Fuzzy Logic Method for Landslide Susceptibility Mapping, "Rio Blanco", Nicaragua

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1. Introduction

In June 2004 the Nicaraguan district of Rio Blanco was severely affected by landslides. Over 700 landslides of changing size and type posed a great impact on the vulnerability of the regions infrastructure, housings and inhabitants. In order to help regional planers a landslide susceptibility map was produced.

In this analysis, a GIS based fuzzy logic approach was used to do a fast and feasible landslide susceptibility analysis of the region of Rio Blanco - Nicaragua.

2. Study Area

The district of Rio Blanco (250 north - east to Nicaraguas´ capital Managua) is part of the department of Matagalpa, Nicaragua. Rio Blanco has an area of approximately 700km².

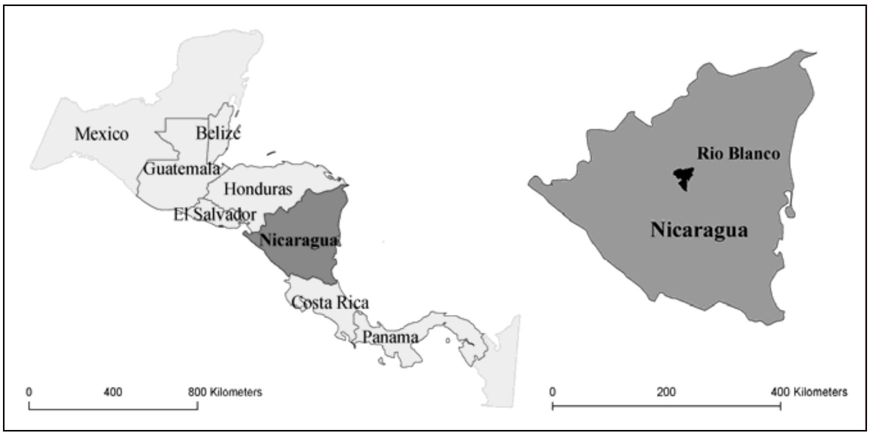

Figure 1. District of Rio Blanco, Nicaragua

3. Landslides in Rio Blanco

For generalization purposes the term landslide in this paper will be used in the broadest sense, regardless of the characteristic of a mass movement. In total 785 landslides have been counted.

Type	Number	%	Volume in m³
Debris flow	483	61,5	50 - 6,000,000
Mud flow	227	28.9	20 - 6,000
Rotational slide	71	9.0	200 - 265,000
Planar slide	3	0.4	3,000 - 300,000
Debris avalanche	1	0.1	> 1,000,000
Total	785	99.9	

Table 1. Landslide types in Rio Blanco

4. Fuzzy logic based method for landslide susceptibility mapping

The landslide analysis approach chosen for this analysis falls under the category of susceptibility mapping. Susceptibility maps predict where slope failures are most likely to occur and disregard out the factor "when" of hazard maps (Brabb 1984).

Methods to make landslide hazard or risk maps have not been used. A regional method was applied in the analysis. Regional methods allow for assessment of slope instabilities over wider areas on a medium to small scales (1:25,000 – 1:100,000). Regional methods can be used for the evaluation of areas where further local geotechnical investigation might be necessary. The idea behind the fuzzy logic method is, to consider all spatial objects on a map, as members of a set.

Fuzzy logic is based on the concept of partial truth. In the classical set theory membership is defined as 1 = true or 0 = false. The classical set theory does not allow thresholds. Thus slope is susceptible for landslides (1) or not (0). In a fuzzy set, membership is expressed on a continuous scale from 1 full to 0 full non-membership. In landslide susceptibility mapping fuzzy logic defines the instability factors as members of a set reaching from 1, expressing the highest susceptibility, to 0, expressing no susceptibility of landsliding, allowing different degrees of membership. Fuzzy logic applied on the search of slopes susceptible to landslides allows the use of thresholds. A slope might become susceptible at a steepness of 5% as lower threshold and can reach up to 30 % as highest threshold. Applying the fuzzy logic approach allows as to define the "steep slopes" in degrees of membership (Lorup 1999).

The classes of any map can be associated with fuzzy membership values, regardless the measurement scale the data. Based on a subjective judgement, values are chosen, to show the degree of a membership (Bonham-Carter 1994). Fuzzy represents membership in vaguely defined sets and not the likelihood or condition. Several fuzzy operators (fuzzy AND, fuzzy OR, fuzzy algebraic sum, fuzzy algebraic product and fuzzy gamma) allow the flexible combination of input maps (instability factor maps) in a series of steps. In this analysis fuzzy gamma is used. The fuzzy algebraic sum and the fuzzy algebraic product were calculated and combined using the fuzzy gamma operator.

Fuzzy gamma is a compromise between increasing tendencies of the fuzzy algebraic sum and the decreasing effect of the fuzzy algebraic product. With y (gamma) the decreasing or increasing tendency can be controlled. Y (gamma) is a parameter chosen between 0 and 1. When y is 1 the combination equals the fuzzy algebraic sum, when y is 0 the combination equals the fuzzy algebraic product.

An advantage of the fuzzy gamma operator is, that different scenarios can be compared easily yet from the maps produced during the process; trends of the final results can be seen.

5. APPLICATION OF THE FUZZY LOGIC APPROACH

Due to limited access to data only the following data layers could be used for the analysis: Digital elevation model, lithology, land cover, land change (LANDSAT classification) and the soil types.

Based on this data, input maps for the fuzzy model have been generated. By considering the spatial distribution of landslides, susceptibility levels have assigned to the input data, resulting in fuzzy membership values. The "fuzzyfied" instability factor maps have been combined using the fuzzy gamma operator.

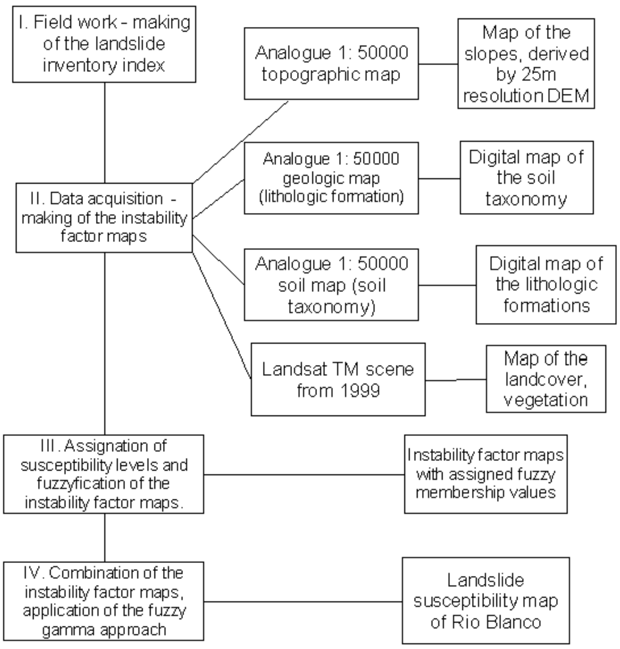

Figure 2. Workflow diagram of the landslide susceptibility analysis (Schernthanner 2005)

NDVI, land cover and land use classes have been derived from a Landsat TM scene covering the area. Slope classes, calculated from the digital elevation model, the distribution of known landslides, soil types, lithology and the vegetation density have been used as parameters to weight the input factor maps according to their landslide susceptibility. Next the weighted input factor maps have been "fuzzfied" and the "fuzzified" instability factor maps have been combined using the fuzzy gamma operator, resulting in the final landslide susceptibility map

To compare several results and to find a good compromise between the decreasing and the increasing effects of the fuzzy algebraic product and the fuzzy algebraic sum, different gamma values have been used. For the final interpretation of the slope instability susceptibility the fuzzy gamma value 0,8 was used, as a compromise between an increasing and the decreasing effect of the fuzzy gamma approach.

5.1 Landslide Susceptibility Levels

As result of the analysis a map showing the calculated fuzzy values was provided. These fuzzy values have been "defuzzyfied" into different landslide susceptibility levels. Defuzzyfication means to translate the calculated fuzzy values back to the "real world".

The final landslide susceptibility levels reach from 0 - 0,5 representing the areas with the lowest landslide susceptibility until 0,6 to 1 representing the highest landslide susceptibility.

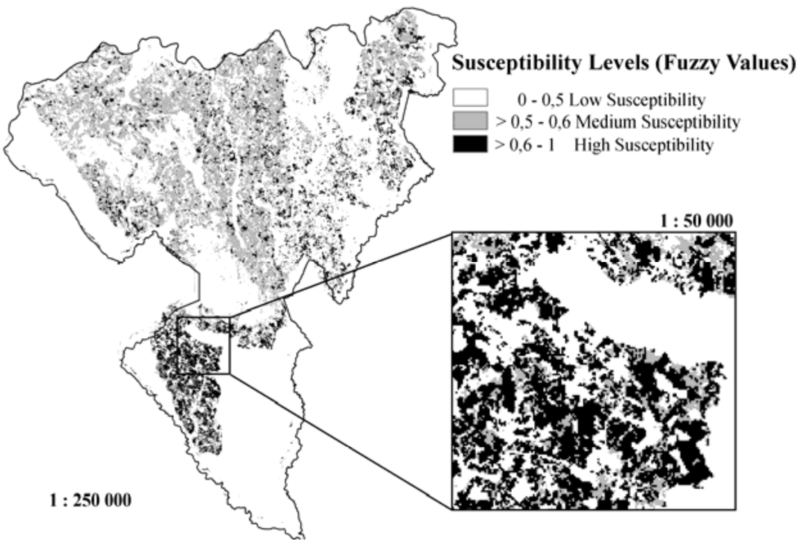

Figure 3. Overview of the zones with low to high landslide susceptibility and detailed spatial clip showing zones with low to high landslide susceptibility.

6. Conclusions

By using the fuzzy logic approach, landslide susceptibility analysis can be done under the circumstance of having few existing data about the factors causing the landslides.

Fast and feasible analysis of landslides can be carried out by using fuzzy logic. Data collection and manipulation and the analysis of the necessary environmental data for landslide susceptibility analysis can be done very cost effective (Carrara 1993).

The output susceptibility map of such an analysis can be used as a good regional planning tool but is not recommended for individual site-specific evaluation of the landslide susceptibility.

One of the most important advantages of fuzzy gamma is the inexpensive fast application by combining few available information. Different scenarios can be examined by GIS operators, because of the flexible combination of input maps. The production of intermediate maps and the flexible integration of new data layers into the model allow testing effects on the final susceptibility map. Because of the membership function approach, areas susceptible to landslides have found, that previously have not been found using other methods (index overlay for example). The fuzzy logic method is subjective and depends on expert knowledge. Data of varying reliability was used in the analyses, however the relative weight of the input data can be controlled, and the importance of each condition can be assessed.

7. References

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