

# Fuzzy modelling and Kriging for modelling imprecise soil polygon boundaries

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**Abstract.** The uncertainty in geographical information is being researched widely. Uncertainty of information may lead to imprecision in analysis and decision-making. The uncertainty issues of geographical information are well known worldwide as well as in Finland. In 2003, the Ministry of Agriculture and Forestry of Finland funded a project to study uncertainty in geographical information of soil data sets. In order to study the issue in depth, imprecision of soil polygon boundaries was selected as a case study because their boundaries are not crisp in reality. From the research project, a fuzzy model and kriged model to study the imprecise soil polygon boundaries were constructed. The further study after the project focuses on geostatistical model and how to develop it for better modelling in order to define the imprecision of soil polygon boundaries. This paper presents the previous models and their results and also the introduction of a new approach, so called fuzzy kriging, which is currently being developed.

**Key words:** fuzzy, kriging, geostatistics, imprecise soil polygon boundaries.

## 1 Introduction

Quaternary deposits mapping process in Finland was mostly done manually. The survey process in order to collect soil data was usually depended on what methods fit best in the particular area. In general, the most commonly used methods were based on aerial photos, geological maps, topographic maps, and knowledge of geomorphology that could be obtained from experts. In this study, the researchers focused on two dimensional quaternary deposits map and concentrated on soil layer at one metre depth. During the soil survey, soil samples were taken and often classified by their types at sites. In some cases, soil surveyors might have taken some samples to the soil laboratory for detailed tests. Soil polygon boundaries were also defined at sites mainly by expert opinions. As Finland is a huge country with the size of 377,000 square kilometres, the manual soil survey process seemed to be the feasible method at the time.

In 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. In this research, the main focus is on the imprecision of soil polygon boundaries (Sunila et. al, 2004).

## 2 Previous study

During the project year, two models to study imprecise polygon boundaries were constructed. The models were based on the fuzzy theories and concepts and geostatistical tools such as kriging.

### 2.1 Fuzzy model

The fuzzy set theory and fuzzy logic were invented by Lotfi Zadeh in the 1960's, and 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.

#### 2.1.1 Fuzzy soil map

The construction of a fuzzy model for managing imprecision of soil polygon boundaries was created and the expert knowledge was transformed into a rule base and the membership functions were produced. The membership functions of soil types were varied according to the soil types and the region where the area is located. The transitional zone was varied according to the soil types and the width was based on the expert opinions. The resulted map is shown in figure 1.



*Figure 1: Fuzzy soil map presents imprecision along the soil polygon boundaries.*

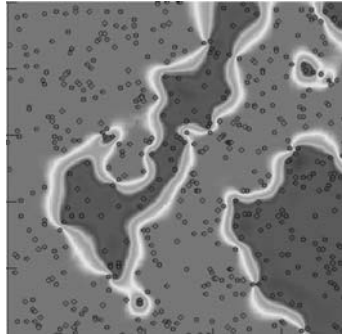
### 2.2 Kriged model

Kriging is a term coined by G. Matheron in 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, 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.

#### 2.2.1 Kriged soil map

The soil map was randomly resampled at 500 hundred locations. Using indicator coding, if there was clay at the sampled location then  $I(x) = 1$ , otherwise  $I(x) = 0$ . Based on variogram

modelling, the range of spatial continuity was about 40 meters, and later on it was rescaled to 25 meters in order to be comparable with a fuzzy soil map. The small circles show the locations of each sample point. In this research, varied numbers of sample points were tested and the reasonable result was considered when the sample points are at 500. In summary, the higher the density of sample points was, the better the interpolation result. The kriged soil map is presented in Figure 2.



*Figure 2: Kriged soil map presents imprecision along the soil polygon boundaries.*

### **3 Further study**

The preliminary study revealed that geostatistical model yielded a better estimation of the imprecise polygon boundaries. The polygon boundaries from the kriged model are not equivalent along the borders as from the fuzzy model. It is good to mention that it may be difficult to apply the kriging method for soil mapping in a country where the area size is huge. The basic requirement of kriging analysis of soil borderlines is a set of sample points or a well-established geometry of soil formations. The whole data collection process is time consuming and involves great efforts and huge resources. 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. Therefore, the development of the imprecise soil polygon boundaries model is carried on in the research.

#### **3.1 Cokriging**

Cokriging is a form of kriging that involves multiple variables. It is an interpolation technique that allows those multiple variables to estimate map values if the secondary sampled distribution is more densely varied than the known primary varying variables. In this study, two variables, soil and electrical data are used in the cokriging model. Soil samples were taken from an area in Hanko. The concentrated area size is about one square kilometre. It was found out that there were four soil types in the area. To construct a cokriged model, electrical data like airborne vertical electrical sounding profiles made by Geological Survey of Finland were also applied and added as input data in the research. Currently, the model is still being developed.

#### **3.2 Fuzzy kriging**

Fuzzy kriging is kriging with imprecise or fuzzy variograms. Fuzzy kriging was first developed by Bardossy et. al, 1990. Both kriged values and estimation variances are calculated as fuzzy members and characterized by their membership functions. Besides estimation variance, the membership functions are used to create another uncertainty measure. In this further research, the researchers aim to use the data from ground penetrating radar and

soil sample points in the area to verify the imprecision of soil polygon boundaries. The research is under the data collection process at the present.

#### **4 Conclusions and Discussion**

The information that is presented on quaternary deposit maps may not be sufficient for those cases, in which deep evaluation of the information is needed. The model of imprecise soil polygon boundaries can be an alternative when the uncertainty of the information needs to be studied. The varied applications and models can provide alternative solutions for users to choose what fits best with their assumptions and resources. For example, for land management project, perhaps, the fuzzy soil map is satisfactory even though fuzzy soil boundaries are not sufficient for detailed analysis, and for environmental land use purposes in a concentrated or contaminated area, perhaps, kriged models can provide better support in the decision making.

#### **Acknowledgements**

The author would like to thank the Ministry of Agriculture and Forestry for supporting the Fuzzy modelling for imprecise soil polygon boundaries project, Professor Kirsi Virrantaus for her comments and suggestions, Docent Eevaliisa Laine for theoretical support in kriged modelling, Dr. Vesa Niskanen for instruction of fuzzy modelling, Dr. Jukka-Pekka Palmu, Ms. Maija Haavisto-Hyvärinen and their team from Geological Survey of Finland for providing expert knowledge and Mr. Rami Immonen for providing the data and expert knowledge for the tested area.

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