Journal of Environmental Management 145 (2014) 170–179

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Land-use suitability analysis for urban development in Beijing

Renzhi Liu [a,*], Ke Zhang [a], Zhijiao Zhang [a], Alistair G.L. Borthwick [b,c]

[a] State Key Laboratory of Water Environment Simulation, School of Environment, Beijing Normal University, No. 19, Xinjiekouwai Street, Haidian District, Beijing 100875, China
[b] School of Engineering, The King's Buildings, The University of Edinburgh, Edinburgh EH9 3JL, UK
[c] St Edmund Hall, Queen's Lane, Oxford OX1 4AR, UK

ARTICLE INFO

Article history:
Received 4 November 2013
Received in revised form
29 May 2014
Accepted 20 June 2014
Available online

Keywords:
Urban development
Land-use suitability
Multi-criteria evaluation
Ideal point method
Ordered weighted averaging
Beijing

ABSTRACT

Land-use suitability analyses are of considerable use in the planning of mega-cities. An Urban Development Land-use Suitability Mapping (UDLSM) approach has been constructed, based on opportunity and constraint criteria. Two Multi-criteria Evaluation (MCE) methods, the Ideal Point Method (IPM) and Ordered Weighted Averaging (OWA), were used to generate the opportunity map. The protection map was obtained by means of constraint criteria, utilizing the Boolean union operator. A suitability map was then generated by overlaying the opportunity and protection maps. By applying the UDLSM approach to Beijing, its urban development land-use suitability was mapped, and a sensitivity analysis undertaken to examine the robustness of the proposed approach. Indirect validation was achieved by mutual comparisons of suitability maps resulting from the two MCE methods, where the overall agreement of 91% and kappa coefficient of 0.78 indicated that both methods provide very similar spatial land-use suitability distributions. The suitability level decreases from central Beijing to its periphery, and the area classed as suitable amounts to 28% of the total area. Leading attributes of each opportunity factor for suitability were revealed, with 2256 km^2, i.e. 70%, of existing development land being overlaid by suitable areas in Beijing. Conflicting parcels of land were identified by overlaying the resultant map with two previous development blueprints for Beijing. The paper includes several recommendations aimed at improving the long-term urban development plans for Beijing.

1. Introduction

Land-use suitability analysis is a very important task faced by city planners and managers, the aim being to identify the most appropriate spatial pattern for future land use (Hopkins, 1977; Collins et al., 2001). In recent years, land-use suitability analysis has been applied to the assessment of agricultural land (Feizizadeh and Blaschke, 2013), determination of land habitats for animal and plant species (Store and Kangas, 2001), landscape evaluation and planning (Girvetz et al., 2008), and regional planning and environmental impact assessment (Marull et al., 2007; Rojas et al., 2013). Land-use suitability analysis methods may be categorized as overlay mapping methods, Multi-criteria Evaluation (MCE) methods, and Artificial Intelligence (AI) methods (see Collins et al., 2001; Malczewski, 2004). Overlay mapping is easy to undertake and is routinely applied in land-use suitability analysis for urban development (see McHarg, 1969; Lyle and Stutz, 1983; Miller et al., 1998), but has shortcomings such as inappropriate standardization of suitability maps, and untested or unverified assumptions of independence among suitability criteria (Hopkins, 1977; Pereira and Duckstein, 1993). To overcome these drawbacks, overlay mapping is often implemented alongside other land-use suitability analysis methods for urban development (McCloskey et al., 2011; Park et al., 2011). Many case studies use MCE methods, including Weighted Linear Combination (WLC) (Dai et al., 2001), the Weighted Potential-Constraint Method (Zong et al., 2007), the Ideal Point Method (IPM) (Ekmekçioğlu et al., 2010), Analytic Hierarchy Process (AHP) (Javadian et al., 2011; Park et al., 2011), Ordered Weighted Averaging (OWA) (Jiang and Eastman, 2000; Malczewski, 2006), the Land Suitability Index (LSI) Model (Marull et al., 2007), and the Ecological Niche Suitability Model (Ouyang and Wang, 1995). Although independence and uncertainty are considered, MCE methods depend heavily on the input data which are assumed precise and accurate. Moreover, the resulting land-use suitability patterns can depend on the choice of standardization method or multi-criteria method. With this in mind, it has been suggested that two or more multi-criteria methods should be applied to dilute the

* Corresponding author. Tel./fax: +86 (0)10 59893106.
E-mail address: liurenzhi@bnu.edu.cn (R. Liu).

http://dx.doi.org/10.1016/j.jenvman.2014.06.020
0301-4797/

effect of technique bias (Carver, 1991) and that a sensitivity study should be undertaken as part of any land-use suitability analysis (Lodwick et al., 1990). Artificial intelligence has also been applied to aid the description of complex systems for inference and decision making using modern computational techniques, such as Matter-Element Model (Gong et al., 2012), Artificial Neural Networks (Park et al., 2011), and Cellular Automata (Ligtenberg et al., 2001). The black box nature of AI methods makes them tolerant of imprecision, ambiguity, uncertainty, and partial truth (Porta et al., 2013), but can often be unconvincing (O'Sullivan and Unwin, 2003).

Taking stock of the foregoing brief review, an Urban Development Land-use Suitability Mapping (UDLSM) approach is proposed which uses overlay mapping combined with Ideal Point Method (IPM) and Ordered Weighted Averaging (OWA) approaches to generate suitability maps that are then compared to generate the resultant maps. These two MCE methods are selected because the multi-criteria involved are reasonably combined, and the results are applicable and convincing (see Jiang and Eastman, 2000; Malczewski, 2004). Beijing is taken as the study area because it is suffering adverse ecological damage resulting from rapid, relatively uncontrolled urban expansion. In 2010, the urban population of Beijing reached 86% of its total population, with more than 200 km^2 of Beijing's previous farmland (in 2000) changed into development land. Importantly, no comprehensive urban development land suitability analysis has previously been undertaken for the whole of Beijing city other than some brief restrictive zone analyses presented in the *Beijing City Master Plan (2004-2020)* (*Master Plan* for short) (BMPG, 2003) and *Beijing Development Priority Zones Planning* (*Priority Zones Planning* for short) (BMPG, 2012). Using the UDLSM approach, a complete land-use suitability map for urban development covering the whole of Beijing is generated, and the resultant maps used to re-evaluate the *Master Plan* and *Priority Zones Planning*. Suggestions and guidance are then offered to support long-term urban development planning in Beijing.

2. Methodology and materials

2.1. Principles behind land-use suitability analysis

Early approaches for land-use suitability analysis evolved from the sun-print overlay of Charles Elliot and Warren Manning (Miller, 1993; Mcharg, 1996), transparent overlay of Jacqueline Tyrwhitt (Steinitz et al., 1976), and ecological inventory process of McHarg (1969). McHarg's approach (Malczewski, 2004) maximizes economic benefits while minimizing environmental damage (Collins et al., 2001), and is regarded as the precursor of ecological suitability analysis in China (see e.g. Ouyang and Wang, 1995; Yang et al., 2009). With advances in land evaluation methodologies, the ecological inventory process gradually extended from physical factors to include ecological and economic-cultural factors (see Boyden, 1981; McHarg, 1981). Examples include urban land-use suitability analyses for Staten Island, U.S.A. (McHarg, 1969), Nakuru, Kenya (Jiang and Eastman, 2000), and South Korea (Park et al., 2011).

Land-use suitability is essentially the capacity or level of land suitable for prescribed uses (see Steiner et al., 2000; Collins et al., 2001; Marull et al., 2007), and involves collective physical, socio-economic, environmental, and ecological perspectives which are quantified through set criteria (see McHarg, 1981; Collins et al., 2001). Land suitability analysis is therefore multi-disciplinary, involving physical science, biophysical science, social science, land science, ecology, and landscaping. The defined land uses can be divided into developmental (Marull et al., 2007) and non-developmental (Malczewski, 2004) categories. Suitability analysis or assessment is made according to specific requirements, preferences, or predictors of certain activities (Hopkins, 1977; Malczewski, 2004). Expert knowledge, the preferences of decision-makers, and public participation are represented in land suitability analysis by the scientific combination of real-world criteria.

2.2. Multi-criteria concerning urban development land suitability

Criteria of land-use suitability for urban development are derived from multi-disciplinary scientific theories related to physical, socio-economical, and ecological attributes. All criteria/factors for evaluation/analysis of land-use suitability fall within two categories, namely the opportunities and limitations/constraints of the environment (see Geddes, 1915; McHarg, 1969, 1981; Zong et al., 2007). Suitability analysis essentially involves identification of opportunities and constraints for prescribed land-use(s) in a city or region or watershed. However, most physical and socio-economic factors have both permissive and restrictive features for a given land-use, which are determined by spatial location (e.g. the factor slope, with a high gradient location restrictive and a low gradient location permissive for urbanization). The resulting factor maps are used to reflect the degree of opportunity (or suitability) with ranked values allocated to all mapping units. An ecological factor (e.g. forest value or historic value) is usually taken to represent the development constraint (or unsuitability) by means of ranked values for a subset of mapping units in a specific area. The composite map of ecological factors is variously called the suitability map for conservation (McHarg, 1969) or the protection map (McHarg, 1981).

Herein, opportunity criteria and constraint criteria were utilized for urban development land-use suitability analysis. The set of opportunity criteria was structured using the physical and socio-economic factors listed in Fig. 1. In considering the ecological impact, safety, and cost of urban development, the topography indicators comprised terrain elevation (S_1), slope (S_2), and geomorphological type (S_3), and the geology indicators were the engineering geological condition (S_4) and exposure to geological hazard (S_5). Socio-economic suitability was assessed as a composite of land use type (S_6), proximity to road (S_7) (city-level and country level), proximity to urban built-up area (S_8), population density (S_9), and air quality (S_{10}) (SO_2, NO_2, PM_{10}). Each indicator played a different role in determining the degree of opportunity for urban development and so was assigned a different weight. Ranked values of all opportunity factors were combined with weights for each mapping unit. The set of constraint criteria was primarily

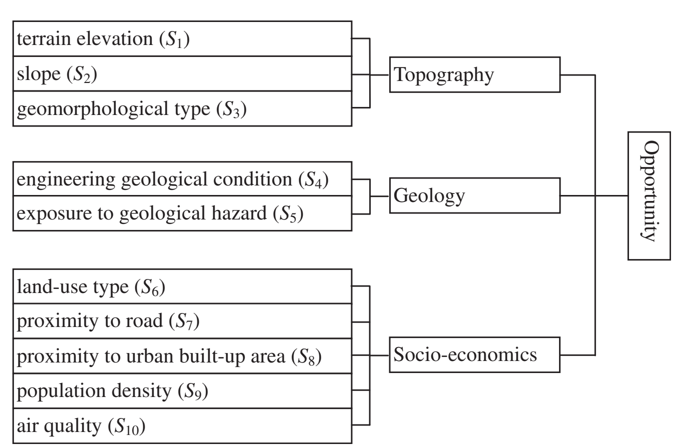

Fig. 1. Physical and socio-economic factors in terms of opportunity for urban development.