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Original Research

Commensurability-Based Flood Forecasting in Northeastern China

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Abstract

Northeastern China is one of the largest industrial and agricultural bases in China, but frequent flooding brings huge losses to the people and country. To forecast floods in northeastern China, we used commensurability forecasting techniques and ordered a network structure chart and butterfly structure diagram. The prediction selected extraordinary flooding years that have occurred in the region since 1856, and it used ternary, quinary, and septenary commensurability calculation models for forecasting. It verified the inevitability of flooding in 2013 and showed that northeastern China would be highly prone to flooding in 2017. The specific locations of flooding would be the second Songhua River or Liaohe River. The ordered network structure and butterfly structure diagram are the extension of commensurability, both of which showed perfect symmetry neatly and orderly, and indicated the great possibility of flooding in northeastern China in 2017. Because of spatial distribution in the region, we also picked up four representative sites in the region to subsidiarily forecast the runoff qualitatively. Except for a site that did not have a significant year, the other three sites showed that the runoff in the second Songhua River would be wet in 2017. The idea of this paper is good in the data-starved area and helpful for improving judgment regarding flood trends.

Keywords: commensurability, ordered network structure chart, butterfly structure diagram, northeastern China, flood

Introduction

A flood is one of the most serious natural disasters, and floods typically take place in plain areas that are densely populated, relatively economically developed, and with high degrees of agricultural reclamation. China is one of the most frequent regions for flood disasters. Flood forecasting is not only used as a scientific basis for flood control, drought relief, and reservoir scheduling decisions, but it is also very important in industrial and agricultural production. At present, there are basically two types of long-term runoff forecast methods. The first type is quantitative prediction. The main methods of quantitative prediction are the time series analysis method [1], which is based on mathematical statistics, and regression analysis [2], which is based on physical cause analysis. The other type of runoff forecasting method is qualitative prediction. The most impressive methods include the commensurability prediction method proposed by Weng WenBo [3], and the grey system prediction method proposed by Deng Julong [4].

The status of current disaster prediction is "more single means, less comprehensive methods; more

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historical evaluation, less trend judgment; more academic research, less reduction value" [5]. Weng Wenbo said: "In mathematics, the more complex operations, the more assuming ingredients, the more distortion will be and the farther results apart with the actual situation will be" [3]. If we can contract out of the cycle and symmetric structure from the disaster years, close to its physical mechanism of disaster, we can improve the judgment level of trends about natural disasters. The commensurability method is concise for forecasting the disasters through periodic, vivid, and intuitive symmetry that avoids complicated and unidentifiable traditional mathematical model analysis. Weng Wenbo first used commensurability in natural disaster prediction and founded information forecasting. He successfully predicted that the Yangtze River flood would occur in 1991 and that the California (United States) earthquake would occur in 1992 [3]. This method is a significant theoretical innovation of contemporary natural disaster forecasting that blends the advantage of Chinese and Western science and culture, and has achieved good effect in earthquake, drought, and flood disaster prediction.

Men K.P. used the commensurability principle to predict the flood in the middle and lower reaches of the Yangtze River, and the result showed that there would be floods in 2008, 2029, and 2051 [6]. Hu H. discovered that the occurrences of earthquakes in the Hualian area of Taiwan within the 20th century are commensurable [7]. Li H. pointed out that flood-causing rainstorm periods in the Nenjiang River and the Second Songhua River both last 10 years [8]. Jin J used ternary, quaternary, and quinary commensurability methods and a butterfly structure diagram to analyzed the Ms≥8.0 strong earthquakes occurring in Chile, and exhibited an evident symmetry and synchronism in longitudinal and latitudinal directions [9].

It should be noted that not all disasters are cyclical and symmetrical and that not all disaster areas are cyclical and symmetrical; it may be that in one area of one disaster is cyclical and symmetrical only part of the time. Through a large number of empirical analysis in typical regions and distinguished disaster types, areas, and time periods, only in this way can the trend judgment of serious disasters go further. The hydrological phenomenon is cyclically obvious; therefore, the mid- and long-term runoff forecasts based on the commensurability method have been more widely used. This paper used the commensurability method to further explore the trend of flood disasters.

Materials and Methods

Materials

Study Area

Northeastern China, including Liaoning, Jilin, Heilongjiang, and parts of eastern Inner Mongolia, is one of the world's three black soil zones [10]. It is the largest grain base of China and has the most potential for the development of agricultural production areas, and it is also an important industry and energy base. Its area is approximately 800,000 km^2, mainly located in the north temperate regions. It is ringed on the east, west, and north by mountains, and the vast Northeast Plain is located in the middle. The river system is various, including the Heilongjiang, Songhua, Ussuri, and Liaohe rivers. Summer rainstorms frequently occur due to the monsoon climate, and this often causes the banks to burst, leading to flooding and serious natural disasters.

In 1998 the Nen River and Songhua River had long, high-intensity rainfall, which was twice more than the same period in an ordinary year, and it triggered a super flood off record. The Jiangqiao hydrological station in the Nen River measured maximum peak flow (26,400 m^3/s) and the flood return period was 480 years. The Harbin Hydrology Station in the Songhua River measured peak flow (16,600 m^3/s) and the flood return period was approximately 100 years. In 2013 the water level soared again in northeastern China, and there was a basin-wide flood in the Heilongjiang River, and the return period of downstream in the Heilingjiang was more than 100 years (Bulletin of Flood and Drought Disaster in China, 2014; www.mwr.gov.cn/zwzc/hygb/zgshzhgb). Based on the important industrial and agricultural status and the flood-prone nature of the region, flood forecasting is even more important.

Because the spatial distribution of summer precipitation in northeastern China is more in the south and less in the northwest [11], when choosing a representative point we chose reservoirs in the east or south. Fengman Reservoir is located upstream, 24 km from Jilin, and the control drainage area is 42,500 km^2, which accounting for 55% of the second Songhua River. The Fengman Reservoir is a large reservoir mainly used for generating electrical power, flood control, irrigation, water supply, and shipping. Fengman Dam, constructed in 1937, was reconstructed on 29 October 2012. Baishan Reservoir is located in the upstream, 200 km from Fengman Reservoir, with a control drainage area of 19,000 km^2. It has given priority to power generation, and also affects flood control, navigation, and fish culture. The plant started production at the end of 1983. The total reservoir capacity of Baishan and Fengman is 1.69×10^{10} m^3, and their capacity accounts for 53.6% of total reservoir capacity (3.15×10^{10} m^3) in the Songhua River, making them both the most important flood control projects in the second Songhua River [12]. Yunfeng Reservoir is located in the middle reaches of the Yalu River and upstream, 50 km from Ji'an. Reservoir catchment area is more than 23,936 km^2 and its total reservoir capacity is 3.90×10^9 m^3. This reservoir is a hybrid development, which gives priority to power generation as well as comprehensive utilization benefits, and it began operation in 1965 [13]. The two plants of the Jingpo River Station are located upstream of Mudanjiang, 100 km from southwestern Mudanjiang. The control area is 11,800 km^2 and it occupies 31% of the Mudanjiang River basin. It is a large reservoir used to generate electrical power and for

Fig. 1. Basin map and reservoir site map of northeastern China.

flood control. The old plant was constructed in 1942 and a new plant began generating electricity in 1978 [14].

Research Object and Data Source

Divided Basis of Research Object

Flood grades are classified based on the hydrological forecasting standard (GB/T22482-2008). According to flood frequency, floods are divided into four levels in Table 1. Flood frequency is defined with water level or discharge. The flood return period beyond 50 years, that is the value of flood frequency beyond 2%, is called an "extraordinary flood."

According to the departure from the mean value (the numerator is the number of runoff in July to September minus the year's average value, and the denominator is the year's average rainfall, then the quotient is the so-called "departure from the mean value") floods are divided into the five levels shown in Table 2.

Data Source

We chose 15 extraordinary flood events (the value of flood frequency beyond 2%) in northeastern China as the research subjects to build the commensurability prediction model. Twelve of these floods were recorded in China Historical Great Flood (1988), and the other floods occurred in 1995, 1998, and 2010. The history was not detailed; therefore, the date was just kept to the month. The majority of floods occurred in the summer; therefore, years without mouth or data were selected in the commensurability prediction program.

Methods

Commensurability

Definition of Commensurability

Commensurability is an order of nature that expresses a certain law stating that various elements of the system can work together and reflect the occurrence rule of special events (small probability events) in nature. We can extract the non-accidental signals from a special series of commensurable numbers to predict flood tendency, which means we use special events to forecast special events.

"Commensurability" was first proposed in the study of astronomy, when Laplace found Jupiter's moons (Io, Europa, Ganymede) and their average distance (x_1, x_2, x_3) to the primary component obeys the commensurability type below:

Table 1. Flood classifications.

Flood Frequency (P)	P<20%	20%≤P<5%	5%≤P<2%	P≥2%
Classifications	Small Flood	Middle Flood	Big Flood	Extraordinary Flood

Table 2. Annual runoff classification table.

Classifications	Dry year	Slightly dry year	Flat year	Slightly wet year	Wet year
Departures(D)	D<-20%	-20%〈〈D<-10%	-10%〈〈D〈〈10%	10%<D〈〈20%	D>20%

$$2x_3\text{-}2\ x_2 = x_2\text{-}x_1 \quad (1)$$

The academician Weng predicted the occurrence time of natural disasters based on setting the commensurability formula with commensurability theory. The formula is usually expressed as:

$$X_{i+1} = \sum_{j=1}^{l} I_j X_j \quad (2)$$

…where j∈{i}, i = 1, 2, … , n, (n is a positive integer), and I_j is an integer.

To prove a non-accidental type of commensurability formula, there must be two or more formulas to verify:

$$\begin{cases} X_{i+1\ ,\ 1} = \sum_{j1=1}^{l1} I_{j1} X_{j1} \\ X_{i+1\ ,\ 2} = \sum_{j2=1}^{l2} I_{j2} X_{j2} \\ \vdots \\ X_{i+1\ ,\ m} = \sum_{jm=1}^{lm} I_{jm} X_{jm} \end{cases} \quad (3)$$

Arrange the above values in a monotonically increasing collection:

$$\{X_{(i+1),1}, X_{(i+1),2}, \cdots, X_{(i+1),m}\} \quad (4)$$

Restrictions:

$$\left|X_{(i+1)\ ,\ m} - X_{(i+1),1}\right| \le \varepsilon \quad (5)$$

ε is the critical value that determines the feasibility of the model. We determined the value of in the practical work according to specific needs. Generally, ε = ±1 is required in the prediction of hydrological disasters [15]. The sample is completely commensurable when ε = 0. If ε>0, the ΔX is the commensurability ash cycle between [-ε, ε]. If the commensurability formulas can be more than one formula, the formula may be not accidental. The larger the m (the number of commensurability formulas) and the smaller the ε, the higher the forecast accuracy.

The three models for the extrapolation forecasts are as follows:

The ternary commensurability equation:

$$X_a + X_b — X_c = X_{u(a,b,c)} \quad (6)$$

Table 3. Sample years of floods in northeastern China.

Serial Number	Prediction year	Illustration	Degree of hazard
1	1856/8	In the middle of Jilin	Peak flow reached 13,800 m³/s in Songhua Reach in the Second Songhua River
2	1888/8/14	East of Liaoning	Peak flow reached 11,900 m³/s in Shenyang Reach at Liaohe river basin
3	1909/7/24	In the middle of the Second Songhua River	Peak flow reached 12,900 m³/s in Jilin Reach at Second Songhua River
4	1911/8/12	Hulan River and Tangwang River in Songhua River	Peak flow reached 11,600 m³/s in Hongshilazi Reach at Second Songhua River
5	1930/8/4	West of Liaoning	Peak flow reached 11,700 m³/s in Jinzhou Reach at Liao River
6	1932/8/6	Songhua River	Peak flow reached 17,800 m³/s in Tonghe Reach at Songhua River
7	1953/8/10	Liaohe and Songhua Rivers	Peak flow reached 3,940 m³/s in Bei'anhe Reach at Nen River
8	1957/9/9	Songhua River	Peak flow reached 17,800 m³/s in Tonghe Reach at Songhua River
9	1960/8/4	East of Liaohe	Peak flow reached 14,300 m³/s in Benxi Reach at Taizi River
10	1962/7/26	West of Liaohe	Peak flow reached 12,200 m³/s in Xiaoheyan Reach at Liao River
11	1981/7/28	Liaodong Peninsula	Peak flow reached 5,460 m³/s in Xiaosongjiatun Reach at Yellow Sea
12	1985/7/20	Liaohe	Peak flow reached 27,400 m³/s in Haicheng Reach at Taizi River
13	1995/7/30	Liaohe and the second Songhua Rivers	Peak flow reached 10,700 m³/s in Dahuofang Reservoir Reach at Hun River
14	1998/8/14	Songhua River	Peak flow reached 26,400 m³/s in Jiangqiao Reach at Nen River
15	2010/8/18	Second Songhua River	Peak flow reached 5,230 m³/s in Harbin station at mainstream of Songhua River

The quinary commensurability equation:

$$X_a + X_b + X_c - X_d - X_e = X_{v(a,b,c,d,e)} \quad (7)$$

The septenary commensurability equation:

$$X_a + X_b + X_c + X_d - X_e - X_f - X_g = X_{w(a,b,c,d,e,f,g)} \quad (8)$$

…where a, b, c, d, e, f, g = 1, 2 ⋯, n; and u, v, w = 1, 2, ⋯m. n and m are positive integers.

This paper adopted ternary, quinary, and septenary commensurability prediction models to forecast floods in northeastern China. The first preference was given to the value of ternary commensurability formula. When the values in the ternary commensurability formula are the same, you can refer to quinary and septenary commensurability formulas. Under normal circumstances we prefer the value of ternary commensurability formula results over the quinary commensurability formula, and prefer the value of quinary commensurability formula results over the septenary commensurability formula.

Commensurability Inspection

Weng Wenbo divided the objective existence into two categories: the normal states subset and the abnormal states subset. The normal states subset includes the general, frequent events, and the main elements are statistics, such as the mathematical expectation, equation, and mean. The abnormal states subset includes unusual, special events, and the data are processed based on the characteristics of each element.

To determine if the original time series has a non-uniform distribution, not accidental, and it has a strong value to extract information, this paper assumed that the original time sequence was an even distribution. If it had a low confidence level by using a statistical test, we believed that the sequence might be a uniform distribution. On the contrary, if we rejected the hypothesis of an even distribution, we could establish their own relationship between years to forecast disaster trends.

F(x) is a sample sequence and (X_1, X_2, ⋯, X_n) is a sample from the population. We assumed that the sample obeyed the uniform distribution function $F_0(x)$ in the interval [a, b]. We examined the overall distribution to determine whether it had a uniform distribution, which meant we tested whether H_0: $F(x) = F_0(x)$ was true. This study applied the ternary commensurability chi-square test method to determine the parameters of uniform distribution. The ternary commensurability formula is $X_m = X_k + X_s - X_n$, m = k + l-n in an evenly distributed case.

Actual frequency X of ternary extrapolation formula:

$$X = \sum_{i=1}^{s} \Delta X_i \quad (9)$$

…where s is the number of the ternary commensurability formula and ΔX is the frequency of each partial interval when extrapolated:

$$\Delta X = \begin{cases} 2 \ , \ k \neq s \\ 1 \ , \ k = s \end{cases} \quad (10)$$

Theory frequency λ_x of uniformly distributed:

$$\lambda_x = Np_i \quad (11)$$

N is the sum of frequency, $N = \sum_{i=1}^{n} X_i$, that is, the sample size. p_i is the theoretical probability of each sample, typically 1 / n.

2) Degrees of freedom in an even distribution:

$$f = r - m - 1 \quad (12)$$

…where r is year span, r = max{(n-k),(n-s)}. If k = s, then m = 1, instead of 2.

3) Use of K. Pearson-Fisher theorem

If H_0 is established, the theoretical frequency and actual frequency should be almost the same. Therefore, we configured the statistics:

$$\chi^2 = \sum \frac{(X - Np_i)^2}{Np_i} \quad (13)$$

According to K. Pearson-Fisher theorem, the distribution obeys $\chi^2 \sim \chi^2\ (r - m - 1)$. At the significance level α, if $\chi^2 \geq \chi^2_{1-\alpha}\ (r - m - 1)$ then refuse H_0; if $\chi^2 \leq \chi^2_{1-\alpha}\ (r - m - 1)$, then accept H_0.

Commensurability Unit and Ordered Network Structure Chart

Commensurability can be view as an expansion of periodicity, and we can call a time scale the "commensurability unit," where there will be a disaster when passing a unit. The same scale occurs repeatedly, which would forecast the disaster relatively simply and practically. The present study showed that the main reasons for the hydrological cycle phenomena are the movement of celestial objects, Earth's rotation and revolution, and solar activity.

The network can extend unlimitedly, and it has been widely used in various subject areas. An ordered network structure chart is a network of visual manifestations that combine cyclicity with the order. The ordered network structure is an ordered collection of nodes and their ligatures. The nodes are sample points, and the ligatures are time scales. When building a chart, we were only concerned with the orderliness about the length of the ligature (time scale) between nodes. We did not care about the position of the nodes or whether the ligatures were straight or intersected, etc., which may be two-dimensional or multidimensional. It may also be a series

Table 4. Reference standard of butterfly structure's probability calculation.

Data	Groups of every unit	Unit
N≤5	groups ≥2	≥1
6≤N≤10	groups ≥3	≥2
11≤N≤15	groups ≥4	≥3
16≤N≤20	groups ≥5	3~4
N≥20	groups ≥6	≥4

of diagrams to describe the network to ensure correlation between all of the samples, and individual samples can be reused.

Butterfly Structure Diagram

The butterfly structure diagram is a method established at equal time scale, connected with a curved profile and shaped like a butterfly to react with time symmetry [16]. In the sample, the random probability of the butterfly structure is calculated using , where T is the probability of occurrence in the predicted year, n is the number of total disaster events used for prediction, and m is the number of disaster events involved in the actual prediction. To improve the judgement level of the disaster trend, generally we determine the lower limit number of butterfly structure according to the amount of year data in the time sequence.

Flood Forecasting Techniques Combined Points with Area

The ability to forecast specific location elements of extraordinary floods is the direction of information forecast development and the key to prevention or mitigation. Based on historical materials regarding the hydrology in the basin, the flood years for the Nenjiang River are 1794, 1886, 1908, 1929, 1932, 1953, 1957, 1969, and 1998, while those for the Songhua River are 1856, 1896, 1909, 1923, 1951, 1953, 1957, 1960, 1991, 1995, and 2010 [8]. With the exception of 1953 and 1957 according to these data, floods in the two places have not occurred at the same time. This phenomenon can be used to reduce flood control pressures, but it also leads to confusion in forecasting flood location and determining which river will flood. Scholars generally just stay in forecast occurrence time as there is little for detailed location prediction.

We combined points (four reservoirs) with area (northeastern China), which not only improves prediction accuracy in entire areas, but also can determine the point location of the floods. The area forecast selected drainage basin floods as samples. We checked the commensurability of the samples first and then used the commensurability formula, commensurability unit, and ordered network structure chart with the butterfly structure diagram to predict the floods in the region. The point forecast would be auxiliary, and picked up the flow series of a particular site as samples to predict the runoff of the watershed. This method ensured the rationality and completeness of the prediction from time and space.

Results and Discussion

Commensurability Formula

First, we tested the non-accidental of the commensurability formula with the uniform distribution hypothesis testing method. As shown in Table 6, X was the actual frequency and the average probability value calculated by the number of years involved in the ternary commensurability formula divided by the total number of years, such as 1856, the years involved in the ternary commensurability formula were 1888, 1909, 1911, 1930, 1932, 1953, 1957, 1962, 1985, and 2010 for a total of 10, and the total number of sample years is 15, so the probability value is 67%. Shown in Table 6, the average value of X was 16, and the average probability value was 69.9%.

We obtained $\chi^2 = 43.74$ from Table 7, then we checked the χ^2 distribution table to obtain $\chi^2_{1-\alpha}(r-m-1) = \chi^2_{1-0.005}\ (14-2-1)) = 26.8$. Because $\chi^2 = 43.74 > 26.8$, we had a 99.5% probability to reject H_0, which meant the sequence was not uniformly distributed. The results showed that the ternary commensurability equation was not accidental. Therefore, we can try it for disaster prediction.

The results of ternary, quinary, and septenary commensurability in the commensurability prediction model are shown in Table 8.

After the mutual authentication of the ternary, quinary, and septenary commensurability calculations, 2013 ranked first in the ternary, quinary, and septenary commensurability calculations. The ternary commensurability formula is shown in Table 9, where we found that most locations of flooding join in the ternary commensurability formula of 2013 were the second Songhua River and Liaohe River,

Table 5. Correspondence between random probability of butterfly structure and capable degree of prediction.

Random Probability (T)	T<1%	1%≤T<10%	10%≤T<33%	33%≤T<66%
Capable Degree	very unlikely	most unlikely	unlikely	not entirely possible
Random Probability (T)	66%≤T<90%	90%≤T<99%	T≥99%	
Capable Degree	possible	basic may	may well	

Table 6. Ternary commensurability formula, frequency, and probability of every year.

Year	Ternary commensurability formula			Frequency x	Probability %
1856	1888+1930-1962	1888+1953-1985	1909+1909-1962	13	67
	1909+1932-1985	1911+1930-1985	1930+1888-1962		
	1957+1909-2010				
1888	1856+1985-1953	1909+1909-1930	1909+1911-1932	17	73
	1909+1932-1953	1909+1960-1981	1911+1962-1985		
	1930+1911-1953	1930+1953-1995	1962+1856-1930		
1909	1856+1962-1909	1888+1930-1909	1911+1930-1932	26	87
	1856+1985-1932	1888+1932-1911	1911+1960-1962		
	1856+2010-1957	1888+1981-1960	1930+1960-1981		
	1932+1930-1953	1962+1932-1985	1962+1957-2010		
	1953+1888-1932				
1911	1856+1985-1930	1909+1932-1930	1953+1888-1930	18	73
	1888+1932-1909	1888+1985-1962	1909+1962-1960		
	1930+1962-1981	1932+1960-1981	1932+1932-1953		
	1953+1953-1995				
1930	1856+1962-1888	1909+1932-1911	1911+1981-1962	24	73
	1909+1909-1888	1888+1995-1953	1932+1960-1962		
	1856+1985-1911	1909+1953-1932	1953+1962-1985		
	1888+1953-1911	1909+1981-1960	1985+1930-1985		
1932	1856+1985-1909	1909+1985-1962	1930+1962-1960	24	87
	1888+1953-1909	1911+1930-1909	1953+1960-1981		
	1909+1911-1888	1911+1953-1932	1957+1960-1985		
	1909+1953-1930	1911+1981-1960	1957+1985-2010		
1953	1888+1995-1930	1930+1985-1962	1981+1932-1960	19	80
	1909+1932-1888	1932+1932-1911	1985+1856-1888		
	1930+1911-1888	1957+1981-1985	1995+1911-1953		
	1930+1932-1909				
1957	1856+2010-1909	1932+2010-1985	1953+1985-1981	14	80
	1909+2010-1962	1953+1957-1953	1960+1995-1998		
	1932+1985-1960				
1960	1957+1998-1995	1981+1888-1909	1981+1932-1953	17	80
	1962+1909-1911	1981+1909-1930	1985+1932-1957		
	1962+1930-1932	1981+1911-1932	1985+1985-2010		
1962	1888+1930-1856	1909+1985-1932	1911+1981-1930	17	80
	1888+1985-1911	1909+2010-1957	1930+1985-1953		
	1909+1909-1856	1911+1960-1909	1932+1960-1930		
1981	1909+1960-1888	1932+1960-1911	1953+1960-1932	12	67
	1930+1960-1909	1930+1962-1911	1953+1985-1957		
1985	1888+1953-1856	1932+1962-1909	1957+1960-1932	20	87
	1909+1932-1856	1932+2010-1957	1957+1981-1953		
	1911+1930-1856	1953+1962-1930	1960+2010-1985		
	1911+1962-1888				
1995	1930+1953-1888	1953+1953-1911	1957+1998-1960	5	47
1998	1960+1995-1957			2	20
2010	1957+1909-1856	1957+1985-1932	1985+1985-1960	7	47
	1957+1962-1909				

Table 7. Theoretical frequency and each parameter value of chi-square test with each year.

Year	Actual frequency (X)	Theoretical frequency (Npi)	X-Npi	(X-Npi)^2/ Npi
1856	13	15.67	-2.67	0.45
1888	17	15.67	1.33	0.11
1909	26	15.67	10.33	6.81
1911	18	15.67	2.33	0.35
1930	24	15.67	8.33	4.43
1932	24	15.67	8.33	4.43
1953	19	15.67	3.33	0.71
1957	14	15.67	-1.67	0.18
1960	17	15.67	1.33	0.11
1962	17	15.67	1.33	0.11
1981	12	15.67	-3.67	0.86
1985	20	15.67	4.33	1.2
1995	5	15.67	-10.67	7.27
1998	2	15.67	-13.67	11.93
2010	7	15.67	-8.67	4.8
Sum	235			43.74

which were obtained the Liaohe River and the second Songhua River most likely flooded in 2013. Indeed, in 2013 in the upper reaches of the Hun River and the Liaohe River a flood return period of over 50 years occurred. In the upper reaches of the Second Songhua River, a flood return period of over 20 years occurred. This verified the reliability of the forecasting methods.

As seen in Table 8, 2017 ranked second in the ternary commensurability calculation, fourth in the quinary commensurability calculation, and second in the septenary commensurability calculation. The specific quinary commensurability formula is listed in the table below. The locations of flooding were the second Songhua River or Liaohe River. Therefore, we predicted that floods in the second Songhua River or Liaohe River in northeastern China would occur in 2017.

Commensurability Unit and Ordered Network Structure Chart

Commensurability Unit Calculation

The commensurability unit (time scale) of the flooding years and frequency were obtained by deviation calculation with the data, taking the frequency above two as the commensurability unit, as shown in Table 10, wherein 21, 23, and 53 appeared four times, and 25, 28, 32, 42, and 51 appeared three times.

It can be seen that units 32, 42, 51, and 53 may be derived by units 21, 23, 25, and 28:

$$25 + 28 = 53$$

$$23 + 28 = 51$$

$$21 + 21 = 42$$

$$25 + 28 - 21 = 32$$

So the basic commensurability unit is 21, 23, 25 and 28.

Ordered Network Structure Chart

We built the ordered network structure chart according to the commensurability unit, as shown in Figs 2 and 3.

Table 8. Results of the prediction model.

Ternary Commensurability		Quinary Commensurability		Septenary Commensurability	
Year	Number of Equations	Year	Number of Equations	Year	Number of Equations
2011	5	2011	177	2011	4,825
2012	6	2012	195	2012	4,676
2013	**10**	**2013**	**234**	**2013**	**6,077**
2014	4	2014	162	2014	4,849
2015	7	2015	215	2015	4,793
2016	5	2016	163	2016	5,092
2017	**7**	**2017**	**207**	**2017**	**5,213**
2018	5	2018	233	2018	4,579
2019	7	2019	195	2019	4,423
2020	3	2020	128	2020	3,994

Table 9. Ternary commensurability formulas of 2013 and 2017.

Year	Ternary Commensurability Formula			Frequency x	Probability %
2013	1888+1981-1856	1960+2010-1957	1981+1985-1953	18	100
	1909+1960-1856	1962+1962-1911	1985+1985-1957		
	1960+1962-1909	1962+1981-1930	1998+2010-1995		
	1960+1985-1932				
2017	1888+1985-1856	1960+2010-1953	1981+1998-1962	14	73
	1911+1962-1856	1962+1985-1930	1985+1985-1953		
	1930+1998-1911				

Table 10. Commensurability unit and frequency.

Serial Number	Unit	Frequency	Serial Number	Unit	Frequency
1	21	4	5	32	3
2	23	4	6	42	3
3	25	3	7	51	3
4	28	3	8	53	4

Fig. 2 is a two-dimensional ordered structure network. There are four very regular and orderly symmetrical rectangles. The commensurability units are 3a, 23a, 25a, 32a, and 53a, which are basic commensurability units or deduced by a basic commensurability unit.

Fig. 3 is a regular closed tetrahedron of three-dimensional ordered structure. The frequency intervals are 3a, 23a, 25a, and 53a, which are basic commensurability units or deduced by a basic commensurability unit.

Butterfly Structure Diagram

We selected the period from 1930 to 2013 to make the butterfly structure symmetry analysis shown in Fig. 4. We set 1981 as the symmetric point, and the vertical line as the axis of symmetry. The number of groups achieved six, the symmetrical structure was very clear, and it reached the reference standard in Table 3. Fig. 4 reflects that the most significant units were 23a, 25a, 28a, 32a, 53a, and 55a. The most typical unit was a 32a, which occurred four times, and 23a, 25a, 28a, and 53a each appeared three times. The predicted year 2017 participated in three groups (23a, 32a, and 55a), and the number of years involved in the prediction was 10. The probability calculation of the event prediction was T = m/n = 10/12 = 83%, which meant there was an 83% probability that flooding would occur in 2017.

Point Forecast

The Baishan, Fengman, Yunfeng, and Jingpohu reservoirs are large, incomplete or complete, multi-year regulating storage reservoirs. Therefore, the peak series data of the reservoirs did not conform to the actual situation of flooding. According to the actual situation of each reservoir data, this paper used the maximum three-day inflow of Baishan Reservoir, the maximum daily inflow of Fengman Reservoir, and the average flow rates in the main flood season of Yunfeng and Jingpohu

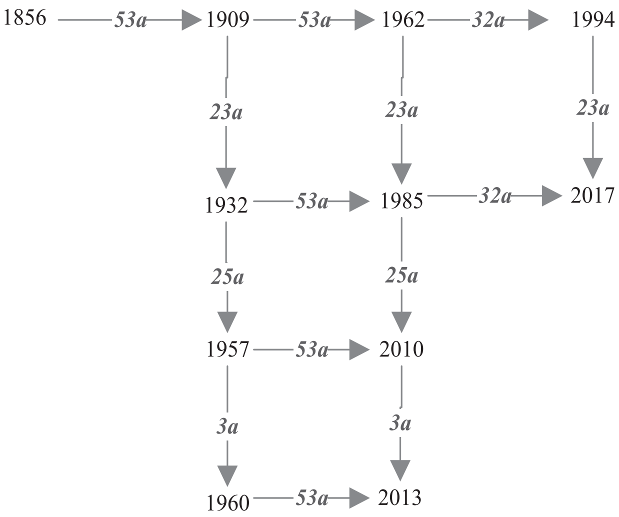

Fig. 2. Two-dimensional ordered structure network.

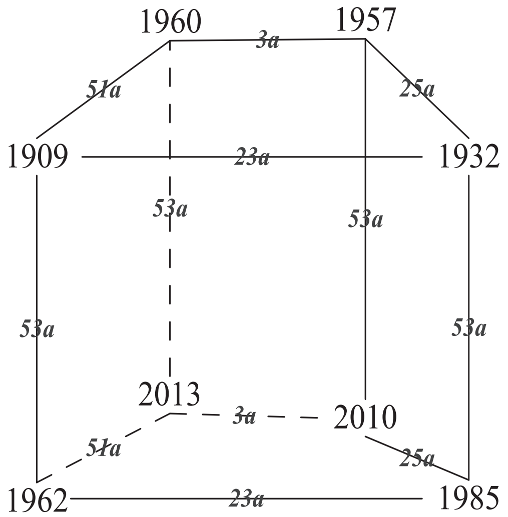

Fig. 3. Three-dimensional ordered structure network.

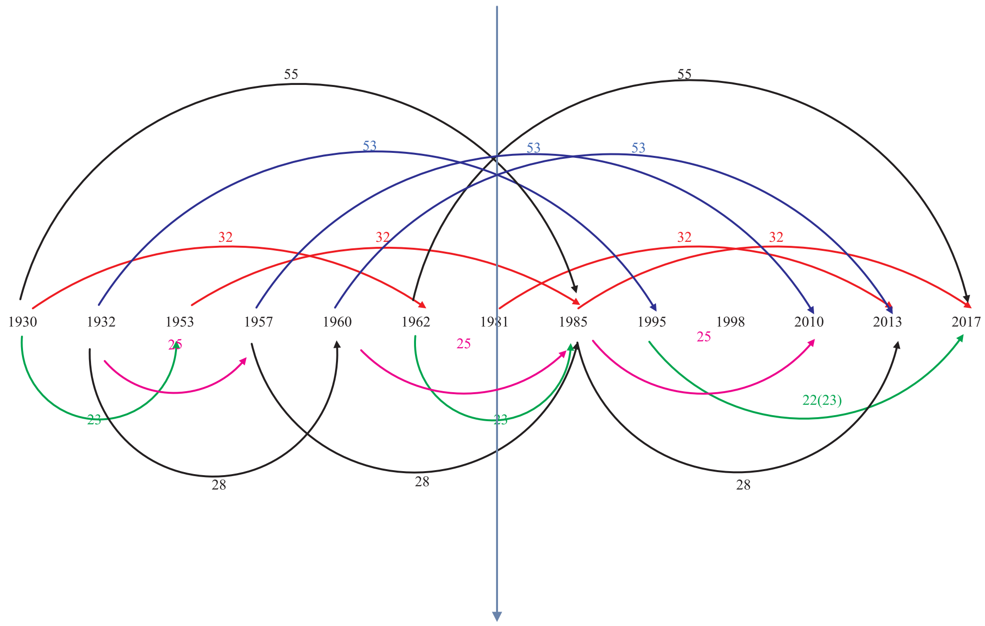

Fig. 4. Butterfly structure diagram.

reservoirs to forecast if the reservoirs would be wet or dry in a given year.

Forecast Result of the Baishan Reservoir Commensurability Formula

The study subject was the years whose three-day average discharge departed from the mean value more than 20% in the Baishan Reservoir from 1933-2010.

Table 12 shows that the maximum of the actual frequency is 2017. The year 2020 may have the greatest probability for a flood. Baishan Reservoir should have abundant water resources in 2017 and 2020.

Table 11. Series sample data of Baishan Reservoir.
(Time was recorded on the first day of the maximum three days)

Serial Number	Time of Sample	Maximum Average Flow in Three Days (m^3/s)
1	1937/8/6	3,441
2	1943/8/29	4,514
3	1953/8/21	3,684
4	1957/8/22	4,630
5	1960/8/24	5,594
6	1975/7/31	3,819
7	1982/8/28	4,259
8	1986/8/29	4,198
9	1994/7/9	3,117
10	1995/7/29	5,752
11	2010/7/28	6,265

Forecast Result of the Fengman Reservoir Commensurability Formula

The study subject was the maximum daily inflow of Fengman Reservoir from 1856-2014. We took the years whose departure from the mean value was greater than 20%, as shown in Table 13.

Table 14 shows that the maximum of the actual frequency and the greatest probability year is 2017, and that inflow should be extremely abundant in 2017.

Forecast Results of the Yunfeng Reservoir Commensurability Formula

The study subject was the average flow rate of the main flood season of Yunfeng Reservoir from 1927-2010. We took the years in which inflow was beyond the average 20% of the average flow rate in the main flood season (see Table 15).

The ternary commensurability model and the results (shown in Table 16) showed that there was no particularly significant year, indicating that the Yalu River would not be wet in nearly five years.

Forecast Result of the Jingpohu Reservoir Commensurability Formula

The study subject was the average flow rate in the main flood season of Jingpohu Reservoir from 1927-2010. From the top down, we took years in which the inflow was beyond the average 20% of the average flow rate in the main flood season (see Table 17).

The results showed that the maximum of the actual frequency and the greatest probability year was 2017, with a 92% chance of being wet. Because the Jingpohu Reservoir is near the Second Songhua River Basin,

Table 12. Ternary commensurability formula, frequency, and probability of Baishan Reservoir.

Year	Ternary Commensurability Formula			Frequency x	Probability %
2016	1943+2010-1937	1975+1994-1953	1982+1994-1960	6	73
2017	1960+1994-1937	1975+1995-1953	1982+2010-1975	10	73
	1960+2010-1953	1982+1995-1960			
2018	1960+1995-1937	1975+1986-1943	1994+2010-1986	6	73
2019	1982+1994-1957	1986+1986-1953	1995+2010-1986	5	64
2020	1953+2010-1943	1982+1995-1957	1986+1994-1960	8	100
	1975+1982-1937				

Table 13. Series sample data of Fengman Reservoir.

Serial Number	Time of Sample	Maximum Daily Average Inflow (m^3/s)
1	1856	15,300
2	1909/7/24	12,000
3	1923/8/14	10,500
4	1939/9/8	7,180
5	1951/8/25	10,367
6	1953/8/20	15,610
7	1957/8/22	14,450
8	1960/8/24	12,751
9	1964/8/14	8,215
10	1975/8/1	8,135
11	1991/7/30	8,984
12	1995/7/31	11,978
13	2010/7/28	10,543
14	2013/8/16	13,251

the forecast result of the Jingpohu Reservoir in the Mudanjiang watershed indirectly demonstrated that the runoff of the second Songhua River Basin would be extremely abundant.

In summary, the runoff of the Second Songhua River in northeastern China in 2017 would be extremely wet, and flooding may occur.

Conclusions

Commensurability was first found in astronomy and was later extended to forecast natural disasters. It has recently been applied to seismology research. Hydrological forecasting needs further research and discussion. This paper adopted ternary, quinary, and septenary commensurability prediction models to forecast floods in northeastern China. The expansion and development of commensurability were corroborated with an ordered network structure chart and butterfly structure diagram, and we could further clarify the disaster year.

We found that the original disaster years had a very strong degree of commensurability by chi-square test, indicating that commensurability was non-accidental.

Table 14. Ternary commensurability formula, frequency, and probability of Fengman Reservoir.

Year	Ternary Commensurability Formula			Frequency x	Probability %
2016	1957+2010-1951	1960+2013-1957	1964+1991-1939	11	79
	1960+1995-1939	1964+1975-1923	2013+2013-2010		
2017	1909+1964-1856	1960+2010-1953	1975+1995-1953	16	86
	1951+1975-1909	1964+2010-1957	1995+2013-1991		
	1957+2013-1953	1964+2013-1960			
2018	1951+1923-1856	1991+1991-1964		3	36
2019	1951+1991-1923	1957+2013-1951	1964+1964-1909	12	86
	1953+1975-1909	1960+2010-1951	1975+1995-1951		
2020	1923+1953-1856	1964+1995-1939	1964+2013-1957	8	71
	1960+2013-1953				

Table 15. Series sample data of Yunfeng Reservoir.

Serial Number	Time of Sample	Average Flow Rate in Main Flood Season (m^3/s)
1	1929	829
2	1934	987
3	1935	950
4	1942	1,240
5	1953	1,165
6	1960	1,058
7	1963	883
8	1966	817
9	1972	897
10	1986	963
11	1995	1,390
12	2004	915
13	2005	854
14	2010	1,019

After mutual authentication of ternary, quinary, and septenary commensurability calculations, the signal of 2013 ranked first and verified the inevitability of the flood in northeastern China in 2013. The signal strength of 2017 followed, and the location of flooding years participated was the second Songhua River or Liaohe River. Therefore, we predicted that flooding would occur in the second Songhua River or Liaohe River in northeastern China in 2017. Commensurability units were obtained by deviation calculation, and the basic commensurability units were 21a, 23a, 25a, and 28a. The ordered network structure chart and butterfly structure diagram were made from commensurability unit information. The graphics were very neat and orderly and showed perfect symmetry, indicating the great possibility of flooding in the region in 2017 intuitively.

Table 17. Series sample data of Jingpohu Reservoir.

Serial Number	Time of Sample	Average Flow Rate in Main Flood Season (m^3/s)
1	1953	360.5
2	1956	599.5
3	1957	386.55
4	1960	434
5	1964	524.5
6	1971	396
7	1972	365.5
8	1983	361.5
9	1985	400.5
10	1986	495
11	1987	625
12	1991	604
13	2002	413

In this paper, we not only forecast the whole region on a large scale, but also combined small-scale points to accomplish flood forecasting. We selected the Baishan,

Table 16. Ternary commensurability formula, frequency, and probability of Yunfeng Reservoir.

Year Prediction	Ternary Commensurability Formula			Frequency x	Probability %
2016	1935+2010-1929	1966+2010-1960	1972+2010-1966	15	79
	1953+2005-1942	1972+1986-1942	2010+2010-2004		
	1963+1995-1942	1972+2004-1960			
2017	1942+2004-1929	1960+2010-1953	1966+2004-1953	14	79
	1942+2010-1935	1966+1986-1935	1972+2005-1960		
	1960+1986-1929				
2018	1942+2005-1929	1966+2005-1953	1986+2004-1972	16	86
	1942+2010-1934	1986+1966-1934	1995+1995-1972		
	1966+1986-1934	1986+1995-1963			
2019	1953+1995-1929	1986+1986-1953	1995+2010-1986	13	79
	1966+1995-1942	1986+2005-1972	2004+2010-1995		
	1972+2010-1963				
2020	1960+1995-1935	1963+2010-1953	2005+2010-1995	8	64
	1963+1986-1929				

Table 18. Ternary commensurability formula, frequency, and probability of Jingpohu Reservoir.

Year	Ternary Commensurability Formula			Frequency x	Probability %
2016	1971+2002-1957	1985+1991-1960	1986+1987-1957	15	92
	1983+1986-1953	1985+2002-1971	1986+2002-1972		
	1985+1987-1956	1986+1986-1956			
2017	1971+2002-1956	1985+1985-1953	1987+1987-1957	19	92
	1972+2002-1957	1986+1987-1956	1987+2002-1972		
	1983+1987-1953	1986+1991-1960	2002+2002-1987		
	1983+1991-1957	1986+2002-1971			
2018	1972+2002-1956	1987+1987-1956	1991+1991-1964	13	92
	1983+1991-1956	1987+1991-1960	2002+2002-1986		
	1985+1986-1953	1987+2002-1971			
2019	1985+1987-1953	1986+1986-1953	2002+2002-1985	6	54
	1985+1991-1957				
2020	1971+2002-1953	1986+1987-1953	1986+1991-1957	8	69
	1985+1991-1956				

Fengman, Yunfeng, and Jingpohu reservoirs at higher flood incidence regions in the east or south of northeastern China as the sample points. The forecast results of the Baishan and Fengman reservoirs in the second Songhua River and the Jingpohu Reservoir in the Mudanjiang River all showed that 2017 would be wet. Because the Jingpohu Reservoir is located near the second Songhua River Basin, it indirectly demonstrated that the runoff of the Second Songhua River Basin would be wet in 2017. By combining specific points with macroscopic surface prediction, we mutually demonstrated the reasonableness of forecasts from time and space.

Some of the floods and the peak series data considered in the study may be due to the operation of the reservoirs. In the point forecast, we used the maximum three-day inflow of the Baishan Reservoir, the maximum daily inflow of the Fengman Reservoir, and the average flow rates in the main flood season of the Yunfeng and Jingpohu reservoirs according to the actual situation of each reservoir data. In the whole northeastern China regional forecast we considered the peak flow for the prediction but did not mention about the duration of the flood. For the next stage we will consider the operation of the reservoirs.

The author of the study also found that in the ordered network structure chart and butterfly structure diagram, not every node confirmed that commensurability would be a disaster, whether false readings also need to be combined with other prediction methods, such as the movement of celestial objects and the El Nino phenomenon. According to astronomical research, 60 years is the synodic period of Saturn, Jupiter, and Mercury. At the same time, the Earth's rotation period is 60 years. For two simultaneous cycles, this synchronization can cause droughts, earthquakes, and other natural disasters. The floods in 1953 and 1957, pushed forward 60 years, corresponded to 2013 and 2017. 2013 was a fait accompli; therefore, the probability of flooding is very large in 2017.

The commensurability research method has its unique accuracy and reasonableness. The commensurability method is a research method of seeking difference. Its main operations are addition and subtraction, effectively saving the authenticity of the information. However, the differential and higher-order differential expression in other methods would be detrimental to the expressed information. The character of commensurability method would also ensure that the method may achieve better results in disaster prediction. The year point predicted uses commensurability only as a necessary condition; the false is inevitable, and disaster prediction also should be combined with other prediction methods.

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