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Improved Flood Disaster Assessment Method Based on Cloud Model and Fuzzy Certainty Degree

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Abstract: Flood disasters always occur occasionally and unpredictably. In order to reflect the fuzzy and occasional characters of flood, furthermore evaluate flood disaster accurately and timely, an evaluation approach based on improved cloud model is proposed in this study. Cloud model is a transformation tool between quantity and quality. It can not only qualitatively analyze the fuzzy character of assessment indexes but also can reflect the randomness of flood disaster. Moreover it can quantitatively evaluate the disaster. The certainty degree method is also used to analysis and solves the problem of failure caused by the maximum membership principle in cloud model. The revised method improves the experiment result. Compared with the assessment result by the grey clustering method and the fuzzy method, the amended cloud model method is confirmed to be a reliable method for rapid assessment.

Key words: Cloud model, flood risk assessment, certainty degree, fuzziness, randomness

INTRODUCTION

Flood disaster is a frequent natural calamity in China which is difficult to control and always loses seriously. It's essential to forecast the possibility and intensity of flood, even more to estimate the possible loss. Obviously, flood risk prediction and evaluation can avoid the disasters or reduce the loss. Flood risk evaluation is to evaluate the occurrence probability of different intensity flood and the possible loss, then judge which damage degree should the flood disaster belong to. Now many researchers estimate flood by fuzzy method (Kumar *et al.*, 2011; Janal and Stary, 2012; Zou *et al.*, 2012), neural network method (Pramanik and Panda, 2009; Sulaiman *et al.*, 2011), support vector machine (Huang *et al.*, 2010), genetic algorithm (Jin *et al.*, 2008), Monte Carlo simulation (Aronica *et al.*, 2012) and so on. However, all these approaches have their disadvantages when the available data are insufficient to estimate or the data are random and unpredictable. Considering the uncertainty and the randomness of flood disaster, cloud model is used to estimate flood risk in this study.

THEORY OF CLOUD MODEL

Suppose U is quantitative domain expressed by accurate value, whose qualitative concept is A. If quantitative value x U and x is a random implement of A. Then the certainty degree of x on A, y = u(x) is random number which has stable tendency. The distribution of x in the domain u is called cloud and each x is called cloud droplet. The realization presents randomness and indeterminacy. Y also represents the determine degree of cloud droplet to the qualitative concept.

Shown as Fig. 1, cloud express overall qualitative concept by three digital characters which are Expected value (Ex), Entropy(En) and Hyper entropy(He). Expectation value (Ex) is the most typical sample which represents qualitative concept. Entropy (En) is the uncertainty measure of the qualitative concept. It not only measures the randomness of concept, reflecting discrete extent of cloud droplets, but also measures the fuzziness of the concept, reflecting the value range of acceptable could droplets in the universe of discourse. Hyper Entropy (He) is the uncertain degree of entropy, that is, the entropy of En. It reflects the cohesion degree of cloud droplets (Li, 2005).

The algorithm of production cloud is called cloud generator, which includes forward cloud generator and backward cloud generator. Besides, forward cloud generator can be divided into X condition cloud generator and Y condition cloud generator. If the digital characteristics of cloud are inputted and the cloud generator outputs many cloud drops (x_i, μ_i), it is called

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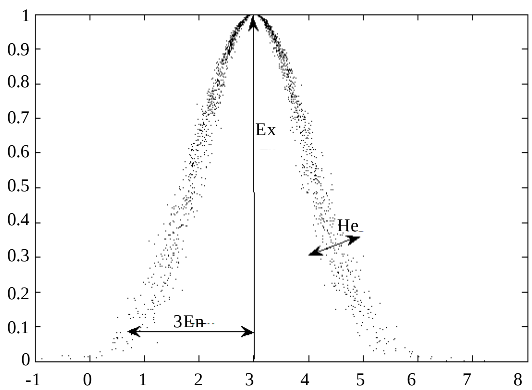

Fig. 1: Chart of normal cloud model

forward cloud generator. On the contrary, if a group of cloud drops(x_i, μ_i) which conform to the normal cloud distributed rule are inputted into the cloud generator while cloud's three digital characteristics (Ex, En, He) and the special value μ_i are outputted, it is named backward cloud generator.

The forward cloud generator is widely applied. In order to discriminate the application area, it is divided into X condition cloud generator and Y condition cloud generator. The difference between them is input type. If cloud's three digital characteristics(Ex, En, He) and the special value x_i are inputted, the cloud generator is called X condition cloud generator. If cloud's three digital characteristics (Ex, En, He) and the special value μ_i are inputted, the cloud generator is called Y condition cloud generator. X condition cloud generator and Y condition cloud generator are the basis of doing uncertainty illation by cloud model (Hu *et al*., 2007).

FLOOD RISK ESTIMATION BASED ON CLOUD MODEL

Flood risk estimation can be divided into chanciness assessment and vulnerability assessment. Flood chanciness is the possible harmful levels of flood such as the intensity and frequency, which is expressed by maximum average velocity, maximum average depth and flood duration in this study. Flood vulnerability is the possible loss levels of various types of hazard-affected bodies in specific region, which is expressed by agricultural output loss, industrial output loss and building loss in this case. Flood risk grade can be calculated after the chanciness factors and the vulnerability factors have been weighted integrated assessed. Risk is divided into four grade in this study, expressed by aggregation B = {B_1, B_2, B_3, B_4}.

Suppose there are m samples denoted as x_1,x_2, ... , x_m and n assessment factors denoted as v_1, v_2...,v_n. The attribute value of flood sample x_j for the assessment factor v_i is x_{ij}.

Foundation of review cloud model and score cloud model: The remark aggregation of assessment factors can be built up according to the disaster grade. It is expressed as A = {A_1, A_2, ...A_k} which is consistent to disaster grade. Then each remark can be quantized by the value and the fuzzy boundaries. According to a certain level review, each factor' grade cloud model can be build as $XC_{Ak}(Ex_{AK}, En_{AK}, He_{Ak})$. The grade cloud model reflect the most typical value expression of each assessment factors under a certain level and reflect the fuzzy boundaries by Entropy.

In order to convert the qualitative words to quantitative value, the united score cloud model is built up. The score grades are expressed as B_1, B_2......B_k. Then the score model of one grade can be defined as $YC_{Bk}(Ex_{BK}, En_{BK}, He_{Bk})$. Hundred-mark system is select in this study.

Forward reasoning by Single rule generator: The forward reasoning by Single rule generator expresses the reasoning course from cloud's quantitative character to cloud's qualitative character. The single rule generator is combined by X condition cloud generator and Y condition cloud generator. The reasoning rule of single rule generation can be expressed as "If A then B" (Hu *et al*., 2007) which is determined by its character. The A and B are respectively the forward parts and backward parts.

Shown as Fig. 1, the specific algorithm is as follows:

- At first build X condition cloud generator by review grade model, after inputting the three digital characteristics(Ex_{AK}, En_{AK}, He_{Ak}) and the number x_{ij} to activate X cloud generator and then produce cloud drop to calculate each factor's membership u^k_{ij} in each grade

- Secondly build Y condition cloud generator by score cloud model, after inputting the three digital characteristics (Ex_{BK}, En_{BK}, He_{Bk}) and the membership, single factor's score q_{ij} can be calculated (Deng *et al*., 2009)

Shown as Fig. 2, the output of X condition cloud generator is the input of Y condition cloud generator and when connecting these two generators can found the single rule generator. It can realize the process of converting quantitative input to qualitative reasoning at first, then converting qualitative reasoning to quantitative output again.

Qualitative reasoning by X cloud generator: Calculate factors' comprehensive evaluation score by weighting Single-factor evaluation scores. Comprehensive evaluation score is quantitative concept which reflects the severity of risk by value. In fact people want to know which risk grade the samples belong, which is the qualitative concept, so it's necessary to qualitative infer it by X condition cloud generator.

REVISION BASED ON CERTAINTY DEGREE

Certainty degree is an important guideline to measure the accuracy of qualitative reasoning in cloud model. In order to make decision or evaluation people always select the maximum degree of membership as the certainty degree to one grade. This method is simple and unilateral, which is easy to increase evaluation error because it only selects the maximum membership but loses the second

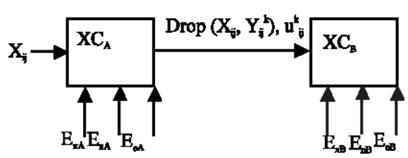

Fig. 2: Forward reasoning by single generator

membership. Then it's essential to analysis the result's effectiveness and to solve the failure of maximum membership principle. The article (Zhang, 2004) analyzes how to measure the effectiveness and the study (Liu *et al*., 2010) proposes the principle of asymmetric proximity to solve the failure of maximum membership. So the method of asymmetric proximity is used to solve the problem in this study. The formulas are as follows:

- Distance formula:

$$D_{i,k}\left(\frac{x_{i,j}}{v^h_{j,T}}\right)=\rho\left(\frac{x_{i,j}}{v^h_{j,T}},\frac{v_{j,k}}{v^h_{j,T}}\right)=\left|\frac{x_{i,j}}{v^h_{j,T}}-\frac{v^h_{j,k}+v^l_{j,k}}{2v^h_{j,T}}\right|-\left(\frac{v^h_{j,k}-v^l_{j,k}}{2v^h_{j,T}}\right) \tag{1}$$

In this formula, $v^h_{j,t}$ represents the maximum value of factor j while $v^l_{j,k}$ and $v^h_{j,k}$, respectively reflect the minimum and the maximum value of factor j on grade k. Formula for calculating closeness:

$$N_{i,k}=1-\frac{1}{n(n+1)}\sum_{j=1}^{n}D_{i,k}\left(\omega_j\cdot D_{i,k}\left(\frac{x_{i,j}}{v^h_{j,T}}\right)\right) \tag{2}$$

- Estimation method:

$$\overline{N_{i,k}}=\left(N_{i,k}-\min_{1\le k\le c}N_{i,k}\right)/\left(\max_{1\le k\le c}N_{i,k}-\min_{1\le k\le c}N_{i,k}\right) \tag{3}$$

$$Z_i=\frac{\sum_{k=1}^{c}\left(k\cdot\overline{N_{i,k}}\right)}{\sum_{k=1}^{c}\overline{N_{i,k}}} \tag{4}$$

Then Z_i is the grade eigen value of sample i. The whole computation flow chart is expressed as Fig. 3.

CASE STUDY

In this study, flood risk statistics and economic statistics of JinJiang diversion area in 1998 are selected to estimate flood risk, shown as Table 1, besides, the flood risk assessment stand is shown as Table 2.

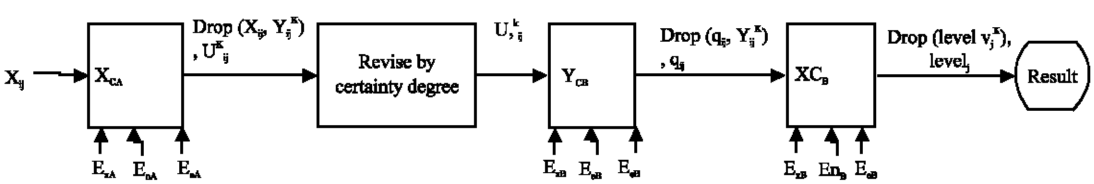

Fig. 3: Flow chart of assessment by improved cloud model

Table 1: Flood risk sample indexes in JinJiang

Samples(town)	Housing loss ($1*10^2$)	Agricultural output ($1*10^6$ RMB)	Industrial output ($1*10^6$ RMB)	Max average velocity (m sec^{-1})	Max average depth (m)	Flood duration (hour)
Buhe	14.652	117.506	209.848	0.329	1.223	147
Douhudi	92.020	93.476	432.122	0.244	1.983	141
Yang JC	1.740	12.309	36.148	0.027	0.523	108
Mahaoko	92.379	180.775	326.748	0.329	1.223	111
Ouchi	71.385	98.187	605.090	0.244	1.983	99
Huang ST	49.473	74.203	68.748	0.027	0.523	87
Zhakou	81.096	114.131	254.380	0.160	2.753	123
Jiazuyuan	41.612	148.499	140.297	0.211	2.805	135

Table 2: Assessment standard of flood risk grade

Flood grade (digital expression)	Housing loss ($1*10^2$)	Agricultural output ($1*10^6$ RMB)	Industrial output ($1*10^6$ RMB)	Max average velocity (m sec^{-1})	Max average depth (m)	Flood duration (hour)
Weak grade (1)	0-30	0-30	0-140	0-0.066	0-0.6	0-70
Moderate grade (2)	31-60	31-70	141-250	0.067-0.133	0.6-1.33	70-100
Serious grade (3)	61¡80	70-133	251-450	0.0134-0.25	1.33-2.4	100-130
Enormous grade (4)	>80	>133	>450	>0.25	>2.4	>130

Table 3: Flood disaster assessment results by different method

Samples	Cloud model method	Revised result by closeness	Grey clustering method	Fuzzy method
Buhe town	3	3	3	3
Douhudi town	3	3	4	3
Yang JC town	1	1	1	1
Mahaokou town	4	3	4	4
Ouchi town	3	3	3	3
Huang ST town	3	2	1	2
Zhakou town	4	3	3	3
Jiazuyuan town	3	3	3	3

Foundation of review cloud model and score cloud model: By analyzing the risk statistics and referring the knowledge and experience of experts, build each factor's remark cloud model. For example, according to the risk of four levels from weak to strong build remark grade cloud model of agricultural output factor, shown as (20,20/3,0.05), (50,50/3,0.05), (100,100/3,0.05), (200,200/3,0.05). The review cloud models of other factors are established by similar method.

In quantitative analysis, it is essential to analyze and quantitative express the quantity grade. So establish score cloud model to convert qualitative reasoning to quantitative expression. In this study, score cloud model is expressed by hundred-mark system, shown as (30,5,0.05),(50,5,0.05),(70,5,0.05),(95,10,0.05). Reasoning by the single generator, the single factor's score can be gotten.

Determination of weighting: In this study, Analytic hierarchy process (AHP) is applied to determine weight. The six factor's ratio is defined as 1:0.5:0.5:.33:0.33:1. So the judgment matrix can be express as:

$$\begin{pmatrix} 1 & 2 & 2 & 3 & 3 & 1 \\ 1/2 & 1 & 1 & 2 & 2 & 1/2 \\ 1/2 & 1 & 1 & 2 & 2 & 1/2 \\ 1/3 & 3/5 & 3/5 & 1 & 1 & 1/3 \\ 1/3 & 3/5 & 3/5 & 1 & 1 & 1/3 \\ 1 & 2 & 2 & 3 & 3 & 1 \end{pmatrix}$$

After it is calculated, the result is as follows: w_i= {0.0817, 0.1485, 0.1485, 0.2698, 0.2698, 0.0817}. The consistent ratio CR = 0.00296<0.1, so the weight is reasonable. The factor's comprehensive assessment score can be obtained after people weighted calculate the weighted factor and the single factor's score.

Qualitative reasoning by X cloud generator: Input the comprehensive score into the X cloud generator to infer the factor's remark grade. In this course the same score cloud model is applied and the inference is finished by X cloud generator.

Revision of cloud model by certainty degree: After substituting the comprehensive score into the above formula and checking calculation, the final results are as follows. The table lists the results by cloud model before correction and after correction by closeness; furthermore the results are also compared with grey clustering method (Wang and Hu, 2010) and the fuzzy method.

Shown from the Table 3, the revised results by certainty degree is different with the results of unrevised in sample 4, 6 and 7, which are all lower one grade than the unrevised result. It reflects the maximum membership principle is ineffective on them because their maximum memberships are similar with the second membership in these three samples. The asymmetric proximity method revises the problem after comprehensively weighted calculating the distance of each factor, which avoid the single factor's abrupt character and more objectively reflect the truth. Further more, the result of this method is similar with the result by grey clustering method or the fuzzy method.

CONCLUSION

In this study, cloud model is applied to estimate flood risk. It is easy to quantitatively or qualitatively analyze risk by the transformation between them, which is the feature of cloud model. It also can provide timely foundation for policy decision. In order to make results tend to be reasonable, the certainty degree method is applied to correct the result. Compared with other two methods, the improved cloud model method is a timely possible assessment method.

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