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Research on flood risk analysis and evaluation method based on variable fuzzy sets and information diffusion

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ABSTRACT

Floods have become increasingly alarming worldwide. Flood risk management in terms of assessing disaster risk properly is a great challenge that society faces today. Natural disaster risk analysis is typically beset with issues such as imprecision, uncertainty, and partial truth. There are two basic forms of uncertainty related to natural disaster risk assessment, namely, randomness caused by inherent stochastic variability and fuzziness due to macroscopic grad and incomplete knowledge sample. However, the traditional probability statistical method ignores the fuzziness of risk assessment with incomplete data sets and requires a large sample size of data. The fuzzy set methodology is introduced in the area of disaster risk assessment to improve probability estimation. The purpose of the current study is to establish a fuzzy model to evaluate flood risk with incomplete data sets. The present paper puts forward a composite method based on variable fuzzy sets and information diffusion method for disaster risk assessment. The results indicate that the methodology is effective and practical; thus, it has the potential to forecast the flood risk in flood risk management. We hope that by conducting such risk analysis, the impact of flood disasters can be mitigated in the future.

1. Introduction

Water, a special resource which sustains all forms of life, is an essential substance for the sustainable development of society. With the recent rapid development of the economy and the growth of population, flood, drought, water resource shortage, and water environment deterioration have become more acute. In particular, recent flooding disasters have shown the vulnerability of developed and developing countries to such events. In China, flood disasters occur frequently, and about two-thirds of its area faces the threat of different types and degrees of floods. These phenomena are the result of natural and unnatural factors, such as social and economic factors. Severe floods occur frequently, so flood risk management plays an important role in guiding the government in making timely and correct decisions for flood rescue and relief.

Risk assessment is the use of scientific data to define the probability of some harm coming to an individual or a population because of exposure to a substance or situation. However, assessing flood risk is difficult because of the lack of objective measures of acceptable risk, scarcity of data, and abundance of unknown probability distributions. In traditional flood risk assessment, probability statistics method is usually used to estimate the exceedance probability of the hydrological variables. However, in the case of practical issues, problems exist in feasibility and reliability without considering the fuzzy uncertainty. In small sample issues, results based on classical statistical methods are sometimes very unreliable, because collecting long-sequence flood data is rather difficult and the sample is always small.

In general, the uncertain feature of risk is relative to both randomness and fuzziness. For example, the occurrence of flood is a random event. However, the flood degree is a fuzzy concept. In the process of risk evaluation, randomness is due to a large amount of existing unknown factors, whereas fuzziness is concerned with the terms of macroscopic grad and incomplete knowledge sample (Huang, 1997). Using fuzzy sets theory (Zadeh, 1965), the data may be defined through vague, linguistic terms, such as low probability, serious impact, or high risk. These terms cannot be defined meaningfully with a precise single value, but fuzzy set theory provides the means by which these terms may be formally defined in mathematical logic. In practice, avoiding the gaps caused by the scarcity of data is impossible, which causes fuzziness (imprecision, vagueness, incompleteness, and so on). Therefore, we have to deal with the fuzziness of a risk system (Huang, 2002).

In many cases, the analysis of a risk system is too complex to understand by random viewpoint. A natural way to improve risk analysis is to introduce a concept of fuzzy risk to overcome difficulties from fuzzy environments with incomplete knowledge. More

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importantly, a concept of fuzzy risk provides flexibility in the way risk information is conveyed.

There are many ways to fill up gaps caused by scarcity of data. The most popular is employing expert experience in empirical Bayesian methods. Many fuzzy methods have been developed to smooth out the gaps to some degree. The objectives of the current study are to find a more effective way of expressing the vagueness and imprecision of natural disaster risk assessment and to find an acceptable way of communicating these imprecisions. Independent of those methods, we use a new technique to transport information carried by the data sets to the gaps. This method is called information diffusion method (IDM), which helps extract as much useful underlying data as possible from the sample, thus improving the accuracy of system recognition (Huang and Shi, 2002; Palm, 2007). Information diffusion is a fuzzy mathematical set-value method for samples, which optimizes the use of fuzzy information of samples to offset the information deficiency.

Constructing a disaster control engineering system is a synthesis of multi-dimensional factors, so its risk evaluation shall be operated from single factor to multifactors. This procedure implies that routine evaluation method often omits important information and cannot obtain integrated risk evaluation for engineering systems. Accordingly, under the global view of systems founded upon the characteristics of risk evaluation, variable fuzzy set (VFS) is presented to evaluate the synthetic risk of disaster control engineering system. The method can scientifically and reasonably determine membership degrees and relative membership functions of disquisitive objectives (or indicators) at level intervals relating to the disaster. Furthermore, VFS can fully utilize one's experience and knowledge and integrate the qualitative and quantitative information of the indicator system with analytical hierarchy process (AHP) to obtain the weights of the objectives (or indicators) for the comprehensive evaluation of floods (Wang et al., 2011; Zhang et al., 2011).

In the current study, we establish a synthetic disaster risk assessment model based on information diffusion and VFS with a small number of measured samples. The model is applied to the flood risk analysis in China successfully. In Section 2, we discuss incompleteness and analyze its relation to fuzziness to show why any incomplete knowledge set carries fuzzy information. In Section 3, we briefly describe some basic concepts and principles of the modeling framework. This is a new attempt at applying information diffusion theory and VFS in flood risk analysis. Computations based on this analytical flood risk model can yield a relatively accurate estimated flood damage value. An example is carried out, and the finding indicates that the model exhibits fairly stable analytical results, even when a small set of sample data is used. The results also indicate that the method is highly capable of extracting useful information, thereby improving system recognition accuracy. These results are shown in Section 4. Finally, discussions and conclusions are presented in Section 5.

2. Incompleteness and fuzziness

When we study a natural disaster risk system, we sometimes meet the small sample problem, where the data is too scanty to make a decision in any classical approach. Therefore, the size of a sample observed must be insufficient. Avoiding the so-called incompleteness is difficult when we study a natural disaster risk system.

Chaitin proposed that incompleteness and fuzziness are subtly related (Chaitin, 1990) because simple mathematical questions do not always have clear answers and some questions can give answers that are completely random and look gray, rather than black or white. Therefore, when we study an incomplete sample, we cannot avoid its fuzziness. In the process of risk assessment, the randomness is due to a large amount of unknown factors. Fuzziness is concerned with the fuzzy information associated with an incomplete data set with respect to scarcity. This kind of fuzzy information is called mass-body fuzzy information (Huang and Shi, 2002). The main task of processing the mass-body fuzzy information is to unearth (or mine) fuzzy information, which is buried in an incomplete data set. This process is called information diffusion, wherein information is defined as the data organized to reveal patterns. The earliest and the most widely used model is the linear information distribution (Liu and Huang, 1990), which divides into two parts an observation-carrying information as a measure value of 1. Another model is the normal information diffusion (Huang, 1997), in which an observation is changed into many parts according to a normal function.

When we study a risk system using a probabilistic method, it is usually difficult to ascertain if a hypothesis of probability distribution is suitable, and sometimes we meet the problem of small samples, wherein the data is too scanty to make a decision. The problem has shown that empirical Bayesian methods (Carlin and Louis, 1997) and kernel methods (Breiman et al., 1977; Chen, 1989; Devroye and Gyorfi, 1985; Hand, 1982; Parzen, 1962; Silverman, 1986; Wertz, 1978) need further development. Obtaining a precise relation between events and probabilities of occurrence is difficult. Going a step further, if we employ other methods to simplify system analysis, obtaining the precise relations we need is also difficult. In other words, the relations we obtain are usually imprecise. To keep the imprecision, the best way is to employ fuzzy sets to represent the relations.

Fuzzy set theory, which deals with uncertainties and allows the incorporation of the opinions of decision makers, may provide an appropriate tool for establishing disaster risk management systems, such as fuzzy rule-based techniques and the combination of the fuzzy approach with other techniques. Risk is expressed in terms of fuzzy risk only when we study it by a fuzzy method. Some early related applications can be found in the literature (Brown, 1979; Clements, 1977; Dong et al., 1985; Esogbue et al., 1992; Hadipriono Timothy and Fabian, 1991; Hoffman et al., 1978). Fuzzy risk is an engineering concept, which can be defined as an approximate representation to show risk with fuzzy theory and techniques. In general, a fuzzy risk is a fuzzy relation between loss events and the factors concerned.

The concept of the fuzzy set was proposed by Zadeh (1965), who bestowed media and fuzziness scientific description and great significance in the academic world. However, the fuzzy set is static if the relativity and variability are not considered. Therefore, the theory is in conflict with the variability of the interim form. Some defects of traditional fuzzy sets are due to approaching the media, variable fuzzy phenomenon, and variable fuzzy objects by static concepts, theory, and method of fuzzy sets.

In light of the foregoing, the theory and method of VFS was proposed by Chen based on opposite fuzzy sets and the definitions of a relative difference function (Guo and Chen, 2006; Wu et al., 2006). The method of Chen is the innovation and extension of the static fuzzy set theory established by Zadeh (1965), which is very important in theory and applications. The comprehensive evaluation of VFS can effectively eliminate the effect of border on the assessment result and can monitor the error of estimation standard.

In the present study, VFS was combined with information diffusion as an integration of techniques. The method proposed in the current research first uses fuzzy multiple indicators of comprehensive evaluation of VFS and converts the multi-dimensional indicators of the samples into one-dimensional degree values. Then, the method turns the degree values of the observed sample into fuzzy sets by information diffusion method, finally obtaining the risk values. The method is then tested by a case showing that