Analysis of Runoff Temporal and Spatial Distribution Based on Cloud Model

Tian Yu[1,2], Lei Xiaohui[2], Li Jie[3], Wang Hao[1,2], Jiang Yunzhong[2]
[1] School of Civil Engineering, Tianjin University, Tianjin, 300072, China
[2] China Institute of Water Resources and Hydropower Research, Beijing, 100044, China
[3] School of Software, Tsinghai University, Beijing, 300072, China
sweetrain511@163.com

Abstract: **In the past data mining and knowledge discovery, people mainly focused on the study of data mining algorithms, while neglected of research on knowledge expression, quantitative and qualitative transformation. The paper put the quantitative and qualitative characteristics of cloud model into hydrological time series analysis, and the construction method of runoff temporal and spatial distribution based on cloud model is proposed, through the numerical features of cloud model, the characteristics of runoff temporal and spatial distribution able to give in quantity and in quality. The method has been applied in the Minjiang watershed, the result has been compared with M-K trend test, is reasonable. In the recent year, droughts and floods have been happened in the upstream of Yangtze River basin including Minjing and other watershed frequently, cloud model able to give quantitative and qualitative water resources assessment, will give suggestive advice for water management.**

keywords: could model; M-K trend test; runoff change; Minjiang watershed;

I. INTRODUCTION

In the past data mining and knowledge discovery, people mainly focused on the study of data mining algorithms, while neglected of research on knowledge expression, quantitative and qualitative transformation, uncertainty reasoning and other key problems, basically followed the previous research results of artificial intelligence[1].

On the basis of traditional probability theory and fuzzy theory, Li Deyi[1] put forward the cloud model for the uncertainty of qualitative and quantitative conversion. Li Zhong[2] (2005) et al proposed a two-dimensional cloud model controller structure, and analysis of nonlinear mapping feature of one-dimensional and two-dimensional cloud model. Zhang Guoying[3] (2005) et al introduced using the concept of attribute similarity to solve the problem of high-dimensional object classification, and combined with cloud model to establish cloud classifier based on attribute similarity. Zhang Guangwei[4] (2008) put forward an evolutionary algorithm based on cloud model, with high accuracy and great speed convergence, broadens the application field of cloud model. Other scholars successfully applied cloud model into association rule mining [5], spatial data mining [6], uncertainty reasoning [7], intelligent control [8] and other fields.

Mingjiang River is the largest tributary of the upper reaches of Yangtze River in water quantity, in the recent year, droughts and floods have been happened frequently. Traditional probability statistic theory and time series analysis method cannot give runoff change process in quality and quantity. The paper put the quantitative and qualitative characteristics of cloud model into hydrological time series analysis of Minjiang watershed, and the construction method of runoff temporal and spatial distribution based on cloud model is proposed, through the numerical features of cloud model, the characteristics of runoff temporal and spatial distribution able to give in quantity and in quality.

978-1-4244-5540-9/10/$26.00 ©2010 IEEE

II. CLOUD MODEL

A. *Cloud and Cloud Droplets*

Set U as a quantitative domain expressed by exact number, C as a qualitative concept on U, if the quantitative value X belongs to U, and x is the random realization of qualitative concept C. μ μ (x)∈[0,1], the determine degree from x to C is the random number with a stable tendency, that is

$$\mu:U\to[0,1] \quad \forall x\in U \quad x\to\mu(x)$$

Then the distribution of x in the domain U is called Cloud, each x is called a cloud droplet..

B. *The Numerical Characteristics of Cloud*

The integrity of concept can be reflected by the numerical characteristic s of cloud, which is the overall quantitative characteristics of the qualitative concept, has an extremely important significance for understanding the connotation and denotation of qualitative concept. Cloud uses three numerical features to demonstrate one concept, including Expectation, Entropy and Hyper Entropy, shown in Fig.1.

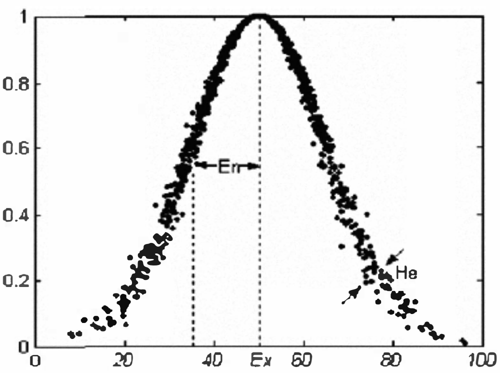


Figure 1. The Numerical Characteristic of Cloud

Expectations: the expectation that the distribution of cloud droplets in the domain. In layman's terms, it is the point that able to represent the qualitative concept, or the typical samples of concept quantify.

Entropy: uncertainty measurement of qualitative concept, jointly determined by the randomness and fuzziness of the concept. On one hand, entropy is a qualitative measurement of randomness, reflecting cloud droplets dispersion represented the qualitative concept, on the other hand, reflecting the acceptable range of cloud droplets. Therefore, entropy necessarily reflects the relevance between randomness and fuzziness.

Hyper Entropy: The uncertainty measurement of entropy, namely, the entropy of entropy, reflects the dispersion degree of clouds, indirectly reflects the thickness of cloud, jointly determined by the randomness and fuzziness of entropy.

III. Cloud Model Construction Method For The Analysis Of The Temporal And Spatial Characteristics Of Runoff

Cloud is the model to express the uncertainty conversion between qualitative concept and quantitative concept, to reflect the uncertainty of the natural language, able to give an explanation from classical stochastic theory and fuzzy set theory, also can reflect the relationship between two theories, constitutes the qualitative and quantitative mapping. The paper uses cloud model to analysis the temporal and spatial characteristics of runoff, given the qualitative and quantitative results. The steps are as follows：

a. According to the runoff data for n years and m stations in one river basin, calculates the arithmetic average of runoff at i time period in different stations as the surface runoff at the whole river basin at i time period.

$$P_i = \frac{1}{m}\sum_{j=1}^{m} P_{ij} \quad i = 1,2,\dots,n$$

Calculate the arithmetic average of runoff in j station in every time period as the average runoff in that time period of j station.

$$P_j = \frac{1}{k}\sum_{i=1}^{k} P_{ij} \quad j = 1,2,\dots,m$$

Where k is the total number of years in each time period.

b. In the process of explore the spatial and temporal runoff distribution, applies M-K trend test method, to find out the mutation point of the year.

c. Calculate the numerical features of each membership cloud. In order to analysis the uneven feature of runoff in the spatial and temporal distribution, the paper uses reverse normal cloud algorithm, restores the cloud numerical features according to statistical characteristics. That is applying reverse cloud generator to realize the transformation from quantitative to qualitative, shown in Fig.2, the formula as follows:

$$Ex = \bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$$

$$En = \sqrt{\frac{\pi}{2}} * \frac{1}{n}\sum_{i=1}^{n} |x_i - Ex|$$

$$He = \sqrt{\frac{1}{n}\sum_{i=1}^{n} (x_i - \bar{x})2 - En2}$$

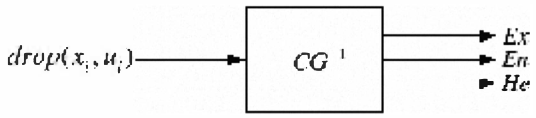


Figure 2. Reverse Cloud Generator

d. Calculate Cloud Droplets. Normal cloud generator is the mapping from qualitative to quantitative, the paper according to the cloudy numerical features calculating by b generates cloud droplets. According to the normal cloud generator algorithm, all cloud droplets sets compose a random variable X. En obedience to normal distribution, taken En as expectation and He^2 as the variance, En's probability density function as follows:

$$f_{En}(x) = \frac{1}{\sqrt{2\pi}He} e^{-\frac{(x-En)^2}{2He^2}}$$

X obedience to normal distribution, taken Ex as expectation and En as the variance, X's probability density function as follows:

$$f_x(x|En) = \frac{1}{\sqrt{2\pi}He} e^{-\frac{(x-En)^2}{2En^2}}$$

Since En is a random variable, through the conditional probability density formula, X's probability density function as follows:

$$f_x(x) = f_{En}(x) \times f_x(x|En) = \int \frac{1}{\sqrt{2\pi}He} e^{-\frac{(x-En)^2}{2He^2}} dy$$

e. Draw the figure of membership cloud.

f. Analysis the spatial and temporal runoff distribution according to membership cloud

IV. Case Study

A. *The General Description of Minjiang River*

Mingjiang River is located in the western region of SiChuan province, which is the largest tributary of the upper reaches of Yangtze River with water quantity, also is one of the important source regions. The total length is about 735km, is like a long strip from northwest to southeast, the watershed area is 135.5 thousand km^2. The map of Minjiang river and runoff station used in this paper analysis is shown is Fig.3.

Figure 3. The watershed of Minjiang River

Through the long series runoff data statistical analysis of Minjiang watershed from 1960 to 2004, shown in Fig.4, demonstrates that the runoff of Minjiang river with great fluctuation and presents a clear linear downward trend. Through 5-year moving average line, can seen that the variation period is not obvious, needed further analysis.

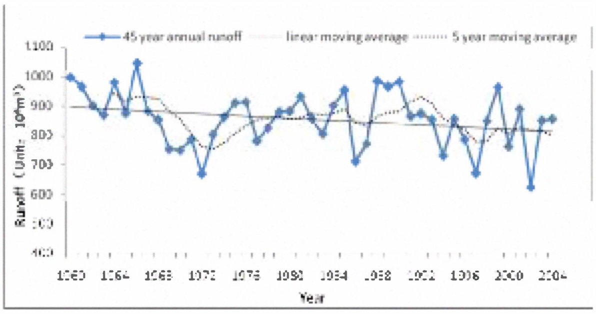


Figure 4. The runoff variation in Minjing watershed from 1960 to 2004

B. The Runoff Spatial Characteristic Analysis Based on Cloud Model

The paper takes multi-year average annual runoff of Minjiang River's hydrological station as research object, in order to analysis the variation of runoff spatial distribution on the time period, analyzes the characteristic annual runoff variation according to M-K trend test, shown in Fig.5.

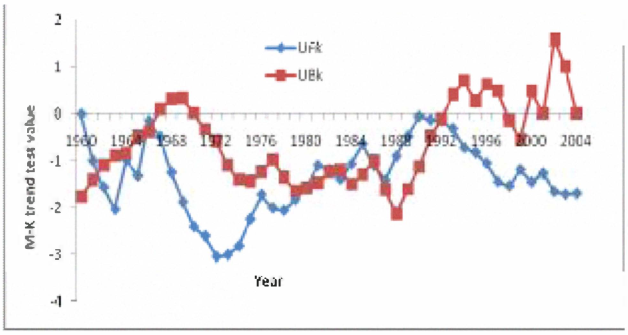
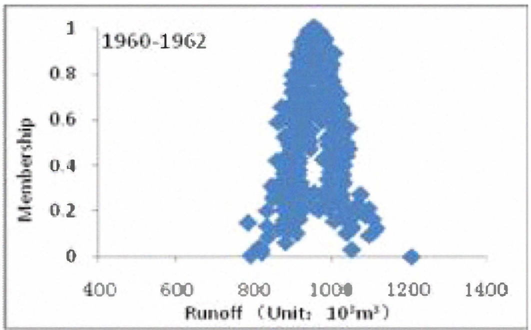
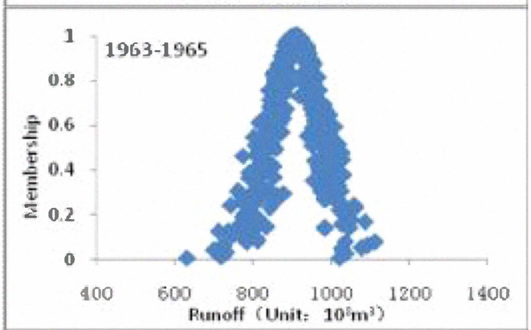
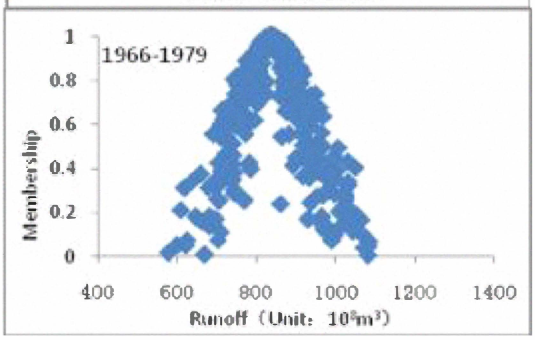


Figure 5. Runoff M-K trend test from 1960-2004

The result of M-K trend test is significant, for Z=-1.73 less than 1.96. The intersection point of UFk and UBk is mutation points, divides a long series from 1960 to 2004 into six periods, namely, from 1960 to 1962, from 1963 to 1965, from 1966 to 1979, from 1980 to 1983, from 1984 to 1992, and from 1993 to 2004. Calculate the numerical characteristics of cloud model respectively, shown in Table 1, and draw the membership cloud in each period, shown in Fig.6 to Fig.10, to conduct runoff spatial analysis.







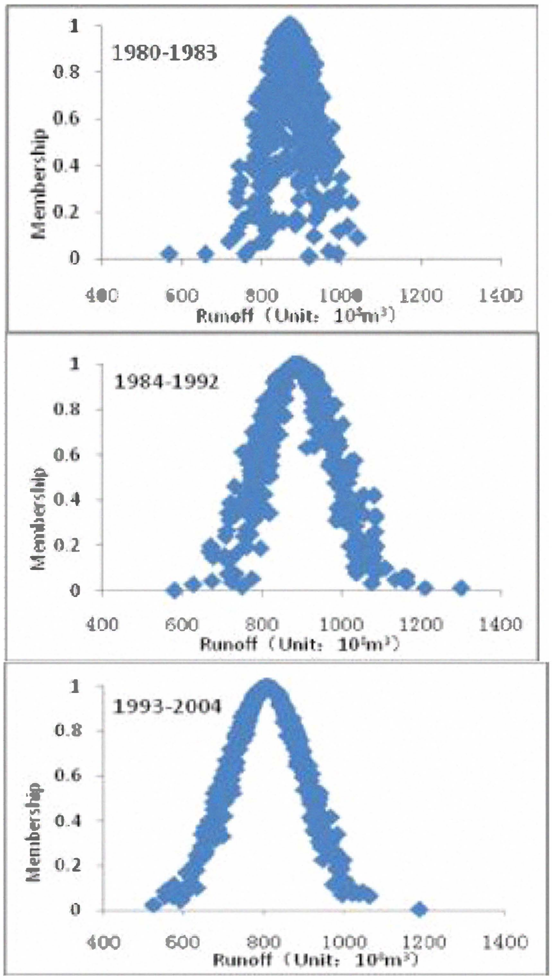


Figure 6. Membership cloud in each time period

TABLE I. THE NUMERICAL CHARACTERISTICS OF CLOUD MODEL IN EACH TIME PERIOD

Time Period	Ex	En	He
1960-1962	955	48.28	19.65
1963-1965	908.06	60.44	16.84
1966-1979	837.07	87.46	25.47
1980-1983	869.5	43.67	22.89
1984-1992	890.22	93.83	20.63
1993-2004	897.83	96.33	9.16

According to the data in Table 1 and membership cloud in various stages, the spatial distribution characteristics of runoff in Minjiang watershed can be summarized as follows: discrete degree has a increasing trend, especially after 1984, the spatial distribution of runoff clearly discrete, and the stability also increased. The He from 1993 to 2004 is 9.3, further indicates that the discrete extent has increased. The main reason is due to dry year and flood year appearing alternatively from the late 1980s in Minjiang watershed, which resulting in the increasing spatial dispersion.

C. The runoff temporal characteristic analysis based on cloud model

In Minjiang watershed flood season is from May to October and dry season is from November to April. The paper takes runoff in the whole year, runoff in the flood season and runoff in the dry season as research objects, given the numerical characteristics of membership cloud by reverse cloud generator, shown in Table 2, then calculating cloud droplets, and drawing the membership cloud, shown in Fig.7 to Fig.9.

TABLE II. THE NUMERICAL CHARACTERISTICS OF CLOUD MODEL OF REGIONAL RUNOFF

Period	Ex	En	He
The whole year	855.42	89.65	26.97
Flood season	631.22	83.17	4.14
Dry season	224.2	24.55	8.91

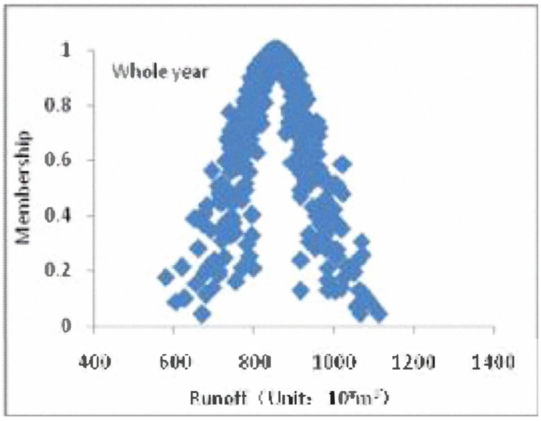


Figure 7. Membership cloud of the whole year

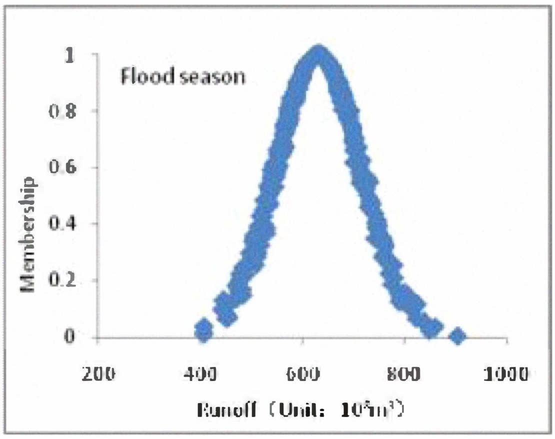


Figure 8. Membership cloud of the flood season

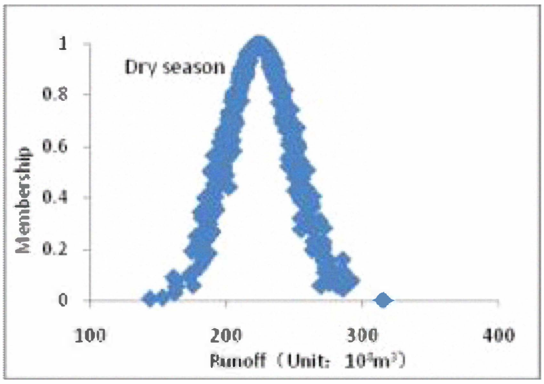


Figure 9. Membership cloud of the dry season

From Table 2 can see that the runoff in flood season is much greater than in dry season, despite the runoff in flood season is more dispersed, and larger uneven features, but the He in flood season is less than in dry season, shows the uneven feature in flood season is more stable. Annual runoff is the most discrete and unstable. From fig.7 to fig.9 can also be clearly seen that the uncertainty of runoff in annual runoff and in dry season is also higher than in flood season.

Fig.5 the M-K trend analysis of annual runoff from 1960 to 2004 shows that the time period from 1960 to 1964, from 1972 to 1988, from 1997 to 2000, have a decreasing trend, demonstrates that the temporal distribution of runoff is uneven, which conclusion is the same as Table 1. However, M-K trend test unable to give a quantitative description, which is the advantage of cloud model in time series analysis.

V. CONCLUSIONS

The paper put the quantitative and qualitative characteristics of cloud model into hydrological time series analysis, and the construction method of runoff temporal and spatial distribution based on cloud model is proposed, through the numerical features of cloud model, the characteristics of runoff temporal and spatial distribution able to give in quantity and in quality. The method has been applied in the Minjiang watershed, three numerical features of cloud model is given, and membership cloud map is shown. The results shows that the spatial distribution of runoff in Minjiang watershed is very dispersed, mainly due to the alternative appearance of dry year and flood year. In the temporal distribution, flood period is more stable, the annual runoff is the most unstable. In the recent year, droughts and floods have been happened in the upstream of Yangtze River basin including Minjing and other watershed frequently, cloud model able to give quantitative and qualitative water resources assessment, will give suggestive advice for water management.

ACKNOWLEDGMENT

The paper is jointly supported by funds from Cooperative operation of Three Gorge and large groups of reservoirs in the upper stream of Yangtze river（2008BAB29B08）of the 11^{th} 5-year plan of China.

REFERENCES

[1] Li Deyi, Du Yi. Uncertainty artificial intelligence. Beijing: National defense industry press, 2005, 57-383.

[2] Li Zhong, Yang Yidong. A new intelligent controller based on two-dimensional cloud model uncertainty reasoning [J]. Control and decision. 2005,8(1): 15-21.

[3] Zhang Guoying. Cloud classifier based on attribute similarity [J]. Journal of Beijing University of Technology. 2005,25(6): 11-15.

[4] Zhang Guangwei, He Rui. Evolutionary algorithm based on cloud model[J]. Journal of computer. 2008,7(31): 1082-1091.

[5] Du Yi. Research and application in association rule of data mining[D]. PLA university of technology, 2000.

[6] Pi Xiaoliang, Wangzheng. Traffic state classification application research based on loop detector l[J]. Journal of road traffic technology. 2006, 23(4) : 115-119.

[7] Yin Guoding, Wei Hong. Cloud computing-the method to realize concept calculation. Journal of southeast university (Natural science edition) [J]. 2003, 33(4) : 502-506.

[8] Li Deyi. Cloud control method and dynamic balance of three-level inverted pendulum[J]. Journal of Chinese engineering science. 1999, 1(2) : 41-46.