Risk Assessment for Urban Area Using Fuzzy Logic

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KEY WORDS: Risk Assessment, Fuzzy Logic, GIS, Urban Area

ABSTRACT:

Regarding the complexity of natural disasters in cities and the urgent need to employ methods in order to reduce the risk in residential areas, the risk management as a new and effective method in preventing and preparation for critical situations, has been employed in different ways throughout the world. Risk management includes a set of processes needed for identification, analysis and reaction against the crisis that aims at maximization of desired goals and minimization of risks and adverse consequences. This paper intends to present a GIS-based fuzzy approach for risk assessment in residential areas. Places such as medical centers and parks are effective factors in reducing the risk and the gas stations and high voltage power stations are factors that increase the risk. Now regarding the distance between each urban feature and the above features, fuzzy linguistic variables are defined and according to the rules extracted by expert, the risk of each feature is separately estimated and designed as a risk map for each area. Now with the help of this map, we can reduce the risk to which every building is subjected by constructing the needed centers and also fortification plans.

1. INTRODUCTION

1.1 Risk Assessment

Risk is, at minimum, a two dimensional concept involving (1) the possibility of an adverse outcome, and (2) uncertainty over the occurrence, timing, or magnitude of that adverse outcome. People talk about risk when there is the chance, but not the certainty, that something they do not want may happen (Chongfu 1996). Risk assessment can be defined as a systematic process for generation a probability distribution or similar quantification that describes uncertainty about the magnitudes, timing and so on. The purpose of risk assessment is to provide an important part of the information needed to support risk management (identifying, selecting, and implementing appropriate action to control the risk (Chongfu 1996). An urban risk assessment is a multi-disciplinary process unavoidably involving different stakeholders. In this context, the implementation of an urban risk assessment requires an extensive participation of various parties at stake, in particular, decision/policy makers and urban planners, who are the most immediate users of the risk assessment results. The purpose of an urban risk assessment is to create an evidence-based understanding of the magnitude, characteristics, spatial distribution, causes and possible mitigation options of disaster risks in an urban area. This understanding of risk is a critical input in the formulation or revision of city disaster risk reduction strategies, action plans, and contingency plans. There are specific objective that urban risk assessment is going to achieve them: To produce a comprehensive multi-hazard urban risk profile, to establish an urban risk information system, to develop the capacity for risk assessment at local level; and to strengthen the urban disaster risk reduction system as a whole.

1.2 GIS and Risk Assessment

GIS technology is increasingly being used in spatial decision support systems. In the past few years, GIS emerged as a powerful risk assessment tool and is being put to use to assess risk to property and life stemming from natural hazards such as earthquakes, hurricanes and floods. Manipulation, analysis, and graphic presentation of the risk and hazard data can be done within a GIS system, and because these data have associated location information which is also stored within the GIS, their spatial interrelationships can be determined and used in computer based risk assessment models. This assessment can be used by insurance companies to help them make decisions on their insurance policy rates, by land developers to make decisions on the feasibility of project sites, and by government planners for better disaster preparedness. GIS in conjunction with remote sensing and photogrammetry, can be used to identify hazards. Seismic faults and flood prone areas can be identified by scientists using GIS to analyse satellite image, aerial photos and field survey data.

2. FUZZY LOGIC

2.1 Introduction

Fuzzy Logic was initiated in 1965 by Lotfi A. Zadeh, professor for computer science at the University of California in Berkeley (Hellmann 2001). Traditionally, fuzzy logic has been viewed in the AI community as an approach for managing uncertainty (Yen 1999). Basically, Fuzzy Logic (FL) is a multi-valued logic that allows definition of intermediate values between conventional evaluations like true/false, yes/no, high/low, etc. Specifically, Zadeh suggested to use fuzzy sets to represent notions like tall and beautiful in natural language phrases like The tall dwarf is more beautiful than the small giant (Freksa 1994). Fuzzy Logic has emerged as a profitable tool for the controlling and steering of systems and complex industrial processes, as well as for household and entertainment electronics, as well as for other expert systems and applications (Hellmann 2001).
2.2 Fuzzy sets and Crisp sets

In most everyday kinds of thinking and linguistic reflections of that, people use crisp sets to categorize things. Being a member of a crisp set is an all or nothing affair. Thinking with crisp sets makes everything simpler, because something either is or is not a member of a crisp set. They can be used to represent black and white conceptual thinking. Oftentimes too, when something is a member of a given crisp set it is then (at the same time) not a member of any other crisp set. Again this simplifies the logic used with this kind of thinking process. Linguistic constructions which reflect this kind of thinking can be quite useful. In the below figure, crisp and fuzzy set are displayed. In the left diagram, the characteristic function of A or Ā assigns a number 1 or 0 to each element in X, depending on whether the element is in the subset A or not.

Fuzziness, or fuzzy sets are used frequently also by most people in everyday thinking and their linguistic constructs reflect them as well. This concept is sufficient for many areas of applications, but it can easily be seen, that it lacks in flexibility for some applications. A fuzzy set allows us to define such a notion. The aim is to use fuzzy sets in order to make computers more "intelligent", therefore, the idea above has to be coded more formally. For example, all the elements were coded with 0 or 1. A straight way to generalize this concept is to allow more values between 0 and 1. In fact, infinitely many alternatives can be allowed between the boundaries 0 and 1, namely the unit interval I = [0, 1]. The interpretation of the numbers, now assigned to all elements is much more difficult. Of course, again the number 1 assigned to an element means that the element is in the set and 0 means that the element is definitely not in the set. All other values mean a gradual membership to the set.

2.3 MATLAB's Fuzzy Logic Toolbox

In the lack of precise mathematical model which will describe behaviour of the system, Fuzzy Logic Toolbox is a good "weapon" to solve the problem: it allows using logic if-then rules to describe the system's behaviour (Nedeljkovic 2004). This toolbox is a compilation of functions built on the MATLAB® numeric computing environment and provides tools for creating and editing fuzzy inference systems within the framework of MATLAB. The toolbox provides three categories of tools (Jang and Gulley 1997):
- Command line functions,
- Graphical interactive tools and
- Simulink blocks and examples.

The Fuzzy Logic Toolbox provides a number of interactive tools that allow accessing many of the functions through a graphical user interface (GUI). Fuzzy Logic Toolbox allows building the two types of system:
- Fuzzy Inference System (FIS) and
- Adaptive Neuro-Fuzzy Inference System (ANFIS).

2.3.1 Fuzzy Inference System

Fuzzy inference is the process of formulating the mapping from a given input to an output using fuzzy logic (Jang and Gulley 1997). The process of fuzzy inference involves membership functions, fuzzy logic operators and if-then rules. There are two types of fuzzy inference systems that can be implemented in the Fuzzy Logic Toolbox:
- Mamdani-type and
- Sugeno-type.

These two types of inference systems vary somewhat in the way outputs are determined. Mamdani's fuzzy inference method is the most commonly seen fuzzy methodology and it expects the output membership functions to be fuzzy sets. After the aggregation process, there is a fuzzy set for each output variable that needs defuzzification. Sugeno-type systems can be used to model any inference system in which the output membership functions are either linear or constant. Sugeno output membership functions (z, in the following equation) are either linear or constant. A typical rule in a Sugeno fuzzy model has the following form (Jang and Gulley 1997):

If Input 1 = x and Input 2 = y, then Output is z = ax + by + c

For a zero-order Sugeno model, the output level z is a constant (a=b =0).

2.3.2 Membership Function

Membership function is the mathematical function which defines the degree of an element's membership in a fuzzy set. The Fuzzy Logic Toolbox includes 11 built-in membership function types. These functions are built from several basic functions (Jang and Gulley 1997):
- Piecewise linear functions,
- Gaussian distribution function,
- Sigmoid curve
- Quadratic and cubic polynomial curve.

2.3.3 Fuzzy Logic Operator

The most important thing to realize about fuzzy logical reasoning is the fact that it is a superset of standard Boolean logic. In other words, if the fuzzy values are kept at their extremes of 1 (completely true) and 0 (completely false), standard logical operations will hold. (Nedeljkovic 2004)
2.3.4 If-Then rules
Fuzzy sets and fuzzy operators are the subjects and verbs of fuzzy logic. Usually the knowledge involved in fuzzy reasoning is expressed as rules in the form (Jang and Gulley 1997):

If x is A Then y is B

Where x and y are fuzzy variables and A and B are fuzzy values. The if-part of the rule “x is A” is called the antecedent or premise, while the then-part of the rule “y is B” is called the consequent or conclusion. Statements in the antecedent (or consequent) parts of the rules may well involve fuzzy logical connectives such as ‘AND’ and ‘OR’. In the if-then rule, the word “is” gets used in two entirely different ways depending on whether it appears in the antecedent or the consequent part.

3. METHODOLOGY

3.1 Data Preparation and Computation
In the first step we need to prepare spatial data for ward 6 of Tehran. In this research for convenient, the ESRI shape files of Tehran is used. Point shape files of parks, schools, hospitals, gas stations and municipalities as point features, polyline of streets as line features and polygon of urban parcels is used as area features. Places such as parks, schools due to large area are positive factors and useful places for refuge. Hospitals, medical centers and municipalities due to offering sanitary and public services are also positive and effective factors for reducing the risk and hazards. In the other hand, places such as gas stations and high voltage power stations are places that at the time of disaster can increase the hazard for their neighbourhoods. Next step is calculating distance between centroid of each parcel to mentioned places. Depending on the type of feature this could be Euclidian distance or distance on the network of street. For calculating distances between parcels and parks, hospitals, schools and municipalities we have to compute distances on the street network, because access to such places must be through street network. For computing these distances we need to use shortest path algorithms such as Dijkstra, Acyclic and Bellman-Ford. In this paper Dijkstra algorithm is used for shortest path computation. In other hand distances to gas stations must not be computed through street network. For computing these distances Euclidian distance must be used.

3.2 Fuzzification
Fuzzification of input variables is the first step in inference system that takes the inputs and determines the degree to which they belong to each of the appropriate fuzzy sets via membership functions. In proposed fuzzy inference system for urban risk assessment, input variables are distances to effective factors such as hospitals that decrease urban risk and deleterious factors such as gas stations that increase urban risk. Figure 6 is shown Membership function plots of input variable following distance to park. In this case, we rated the distance as 400m, which, given our graphical definition of medium, corresponds to μ = 0.8 for the “Medium” membership function.

Figure 4. Membership function plots of input variable(Distance)

3.3 Fuzzy Rule Defining
Linguistic fuzzy rules describing the fuzzy systems consist of two parts; an antecedent block (between the IF and THEN) and a consequent block (following THEN). In this research the antecedent blocks are consist of linguistic values for distances, contain near, medium and far that indicate distance between each parcel to mentioned places. The consequent blocks indicate linguistic value for risk, include: very low, low, medium, high and very high. Finally for generating a risk map of ward 6 of Tehran, 60 fuzzy rules in this fuzzy system is used. Examples of fuzzy rules are bringing in following table.

<table>
<thead>
<tr>
<th>R#</th>
<th>D to Park</th>
<th>D to Hospital</th>
<th>D to School</th>
<th>D to Gas Station</th>
<th>Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>1:</td>
<td>low</td>
<td>low</td>
<td>low</td>
<td>high</td>
<td>low</td>
</tr>
<tr>
<td>2:</td>
<td>low</td>
<td>medium</td>
<td>medium</td>
<td>medium</td>
<td>medium</td>
</tr>
<tr>
<td>3:</td>
<td>high</td>
<td>high</td>
<td>high</td>
<td>low</td>
<td>high</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>N:</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>

Table 1. Example of fuzzy rules applied to fuzzy logic-based risk assessment (D stands for Distance).

The surface relationships of input and output linguistic relations as per the fuzzy logic rule-base are shown in Fig. 3.
3.4 Defuzzification

Defuzzification is the process of transforming a fuzzy output of a fuzzy inference system into a crisp output; but before defuzzification, aggregation is necessary. Aggregation is the combination of the consequents of each rule in a Mamdani fuzzy inference system in preparation for defuzzification. The fuzzy outputs for all rules are finally aggregated to one fuzzy set. To obtain a crisp decision from this fuzzy output, we have to defuzzify the fuzzy set, or the set of singletons. Therefore, we have to choose one representative value as the final output. Perhaps the most popular defuzzification method is the centroid calculation, which returns the center of area under the curve. The consequence of each rule refers to one output membership function such as very low. Membership function plots of output variable are shown in figure 5. Now regarding the consequences of all rules, using center of gravity (COG) defuzzification method, we will be able to obtain a crisp value between zero and one refers to risk of each parcel.

Running proposed fuzzy inference system for all of urban parcels will generate a fuzzy risk map (Figure 7).

4. CONCLUSIONS AND DISCUSSION

This paper presents a methodology for risk assessment of urban area. The implementation of fuzzy logic based risk assessment is providing a framework for addressing to vague and uncertain parameters in risk assessment; the risk factors which affect the risk of urban area are varied and complex and the properties of these factors are very different. Damage estimation leads to the knowledge and awareness of the possible hazards related with some region and they can be used for educating the people about such disasters and thus improving the preparedness to face such disasters. Generated risk map, could be a reliable map that indicates area subjected to danger and with the help of this map urban planners and managers will be able to reduce the by constructing the needed centers and also fortification plans.

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