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A state-impact-state methodology for assessing environmental impact in land use planning

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ABSTRACT

The implementation of land use planning (LUP) has a large impact on environmental quality. There lacks a widely accepted and consolidated approach to assess the LUP environmental impact using Strategic Environmental Assessment (SEA). In this paper, we developed a state-impact-state (SIS) model employed in the LUP environmental impact assessment (LUPEA). With the usage of Matter-element (ME) and Extenics method, the methodology based on the SIS model was established and applied in the LUPEA of Zoucheng County, China. The results show that: (1) this methodology provides an intuitive and easy understanding logical model for both the theoretical analysis and application of LUPEA; (2) the spatial multi-temporal assessment from base year, near-future year to planning target year suggests the positive impact on the environmental quality in the whole County despite certain environmental degradation in some towns; (3) besides the spatial assessment, other achievements including the environmental elements influenced by land use and their weights, the identification of key indicators in LUPEA, and the appropriate environmental mitigation measures were obtained; and (4) this methodology can be used to achieve multi-temporal assessment of LUP environmental impact of County or Town level in other areas.

1. Introduction

Land is one of the most pivotal resources in supporting regional development coupled with increasing population and environmental pressures. According to the FAO's statistics in 2012, about 20% population of the world (near 1.4 billion people)[1] live in China, but only 7.8% of the total area in China (arable land, 0.08 ha per capita acreage in 2009) is available to support the social and economic development. The shortage of land, especially the arable land, hinders the social development of the biggest developing country in the world with food and other essential resources supplies. Additionally, the rapid urbanization coupled with the encroachment of land near suburbs aggravates the shortage of fertilized arable land (Wang et al., 2012a).

Now more than ever, the over-exploitation of land resources inevitably leads to more serious environmental problems, hence challenges the quality of the environment even the sustainable development strategy in China. It is of vital importance to arrange land patterns and distribution rationally under the limitation of land resources and environmental quality.

As a necessary tool to ensure the regional sustainable development and balances among environmental health, economic competitiveness and social equity, land use planning (LUP) presents the regional development issues especially the future land patterns and distribution (Tang et al., 2009). Well-executed planning should produce a balanced and transparent relationship between the various relevant needs and social interests, and ameliorate (at least not worsen) the regional and national environment quality (Calbick et al., 2003; Sikdar et al., 2002; Wang et al. 2012b).

Strategic Environmental Assessment (SEA), a systematic on-going scheme to evaluate the environmental effects of alternative decisions in policies, plans and programs (PPP), is used to integrate environmental impact assessment in LUP in order to minimize negative impacts of the proposed strategic action and to maximize positive impacts on the environment (Brown and Thérivel, 2000; Chaker et al., 2006; Jiricka and Pröbstl, 2008; Partidário, 2003; Tang et al., 2007). The application of SEA in LUP is known as land use planning environmental assessment (LUPEA). It is a tool to assess the environmental effect of LUP, including before, during, and after the implementation (Chen et al., 2009(a)), and has gained more and more considerations (Fischer, 2002; Geneletti, 2012).

For example, Barral and Oscar (2012) developed a methodological protocol of SEA to incorporate the valuation of ecosystem services in land use plans and applied it in rural land planning at Balcarce. Belcakova (2003) presented an SEA framework in land-use planning with integrated consideration of ecological, social and economic impacts. This approach can meet those impacts that interfere above the

Abbreviations: LUPEA, is land use planning environmental impact assessment (LUPEA); Me, is Matter-element; SIS, is the state-impact-state model.

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[1] The data was calculated based on the data produced by Food and Agricultural organization of the United Nations (FAOSTAT) which can be accessed online at http://faostat3.fao.org/home/index.html#HOME, [last accessed 04 June 2013].

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framework of the actual decision-making process in land-use planning. Bień et al. (2005) developed a Health Index/Risk Evaluation Tool (HIRET) using GIS capabilities to assess the human health risk in long-term land use planning. Marull et al. (2007) used the Land Suitability Index (LSI) to evaluate the impact of municipal urban plans in the Barcelona Metropolitan Region in the SEA framework. Gómez-Navarro et al. (2009) introduced a new approach including three procedures to prioritize urban planning projects according to their environmental pressure in an efficient and reliable way. García-Montero et al. (2008) developed an environmental screening tool to provide a preliminary diagnosis of the impact of a Spanish infrastructure plan in order to propose territorial alternatives for decision-making. Mörtberg et al. (2007) described methods for integrating biodiversity issues in planning and strategic environmental assessment in an urbanizing environment on landscape and regional levels. Dai et al. (2001) illustrated a GIS-aid geo-environmental evaluation through developing suitability maps for single urban land use patterns to evaluate the land-use planning of Lanzhou City in Northwest China. Barral and Oscar (2012) developed a methodological SEA protocol to incorporate the valuation of ecosystem services in land use planning at Balcarce.

Despite the varieties of approaches embedded in SEA to evaluate the environmental effect of LUP, a widely accepted and consolidated approach is still needed, and the technical support (e.g., guidelines, best-practice handbooks) is lacking especially in China. This problem has led to many studies lacking the necessary spatial representation of impact predictions and disregarding the key issues such as cumulative effects in practices (Geneletti et al., 2007). Moreover, the intensive use even over-exploitation of land resources in China leads to a high risk in environmental degradation, suggesting the necessity of LUPEA in the biggest and fast developing country around the world.

The LUP system in China consists of five administrative levels matching five main levels of government respectively: state, province (autonomous regions, and directly governed city region, i.e., Beijing, Tianjin, Shanghai and Chongqing), prefecture (city), county and town (Tang et al., 2007). The LUP at higher level is an instrument to manage broader interests covering the region than lower level, and also provides the basis for the development of plans at lower levels. Among the five levels, the LUP in county and town are the spatial basis of the implementation of various land parcels layout and arrangement (e.g. land for transportation, industrial, residential, agricultural, environment). Despite the implementation of *Land Use Planning Environmental Assessment technical criterion (LUPEAC)* at prefecture (city) level in 2009, the LUPEACs at county and town level still lack in China, leading to the rather spotty quality of LUPEA both in county and town.

To assess the environmental impact of LUP more effectively, a cost reduction and easy understanding methodology based on varieties of scales may be more feasible. In this endeavor, we proposed a new framework named state-impact-state (SIS) model to integrate the SEA in LUP. This model conceptualizes that the environmental quality state is/will be impacted by the pressure of land use (LU) and/or the presumptive implement of LUP. We also integrated the Matter-element (ME) model and the Extenics method in the SIS model to assess the environmental impact of LUP. The ME model, a unit of "state description and cognitive action" (Smarandache, 2010), and Extenics were developed by Cai (Cai, 1983, 1987 and 2003)[2] and has been globally introduced into many fields (Ji, 2006; Ng and Cai, 1997; Qian et al., 2009; Smarandache, 2005; Sreenivasarao et al., 2010).[3] Finally, we selected a county named Zoucheng located in China as an empirical example to validate the applicable feasibility of the model. In this paper, the SIS model and methods employed in LUPEA were described in the 2nd section, and the environmental assessment of LUP in Zoucheng County was described in the 3rd section. The 4th section shown the results of LUPEA in Zoucheng, the 5th section analyzed and discussed the methodology and results of LUPEA in Zoucheng, and 6th section are the major conclusions of the research.

2. Model and methods

2.1. The elements and structure of SIS model

The LUP implementation inevitably have impacts on regional environmental quality through the change of landscape distribution, land patterns and land use policy, as well as the discharge of pollutants, and so on. To evaluate the environmental impact, the integrated systematical structure of focused regional environment need to be represented based on the identification and assessment of the driving forces from LUP implementation. The SIS model describes the mechanism of the land use effects on environmental quality. It consists of three types of elements: object, state, and force.

2.1.1. Object, state and force

In SIS model, we defined object as anything with integrated and systematic structure and function including the material entities or conceptual/abstract objects. The state is an external form or description of the object.

In order to describe and assess an object with certain temporal states, the object is regarded as stationary relatively without respect to the characteristic of absolutely continuous motion. The relatively stationary characteristic builds the basis of state description. The object state is described and analyzed with the contribution of individual interior elements, in other words, it is described as overall assessment of a system containing several characteristics/indicators. Hence the environment impacted by the presumptive implementation of regional land use planning is regarded as an object with certain structure and function.

When the driving forces from external and internal have pressures on it, the object transfers from one state to another. The internal forces are endogenous stresses of an object driving it transferring from one state to another. For example, the change of precipitation may lead to the land use/cover change, the change of temperature and moisture content, the change of biodiversity, and so on. The external forces come from the external environment other than the object itself. Both the internal and external forces have positive or negative impacts on the object. For example, the land use may influence the regional environment positively or negatively.

The object can be described as $N = (m_1, m_2, \ldots m_n)$, where object N is composed of the ingredient or element m_i. Hence the environment influenced by the presumptive implementation of land use planning is described with this model, where m_i is the individual environmental element. The environmental elements are the indicators employed in the LUPEA accordingly.

2.1.2. The logical model of SIS

When the object in base time is under the impacts of forces, the transform occurs and the base time state changes into second state subsequently. After the second driving forces exerted into the object, the second state changes into the third state continuously. Then the SIS logical model is shown as Fig. 1.

Where N_I is the object with state I consisting of element m_i and its value v_{1i}, while N_{II} with state II has the element m_i and its value v_{2i}. For the land use environment, the transform procedure could be described as Fig. 2.

Fig. 2 shows the environmental impact of presumptive implementation of land use planning. The forces come from the land use planning scheme including residential, transportation, water, crop, wood, grass, etc., the adjustment and optimization of land use structure, and the land use planning policies including land use control and permitted

[2] The achievement list can be seen in http://web.gdut.edu.cn/~extenics/ktxchengguo1.htm, 2013-04-02 [last accessed 04 October 2013] (in Chinese).

[3] Many scholars other than China have published several articles related this research field, which can be seen in http://web.gdut.edu.cn/~extenics/index.htm as well. 2013-04-02[last accessed 04 October 2013] (in Chinese).