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GIS- Based Land use Suitability Analysis for Urban Development

Geography

KEYWORDS : Land, Suitability, GIS, Urban, evaluation, development.

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ABSTRACT

Land-use suitability analysis aims at identifying the most appropriate spatial pattern for future land uses according to specify requirements, preferences, or predictors of some activity. The GIS-based land-use suitability analysis has been applied in a wide variety of situations including ecological approaches for defining land suitability/habitant for animal and plant species, geological favourability, suitability of land for agricultural activities, landscape evaluation and planning, environmental impact assessment, selecting the best site for the public and private sector facilities and regional planning. This present paper focuses on land-use suitability analysis as applied particularly to urban and regional development by outlining the different approaches to GIS based land use suitability analysis.

Introduction

The GIS-based approaches to land-use suitability analysis have their roots in the applications of hand-drawn overlay techniques used by American landscape architects in the late nineteenth and early twentieth century. McHarg (1969) advanced the overlay techniques by proposing a manual overlay cartographic procedure. One can distinguish three major groups of approaches to GIS-based land-use suitability analysis: (i) computer-assisted overlay mapping, (ii) multi criteria evaluation methods, and (iii) AI (soft computing or geo computation) methods.

The *computer-assisted overlay techniques* were developed as a response to the manual method's limitations of mapping and combining large datasets. Rather than manually mapping the values of a series of suitability factors in gray—or color scales, the models are stored in numerical form as matrices in the computer

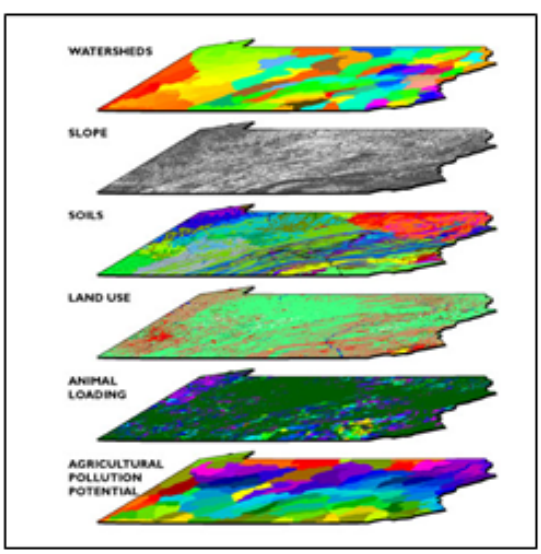
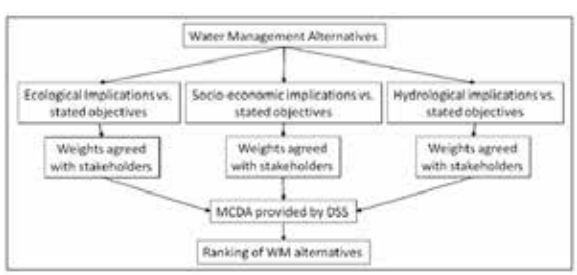


Diagram illustrating the map overlay process

The individual suitability maps can then be analyzed and combined to obtain an overall suitability map. The Harvard's SYMAP and GRID systems included a set of modules allowing for performing land-use suitability analysis in which it focused on evaluating a proposed flood-control reservoir and parkway for their suitability for recreation and other land uses. On the other hand GRID-based overlay analysis can be incorporated for developing alternative interstate corridors. The introduction of cartographic modelling and map algebra techniques into computer assisted mapping was an important advancement of the land-use suitability methods. The map overlay approach typically is applied to land-use suitability in the form of Boolean operations and weighed linear combination (WLC). The primary reason for the popularity of these methods is that they are easy to implement within the GIS environment using map algebra operations. The methods are also easy-to-understand and intuitively appealing to decision makers. The method is often applied without any insight into the meanings of two critical elements of WLC: the weights assigned to attribute maps and the procedures for deriving commensurate attribute maps. The major criticism of the conventional map overlay approach is related to the inappropriate methods for standardizing suitability maps and untested or unverified assumptions of independence among suitability criteria. Hobbs (1980), Lai and Hopkins (1989), Heywood et al. (1995) and Malczewski (2000) provide discussions on some aspects of the incorrect use of the methods. It is suggested that the classical Boolean operations and WLC methods oversimplify the complexity of the process underlying land use planning problems by focusing on the facts (that can be effectively represented in GIS) rather than a right combination of facts and value judgments (that are difficult to represent in a computer environment in general and in GIS in particular). This limitation can be removed by integrating GIS and multicriteria decision making (MCDM) methods.

The integration of *Multicriteria decision making* (MCDM) with GIS has considerably advanced the conventional map overlay approaches to the land-use suitability analysis (Carver, 1991; Banai, 1993; Eastman, 1997; Malczewski, 1999; Thill, 1999). GIS-based can be thought of as a process that combines and transforms spatial and aspatial data (input) into a resultant decision (output).



Multi Criteria Decision Making

The MCDM procedures (or decision rules) define a relationship between the input maps and the output map. The procedures involve the utilization of geographical data, the decision maker's preferences and the manipulation of the data and preferences according to specified decision rules. Accordingly, two considerations are of critical importance for spatial MCDA: (i) *the GIS capabilities of data acquisition, storage, retrieval, manipulation and analysis*, and (ii) *the MCDM capabilities for combining the geographical data and the decision maker's preferences into unidimensional values of alternative decisions.* A number of multicriteria decision rules have been implemented in the GIS envi-

ronment for tackling land-use suitability problems. The decision rules can be classified into multi objective and multi attribute decision making methods The multi objective approaches are mathematical programming model oriented methods, while multi attribute decision making methods are data oriented. Multi attribute techniques are also referred to as the discrete methods because they assume that the number of alternatives (plans) is given explicitly, while in the multiobjective methods the alternatives must be generated (they are identified by solving a multiobjective mathematical programming problem).

The potential of integrating linear programming through multi objective method, as a tool for GIS-based land-use suitability analysis can be used to optimize spatial pattern of land use, generate different planning scenarios, and analyze the relationships between decision variables and the problem constraints. The rapidly increasing problem size, particularly if the allocation decisions are defined as the integer variables, is perhaps the major barrier blocking more rapid integration of optimization techniques with GIS. One possible solution to this problem is to use heuristic algorithms. The algorithm is useful for solving very large land allocation decision problems. While the heuristic does not guarantee an optimal solution, in most cases the suggested allocation is near optimal, and much larger problems can be handled effectively than is possible in the formal linear/integer programming format. An advantage of the model (and the linear programming approaches in general) is the ability to map the patterns of location rent and opportunity costs in addition to the optimal land suitability pattern. This added information can be used for evaluating the robustness of land suitability patterns and identifying areas were modifications could be made without significant impacts however, one problem with traditional multi criteria approaches to land use suitability analysis is that they do not assure a spatial pattern with contiguity or compactness in land allocations for different land use types.

AI techniques such as genetic algorithms (GA) It should be noted that additional constraints guaranteeing contiguity and compactness further exacerbate the computational complexity of the land use suitability models. The computation complexity is one of the reasons that multi objective optimization methods are difficult to implement in GIS environment. They required a considerable effort in terms of developing mathematical programming algorithms or integrating commercially available optimization packages (solvers) and GIS. The multi attribute approaches are much easier to implement in GIS (especially, for the raster data model). Consequently, there are a considerable number of GIS multi attribute applications to land-use suitability analysis. Over the last decade or so, a number of multi attribute (or multi criteria) evaluation methods have been implemented in the GIS environment including WLC and its variants, Among these procedures, the WLC and Boolean overlay operations, such as intersection (AND) and union (OR), are considered the most straightforward and the most often employed. WLC (or simple additive weighting) is based on the concept of a weighted average. The decision maker directly assigns the weights of 'relative importance' to each attribute map layer. A total score is then obtained for each alternative by multiplying the importance weight assigned for each attribute by the scaled value given to the alternative on that attribute, and summing the products over all attributes. When the overall scores are calculated for all of the alternatives, the alternative with the highest overall score is chosen. The method can be operationalized using any GIS system having overlay capabilities. The overlay techniques allow the evaluation criterion map layers (input maps) to be combined in order to determine the composite map layer (output map). The methods can be implemented in both raster and vector GIS environments.

Broadly defined, AI includes the modern computational techniques that can help in modeling and describing complex systems for inference and decision making. The major area of AI is soft computing. From this perspective, AI seeks to develop systems that attempt to mimic human intelligence without claiming an understanding of the underlying processes. The common denominator of these methods is that, unlike conventional approaches, they are tolerant of imprecision, ambiguity, uncertainty, and partial truth. AI is a general term covering a number of methods such as *evolutionary algorithms (EAs)*, genetic programming, artificial *neural networks*, *cellular automata (CA)* and *fuzzy systems*. The term of geocomputation is sometimes used to cover these new computer-based techniques for analysis and modeling geographic data and solving spatial problems. During the past decade many advanced paradigms integrating individual components of AI and GIS have emerged.

Prominent research areas in developing hybrid systems include the integration of GIS and AI approaches such as *fuzzy logic* techniques One of the criticisms leveled at the conventional land-use suitability analysis is that the underlying assumptions of precise (crisp) input data are unrealistic. In a complex land-use suitability analysis, it is difficult (or even impossible) to provide the precise numerical information required by the conventional methods based on the Boolean algebra. For example, for some activity, there may exist natural dividing boundaries between suitable and unsuitable areas (e.g. in the case of legal requirements). However, in many situations attributes associated with the land uses lack natural cut-offs (constraints or thresholds). In conventional approaches a cut-off is defined as 'the acceptable site must be located within 1 km of a river', for example. Such a cut-off is not a natural one. Why would a site within 0.99 km be acceptable and a site located 1.01 km away from a river would be categorized as an unacceptable one? There is usually an ambiguity and imprecision involved in defining such constraints. In addition, the conventional methods often assume that the criterion weights are given in a numerical form. Contrary to these assumptions the weights of importance are often specified by means of some linguistic statements that provide an ordering of the criteria for land suitability from the most important to the least important one. Therefore, issues related to vagueness, imprecision and ambiguity should find a proper place in the land-use suitability procedures. Fuzzy logic represents an extension of the classic binary logic, with the possibility of defining sets without clear boundaries or partial memberships of elements belonging to a given set whose members may have degrees of membership between 0 and 1, as oppose to classical set where each element must have either 0 or 1 as the membership degree. It provides a framework for representing and treating uncertainty in the sense of vagueness, imprecision, lack of information, and partial truth. There are three approaches for defining fuzzy membership: the semantic import model, the similarity relation model, and an experimental analysis.

The *neural network* model is derived from a simulation of the human brain. It has its origin in the attempt to simulate an idealized form of the elementary processing units in the brain and of their interconnections, signal processing, and self-organization capabilities. The basic structure of a neural network resembles that of a simplified human brain; that is, many individual processing elements (artificial neutrons) are joined by a series of interconnected weights. It is convenient to think of neural networks in terms of the following three steps: input (e.g. data for land use analysis), model (e.g. model of land use), and output (e.g. the best pattern of land use). In a neural network procedure, each input is presented to the network during a training phase, where the network is told the correct output for each given set of inputs. The network is presented with many of these input and output sets, and it begins identifying the relationships between in the data. Like a brain, the memory or 'knowledge' of the resulting network is stored in the overall pattern of con-

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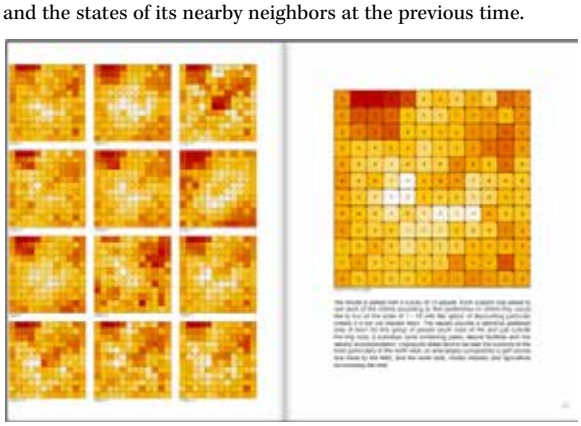
nections that determine the network's structure. Among many training procedures, the back-propagation learning method is by far the most common learning mechanism (Sui, 1993; Hewitson and Crane, 1994). Back-propagation neural network processes the errors created by propagating the input forward through the hidden layer to the output layer. Error is determined at the output layer, and then the errors are propagated back through the network from the output layer to the input layer. After training, the network model is 'tested' by taking a set of new input data (datasets that were not a part of training data), and feeding it through the network to see which output it will produce. The resulting output 'guess' is then compared to the know answer, and an accuracy rating can be assigned. This allows us to determine how well the neural network has 'learned' to place the correct dependencies and weights to the various inputs to produce an output. When a neural network works well, it 'learns' which inputs are influential to the output, which are not important at all, and what complex relationships exist An advantage of neural network methods is that a user can focus on the problems themselves rather than on the details of the techniques. The neural network approaches are best suited for tacking planning tasks in which there is little or incomplete understanding of the problem structure. Also, the techniques are data-driven so that they work best for problems involving very large datasets. The problem with neural networks is that it is not clear what constitute the optimal structure of the network (i.e. how many hidden layers and how many neurons in each layers should be used). This structural problem leads to another problem with applying the neural network to land-use suitability analysis; namely, the internal workings of the approach are intentionally hidden from the analysts (and decision-makers). There are many parameters to set when developing a neural network, all of which can affect its accuracy. The specification of such parameters requires the user to have a basic understanding of a complex algorithm or data set, yet this is often prohibitive thus leading to less than optimal performance. Another drawback is overtraining, where the network seems to perform well in training, but is just memorizing solutions specifically for the training data, and will perform poorly on the real data. The 'black box' nature of the neural network methods is a limitation as far as real-world applications are concerned.

A *Cellular Automata* (CA) is a discrete dynamic system composed of a set of cells in a one-or multidimensional lattice. The state of each cell in the regular spatial lattice depends on its previous state and the state of the cells in its neighborhood. The states of the cells are updated according a set of deterministic or probabilistic local rules. Specifically, the state of a cell at a given time depends only on its own state in the previous time period and the states of its nearby neighbors at the previous time.



All cells of an automaton are updated synchronously in parallel. Thus, the state of the entire automaton advances in discrete time steps. The locality of the interactions between a cell and its neighbors is a defining characteristic of CA. Because CA models are explicitly spatial, they have been used for simulating urban development, as well as for other applications such as simulating change in land use, freeway traffic, or the spread of fires. A relaxation of CA based upon the discrete event simulation theory widens the applicability of CA to describe non autonomous geographical processes. Accordingly, the models attempt to capture essential features of human–environment interaction by providing means to include human decision making without losing the strength of the concept of self-organization. It is suggested that GIS-based integrated agent models will become a powerful tool for land-use suitability analysis.

The integration of AI and GIS is a relatively new area of research and software development and currently, AI systems are not easily set up to be interfaced with a GIS. Those exploring AI-GIS applications are frequently required to create their own interface links. The current lack of easily utilized connections between GIS and AI presents a formidable barrier to planners and decision makers without the necessary computer programming skills. Overall, the advanced concepts of neural networks and the work required to link current AI systems to GIS, render these approaches inaccessible to most planners, mangers, and decision makers. Also, it is important to note that the AI technology does not guarantee more accurate decision making, although one can expect that it should provide for more informed decisions

Conclusion:

The development of GIS-based methods for land-use suitability analysis has evolved over the last 30 years or so from the map overlay modeling through MCDM techniques to a wide range of AI approaches. It is important to point out that many case studies use a combination of these methods; e.g. multicriteria evaluation methods can be used in conjunction with AI techniques. In addition, the classical overlay modeling is present, in one way or another, in most, if not all, of the methods. The classical overlay mapping and modeling approaches are the most commonly used methods for land-use suitability analysis in the GIS environment.

The major limitation of these approaches is the lack of well defined mechanize for incorporating value judgments (e.g. the decision-makers preferences) into the GIS-based procedures. This limitation can be removed by integrating GIS and MCDM methods. Some researchers suggest that these problems can be, at least partially, resolved by using the AI based methods. However, there is not enough real world applications using the AI methods to verify their usefulness for tackling complex land use planning problems. Arguably, the major limitation of these methods is their 'black box' style of analyzing spatial problems. It is important to note that some of the methods overviewed here have been implemented using a variety of computer technologies including the Internet-GIS and Web-GIS, multimedia-GIS and GIS-based visualization techniques. Like many GIS applications, the land-use suitability analysis has recently been influenced by the development of the Internet. The multimedia-GIS provide a platform for extending the traditional approaches by using modern technologies such as video, audio, virtual reality, etc. The use of GIS and web-based multimedia technologies has considerable potential as visualization tools for adaptation in the land use planning. The ability to view data from many perspectives and to conduct many 'what-if' scenarios can lead to better-informed decision making. As the software visualization tools become more widely available on the Web, the potential exists to undertake networked GIS-based land-use satiability analysis, which may be particularly applicable to widening public participation approach to land use planning

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