FUZZY MODEL AND KRIGING FOR IMPRECISE SOIL POLYGON BOUNDARIES

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Abstract

Imprecise information in spatial data leads to uncertainty in analyses results and consequently to ineffective decision-making. Uncertainty information for risk management and analysis is a crucial topic. In Finland, issues related to uncertainty geographical information are presently well aware and many researches in vagueness in geographical data are in progress. The Ministry of Agriculture and Forestry of Finland is funding for a project to study uncertainty information in geographic databases focusing on soil data sets. The project is an offspring from the military terrain analysis project conducted by the Scientific Board of the Finnish Defence Forces (Virrantaus, 2003). The project will concentrate on imprecision of soil polygon boundaries in order to construct a model to improve the quality of spatial data analyses. Soil data was selected to study in depth because it is used often as source data for various GIS analyses and soil polygons are a good example of imprecision as their boundaries are not crisp in reality. In this paper, the basic concepts of fuzzy and kriging are described. The abstract ideas of fuzzy model of imprecise soil polygon boundaries and kriged soil map are drawn. The case study of selected test area is evaluated and the results from different methods are compared and discussed. The pros and cons of fuzzy modelling and kriging for studying imprecision of soil polygons are also included in the discussion.

INTRODUCTION

In Finland, manual interpretation is the only feasible alternative in conducting soil maps. To define soil polygon boundaries, geologists or soil surveyors use aerial photos, geologic maps, topographic maps and knowledge of geomorphology. To classify soil types, drillings are made in order to take soil samples from 1 m. depth to examine their properties. Some samples may be taken to the soil laboratory for detailed test. As the country is big with the area size of 337,000 square kilometres, it is difficult for soil surveying to have dense drilling points and the field observations are therefore relatively sparse. As a result, differences between soil surveyors on how to partition landscapes can lead to different data, and hence decisions based on them could be intrinsically (Burrough and McDonnell, 1998).

As it was briefly mentioned earlier about the soil mapping process in Finland, the uncertainty information of soil maps can be summarized into two categories, soil type misclassification and imprecision of soil polygon boundaries. The vagueness of soil type misclassification is left out of the research topic here. In this research, the main focus is on the imprecision of soil polygon boundaries.
Soil polygon boundaries are not crisp in the real world and there is no rule base to model or store soil data as crisp objects in databases. To study imprecision of soil polygon boundaries, a fuzzy model was selected as a fundamental alternative. Fuzzy concepts are more realistic approach and they contain some kind of uncertainty information. The fuzzy expert system was based on the behaviour of soils within neighbouring soil types together with the spatial variation of the phenomenon. To simplify the problem, the uncertainty was concentrated on the polygon boundaries. The concept of expert systems, however, enables the model to be extended and modified later on. A new uncertainty data layer expressing membership to particular soil type was produced in order to deal with the uncertainty issue of spatial data analyses. Fuzzy concepts and tools, therefore, were chosen because theirs theories can explain and suit our assumptions of our research.

Nevertheless, since fuzzy concepts and tools are based on possibility theories, the result from the fuzzy model alone may not meet the satisfactions. Probability tool like kriging is therefore possibly used to interpolate the soil borderlines. The aspiration of this concept is from Uncertainty in Geographical Information textbook by Zhang and Goodchild (2002). Kriging can be applied as an interpolation method, which considers the spatial variation of the geographical properties and provides optimal estimates of values at unsampled points. Kriging also returns estimation variances of the kriged points at the same time, which is of great importance. Besides, it has been used for soil classification in many countries; however, this method requires detailed data collection, which has not been applied for the whole Finland. In this research, kriging is used for interpolation of the soil polygon borderlines to study imprecision on the boundaries. Implementing kriging together with fuzzy is therefore a great expectation. The results from these two models are compared for better spatial analysis and supporting decision analysis.

FUZZY

Fuzzy set theory and fuzzy logic were invented by Lotfi Zadeh in the 1960’s, they provide an intelligible basis for coping with imprecise entities (Niskanen, 2004). Unlike crisp sets that allow only true or false values, fuzzy sets allow membership functions with unclear defined boundaries. The grade of membership is expressed in the scale of 0 to 1 and it is a continuous function. Fuzzy approach is based on the premise that key elements in human thinking are not just numbers but can be approximated to tables of fuzzy sets, or in other words, classes of objects in which the transition from membership to non-membership is gradual rather than abrupt (Sankar and Dwijesh, 1985). In general, fuzzy concepts allow possibility and overlapping classes as a way of thought.

In GIS, the boundaries between sure and unsure information are experienced. For instance, where should the borderline of clay end? If a soil surveyor stand on the edge of borderline of clay, how he/she can be sure that the position at the point where he/she stands is clay. Consequently, it is clearly seen here that fuzzy concepts and tools are suitable for this research in imprecision of soil polygon boundaries especially in Finland since the Finnish soil maps are mostly based on human reasoning logic as mentioned in the previous section. It is very reasonable to implement fuzzy logic to construct a fuzzy model for presenting imprecise soil polygon boundaries.

Nevertheless, while fuzzy sets are widely seen as being able to represent inherently fuzzy concepts and linguistic fuzziness, critics are wary of certain negative aspects of fuzzy sets,
notably the arbitrary definition of membership functions and, in addition, their relatively short development history and weak mathematical basis (Zhang and Goodchild, 2002).

There are no certain rules for sketching or defining a soil boundary on the map, expert knowledge documentation seems to be the only feasible alternative to describe and understand the imprecision of soil boundaries. At the beginning stage of the project, knowledge from geologists and soil surveyors are collected and documented in order to create rule-based model for managing imprecise soil polygon boundaries. The knowledge obtained from geologists is complex and diverse from various backgrounds and mostly it depends on their experiences and opinions. To simplify the models in this research, only basic rules and general expert knowledge are turned to account.

Instead of probability, fuzzy set theory uses concepts of admitted possibility, which is described in terms of the fuzzy membership function (Burrough and McDonnell, 1998). To construct fuzzy membership functions for a fuzzy model of imprecise soil polygon boundaries, the expert knowledge and opinions are collected. Some examples of expert knowledge are the level of uncertainty of soil polygon boundaries, the transitional zones of the borderlines between two soil types and uncertainty information of soil polygon boundaries in different regions.

In order to outline fuzzy rule base for fuzzy soil map, the knowledge from experts is used together with other related information like geomorphology, topography, soil type and neighbouring soil type information. The description of the fuzzy expert system can be described in Figure 1.

![Figure 1: Description of fuzzy expert system.](image)

The input and expected output of the fuzzy model are shown in Figure 2. From the soil map that presents crisp soil polygon boundaries, the expert knowledge together with other related information, as mentioned previously, are used to create rule base to get the result which is fuzzy soil map. The collection of expert knowledge is obviously a continuing process due to the complexity and many influencing factors and so on. It is somehow difficult to finalise and conclude the expert knowledge and set up restrictive rules.

![Figure 2: Left: Soil map presents crisp soil polygon boundaries. Right: Expected output map that presents the imprecision on the borderlines.](image)
KRIGING

Kriging is a term coined by G. Matheron (1963) after the name of D.G. Krige. Kriging is based on a statistical model of a phenomenon instead of an interpolating function. It uses a model for a spatial continuity in the interpolation of unknown values based on values at neighbouring points. Spatial continuity, i.e., the property that the variable values are more similar at sites that are close together in space than those farther from one another (Oliver and Webster, 1990; Jesus, 2003), is modelled by using a covariance model. The model is applied in kriging, which is an optimal interpolator in the sense that interpolated values are unbiased and the estimation variance is minimized (Mason et al., 1994).

The question may arise here whether or not kriging can be used for studying imprecision soil polygon boundaries. Clearly, kriging is a reasonable tool for soil classification when using soil properties to classify the soil types. This approach implies that higher correctly classified soil of types give higher certainty of border location. Hence, its concepts and probabilistic background can be applied to solve the problem of imprecise borderlines. The general concepts of using kriging to create kriged soil map are described in Figure 3.

CASE STUDY

The area of Vampula in the coastal region and central of Finland is selected to be the tested area of these two methods. The different results from possibility and probability methods will present the imprecision of soil polygon boundaries. The tested area is about 3.2 square kilometres with resolution of 25 meter per grid cell. The soil map of this area is shown in Figure 4 and for better understanding and clearer image, soil types are also presented on the map.
Fuzzy model and kriging for imprecise soil polygon boundaries

Figure 4: The original soil map or input soil map.

Fuzzy soil map

Using Fuzzy Logic Toolbox in Matlab, the construction of a fuzzy model for managing imprecision of soil polygon boundaries is created. The expert knowledge is transformed into rule base and produce membership functions. The membership functions of soil types are varied according to the soil types and the region where the area is located. The transitional zone is varied according to the soil types and the width is based on the expert opinions. The differences of membership functions of coastal region and central region are shown in Tables 1 and 2. To simplify the model, symmetric matrix is used for defining membership functions. (In real case, geologists give different values of clay-moraine and moraine-clay.)

Table 1: Membership functions of different soil types of coastal region.

<table>
<thead>
<tr>
<th>Coastal</th>
<th>Clay</th>
<th>Moraine</th>
<th>Heath</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clay</td>
<td>0.90</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moraine</td>
<td>0.93</td>
<td>0.85</td>
<td></td>
</tr>
<tr>
<td>Heath</td>
<td>0.85</td>
<td>0.90</td>
<td>0.90</td>
</tr>
</tbody>
</table>

Table 2: Membership functions of different soil types of central region.

<table>
<thead>
<tr>
<th>Central</th>
<th>Clay</th>
<th>Moraine</th>
<th>Heath</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clay</td>
<td>0.87</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moraine</td>
<td>0.93</td>
<td>0.91</td>
<td></td>
</tr>
<tr>
<td>Heath</td>
<td>0.88</td>
<td>0.85</td>
<td>0.93</td>
</tr>
</tbody>
</table>

The output map is shown in Figure 5. There is a thin line shown on the output map and it presents the influence between the two regions, coastal region and central region, which was already explained previously.

Figure 5: Output map of Fuzzy model presents imprecision along the soil polygon boundaries.
Kriged soil map
The soil map was randomly resampled at 500 hundred locations. Using indicator coding with \( I(x) = 1 \), if there is clay at the sampled location and 0 else. Based on variogram modelling, the range of spatial continuity is about 40 meters, and later on it was rescaled to 25 meters in order to competent when comparing with fuzzy soil map. The small circles show the locations of each sample point. In this research, varied numbers of sample point were tested and the reasonable result was considered when the sample points are at 500. In summary, the higher density of sample points is, the better interpolation result. Using SADA, Spatial Analysis and Decision Assistance software, for kriging interpolation, the kriged soil map is presented in Figure 6.

![Figure 6: Output map of kriging model presents imprecision along the soil polygon boundaries.](image)

Comparison of the result maps
The resulted fuzzy soil map and kriged soil map are compared to evaluate the differences between these two models. It is seen clearly that the fuzzy soil map gives the equivalent imprecision band along the border whereas kriged soil map has different width of imprecision zone along the borderlines. There is no right or wrong answer for these resulted maps, they leave the alternative open for users who can decide which result suit them the best in terms of purposes of use, i.e. for land management project, perhaps, the fuzzy soil map is satisfactory for the reason that fuzzy soil boundaries are sufficient for not detailed analysis.

SUMMARY AND DISCUSSION
The positive of fuzzy model is its own abstract ideas in knowledge modelling. It is a tool that competent with modelling linguistic, human reasoning and knowledge. Fuzzy seems to give simple method that does not require great effort in solving the problem of imprecise soil polygon boundaries. The fuzzy model appears to provide unenclosed rules to be added in and regulated knowledge based into the model. On the contrary, modelling the knowledge needs much effort and skill. Besides, it is complicated to value the human knowledge because of complexity of soil information and many relevant circumstances.

Kriging seems to give more accuracy and reliable result in estimating imprecise soil polygon boundaries. Nevertheless, it is difficult to apply the kriging method for soil mapping in a country where the area size is huge. As it was mentioned earlier, the basic need for kriging analysis of soil borderlines is sample points along the borderlines or a well-established geometry of soil formations. Moreover, a whole process is too time
consuming and high expenses. Nevertheless, kriging may give better spatial analysis and more effective decision-making in some specific areas that are worth for investing time and resources, for example, geoenvironmental studies.

For both methods, it is, however, adequate to mention that whatever the number of observations, this estimation will never be perfect since there will always remain ambiguity about the location at which to end a transition zone (Lagacherie et al., 1996).

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REFERENCES