolution Imaging Spectroradiometer (MODIS) products. To minimize the influence of aerosols, water vapors, and clouds, a series of multi-temporal images within a 1-year period will be processed to a new $\mathrm{NDVI}_{\max}$ image through the maximum value composite procedure (Holben, 1986).

(2) Normalized difference water index (NDWI)

The aquatic natural area should also be taken into consideration since it is crucial for water supply, climate regulation and so on. NDWI can effectively separate water bodies from other land cover types. This index can be calculated using the equation given by (McFeeters, 1996):

$$\mathrm{NDWI} = \frac{\rho_{857} - \rho_{1241}}{\rho_{857} + \rho_{1241}} \tag{2}$$

where ρ_{857} denotes the reflectance value in the band at 857 nm, and ρ_{1241} denotes the reflectance value in the band at 1241 nm.

(3) Habitat heterogeneity ($\mathrm{H_h}$)

Habitat heterogeneity is a good metric for representing the spatial distribution pattern of the heterogeneous environmental conditions of a region (Svoray et al., 2005; Liu et al., 2012). Previous studies have shown that eco-diversity will increase with habitat heterogeneity on a landscape scale (Freemark and Merriam, 1986; Benton et al., 2003). The habitat of land units consists of three parts: wetness index, slope orientation, and soil attributes (Svoray et al., 2005). The wetness index was calculated as follows: