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A worst-case scenario based methodology to assess the environmental impact of land use planning

Longgao Chen [a,*], Long Li [b,c], Xiaoyan Yang [a,b], Jian Zheng [d], Longqian Chen [b], Zhengping Shen [a], Matthieu Kervyn [c]

[a] School of Geography, Geomatics and Planning, Jiangsu Normal University, Xuzhou 221116, China
[b] School of Environmental Science and Spatial Informatics, China University of Mining and Technology, Xuzhou 221116, China
[c] Department of Geography, Earth System Science, Vrije Universiteit Brussel, Brussels 1050, Belgium
[d] Land and Resources Bureau of Lianyungang, Lianyungang 222001, China

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ABSTRACT

The implementation of inappropriate land use planning has negative impact on environmental quality, threatens food, health and residential security, and can even lead to regional environmental disaster. In this paper, a worst-case scenario based methodology using the land use environmental tolerance index (LETI) was proposed to assess the impact of land use planning on the environment. The land use planning environmental impact assessment (LUPEA) of Lianyungang City was performed as a case study to demonstrate the novel methodology. The inappropriate land use planning of the study area was spatially identified, and adjustments for the land use planning scheme to minimize the adverse impacts were accordingly recommended. Results show that the land use planning layout of the study area is fundamentally rational as most of the planned production and living land parcels are located outside the worst-case scenario areas, but the small fraction of the parcels in the worst-case scenario areas indicates a need for an improved land use planning scheme. This methodology provides a new perspective to evaluate the impact of land use planning on the environment, especially for densely populated countries which still suffer food, health and residential security issues and thus require much attention to environmental safety.

1. Introduction

Globalization together with population growth has increased the demand for various resources, mostly derived from land, to support socio-economic development. This is causing drastic land use/cover (LUC) changes across the world (Carpio & Fath, 2011; Güneralp & Seto, 2008; Liu, Huang, Yang, & Zhong, 2014; Seto, 2011). The resulting adverse environmental impact inevitably influences human habitat as well as human health (Chester, Nahlik, Fraser, Kimball, & Garikapati, 2013; Shahraki & Turkay, 2014; Wang, 2012), thus challenging the sustainability of human society. The challenges highlight the crucial importance of rationally regulating future land use.

In populated developing countries such as China, environmental issues have become increasingly prominent due to shortage of land resources. China is home to about 20% of the global population but has limited arable land (only accounting for 7.8% of its total area, 0.08 ha per capita in 2009) to feed its 1.4 billion population (Chen, Li, Chen, & Yang, 2014; Chen, Yang, Chen, Potter, & Li, 2014). Although China proposed a socio-economic, resource and environment sustainable development strategy in 1994 at national level (Bradbury & Kirkby, 1996), this highly populated country remains affected by serious environmental pollution and degradation. There is a growing concern among the public on the human health impacts of f water and soil contamination, and emissions of $PM_{2.5}$ (Pathak, Wu, & Wang, 2008; Xie et al., 2015). For China, and similar countries with rapid economic and urban development and high population pressure, a current practical and primary goal of social development should be guaranteeing food, health and residential security which mainly depend on the basic environmental safety, to

* Corresponding author.
E-mail addresses: chenlonggao@163.com (L. Chen), long.li@cumt.edu.cn, long.li@vub.be (L. Li), yangxy0705@163.com (X. Yang), zj7220@126.com (J. Zheng), chenlq@cumt.edu.cn (L. Chen), zhenpingshen@163.com (Z. Shen), matthieu.kervyn.de.meerendre@vub.be (M. Kervyn).

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reach the basic life standards before pursuing a high quality environment and comfortable habitats (Pui, Chen, & Zuo, 2014; Ye & Van Ranst, 2009; Zheng, Zhang, Hao, Lin, & Liu, 2005).

As a key means of allocating land for different uses in the future (Chen, Chen, Xu, & Tian, 2016; Sutanta, Rajabifard, & Bishop, 2013), land use planning (LUP), if well informed, formulated and implemented, has proven effective in reducing the threat to food, health and residential security, e.g. avoiding the arrangement of residential and agricultural land in the areas with high ecological or pollution risk (Karmaker, 2010; Maqsood, Li, Huang, & Huang, 2005). While the inappropriate land use (i.e. land use is inappropriately distributed with respect to environmental components, e.g. arable land in steep terrain) due to the implementation of land use planning may threaten food, health and residential security, affect regional environmental quality (Barral & Oscar, 2012) and even lead to the environmental disasters (Kötter, 2003). It is therefore very important to assess the impact of land use planning and develop the corresponding measures to avoid or mitigate such adverse influence.

Land use planning environmental impact assessment (LUPEA) is a widely used tool to minimize the negative impact of land use planning and to maximize the positive impact on the environment (Chaker, El-Fadl, Chamas, & Hatjian, 2006; García-Montero, Otero Pastor, Quintana, & Casermeiro, 2008; Pinfield, 1992). A number of methodologies have so far been developed to assess the land use planning impact on the environment, e.g. the Health Index/Risk Evaluation Tool (HIRET) for integration of risk assessment and spatial planning (Bien, Ter Meer, Rulkens, & Rijnaarts, 2004), the Land Suitability Index (LSI) for regional planning assessment (Marull, Pino, Mallarach, & Cordobilla, 2007), the GIS raster screening model for infrastructure plan assessment (García-Montero et al., 2008), and the ecosystem services valuation method for rural land planning assessment (Barral & Oscar, 2012). They served as practical tools to tackle environmental issues related to regional land use patterns (Loiseau, Roux, Junqua, Maurel, & Bellon-Maurel, 2013; Recatalá & Sacristán, 2014). Most of these methodologies look at LUP impact on the environment from the perspective of maintaining or promoting environmentally friendly land use but without much consideration of the basic objectives (i.e. guaranteeing food, health and residential security).

In risk management, a worst-case scenario is a concept wherein planners consider the most serious likely outcome that can reasonably occur in a given situation (McCready, 1996). It has been introduced to many different fields, including environmental impact assessment (Bolland, Karl, Wright, Berglen, & Denby, 2011), biodiversity assessment (Maes & Van Dyck, 2001), management of chemical accidents (Batterman & Kovacs, 2003) and natural hazards (Armigliato, Tinti, Pagnoni, Zaniboni, & Paparo, 2015; Eguchi, 2013). No studies however have tested this analytical method for assessing the environmental impact resulting from land use planning. Inappropriate land use planning can affect the environment: the original stability of the environment can be undermined and, in the worst case, the health and safety risk can rise to a critical level. The worst-case scenario seems to be an appropriate approach for land use planning environmental impact assessment for populated developing countries which are struggling to reach basic life standards—this is because a worst-case scenario based environment assessment takes into account potential factors that threaten their food, health and residential security, in the process of implementing LUP.

In order to define the worst-case scenario for LUPEA, the environmental tolerance (or its components) to land use was used in this study. We here refer to the environmental tolerance to land use as the ability of (the components of) the environment to tolerate the disturbance from land use to maintain its health or stability (Chen, Li et al., 2014). Such tolerance to inappropriate land use planning (e.g. planning residential land in flood storage area) can be quantified by the land use environmental tolerance index (LETI). If the land use related disturbance reaches the minimal value of the land use environmental tolerance index, the regional environmental risk rises to its critical level, and serious consequences will occur such as causalities and property damage. This situation is defined as an environmental worst-case scenario. The LETI is therefore a good indicator for the environmental tolerance to land use disturbance, hence supporting the LUPEA.

The goal of this study is to develop a worst-case scenario based methodology using LETI to assess the LUP environmental impact in countries or regions which face challenges to ensure food, health and residential security for their population. Application of this methodology is demonstrated by a case study of the coastal Chinese city of Lianyungang. Detailed objectives are as follows: (1) to provide a worst-case scenario based perspective for the land use planning environmental impact assessment in a developing region; (2) to spatially identify individual land use types planned in the worst-case scenario areas (i.e. areas where planned land use is going beyond the tolerance value of environment); and (3) therefore to recommend adjustments for the LUP scheme.

2. The worst-case scenario method using LETI

As briefly mentioned in Section 1, the worst-case scenario is the situation in which the regional environmental risk rises to its critical level, and serious consequences will occur due to land use disturbance. An environment consists of different components (soil, hydrology, terrain, the atmosphere, biotic community etc.) and each component is characterized by a range of indicators (e.g. topography can be described by elevation and slope, and water by water pollutants, source areas for drinking water and flood storage) (See Table 1). Different land use types have contrasted impacts on the same environmental component while environmental tolerance of each component depends on the land use type that impacts it.

For an indicator i, there are the lower value a and upper b defining the tolerance interval (a, b), and the optimal value x_0 or interval (a_0, b_0) for a land use type. The optimal value x_0 or interval (a_0, b_0) of indicator i is within the interval (a, b), i.e. $x_0 \in (a, b)$ or $(a_0, b_0) \subset (a, b)$. If value x of indicator i in a parcel is in the interval (a, b), the tolerance value of indicator i to land use type j $LETI_{ji}$ is within the acceptable range. For the parcel with the value x of indicator i out of the interval (a, b), $LETI_{ji}$ is beyond the acceptable range.

The $LETI_{ji}$ is then determined as the distance from the value x of indicator i to the interval (a, b) in a spatial unit. The farther the distance from x to (a, b) is, the lower $LETI_{ji}$ value is. For an environmental component indicator with optimal value x_0, Formula (1) is used to calculate $LETI_{ji}$, the tolerance value of indicator i to land use type j:

$$\begin{cases} LETI_{ji} = \dfrac{x-a}{x_0-a} \times 100 & a < x \le x_0 \\ LETI_{ji} = \dfrac{b-x}{b-x_0} \times 100 & x_0 \le x < b \\ LETI_{ji} = \dfrac{x-a}{b-a} \times 100 \text{ or } \dfrac{b-x_{ji}}{b-a} \times 100 & x < a \text{ or } x > b \end{cases} \quad (1)$$

For the environmental component indicator with optimal interval (a_0, b_0), the $LETI_{ji}$ value is calculated using the Extenics theory (Cai, 1987):