MULTIPLE CRITERIA ANALYSIS OF SPATIAL INFORMATION FOR A PRELIMINARY ASSESSMENT OF THE LANDSLIDE SUSCEPTIBILITY FOR ENVIRONMENTAL PROTECTION IN THE ZAGREB REGION BASED ON GEODYNAMIC NETWORK

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ABSTRACT

'Land' plays multidimensional role in maintaining many global processes, therefore sustainable planning and management of land resources is an important issue at the global forum. The process of land resource planning and associated decision-making invariably involves multiple objectives, multiple criteria and multiple social interests and preferences. Such complexity necessitates a systematic approach to the decision-making process to accommodate the multiplicity and multi dimensionalities of the problem to improve the reasonability of decisions and to justify the actions to be taken. The objective of this study is to perform a preliminary assessment of the landslide susceptibility for enviroment protection in the City of Zagreb. A geographic information system (GIS) database was compiled based on data from topographical and geological maps. Weight of evidence, analytic hierarchy process (AHP), and fuzzy logic methods, as well as hybrid methods, were used to establish the rating of classes for each factor, weightings for the factors, and to combine multiple factor layers into landslide-susceptibility maps. The results recognize relative weights between the influential factors and promote the real efficiency on City of Zagreb hillsides disaster can be important references for establishing the evaluation model.

INTRODUCTION

Landslides cause extensive damage to property and occasionally result in loss of life throughout most of Zagreb. So it is necessary to delineate the area that will be likely to be affected by the future landslides. Conventional probabilistic approaches implicitly assume that most of the information on which decision-making is based is probabilistic in nature, and that precise probability judgements can be formulated for each hypothesis of the problem concerned. On the other hand, in terms of soft computing, uncertainty may have different nature and should be modelled in different frameworks, and a hard decision should be drawn only towards the end of the processing. Especially, fuzzy set theory can provide us with a natural method of quantitatively processing multiple data sets and many scientists have applied the fuzzy set theory to their studies and proved that this theory is very useful to reflect natural phenomena or irregular behaviros (Robinson, 2003).
In this paper, we apply and investigate the fuzzy logic information representation and integration for landslide hazard mapping. First, we construct the input causal factors related to landslide occurrences, and then assignment of fuzzy membership functions is followed. To integrate fuzzy membership functions, we construct "fuzzy inference network" by using various fuzzy operators. As an essential part for landslide hazard mapping, in order to validate the significance of the prediction results, we exemplify whether and to what extent a prediction can be extended, in space, to neighbouring areas with similar geology (De Smith et al 2009).

STUDY AREA AND DATA SETS

The study area is located in north-western Croatia, on downhills of Mount Medvednica (Fig. 1). Landslides are usually induced due to rainfall, local downpour and earthquakes. The area is seismically very active (Medak et al, 2006). Geodynamic research has been performed by recurring satellite measurements, as a part of CERGOP2/Environment project (Caporali et al, 2008). The input data for the test consist of several layers of map information. The slope and aspect were calculated from the 1:5000 scale DEM *and SRTM 1″* DEM. As for the soil data sets, the texture, topography, drainage, material, and thickness of soil were acquired from 1:25000 scale soil maps.

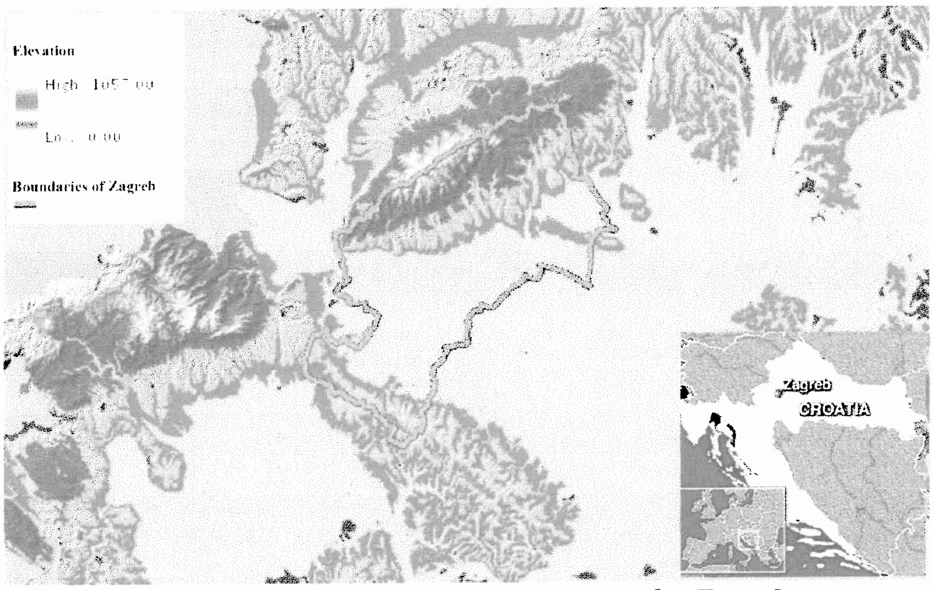


Figure 1: Raster display of the SRTM data for Zagreb area

As for the forest data sets, the type, diameter, age, and density of timber were acquired from 1:25000 scale forest maps.

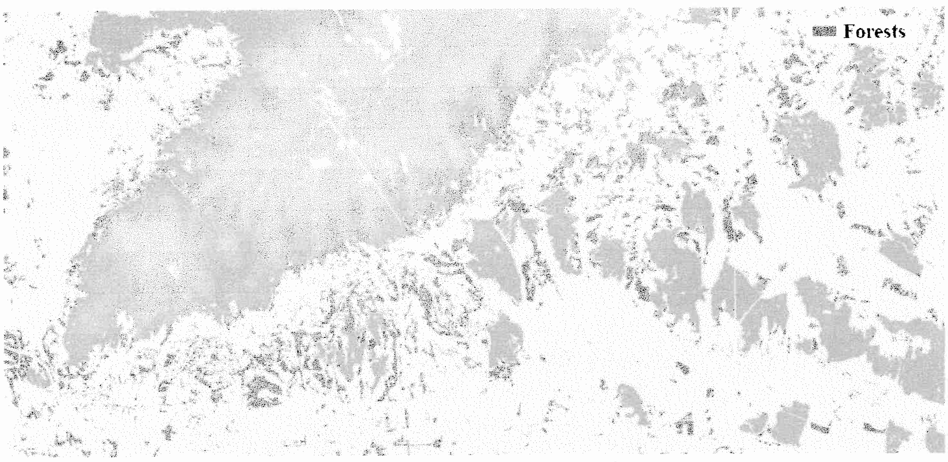


Figure 2: Area covered by forests

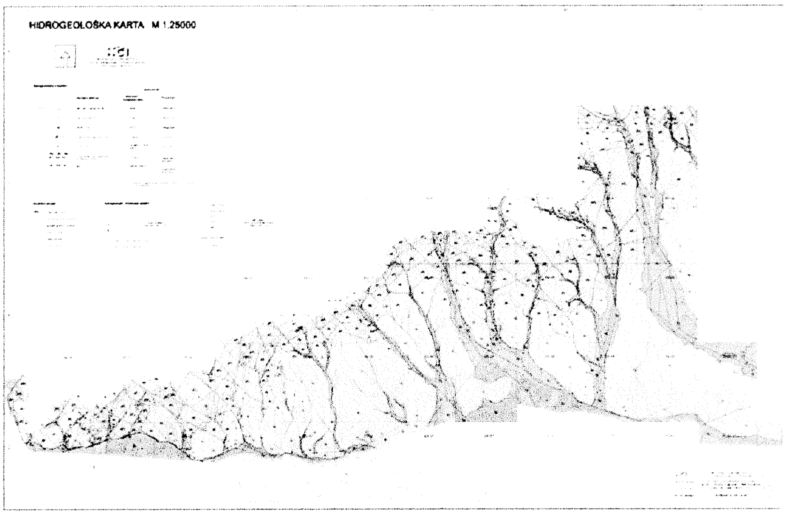


Figure 3: Hydro-geological map of the Zagreb area

In total, *478* type landslides were mapped. In this study, the topographically highest 20% of the scars of the landslides are considered as trigger areas (Medved et al, 2009). The fuzzy set theory was introduced by Zadeh (1965), which facilitates analysis of non-discrete natural processes or phenomena as mathematical formulae (Zimmermann, 1996). If X={x} denotes a universe of the attribute values, the fuzzy set A in the X is the set of ordered pairs

$$A=\{x, \mu_A(x)\}, x \epsilon X$$

$\mu_A(x)$ is known as grade of membership of x in the A. Usually, $\mu_A(x)$ is an integer or a floating number in the range [0,1] with 1 representing full membership and 0 non-membership. The grade of membership reflects a kind of ordering that is not based on probability but on admitted possibility. The value of $\mu A(x)$ for the attribute value x in A can be interpreted as the degree of compatibility of the predicate associated with set A and attribute value x.

ASSIGNMENT OF FUZZY MEMBERSHIP FUNCTION

In this study, assignment of fuzzy membership functions to each data layer followed Chung and Fabbri (2001)'s approach. Our target proposition is "a pixel p in the study area will be affected by future debris flow type landslides".

First, we investigated the relationships between input causal factors and past landslides. For this, the likelihood ratio function of each map, which can highlight the difference between areas affected by past landslides and areas not affected by past landslides, was calculated and compared with each other. In slope map, the steeper the slope, the greater the landslide possibility. Most landslides occurred between 15° and 35°. The slope angle is an essential component of landslide susceptibility. In general, it is expected that low slope angles have a low possibility of landslides due to lower shear stresses associated with low gradients. Steep natural slopes, however, may not be susceptible to shallow landslides. In aspect map, the landslide occurrence possibility value was similar at all directions. In forest maps, the possibility of landslide occurrence is higher in larch and artificial Chestnut trees, very small diameters, younger timber, and loose density forest. These results are related to location of forest and amount of roots. In soil maps, the possibility of landslide occurrence is higher in well-drained soil, red-yellow podzolic soils and lithosols, acidic rocks residuum, mountainous areas, thick soils. These results are

related to increase of unit weight and shear stress of soil due to pore-water increase (Ananda, et al 2003)
The critical strategy in prediction models is the task of validating the prediction results, so that the prediction results can provide meaningful interpretation with respect to the future landslides. To carry out the validation, we must restrict the use of all the data of the past landslides in the study area. By partitioning the data, one subset is used for obtaining a prediction map; the other subset is compared with the prediction results for validation. To establish whether and to what extent a prediction can be extended, in space, to neighbouring areas with similar geology.

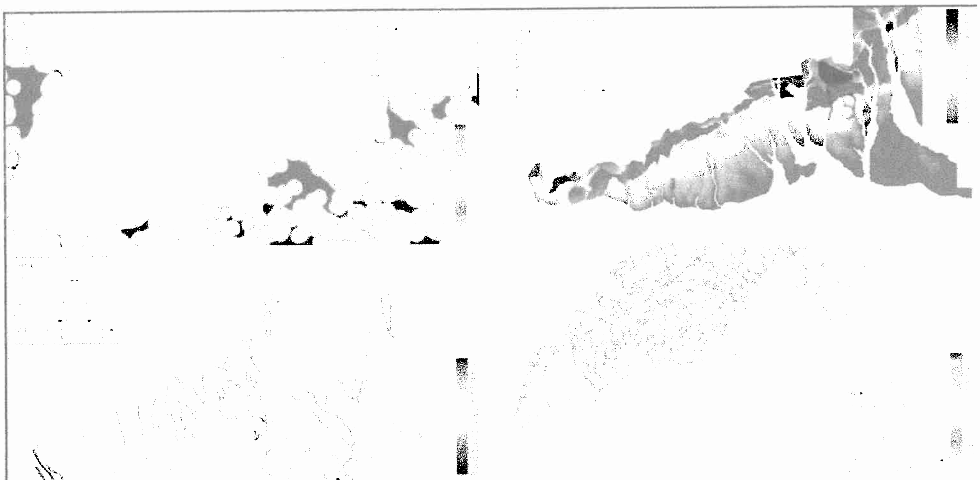
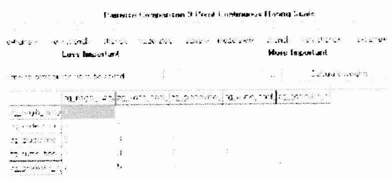


Figure 4: Fuzzy models for forest area, hydrogeological area, water area and slope

MULTI-CRITERIA ANALYSIS

MCA is a technique that allows for the measurement and aggregation of the performance of alternatives or options, involving a variety of both qualitative and quantitative dimensions. As a means of considering the links among biophysical, economic and social data with human imperatives, it is therefore particularly useful for approaching complex interactions and effects in the context of land use and land management (Medved, 2010).
There are many variants of the general MCA method that can be applied in a wide variety of contexts. Many approaches are based on the pairwise comparison method of the Analytical Hierarchy Process (Saaty 2000; Ramanathan 2001). Well-developed MCA methods usually share a number of characteristics. Generally, they are flexible, enable the capture of quantitative and qualitative data and issues, are relatively simple for clients and stakeholders to use, permit the development of many alternative scenarios, allow the exploration of trade-offs, and enable stakeholders to factor results into decision making.



Input data	Weight
Slope	0.21
Water surface	0.09
Construction	0.05
Forest areas	0.19
Hydro-geological properties of soil	0.47
Coefficient of consistency: (CR)	**0.03**

Figure 5: Saaty's scale interdependence to define weight and weight and the coefficient of consistency

The MCA process is a tool to assist decision makers in reaching outcomes it does not do the decision making, or produce a solution. Attention must be given to how information quality and uncertainty is factored in and integrated with stakeholder viewpoints and biases, political and structural realities, and achievability versus optimality. It is important that each stage of the MCA process is carried out rigorously, in parallel with stakeholder engagement. Matching the spatial and temporal scale of the input information and analysis to the issues and processes under consideration is also critical (Sharifi et al, 2003).

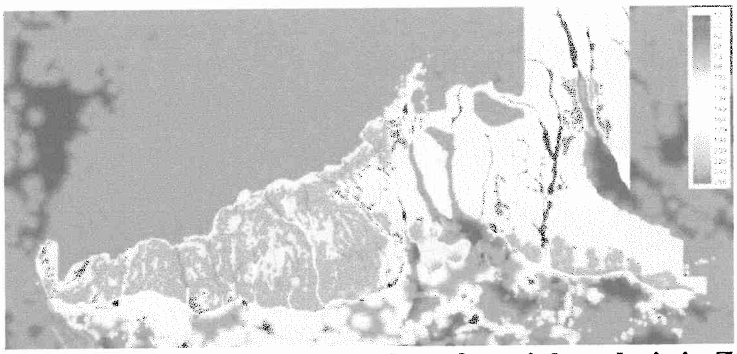


Figure 6: The result of multi-criterion of spatial analysis in Zagreb

CONCLUSION

In this study, we applied fuzzy logic integration approach for landslide hazard mapping using multiple spatial data sets, and outlined the areas that will be affected by future landslides. To combine various spatial data, fuzzy inference networks using combining some fuzzy memberships in series and others in parallel. We remind that the results in this study are not general ones, so extensive experiments should be made in several study areas to strengthen the situation here identified. To assess quantitatively the prediction powers of various fuzzy inference networks, cross-validation approach was also performed. With the help of cross-validation approach, we can evaluate the prediction results quantitatively, and compare with models. Without this kind of the cross-validation technique, prediction maps cannot be evaluated. For the future works, several aspects still need to be considered. For any prediction models to generate reasonably "good or significant" results, the prediction result should be robust and stable. For this, we are currently evaluating the stability analysis using matching rate function. In addition, we will try to involve the fuzziness of boundaries in categorical maps such as forest, soil, and lithology maps, in data representation stage. Visual evaluation of overlapping of landslide susceptibility zones and landslides shows that the most of landslides are correctly placed in high susceptibility areas. It is concluded that the content and quality of input data are satisfactory for better understanding of regional landslide cause.

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