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Research article

Improved Information Diffusion Method in Disaster Risk Analysis

Qiong Li

School of Mathematics and Physics, Hubei Polytechnic University, Huangshi, Hubei,China.
E-mail: liqiong070108@163.com

Abstract

Drought is a most serious hazard to life and property. The traditional probability statistical method is acceptable in analyzing the drought risk but requires a large sample size of hydrological data. This paper puts forward a improved method based on information diffusion method for drought analysis. Information diffusion theory helps to extract as much useful information as possible from the sample and thus improves the accuracy of system recognition. Furthermore, information diffusion theory helps to extract as much useful information as possible from the sample and thus improves the accuracy of system recognition. This technique contributes to a reasonable prediction of natural disasters risk. As an example, its application is verified in the drought risk analysis in China, and the risks of different drought grades are obtained. Our model yield very good results and suggests that the methodology is effective and practical so that it has the potentiality to be used to forecast the drought risk in drought risk management.

Keywords: improved information diffusion, drought, risk assessment

1 Introduction

Droughts are extreme events of nature that cause huge damage to human society. Droughts are very serious problems in our country, especially in north and northwest China. In ordinary drought risk assessment, probability statistics method is the main tools which is used to estimate hydrological variables' exceedance probability. But droughts are the rare phenomenons of natural mutations. The conventional hydrological frequency analysis method often becomes invalid due to the shortage of historical measured data in the degree and frequency. In fact it is rather difficult to collect long sequence of extremum data and the sample is often small. So we can use fuzzy mathematical method for comprehensively disaster risk evaluation. In view of this, this paper discusses a method of disaster risk calculation in small sample cases, and the results of the examples show the superiority of this model based on IIDM and VFS in the disaster risk management.

On the subject of the risk management process, there has recently been a large number of researchers who have proposed different processes. Some of the most important approaches are: PRAM [1], RAMP [2], PMBOK [3], and RMS[4]. Almost all of these approaches have a similar framework with differences in the established steps in order to get the risks controlled.

In traditional disaster risk assessment, the probability statistics method is usually used to estimate the hydrological variables' exceedance probability. This method has the advantage of its mature basic theory and easy application. However, when it comes to practical issues, problems exist in the feasibility and reliability without considering its fuzzy uncertainty. In the case of small sample issues, results based on the classical statistical methods are very unreliable sometimes. In fact, it is rather difficult to collect long sequence disaster data and the sample is usually small. The information diffusion theory helps to extract as much useful underlying data as possible from the sample, thus improving the accuracy of system recognition [5-6]. Information diffusion is just a fuzzy mathematical set-value method for samples, considering one optimizes the use of fuzzy information of samples in order to offset the information deficiency.

2 Information diffusion

2.1 Definition of Information diffusion

Information diffusion is a fuzzy mathematic set-value method for samples, considering optimizing the use of fuzzy information of samples in order to offset the information deficiency. The method can turn an observed sample into a fuzzy set, that is, turn a single point sample into a set-value sample. The simplest model of information diffusion is normal diffusion model.

Information diffusion: Let V be the small sample and W be the basic universal field. The information diffusion is defined as a map $\mu : V \times W \to [0,1]$ satisfying

(1) $\forall v_j \in V$, if w_j is the observed value of v_j, then $\mu(v_j, w_j) = \sup_{w \in W} \mu(v, w_j)$

(2) $\forall v_j \in V$, $\mu(v_j, w_j)$ decreases with $\|w_j - w\|$ increasing

(3) $\forall v \in V$, $\int_W \mu(v, w) dw = 1$, and $\int_W$ is replaced by $\sum_W$ in a discrete case.

2.2General Information Diffusion Method (GIDM)

In Shang et al. [7], the uniform information diffusion method (UIDM) is presented and described by

$$\frac{\partial u}{\partial t} = \frac{\partial}{\partial x}\left(K \frac{\partial u}{\partial x}\right) \tag{1}$$

where K is a constant. Then the above equation can be written as

$$\frac{\partial u}{\partial t} = K\frac{\partial^2 u}{\partial x^2} \tag{2}$$

However, as most materials have uneven distributions and different consistency themselves, and materials move from higher to the lower level of consistency [8]. Thus in this paper, a variable K is defined as a function of u i.e. $K(u)$, rather than a constant. Here $K(u)$ can be selected freely if it satisfies certain conditions. Here the simplest form of the quadratic function $K(u) = (u+1)^2$ is used. It satisfies the following conditions:

(1) Non-negative increasing function;
(2) Irregularity of diffusion velocity, i.e., faster diffusion as consistency increases;
(3) There will be a little diffusion even without any consistency.

Then general information diffusion method (GIDM) problem can be described as

$$\begin{cases} \frac{\partial u}{\partial t} = \frac{\partial}{\partial x}(K(u)\frac{\partial u}{\partial x}) \\ u\big|_{t=0} = \delta(x) \end{cases}, \tag{3}$$

For this quasi-linear diffusion equation

$$\frac{\partial u}{\partial t} = K(u)\frac{\partial^2 u}{\partial x^2} + \frac{\partial K(u)}{\partial u}(\frac{\partial u}{\partial x})^2, \tag{4}$$

we can use the MacCormack difference scheme to obtain solutions. The MacCormack difference scheme is a special form of the Lax-Wendroff difference scheme and it follows a two-step predictor-corrector mechanism. As this technique is used with forward differences on the predictor and with rearward differences on the corrector, it is a second-order-accurate method.

Let the information diffusion function be $v_t(w_n, x) = u(w_n - x, t)$ and $W = \{w_1, w_{2,} \cdots, w_n\}$ be the variable of degree of the sample. Here, $u(x,t)$ is the solution of Eq. (4). Then the information carried by the sample diffuses to the whole field and the function for the disaster degree can be written as $f_t(x) = \frac{\sum_{i=1}^{n} v_t(w_n, x)}{n}$

3 Application example

To test the accuracy of the model, we apply the model to the drought analysis of an area in North China and by contrast with NIDM and traditional statistics, the superiority of the method is indicated. We chose the measured monthly rainfall sequence of the area from January 1953 to December 2010 as the representative of rainfall because the underlying surface and the climate conditions are stable in the whole observation period. Then a one-step seasonal autoregressive (SAR(1)) process is applied to simulate the data in 1953-2010 and simulated data for 10,000 years are obtained. By comparing the main statistical parameters of the measured and the simulated data, there was an insignificant difference between both the groups shown in **Table 1**. The

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simulated data sequence can represent the changes of the monthly rainfall in the area.

By using VFS[9-11], the drought degree values of the simulated sequence can be calculated out based on the drought assessment standard in **Table 2**. Because the size of the simulated sequence is very large, the analysis results for the simulated sequence can be used as the standard. We then select the set of 60 records from the simulated data sequence and compare the estimated risk by IIDM, NIDM, and the statistics. In Fig. 1, by comparing the results, we can see the results by IIDM are obviously much more precise than those by others. Furthermore, we can identify the risk as well as the return period of drought from **Fig 1**. The drought risk at the level of degree j is the probability of the degree lager than j, i.e. $P(R \geq j) = S_j / N$, where S_j is the event number whose degree is larger than j.

Table 1 the main statistical parameters of the measured and the simulated data sequence

statistical parameters		monthly rainfall (mm)											
		Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
u(mm)	measured	417.3	632.5	963.3	1380.6	1644.5	2146.9	1904.1	1184.1	751.9	719.4	546.6	300.4
	simulation	417.5	635.3	963.6	1399.6	1653.2	2162.6	1881.8	1182.0	748.7	716.1	547.7	302.9
s(mm)	measured	252.1	378.6	493.6	695.0	673.9	1225.8	1603.8	1096.1	573.3	673.5	409.2	255.4
	simulation	253.1	380.6	493.8	701.2	679.5	1214.7	1597.3	1094.3	573.9	678.1	404.1	257.0
C_υ	measured	1.6554	1.6709	1.9516	1.9867	2.4404	1.7513	1.1872	1.0803	1.3114	1.0681	1.3359	1.1762
	simulation	1.6496	1.6693	1.9514	1.9961	2.4329	1.7804	1.1781	1.0801	1.3046	1.0561	1.3553	1.1786
C_s	measured	0.9686	0.7494	0.5366	0.7181	0.5914	0.7740	1.7476	1.5036	0.7904	2.4685	0.8537	1.0399
	simulation	1.0557	0.7848	0.5116	0.6980	0.6224	0.7187	1.8760	1.4662	0.8084	2.8071	0.9025	1.0741

Table 2 Drought rating standard

Season	Time	Extreme drought	Large drought	Medium drought	Small drought	No drought
Spring	Mar.~ May	<-75	-75 $\leq D_p$ <-65	-65 $\leq D_p$ <-50	-50 $\leq D_p$ <-30	-30 $\leq D_p$
Summer	Jun.~ Aug.	<-80	-80 $\leq D_p$ <-60	-60 $\leq D_p$ <-40	-40 $\leq D_p$ <-20	-20 $\leq D_p$
Autumn	Sep.~ Nov.	<-75	-75 $\leq D_p$ <-65	-65 $\leq D_p$ <-50	-50 $\leq D_p$ <-30	-30 $\leq D_p$
Winter	Dec.~ Feb.	<-55	-55 $\leq D_p$ <-45	-45 $\leq D_p$ <-35	-35 $\leq D_p$ <-25	-25 $\leq D_p$

($D_P = \frac{P - \bar{P}}{\bar{P}} \times 100\%$, where P is the rainfall; $\bar{P}$ is the average rainfall of years.)

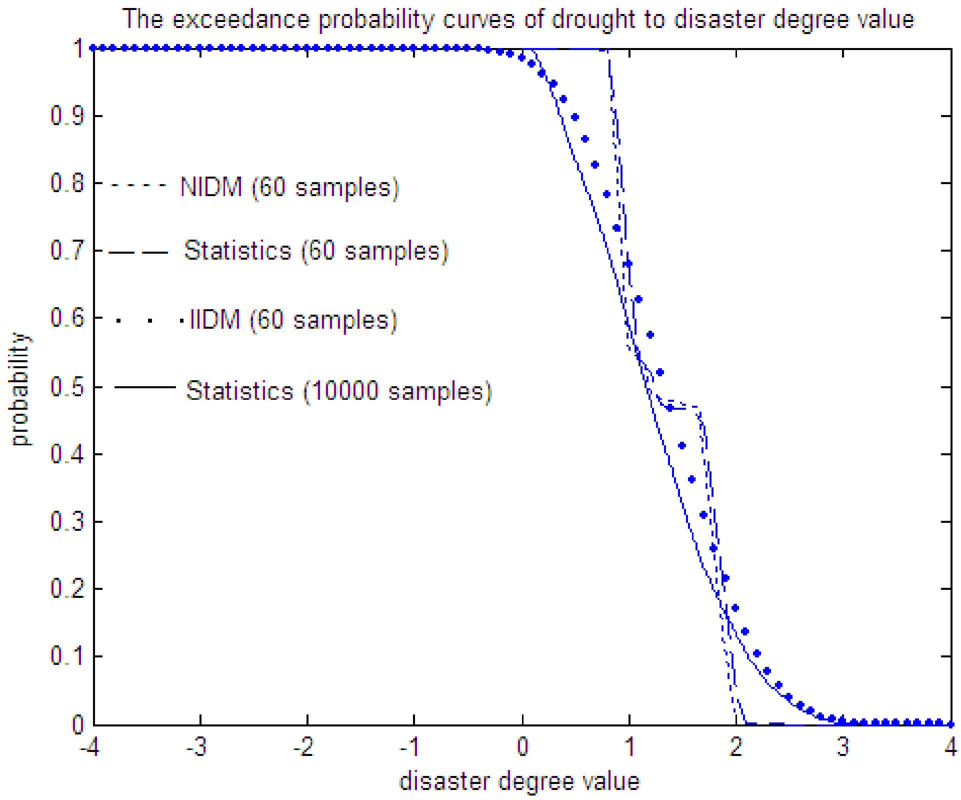

Fig.1 Comparisons of the risks by IIDM, the traditional statistical method, and NIDM

Due to the standard of four grades, we have that [12]:

(a) If $0 \le H \le 0.5$, then the drought degree belongs to no drought (0 grade).

(a) If $0.5 \le H \le 1.5$, then it belongs to small drought (1 grade).

(b) If $1.5 < H \le 2.5$, then it belongs to medium drought (2 grade).

(c) If $2.5 < H \le 3.5$, then it belongs to large drought (3 grade).

(d) If $3.5 < H \le 4$, then it belongs to extreme drought (4 grade).

So we can get the risks of small, medium, and large droughts as 0.8342, 0.3256, and 0.0343 respectively as well as their recurrence intervals as 1.1988 years, 3.0713 years, and 29.1545 years respectively.

4 Conclusions

The disaster risk assessment is a complex multi-criteria problem which is crucial to the success of strategic decision making in disasters. The traditional statistics are frequently inaccurate, especially in small sample problems. In this article, we develop a comprehensive methodology of risk assessment of disasters. The methodology is based on variable fuzzy sets and the improved information diffusion method which has been tested in the example.

In the disaster study, our methodology achieved better precision, stability, and risk predictions of different disaster grades. In the information diffusion method, we replace the diffusion velocity K with a variable K(u) and then we use IIDM to get the disaster risk estimation. This improved method provides an improved implementation of information diffusion process and corresponds to the actual situation better.

Our methodology is based on a improved modeling framework and the techniques used are applicable for other natural disasters. Thus, our methodology can be easily extended to other natural disasters if relevant data are available.

With this information, this study develops a method of disaster risk assessment based on variable fuzzy sets theory and improved information diffusion method which can be generalized as an integration of techniques. It has been tested that the method is stable and reliable, and the results are consistent with real values.

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