Ecological Indicators 93 (2018) 581–590

Contents lists available at ScienceDirect

Ecological Indicators

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

Original Articles

Linking GRNN and neighborhood selection algorithm to assess land suitability in low-slope hilly areas

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ARTICLE INFO

Keywords:
Low-slope hilly areas
Land suitability
GRNN
Neighborhood selection algorithm

ABSTRACT

Land resources in mountainous areas have become severely inadequate because of accelerated urbanization and industrialization, rational land exploitation in low-slope hilly areas can solve this issue. Under the protection of ecological security, this study applied a new method that combined generalized regression neural network (GRNN) and neighborhood selection algorithm (NSA) to evaluate the land suitability with a case study in Dali Prefecture, China. Land development potential was also measured and mapped according to the area proportion of land suitable to be exploited in each township. The results demonstrated that 2139 km^2 and 871 km^2 of low-slope hilly land were suitable for development of farmland and construction land, respectively. Of this resource, 1687 km^2 and 419 km^2 were identified as single-suitability area for farmland and construction land respectively, with 452 km^2 of multi-suitability area. After trade-off analysis based on NSA, the final area suitable for development of farmland and construction land were 1909 km^2 and 387 km^2 respectively, with 4600 km^2 restricted to development. The township development priority was determined according to the land development potential, which helped for local development planning. The methodology applied in this study provides an effective way to make decisions on land development and management in mountainous areas.

1. Introduction

Since the industrial revolution, the land surface has been changed gradually by human activities (Goldewijk et al., 2011), among which, urbanization have had the most significant and irreversible influence. Recently, ongoing urbanization in some developing counties has expanded to mountainous areas. The lack of space for agricultural and urban development has become the major issue facing the development and construction in mountainous areas. In the alpine-gorge regions, numerous limitations present challenges for land development, such as rough terrain, frequent disasters and poor transportation (Lin et al., 2010). As the transition between plains and mountains, low-slope hilly areas possess many geographical advantages over deep mountain area (such as lower elevation and gentle slope), which make them more suitable for multipurpose land exploitation (Luo et al., 2014). However, given that land needed for ecological sustainability has been preserved, optimizing the amount and location of land units that can be exploited has been technically difficult. As an effective approach to finding the development space for urban settlements and agricultural production, evaluation of land suitability is a significant prerequisite for land use decision-making in low-slope hilly areas.

Land suitability evaluation aims at identifying the most suitable land use type and degree in a land unit, which is the scientific basis of conducting a general land use planning (Liu et al., 2006). As a key approach to promoting the sustainable development of agriculture, land suitability evaluation is most widely used to optimize the planting structure and spatial pattern of agriculture (Baroudy, 2016; Falasca et al., 2012). For instance, Mendas and Delali (2012) established a land suitability map for durum wheat in Algeria based on multi-criteria decision analysis. Kazemi et al. (2016) evaluated the land suitability for rain-fed faba bean in the Gonbad-Kavous region of Iran, using GIS and an analytical hierarchy process. In addition, some studies aiming at expanding human living space evaluated land suitability to determine the directions for future urban expansion (Svoray et al., 2005; Xia et al., 2016). For instance, Malmir et al. (2016) identified suitable sites for future urban development in Ahwaz County, Iran. Gong et al. (2012) evaluated the land suitability in an urban fringe of Guangzhou City in China.

Recently, the effect of land development on regional ecological security has been scrutinized. Peng et al. (2016a) evaluated the ecological

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https://doi.org/10.1016/j.ecolind.2018.05.008
Received 27 August 2017; Received in revised form 12 March 2018; Accepted 3 May 2018
1470-160X/

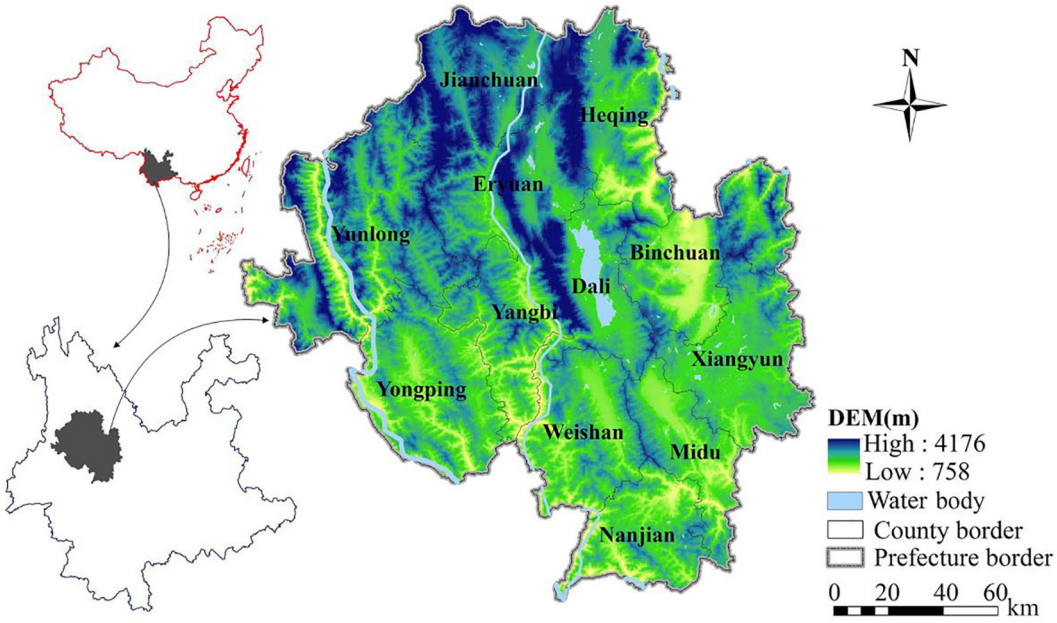

Fig. 1. Location of the study area.

impact of land development in a mountainous area of China based on landscape structure, landscape function and landscape dynamics. Ferretti and Pomarico (2013) quantified ecological risks in northern Italy based on the ordered weighted average method, which could be used as a decision variable in spatial planning. However, most of these studies separately evaluated land suitability for a single land use type (Reshmidevi et al., 2009), and comprehensive assessment of multi-suitability has not been attached enough concerns. Consequently, through identifying the most suitable land use in multi-suitability areas, such as the area both highly suitable for farmland and construction land, further study on trade-off analysis is needed to improve the usability of land suitability evaluation.

Methods of evaluating land suitability have developed from qualitative to quantitative techniques in recent years, and are divided into three common types. The first type is the multi-objective decision-making method, in which the multi-objective decision problems are usually converted to single-objective decision problems with the help of linear programming (Sadeghi et al., 2009). However, this method involves complicated calculations and is difficult to operate in a GIS environment. The second type is the multi-attribute decision-making method based on GIS. By weighting and summing the evaluation factors, the results are taken as the basis for distinguishing differences in land suitability (Zhang et al., 2013a,b). The weighting of evaluation factors always changes as study areas and evaluation targets change, and the widely used weighting methods are relatively subjective, such as Delphi and Analytic Hierarchy Process (Elaalem et al., 2011; Mosadeghi et al., 2015; Romano et al., 2015). Therefore, this method relies on a priori information and generates a relatively approximate result, which may be laden with subjectivity and uncertainty. The third type of land suitability evaluation combines GIS and an artificial intelligence algorithm, such as genetic algorithm (Li and Parrott, 2016), cellular automata (Berberoğlu et al., 2016), and artificial neural network (ANN) (Ketterer and Matzarakis, 2016). Among these algorithms, ANN has been verified to have strong nonlinear forecast capability and performs well with complex information (Geman et al., 1992), making it more suitable than other algorithms for land suitability evaluation.

Several studies have highlighted the superior predictive ability of ANN. For instance, Liu and Jiao (2002) found that the prediction precision of ANN in land suitability evaluation was higher than that of fuzzy comprehensive evaluation. Xu et al. (2011) found that land suitability evaluations for construction land in Hangzhou City, China based on ANN provided similar results as K-means clustering. In addition, results from a study using ANN to evaluate land suitability for crop production were highly accurate and consistent with the actual crop distribution (84.3%) (Ahmadi and Layegh, 2015). Overall, based on self-learning, ANN trains the network with training samples and adjusts the weights repeatedly to reduce error, which effectively avoids evaluation errors resulting from subjective cognition. As a modified algorithm of ANN, general regression neural network (GRNN) have significantly improved the nonlinear function capability of neural networks (Li et al., 2014). Wei et al. (2014) firstly used GRNN to evaluate land suitability in China's Wumeng Mountain area. However, the learning rules of GRNN were subjectively decided using the combined suitability level of evaluation indexes under ideal conditions. Another learning rule of GRNN is to use the combined suitability level of evaluation indexes obtained from the current land use type to be taken as the criteria to identify the land suitability of other units to be evaluated, which could better meet the land development needs and was adopted in this study.

During the rapid urbanization in China, high-quality farmland has been continuously converted to construction land for economic development. Although China has implemented land management policy to ensure at least 1.2 million km^2 of farmland, the newly-developed farmland is generally to be distributed in areas with poor conditions, which poses potential threats for national food security. The Dali Bai Autonomous Prefecture (Dali Prefecture) is located in the southwestern China, where urban sprawl is limited due to the expansive mountains. Although facing the urgent demand of urbanization, it must protect the natural habitats before exploiting land resources because of the extremely frail eco-environment in mountain areas. In this study, ecological security source in the study area was firstly identified and protected before land suitability evaluation. Then, a new method capable of comprehensively land suitability evaluation was proposed. Through GRNN, the suitability of farmland and construction land was evaluated respectively, followed by the single-suitability as well as multi-suitability areas identification. Subsequently, trade-off analysis based on neighborhood selection algorithm (NSA) was applied to generate the optimal spatial pattern of land development.