A soft computing logic method for agricultural land suitability evaluation

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Abstract

There is a need for expanding agricultural lands due to increased demand for food production and security. Some regions can convert available land to agricultural land use. In order to evaluate available land for future agricultural production, multi-criteria evaluation (MCE) methods can be used to identify the land suitability. This study proposes and implements the soft computing logic and Logic Scoring of Preference (LSP) method as an improved MCE method for evaluating areas suitable for agriculture in Boulder County, Colorado, USA. Resulting LSP-based agricultural land suitability maps and LSP method can be used as integral part of the land use planning.

Keywords: soft computing logic, logic scoring of preference, multi-criteria evaluation, geographic information systems, agricultural land suitability evaluation.

1. Introduction

Multi-criteria evaluation (MCE) is a well-known methodology for spatial decision making in the field of geography (Voogd, 1983, Carver, 1991, Jankowski, 1995, Thill, 1999, Malczewski, 2004). Spatial decision making is focused primarily on urban land use (Wu 1998), environmental planning and management (Store and Kangas, 2001), and agriculture (Ceballos-Silva and Lopez-Blanco, 2003). The most commonly utilized MCE methods supported by GIS software are simple additive scoring, multi-attribute techniques, analytical hierarchy process (AHP), ordered weighted averaging (OWA), and outranking methods. The AHP and OWA methods are popular because of their ability to calculate weights and evaluate a range of decision-making alternatives (Saaty, 1980, Yager 1988, Jiang and Eastman, 2000). These methods are used in GIS and GIS-based software like IDRISI (Jiang and Eastman, 2000); however, issues arise due to model assumptions and a lack of flexibility (Malczewski, 2006, Dujmović et al., 2009). The MCE methods rely on simple aggregation models to represent human decision making processes, which restrict the complete representation of human reasoning. Through the use of hard and soft partial conjunction/disjunction, conjunctive/disjunctive partial absorption, and a range of logic conditions, the Logic Scoring of Preference (LSP) method provides the necessary components to effectively represent human evaluation logic (Dujmović and De Tre, 2011). Therefore, the main objective of this study is to develop and apply the LSP-based soft computing logic criteria for agricultural land suitability evaluation.

2. Context of the case study

Due to increases in the global population and its subsequent demand for food, it is important to allocate more land for increased food production. Evaluating the suitability of agricultural land is important in determining areas of future agricultural production. As agricultural land suitability is influenced by a combination of socio-economic and environmental factors, methods are needed to address the large range of criteria. Previous studies have used AHP and OWA methods with a relatively small number of criteria to evaluate land suitability. This has limited the ability to incorporate a sufficient amount of input criteria and completely represent observed human decision-making logic. There is a need for methods that can permit a detailed evaluation and optimisation based on justifiable criteria in order to identify suitability of land for conversion to agricultural use. The LSP method is proposed to evaluate the agricultural land suitability. The land use and soil data sets for Boulder County, Colorado, USA have been used to demonstrate the applicability of LSP-based evaluation criteria.

3. Logic Scoring of Preference Method

The LSP method is based on soft computing evaluation logic and is used for evaluation of any (typically large) number of input attributes. It provides logic operators that are observed in human reasoning (Dujmović et al., 2009). LSP was initially applied in computer science, but recently has been linked with GIS and applied to geographic applications such as urban points of interest (Dujmović and Scheer, 2010), residential home location (Dujmović and De Tre, 2011), and residential land use (Hatch et al., 2014). The LSP method is comprised of three main components: an attribute tree, elementary attribute criteria, and LSP aggregation structure. The attribute tree (Fig. 1) is created by hierarchical decomposition of suitability categories (Dujmović et al., 2010). For each suitability attribute it is necessary to create an elementary attribute criterion that specifies individual requirements for that specific attribute. Fuzzy suitability functions are used to standardize attribute criteria as well as determine the level of satisfaction for each attribute criterion. As a result, elementary criteria generate attribute preference scores representing the degree of satisfaction of attribute criteria. All preference scores are normalized from 0 to 1, where 0 is unacceptable and 1 is perfect.

Elementary attributes are classified in Fig. 1 as mandatory (+) or optional (-) based on their need to be satisfied in evaluation. If a mandatory requirement is not satisfied the resulting overall suitability is 0. For each point in an evaluated area the attribute suitability degrees are stepwise aggregated using LSP aggregators until an overall suitability degree in the analyzed point is computed and the final suitability map is generated. The goal of LSP aggregators is to model logic relationships between suitability of attributes according to those relationships that are observable in intuitive human evaluation reasoning. It is immediately clear that human reasoning is not based on only one aggregator, the simple arithmetic mean, which is frequently used in the context of AHP and some forms of OWA. Table 1 summarizes nine basic types of logic aggregators that are visible in human reasoning and are used in the LSP method. The nine basic types of aggregators are necessary and sufficient for creating all LSP aggregation structures.

A sample aggregation structure we used for aggregating agricultural land suitability attributes is shown in Fig. 2. The aggregators denoted C-+, CA, C+-, C+ and C++ belong to the HPC type with an increasing degree of simultaneity, A denotes the simple weighted arithmetic mean, and the compound aggregator consisting of combination of A and CA aggregators is an implementation CPA. The logic properties of these aggregators are precisely described in Table 1 and the mathematical implementation details can be found in Dujmović 2007.

1. Agricultural Land Suitability
   - 1.1 Land Capability
     - 1.1.1 Slope (+)
     - 1.1.2 Elevation (-)
     - 1.1.3 Aspect (-)
     - 1.1.4 Soil Texture (+)
     - 1.1.5 Organic Matter (+)
     - 1.1.6 Depth to Restrictive Layer (+)
     - 1.1.7 Available Water (+)
     - 1.1.8 Drainage Class (+)
     - 1.1.9 Bulk Density (+)
   - 1.2 Climate
     - 1.2.1 Precipitation (+)
     - 1.2.2 Temperature (+)
     - 1.2.3 Frost Free Days (+)
     - 1.2.4 Water Retention (-)
     - 1.2.5 Flooding (-)
   - 1.3 Accessibility
     - 1.3.1 Location of Highly Capable Soils (+)
     - 1.3.2 Distance to Water for Irrigation (-)
     - 1.3.3 Distance to Open Space (-)
     - 1.3.4 Distance to Major Roads (+)
     - 1.3.5 Distance to Local Roads (+)
     - 1.3.6 Distance to Urban Areas (+)
     - 1.3.7 Distance to Markets (+)
   - 1.4 Management
     - 1.4.1 Designated Open Space (+)
     - 1.4.2 Zoning (+)
     - 1.4.3 Crop Type (+)
     - 1.4.4 Farm Product Consumption (+)
     - 1.4.5 Vacant Land (-)
   - 1.5 Economics
     - 1.5.1 Cash Crops (+)
     - 1.5.2 Annual Income (+)
     - 1.5.3 Price of Land (+)
     - 1.5.4 Economic Hazards (-)
     - 1.5.5 Land Renting (-)

Figure 1. A sample attribute tree for agricultural land suitability.

It is easy to verify that other MCE methods do not support the nine types of logic aggregators that are observable in human reasoning and therefore necessary if we want to model suitability in a way that is consistent with human decision making. These capabilities make the LSP method more effective than other MCE methods.

4. LSP Land Suitability Maps

In order to evaluate agricultural land suitability, an attribute tree was designed, followed by elementary criteria for evaluating agricultural land suitability. Additionally, the LSP aggregation structure (Fig. 2) was developed using the five categories in Fig. 1: land capability, climate, accessibility, management, and economics. Weights and logic aggregators were adjusted to reflect agronomic requirements. The resulting suitability map is presented in Fig. 3.

Table 1. Logic properties of nine basic types of LSP aggregation operators

#	Name of aggregator	Logic properties of aggregator
1	Pure disjunction (D)	Model of the highest degree of substitutability. Output is defined as the largest of input values (all other inputs do not affect the output).
2	Hard Partial Disjunction (HPD)	Modeling the requirement for an adjustable high degree of substitutability that supports sufficient requirements. All inputs represent sufficient requirements, and a single completely satisfied input is sufficient to completely satisfy this criterion. If no input is completely satisfied then all inputs affect the output. High input values have a significantly stronger influence on the output than the low input values. The criterion is not satisfied only if all inputs are not satisfied.
3	Soft Partial Disjunction (SPD)	Modeling the requirement for an adjustable low to medium degree of substitutability that does not support sufficient requirements. All inputs affect the output. High input values have a stronger influence on the output than the low input values. To completely satisfy this criterion all inputs must be completely satisfied. The criterion is not satisfied only if all inputs are not satisfied.
4	Neutrality (A)	The weighted arithmetic mean of inputs. Fixed and balanced simultaneity and substitutability requirements. Low and high inputs have equal opportunity to affect the output. This criterion is not satisfied only if all inputs are not satisfied. The criterion is completely satisfied only if all inputs are completely satisfied. Neither the mandatory/sufficient requirements, nor the adjustable degree of simultaneity/substitutability can be modeled using this aggregator.
5	Soft Partial Conjunction (SPC)	Modeling the requirement for an adjustable low to medium degree of simultaneity that does not support mandatory requirements. All inputs affect the output. Low input values have a stronger influence on the output than the high input values. To completely satisfy this criterion all inputs must be completely satisfied. The criterion is not satisfied only if all inputs are not satisfied.
6	Hard Partial Conjunction (HPC)	Modeling the requirement for an adjustable high degree of simultaneity that supports mandatory requirements. Only one completely unsatisfied input is sufficient to completely not satisfy the whole criterion; so, it is mandatory to at least partially satisfy all inputs. If no input is completely unsatisfied then all inputs affect the output. Low input values have a significantly stronger influence on the output than the high input values. To completely satisfy this criterion all inputs must be completely satisfied.
7	Pure conjunction (C)	Model of the highest degree of simultaneity. Output is defined as the smallest of input values (all other inputs do not affect the output).
8	Conjunctive Partial Absorption (CPA)	The output depends on two asymmetric inputs: the mandatory input and the optional input. If the mandatory input is completely unsatisfied and has the zero value, then the output is also zero. If the mandatory input is positive, and the optional input is zero, then the output is positive. For a partially satisfied mandatory input, a higher/lower optional input can increase/decrease the output value with respect to the mandatory input for an adjustable reward/penalty.
9	Disjunctive Partial Absorption (DPA)	The output depends on two asymmetric inputs: the sufficient input and the optional input. If the sufficient input is completely satisfied, then the whole criterion is completely satisfied regardless the optional input. If the sufficient input is partially (incompletely) satisfied, and the optional input is completely satisfied, then the output is incompletely satisfied. For a partially satisfied sufficient input, a higher/lower optional input can increase/decrease the output value with respect to the sufficient input for an adjustable reward/penalty.

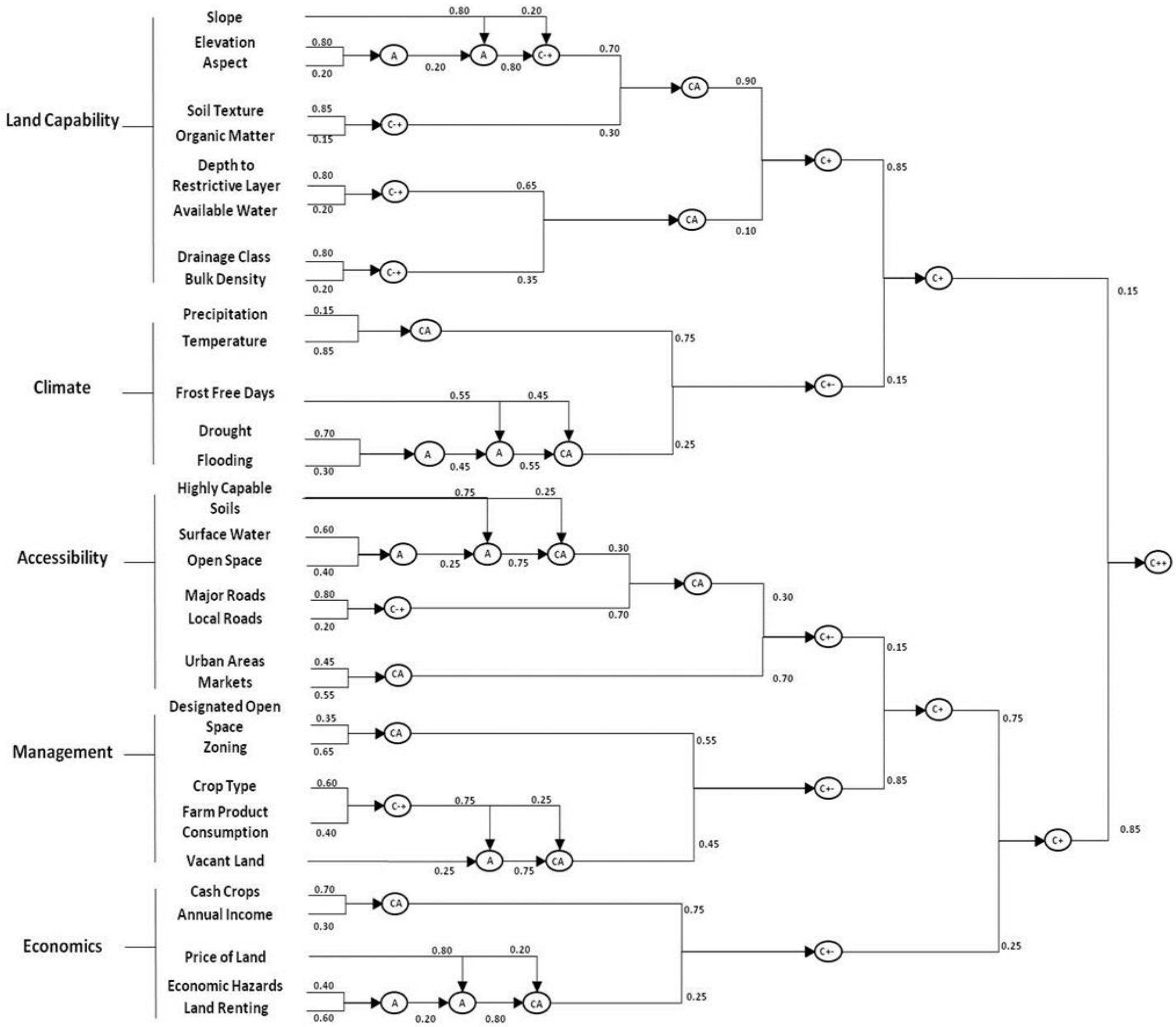

Figure 2. The LSP aggregation structure.

The presented results show the areas with different values of suitability for agricultural land use and production. The location of excellent suitability was determined to be in close proximity to municipalities and corresponding to farmer access to urban markets. LSP method demonstrates that it is an improved MCE approach by its ability to incorporate a large number of inputs and precisely reflect the goals and interests specified by stakeholders. The resulting LSP suitability maps can be efficiently used by various planners, land evaluators, farmers, investors, managers, governmental officials, decision analysts and stakeholders making the LSP method an integral part of the land use management and planning decision procedures.

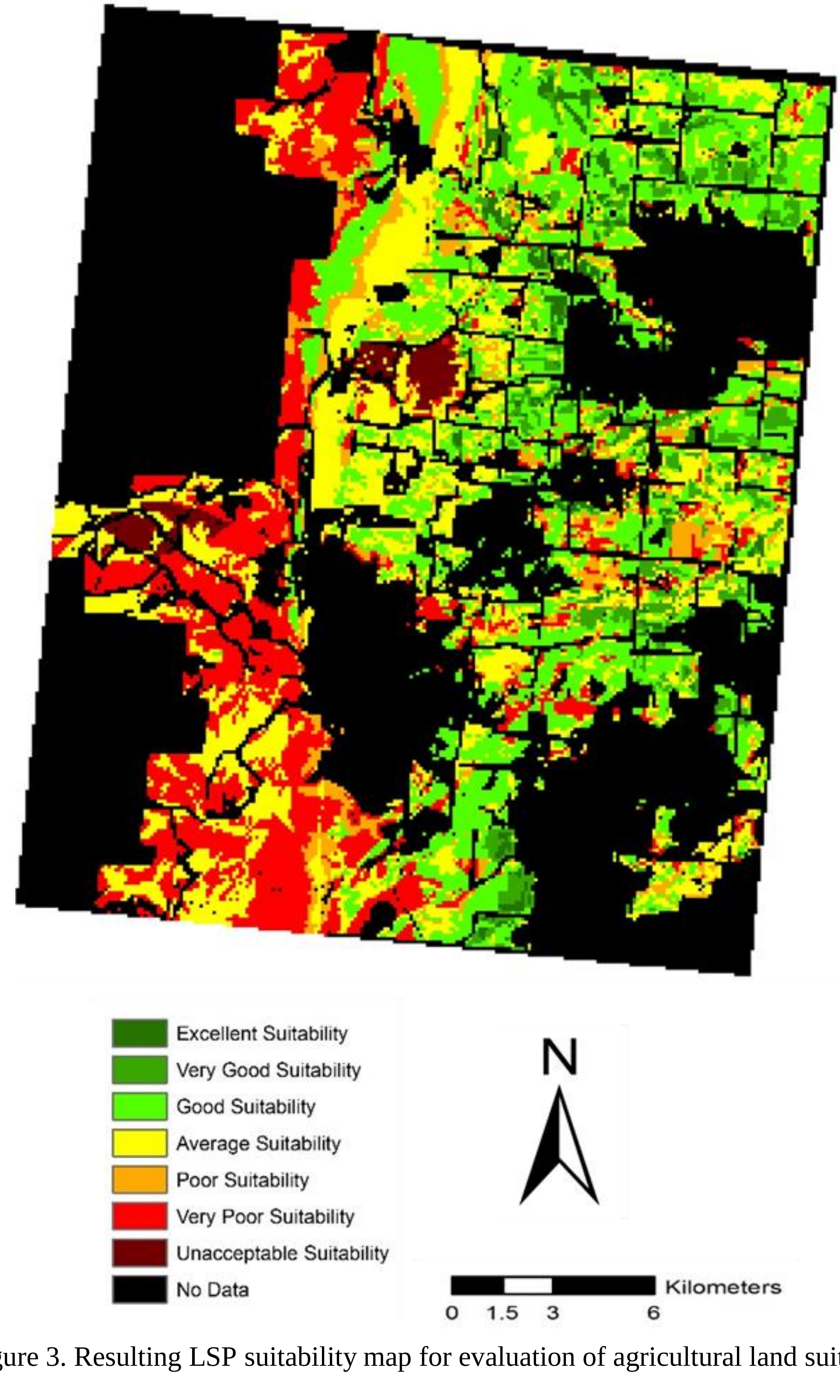

Figure 3. Resulting LSP suitability map for evaluation of agricultural land suitability

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