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Research article

An interval chance-constrained fuzzy modeling approach for supporting land-use planning and eco-environment planning at a watershed level

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ABSTRACT

An interval chance-constrained fuzzy land-use allocation (ICCF-LUA) model is proposed in this study to support solving land resource management problem associated with various environmental and ecological constraints at a watershed level. The ICCF-LUA model is based on the ICCF (interval chance-constrained fuzzy) model which is coupled with interval mathematical model, chance-constrained programming model and fuzzy linear programming model and can be used to deal with uncertainties expressed as intervals, probabilities and fuzzy sets. Therefore, the ICCF-LUA model can reflect the tradeoff between decision makers and land stakeholders, the tradeoff between the economical benefits and eco-environmental demands. The ICCF-LUA model has been applied to the land-use allocation of Wujiang watershed, Guizhou Province, China. The results indicate that under highly land suitable conditions, optimized area of cultivated land, forest land, grass land, construction land, water land, unused land and landfill in Wujiang watershed will be [5015, 5648] hm^2, [7841, 7965] hm^2, [1980, 2056] hm^2, [914, 1423] hm^2, [70, 90] hm^2, [50, 70] hm^2 and [3.2, 4.3] hm^2, the corresponding system economic benefit will be between 6831 and 7219 billion yuan. Consequently, the ICCF-LUA model can effectively support optimized land-use allocation problem in various complicated conditions which include uncertainties, risks, economic objective and eco-environmental constraints.

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1. Introduction

For decades, controversial and conflict-laden land-use allocation issues among competing commercial, industrial, and agricultural interests have raised increasing concerns (Burtaon, 1994; Lu et al., 2015). The growing population and shrinking land availability have exacerbated fierce competitions which leading to complexities in generating desired decisions, particularly under varying ecological/environmental conditions and deteriorating quality of land resources (Pichon, 1997; Lambin and Meyfroidt, 2011; Zhou, 2015). Consequently, the constantly increasing demand for land in terms of both sufficient quantity and satisfied quality has forced managers to contemplate and propose ever more comprehensive, complex, and ambitious plans for land-use systems (Qu et al., 1995; Castella et al., 2006).

Previously, many effective measures have been taken for solving the land-use allocation problem. Among these endeavors, mathematical models take an important role in this field. These models can be divided into four types: 1) simulation models (Wu, 1996; Verburg et al., 1999a, b; Polhill et al., 2001; Stéphenne and Lambin, 2001; Brown et al., 2002; Ito and Oikawa, 2002; Gao et al., 2003; Parker et al., 2003; Brath et al., 2006; Kamusoko

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et al., 2009) which have advantage in simulating land-use cover/change and its principle; 2) spatial optimization models (Cromley and Hanink, 1999; Verburg et al., 1999a, b, 2002; Jenerette and Wu, 2001; Ligmann–Zielinska et al., 2008; Santé-Riveira et al., 2008; Aerts et al., 2005; Chu et al., 2010; Eldrandaly, 2010; Arciniegas et al., 2011; Chakir and Gallo, 2013) such as GIS-based models which are used to handle spatial optimization problems in land-use allocation; 3) intelligent models (Braithwaite et al., 1993; Riveiro et al., 2005; Svoray et al., 2005; Santé-Riveira et al., 2008; Wu, 1998; Liu et al., 2012a, b, 2013; Wang et al., 2012; Sharawi, 2006; Verburg et al., 2008) such as agent-based model, cellular automata model which can handle small scale land-use allocation problems; 4) programming models (Mendoza, 1987; Diamond and Wright, 1989; Aerts et al., 2003; Zhou et al., 2015a, b) such as linear programming model, multi-objective programming model, non-linear programming model which can handle quantitive land structure optimization problems. Mathematical land-use allocation models may be used in many geographical scales; different geographical scales will lead to different model framework (Sklenicka, 2006; Zhou et al., 2015a, b). Above models can handle many structure and spatial optimization problems in a typical land-use allocation; however, when the practical conditions change, some uncertain or big-scale factors may influence the accuracy of the model results. Existing models often simplify these factors and give too many assumptions. Uncertain mathematical models have advantages in simulating and optimizing actual problems with litter assumptions. Uncertain models have been used in many resource management problems, such as water resource allocation, energy management, and so on; few studies consider uncertainties in land-use allocation models (Zhou, 2015).

Therefore, the main task of this study is to establish a new land-use allocation model which has a complete logic system and an accurate ability of simulation and optimization under uncertainty. An interval chance-constrained fuzzy land-use allocation (ICCF-LUA) model is proposed in this study to face above challenges. First, the ICCF-LUA model can handle uncertainties expressed as intervals, possibilities and fuzzy sets; second, the model considers various economical and ecological factors that former studies doesn't consider. The ICCF-LUA model is applied to sustainable land-use planning in Wujiang watershed, Guizhou province, China. ICCF-LUA model is first proposed in this study and it is a useful innovation to land-use planning as it can generate land-use allocation patterns and environmental/ecological discharge patterns; furthermore, the model can help land decision makers and government to understand the complex relationship among economy, environment, ecology, society and land-use planning.

2. The study area

The Wujiang watershed locate in 103°38′~108°38′ E, 25°59′~29°11′ N, China (Fig. 1). The watershed area is 66.8 × 10^3 km^2, occupying 30% land area of Guizhou province, China. The watershed contains 23 districts and the population is approximately 21 958 000 (2015). The watershed's gross domestic product (GDP) increased rapidly from 0.15 × 10^{12} RMB in 2000 to 2.15 × 10^{12} RMB in 2015, in concert with a population increase from 10 279 000 million to 21958 000. From Fig. 1, we can see that this area has been divided into three zones: core protection zone, control development zone and key development zone. Land-use types in core protection zone mainly are forest, green land and wet land; the function of this zone is to maintain ecological balance; Land-use types in control development zone

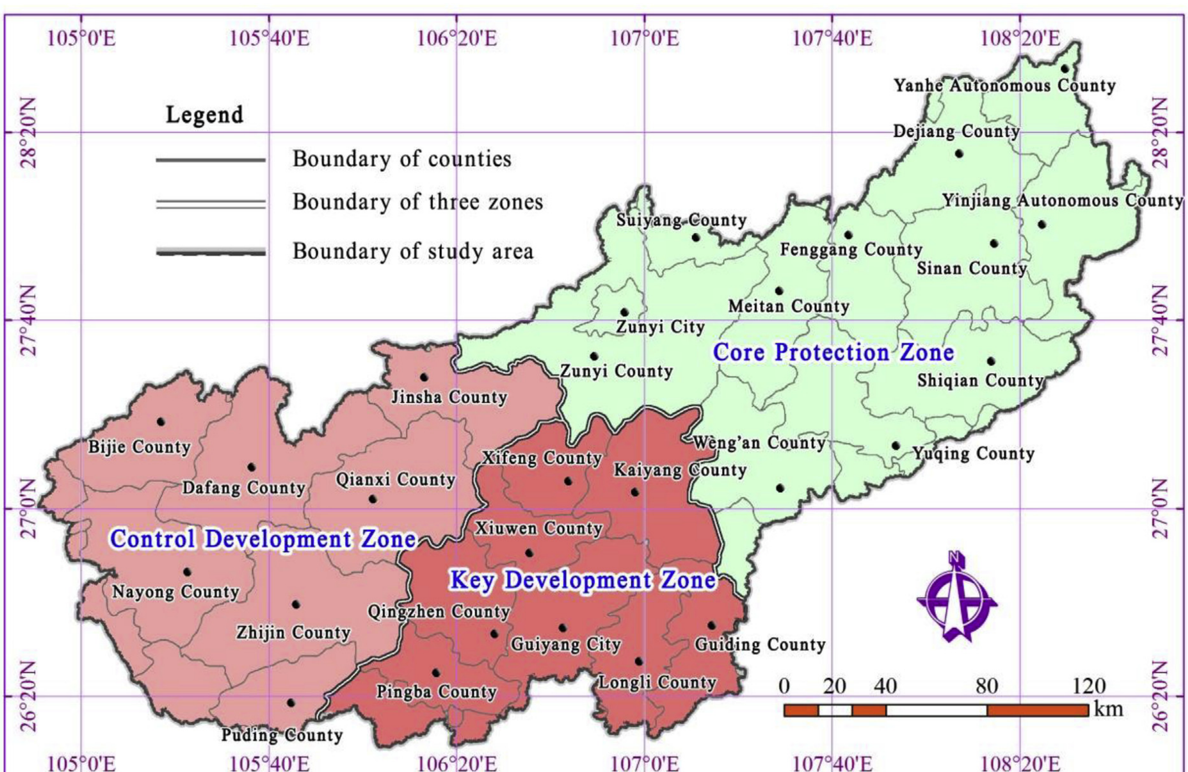

Fig. 1. The study area (Wujiang watershed).

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