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Implementation of Overlay Function Based on Fuzzy Logic in Spatial Decision Support System

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Abstract: The overlay functions in GIS are well known and often needed tools for integrating different factors and generating useful information for decision makers. Both the integration model and the generated information usually rely on crisp set theory. In many cases, either the boundaries of classes are not clearly defined, or the classification of a feature into a class is not obvious. In such cases, overlay based on fuzzy set and fuzzy logic is unavoidable. The aim of this study is to develop overlay functions on the basis of fuzzy logic and to examine the usability of such functions in integrating data related to indeterminate aspects of a phenomenon. To implement and examine the idea, an application program is developed using VBA programming language and the available Arc Object library. Using this application, a user can generate fuzzy data and use different fuzzy overlay functions to integrate those data. To test the applicability of the model and application, the suitable locations for building commercial sites of oil products are determined using this application. In summery, data integration using fuzzy overlay functions can improve the reliability of decisions, when dealing with indeterminate phenomena.

Key words: GIS · Fuzzy overlay · Fuzzy operators · Fuzzy membership function

INTRODUCTION

Scientists try to model and understand the mutual relation between environment and human activities in order to predict and analyze the effect of different scenarios of action by human. A GIS is capable of relating different information in a spatial context and making conclusions about existing relationships between different phenomena [1].

GIS can be used to generate new field data from old ones or to integrate different factors of a phenomenon and produce a new understanding of it. The overlay tools are often used to merge different factors of a model. For example, by combining different parameters such as slope, climatic factors, vegetation cover, etc. soil erosion phenomena can be modeled. Such a model can be created easily using field-based spatial data and proper overlay tools. Both model and generated information usually are based on crisp set theory, often known as set theory. It assumes that classes of each factor and classification of each object or location into one of the categories are clearly defined [1-2].

Nevertheless, situation may happen where either the classes are not well defined (fuzzy boundary) or the classification of an object or location into a class is not certain (fuzzy classification).

The current study proposes a solution on the basis of fuzzy logic for such situations. The next section describes the problem. Section two explains the fuzzy-logic model as a response to the problem. Section three is on the elaboration of the proposed solution. The fourth section discusses the development of an application based on fuzzy-logic model. Section five explains the solution of a case study using the developed application. The study comes to end by conclusion and discussion.

Problem Description: The values describing parameters of an environmental phenomenon can commonly be

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classified into ratio, interval, ordinal, and nominal [1-6]. The overlay tool based on crisp set theory can be used for combining factors with ratio values. The class boundary of factors represented by ratio or interval values and categorization of each ratio or interval value can be exactly determined. For the implementation, Boolean logic or index overlay model can be used.

The problem appears when dealing with factors represented by ordinal or nominal values. In such cases, the classes of factors are verbally defined. For examples, substrate of ocean bed is described by ranked data such as mud, fine sand, etc. In this case, the class boundary, i.e. where mud is finished and fine sand is started, can not be sharply defined. In addition, we cannot easily decide if a particle belongs to a certain category. In such cases, overlay based on crisp set theory cannot model the problem properly. In this study, a methodology based on fuzzy set theory is proposed as a solution to such problems.

Fuzzy-Logic Model: Fuzzy logic was first developed to provide mathematical rules and functions that permit natural language queries. It enables many variables, concepts and systems to be described mathematically and provides a basis for reasoning and decision making in vague situations. Fuzzy logic is fully related to fuzzy set theory, in which, a membership function defines the level of confidence, whether an element belongs to the set or not.

A common approach to model location uncertainty in GIS is the application of fuzzy set and fuzzy logic theory. For more information on this, readers can refer to Worboys and Duckham [2]. An example of using fuzzy set theory in GIS is a region with an uncertain boundary that is represented by a raster. In such a raster, each pixel is labeled with a fuzzy set value, indicating the strength of belief that the pixel belongs to the region. The degree of belief for any pixel may come from earth observation.

Proposed Solution: The most common spatial application of fuzzy set theory has been the representation of indeterminate boundaries. In such cases, neither class's boundaries of a factor or a feature's membership regarding a class are well established. The key issue here is how to assign the function membership. For example, the classes related to the substrate of sea bed, are expressed by ranked values. In such cases, the J-shaped curve is used to calculate membership degree or Certainty Factor (CF). Assume we want to know where the substrates sand-pebbles can be found. According to the expert's opinion, the sand-pebbles are, with 100% certainty, between coarse sand and coarse gravel range. Therefore, the J-shaped curve for such a scenario is as shown in Fig. 1. After defining membership values for classes of a factor, fuzzy set operators are used to develop fuzzy overlay functions for integrating these factors.

Implementing the Solution: In this study, an application program using VBA programming language in ArcObject library and in ArcGIS interface is designed and developed to perform overlay function based on fuzzy logic.

The required user interface is structured as a simple menu (Fig. 2). It includes the operators of 'Straight Line' (for preparing distance maps), 'Reclassify' (to reclassify the maps), 'Fuzzy Membership' function (to determine membership degree of each pixel in the classes) and 'Fuzzy Overlay' (to overlay layers based on fuzzy operators).

By selecting fuzzy membership item, the fuzzy membership dialog box appears. The user can introduce input layer and select proper membership function in order to assign a membership degree to each pixel of the input layer (Fig. 3).

By selecting fuzzy overlay item, the fuzzy overlay dialog box opens (Fig. 4). The user can select input layers to be overlaid and fuzzy operator for performing overlay process. In the first version of the application, three operators of Sum, Product and Gamma are implemented.

Using the Solution for a Case Study: Some refineries will be operational in west of the country in 2008 (Fig. 5). The followings describe briefly the site selection of commercial sites for petroleum products of these refineries, using the developed solution.

Identification of Parameters Affecting the Suitability of a Site: Location of existing refineries, industrial cities, railroad and train stations, transportation roads and cities are factors that affect the suitability of a site for this purpose.

Creation of Distance Maps: Suitable location for industrial sites should be within 50 km buffer of the refineries, cities, railroads and railroad stations, and within 20 km buffer of the commercial cities and transit roads (Fig. 6).

Reclassification of Distance Maps: After determination of required factors and creating distance maps, the distance

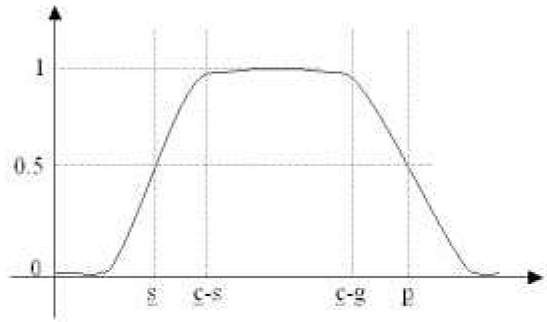

Fig. 1: The J-shaped curves for ranked values of seabed substrate, where s is"sand", c-s is "coarse sand", c-g is "coarse gravel" and p is "pebbles"

Fig. 2: Fuzzy overlay user Interface

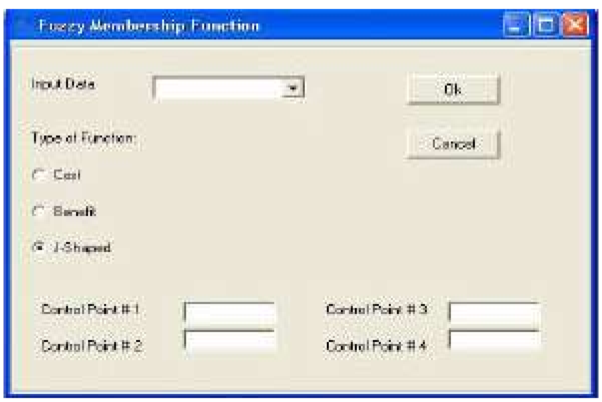

Fig. 3: Selecting of fuzzy membership functions

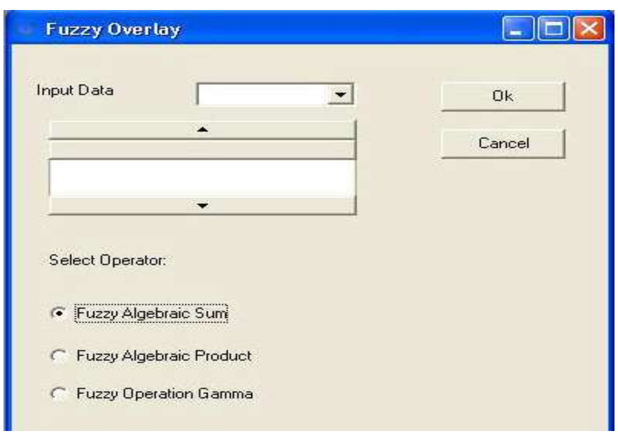

Fig. 4: Selection of fuzzy overlay operators

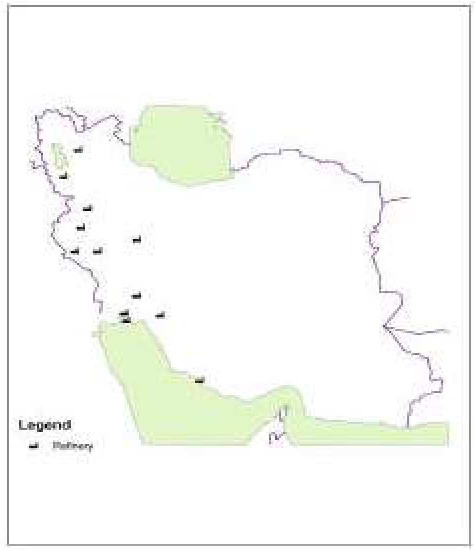

Fig. 5: Location of refineries in the study area

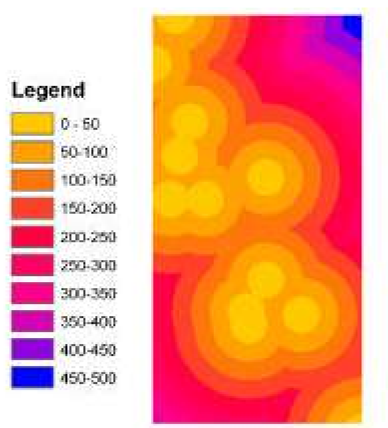

Fig. 6: Distance map to refineries

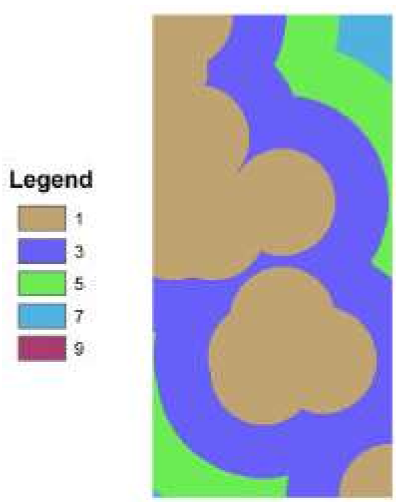

Fig. 7: Reclassification of distance map to refineries

$$\mu(x) = \begin{cases} 0 & x \le 1 \\ \dfrac{x-1}{2} & 1 < x < 3 \\ 1 & 3 \le x \le 5 \\ \dfrac{7-x}{2} & 5 < x < 7 \\ 0 & x \ge 7 \end{cases}$$

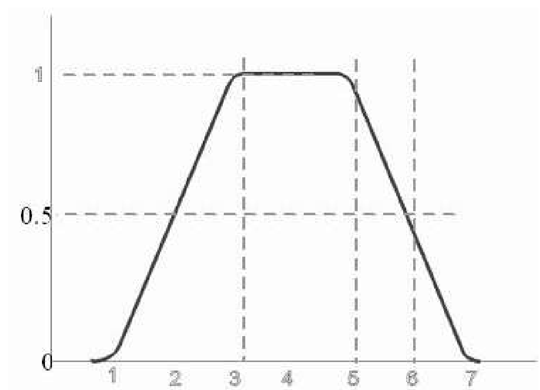

Fig. 8: The J-shaped curve for refinery layer

Fig. 9: Suitability classification based on fuzzy overlay

maps are classified. In this step, all distance maps produced in pervious steps, are reclassified and for each distance map, different classes are created (Fig. 7).

Development of a Fuzzy Membership-function for Each Factor Class: In order to assign a membership degree to each Class of a factor, a J-shaped curve membership-function is created. For example, Fig. 8 shows the J-shaped curve for distance to refineries based on the following statements:

Fuzzy Overlay of the Fuzzy Layers: relevant layers are overlaid using the fuzzy sum operator and the suitable sites for building commercial sites are obtained. Figure 9 shows the result of the fuzzy overlay in which, the locations are classified from the most suitable (colored as red) to the least suitable (the darker blue colors).

CONCLUSIONS AND RECOMMENDATIONS

Many spatial phenomena are intrinsically fuzzy, at least in two aspects: First, either the spatial features or at least their effects are usually without determinate boundaries. Second, every location can be categorized into different classes simultaneously with different degrees of certainty. The models based on fuzzy logic and fuzzy set can be used to integrate data related to indeterminate factors and phenomena and to help decision makers decide in uncertain situations.

Using the definition of fuzzy membership functions, the overlapping of factor classes, or in another words, the co-existence of different classes in one location can be modeled properly. In addition, the effect of simultaneous presence of different factors can be modeled by integrating the maps related to those factors using fuzzy overlay functions. Such fuzzy overlay functions are developed using the conceptually-rich fuzzy operators of Sum, Product, Union, Intersection, Gamma, etc.

Fuzziness could be assumed regarding many different aspects of the spatial features and phenomena. For example, in the above application, the effects of cities with different levels of industrial activity are not identical. More research is needed to evaluate the effectiveness of fuzzy logic theory in modeling different aspects of fuzziness in different phenomena [1-10].

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