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# Assessment of failure susceptibility of soil slopes using fuzzy logic

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**Abstract**

Generally, the process of land occupation in urban areas involves spaces that are not suitable for construction. In most cases these areas are subject to landslides. Therefore it is mister the development of models to evaluate the susceptibility of occurrence of landslides in these areas. For this, Fuzzy Logic is used herein for modeling such areas where landslides are susceptible to occur and, therefore, a direct evaluation is important. The possibility of capturing the judgment and the modeling of linguistic variables are the main advantages of using Fuzzy Logic. These models are capable to capture the factors directly affecting the slope stability and also the inter-relationship amongst them. These factors were chosen by experts to whom a questionnaire was sent. Fuzzy Logic was then used to transform the linguistic variables into fuzzy number, allowing thus, the calculation of failure potential index (FPI). Herein the MAX–MIN Mamdani strategy for the inference of the rule base was used. This methodology has been applied to identify the susceptibility of landslides in a chaotic occupied urban area of Itaperuna City in northeastern of Rio de Janeiro, Brazil, where some occurrences have been reported.


*Keywords:* Fuzzy logic; Susceptibility mapping; Soil slope

## 1. Introduction

Slope stability is one of the most important and complex issues for geotechnical engineers, mainly due to high economical and life losses resulting from these failures. Thousands of deaths and billion dollars of damages are credited to slope failures each year throughout the world. This is particularly important in developing countries where the land occupation is almost always done in unrestrained way. Moreover, the urbanization phenomena under pressure, intensifies chaotic search for places, generally geologically unsuitable, where the population lives under constant disaster threats. This disordered occupation model is one of the main causes of problems in urban hillside areas. In organized model, geological factors prevail over anthropogenic ones, however in chaotic occupation, environmental factors will prevail over all others. Suarez (1997) has found a direct relationship amongst the number of occurrence in Rio de Janeiro city and the localization of chaotic occupied areas (slums), where 60% of failures were linked to cuts, embankments over steep slopes, lack of drainage systems, domestic waste disposal and deforesting.

In order to improve this scenario, most developing countries have endeavored efforts to offer the population technical and scientific support as helpful tools to identify and, when possible, repair potentially dangerous areas. Most of these actions are concerned in establishing a database of case histories and thus, develop methodologies for mapping dangerous areas. The main aim of these actions is not to

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assess the stability in critical isolated points, but yes, to evaluate the landslide susceptibility of extensive areas.

In this paper, a methodology is shown to assess the susceptibility areas regarding slide in soil slopes. This methodology is based on susceptibility analysis, which has the Fuzzy Logic as the theoretical background. It seems important to mention that the study proposed here does not consist of risk evaluation but to evaluate the susceptibility of sliding based on surface and subsurface characteristics of the area.

Fuzzy Logic, a generalization of classical set theory, is very attractive for the evaluation of slope failure susceptibility, due to its capability of transporting to the mathematical field, the subjective, inductive and deductive judgments that are essentials in such a comprehensive study. This is especially important and attractive in cases where data are imprecise and the available information is somewhat vague. Fuzzy Logic also allows one to take into account the relationship among these factors, which seems to be crucial in assessing the potential of failure of soil slope.

Finally, this methodology is applied to a hillside area in Itaperuna city in the State of Rio de Janeiro, Brazil, where several cases of sliding have been reported recently, with casualties.

## 2. Fuzzy Logic

Fuzzy Logic is the only mathematical theory with capability of processing linguistic terms and was developed approximately three decades ago (Zadeh, 1975; Sundararajan, 1998), being the fuzzy sets theory as background. Since then, it has been applied to a wide range of knowledge expertise areas. The most notable aspect of this methodology is the possibility of capturing, in a mathematical model, intuitive concepts which are the base of consistent judgment.

Fuzzy Logic was first proposed by Zadeh (1965) to allow modeling of the vagueness in information. In the classical Boolean Logic, a given element either, belongs or does not belong to a specific set, i.e., there is no possibility of modeling a degree of "belonging". On the other hand, Fuzzy Logic specifies a membership function that can vary from 0 to 1, where the extreme values represent the Boolean Logic (Fig. 1). The membership function associates the linguistic terms to degrees of membership allowing, thus, a numerical meaning of the "degree of belonging" of a variable to a specified universe of discourse. It is the key for modeling ill-defined systems mimicking the human brain when managing unclear information. Adjectives as *old*, *hot*, *tall*, etc. are clear examples of vague information with cloudy domain or boundaries.

Despite being incipient in civil engineering, this methodology has found great applicability in this field where, most of time, the objective determination of variables involved on certain problems is replete of uncertainty, or yet, where the degree of subjectivity is rather high.

Thus, for geotechnical problems like borehole interpretation, reducing data instrumentation, risk analysis and mapping of susceptibility areas, among others, it is very convenient to capture the expert's experience in order to transform it in membership degree, rule base and, subsequently, in a decision.

In the case of a soil slope, the basic idea is to try to "model" the expert's mind during field inspection of slope conditions. In order to construct a comprehensive model based on human thinking, it is necessary firstly to answer the following questions: What does this specialist really takes into account? What are the main factors to be observed in the field? What are the interrelationships among these factors? The answers to these questions constitute the basis where a comprehensive rule base in Fuzzy Logic model should be anchored.

Finally, it is important to stress that Fuzzy Logic applied to analysis of landslide susceptibility, as proposed herein, does not intend to replace traditional methods, but yes to be a complementary option. These, most of the time, call for comprehensive field and laboratorial geotechnical investigation. On the other hand, Fuzzy Logic has as the main advantage, the possibility to take into consideration the expert opinion, the case history and the degree of subjectivity. The later is considered to be one of the most important features in geotecnhical analysis. For this particular purpose, Fuzzy Logic can be easily used as a first approach to the selection or identification areas to be studied with more detailed.

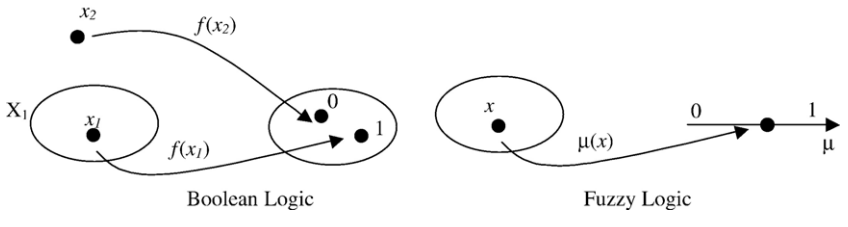


Fig. 1. Boolean logic and Fuzzy Logic concepts (Bueno et al., 2000).