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A conceptual framework and its software implementation to generate spatial decision support systems for land use planning

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ABSTRACT

In a context where several sectors of society compete for space, land use types must be carefully designed and spatially allocated to guarantee a sufficient level of relevant ecosystem services (ES) in a territory of interest. In this respect, contemporary land use planning involves multiple, often conflicting objectives and criteria. Consequently, major benefits can be expected from spatial decision support systems (sDSS) designed to deal with complex spatial allocation problems.

This paper presents the generic conceptual framework 'OSMOSE' and its free and open source software implementation, for the generation of specific sDSSs for spatial land use planning. The specific sDSSs generated with OSMOSE are meant to (i) identify land units which meet multiple predefined ES-attribute values for a specific land use type (LUT) and (ii) rank land units for a given LUT according to these multiple ES-attributes. A complementary purpose is to (i) identify and (ii) rank LUTs for a given land unit. Whereas 'identification' is done by means of a threshold query, 'ranking' is based on the Iterative Ideal Point Thresholding (IIPT) method. The proposed framework is extremely flexible as it can accommodate differentially weighted, continuous and/or ordinal attributes with, for the latter, equal or unequal number of classes, alternative land unit definitions and land use types. Moreover, assessments cannot only be made using ES-levels for the land unit/LUT combinations but also in terms of changes in ES-levels after a particular change of LUT.

The OSMOSE framework is illustrated by means of the specific sDSS BoLa which is generated to support land use planning in the region of Flanders (Belgium) with focus on soil protection. Four cases are presented in which the decision support varies between the available approaches (threshold – selection, threshold – ranking, IIPT – selection, IIPT – ranking).

Introduction

Land contributes in multiple ways to the delivery of a variety of ecosystem services (ES) which are fundamental for life on earth (European Commission, 2006). Land use, land use change and climate change and their interactions alter the state and functioning of land and hence the delivered services (European Commission, 2006; Eppink et al., 2008). Under changing climate and in a context where several domains of society compete for land (European Commission, 2006; Kerselaers et al., 2011), land use types must be carefully designed and spatially allocated to guarantee a sufficient level of ES that can be sustainably delivered by and in a territory of interest (Gal and Hadas, 2013).

To ensure judicious spatial land use planning, the characteristics and qualities of the territory of interest, including their spatial variability, must be inventoried. Also the requirements and tolerances of the candidate land use systems must be known. As a linkage between the disciplines of land resources inventory and land use planning, a major role is to be played by the science and discipline of land evaluation (Wijffels et al., 2010). In this context, land evaluation aims to develop and apply methods and procedures for the determination of a land unit's suitability (i.e. a part of the earth's surface that is sufficiently homogenous with respect to soil, subsoil, climate and land cover) for a given type of land use (FAO, 1976). Literature reveals that most land evaluation methods and systems focus on economical profitability of agriculture, are based

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on soil and climatic constraints and are developed to deal with one specific problem and/or one specific objective. The Land Capability Classification System (Klingebiel and Montgomery, 1961) is an early example of such a specific land evaluation method which was developed to assist farmers in delineating parcels based on differential production possibilities, soil erosion risk and management difficulties. Also the Agro-Ecological Zoning Method (FAO, 1996) is a specific land evaluation method in which zones are identified based on the combination of soil, land form and climate characteristics. The resulting agro-ecological zones are assumed to have similar possibilities and constraints for agricultural use. The Decision Support System for Agrotechnology Transfer (Jones et al., 1998, 2003), the Land Evaluation Site Assessment (Daniels, 1990), the Great Plains Framework for Agricultural Resource Management (Ascough II et al., 1999) and the Florida Agroforestry Decision Support System (Ellis et al., 2000) are land evaluation systems developed for decision support in specific agricultural problem situations. Some land evaluation systems exist focussing on decision support in forestry related problems, e.g. AFFOREST (Van Orshoven et al., 2007), ForAndesT (Estrella and Van Orshoven, 2009), GISCAME (www.giscame.com).

Contemporary land use planning must be capable of dealing with multiple, often conflicting objectives and criteria while this is not the case for most available land evaluation methods. Consequently, major benefits can be expected from multiobjective optimisation algorithms or techniques incorporated in spatial decision support systems (sDSS) (Wijffels et al., 2010). Examples of sDSS encompass the Multi Objective Land Allocation Method (MOLAM) (Eastman et al., 1995), the Mediterranean Land Evaluation Information System (MicroLeis) (de La Rosa et al., 2004) and the Land Allocation Decision Support System (LADS) (Matthews et al., 1999). MOLAM is a specific land evaluation method which takes into account different, conflicting objectives. By attributing an ideal value to each criterion, that alternative is selected which corresponds best to the ideal value of all criteria. Also MicroLEIS combines different climate, soil and farming objectives to determine the suitability and vulnerability of different geographic regions for different agricultural systems. In the LADS (Matthews et al., 1999) the survival-of-the-fittest method is used to determine the optimal land use change.

As knowledge, societal needs, data availability and environmental conditions evolve, it is an illusion to claim that land units, ES-attributes and objectives can be defined only once and for all. A specific, closed land evaluation system, developed for a certain objective and for well-defined criteria, will become irrelevant for land use planning with time. To avoid fast irrelevancy, land use planning systems must allow for adaptation of existing data and integration of new data and better insights. This is what we call a generator of land use planning systems or spatial decision support systems, i.e. a conceptual framework and software system in which the user can modify existing and add new data (e.g. of improved resolution), criteria and land units without questioning the foundations of the system and without necessitating major, new software developments. EXGIS (Yialouris et al., 1997) and ForAndesT (Estrella and Van Orshoven, 2009) claim to meet these requirements. However, the flexibility of EXGIS is mainly limited to the adaptation of crops, soil conditions, climate conditions and environment. In contrast, ForAndesT comes as a data model and toolbox with which targeted DSS for land use allocation can be developed. The data model is a generic template for a database while the toolbox is conceived in such a way that it can deal with whatever data that is stored according to the data model.

This paper addresses three main objectives. The first objective is to define the conceptual framework of a system which can be applied as a generator for specific sDSS for land use planning. The conceptual framework encompasses the questions to be answered, the attribute types to be included and assumptions and requirements to be considered. The second objective is to present a free and open source software system OSMOSE (On-Site Multi-criteria, Optimisation for Spatial Evaluation) that materialises the conceptual framework for the generation of specific decision support systems for spatial land use planning. This software system is a consolidation and extension of the above mentioned ForAndesT system. The third objective is to illustrate the applicability of the OSMOSE framework and system by means of the specific sDSS BoLa to support land use planning in the region of Flanders (Belgium) with focus on soil protection. Therefore, the data model of OSMOSE is populated with data characterising land units in Flanders in terms of several soil-related ES. The discussion points to the applicability and policy relevance of the decision support routines but also to the possible further improvements of this type of spatial planning support systems.

OSMOSE: conceptual framework

OSMOSE stands for a concept of a generator of specific decision support systems for spatial allocation of land use types. The OSMOSE concepts are designed to address four types of questions relevant for land use planning. Although these question types have been identified in close cooperation with regional government officials dealing with soil protection and land use planning, they are believed to be generic.

1. *What is the performance of a considered land unit under the current land use type?* This 'What?' question returns for the selected land units the value of one or more specific ES-attributes for the current (initial) land use type (iLUT);
2. *What would be the performance of a land unit if iLUT is converted into a new 'target' land use type (tLUT)?* This 'What if?' question returns for the selected land units the value of one or more specific ES-attributes after a particular change from iLUT to a specified tLUT;
3. *Where (on which land units) should a tLUT be applied to obtain the specified threshold performance or the best possible performance?* This 'Where?' question returns those land units which meet the proposed ES-attribute values or which are best ranked according to these attributes after conversion from iLUT to tLUT;
4. *Which tLUT should be applied to obtain the specified threshold performance or the best possible performance?* This 'How?' question identifies for each land unit the tLUT that meets the proposed ES-attribute values or that is best ranked according to these attributes.

Variants of the basic questions can easily be envisaged:

- In addition to finding the best result also finding the worst result may be informative;
- In addition to determining the best/worst result according to the (future) level of the selected ES-attributes under tLUT (i.e. ES-level) also 'best/worst' in terms of change in ES-level between tLUT and iLUT (i.e. ES-gain or profit) may be of interest;
- Since ES-performances are heavily climate dependent, other climate scenarios than the persistence of the current climate may be considered.

In all these questions 'performance' is multi-dimensional. This means that the performance of a land use type (LUT) on a land unit is determined by at least one but typically more ES-attributes. Consequently, each question can encompass a multicriteria analysis in which multicriteria decision methods must be applied and in which the ES-attributes may be of continuous or ordinal type