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ORIGINAL PAPER

Risk assessment of rainstorm and flood disasters in China between 2004 and 2009 based on gray fixed weight cluster analysis

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Abstract Rainstorm and flood disasters frequently occur in China, causing heavy losses for people's lives and property and reducing the capability of sustainable development of the national and local economy. In this study, the risks of the rainstorm and flood disasters are assessed for the Chinese mainland, excluding Hong Kong, Macao, and Taiwan and also employ the historical data of seven indicators, including the affected area of crops, the affected population, the direct economic loss, and etc., from 2004 to 2009. Based on the large 1,302 historical sample data, the impact of rainstorm and flood disasters were analyzed using the methodology of gray fixed weight cluster analysis according to disaster losses, which were divided into the three gray classes of high, medium, and low. The regional differences of the risk assessment of the rainstorm and flood disasters are discussed, and the dynamical risk zoning map is conducted. The results show a consistent conclusion with the actual losses of rainstorm and flood disasters over each administrative district, which can provide more scientific evidence for the relevant departments of disaster prevention and mitigation.

Keywords Risk assessment and zoning · Rainstorm and flood disasters · Gray fixed weight cluster

1 Introduction

Rainstorm and flood disasters are serious natural disasters because they tend to happen suddenly and frequently while covering a wide area. In this century, catastrophic flood disasters all over the world have taken place nearly 40 times. Flood is also one of the main meteorological disasters in China, and about 50 % of the population and 70 % of property are located in flood-threatened areas (Gu et al. 2011). In recent decades, as the global climate continues to warm, all kinds of extreme weather and climate events have occurred frequently, with the frequency of flood occurrences and the losses increasing year by year.

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Taking 2004–2009 for an example, the area of crops affected by rainstorm and flood disasters was 118,884,000 hectares, the affected population was 625.526 million, and the direct economic losses amounted to 403.27 billion RMB yuan (Ren Min Bi), accounting for 28.2 % of all the periods of meteorological disasters economic loss and accounting for 0.27 % of the GDP. In recent years, rainstorm and flood disaster risk research in China has attracted extensive attention. In order to cope with the long plagued rain floods, reduce rainstorm floods brought by secondary disasters, protect ecosystems, ensure economic and social development, safeguard national security and stability, and strengthen disaster prevention, emergency response and post-disaster recovery efforts, it is urgent to improve the level of flood risk research and provide solid scientific and technological support for sustainable socio-economic development, which is of great significance for implementing effective flood disaster management, the capacity building of meteorological disaster prevention, and mitigation tasks and the sustainable development of the national economy.

In recent years, scholars have made great progress in the research of flood disaster risk assessment and regionalization. For example, Jiang et al. (2009) adopts fuzzy comprehensive assessment (FCA), simple fuzzy classification (SFC), and the fuzzy similarity method (FSM) to assess flood disaster risk in Kelantan, Malaysia. Validation data, such as the flooded area, paddy area, urban area, residential area, and refuges, were overlaid to validate and analyze the accuracy of flood disaster risk. Shao and Xiang (2009) analyzed the characteristics and classification of meteorological disasters in Hubei province, concluding that meteorological disasters in Hubei province have characteristics of great harmfulness, severe damage, and high frequency of occurrence. Zhang et al. (2000) studied the degree of risk of flood zoning. Wang et al. (2005) built a dynamic monitoring system of agro-meteorological disasters by using the 3S (Remote sensing, RS; Geography information systems, GIS; Global positioning systems, GPS) technology. GIS technology has a good advantage in early disaster warning, monitoring, and evaluation. Chinese scholars have widely applied the technology in studying the risks of floods and regionalization, and they have achieved good results. The representative researchers are Li (2005), Chen (2008), Yao (2000), Wan et al. (2007), Zhang et al. (2011), Gashaw and Legesse (2011), Ramlal and Baban (2008), Dewan et al. (2007), Liu and Liu (2001), Islam and Sado (2000), and Luo et al. (2007).

However, the GIS technology owns a relative single function with disadvantages in poor ease of development for the system structure and difficulties in ensuring the quality of data sources and capturing the accurate meteorological disaster information, which also brings more difficulties to flood disaster risk assessment. Scholars try to use the soft evaluation technique theory to assess the disaster risks, such as fuzzy techniques and gray evaluation techniques. For examples, Goro et al. (2013) estimated by integrating a physical-based approach as a total runoff integrating pathways (TRIP) model with Gumbel distribution metrics. The resulting equations are used to predict potential flood damage based on gridded Japanese data for independent variables. Li et al. (2011) used the method of attribute hierarchical model (AHM) to assess the meteorological disaster risk, which provided a more practical and scientific basis for meteorological disaster risk assessment and decision-making problems. Guo and Zha (2010) used AHP to analyze the Anhui province flood disaster losses and flood risk zoning, having a very positive effect on the assessment of disaster losses, prediction accuracy, and flood control. Li et al. (2012) put forward a composite method based on variable fuzzy sets and information diffusion method for disaster risk assessment. Kyung et al. (2013) used three multi-criteria decision-making (MCDM) techniques to quantitatively evaluate and compare 19 flood risk vulnerabilities of South Korea, including present conditions. Hochrainer and Mechler (2011) assess the rationale and applicability of such deliberations given the dynamic nature of vulnerability and risk and discuss conditions for conducting similar transactions for Asian megacity risks.

Over the years, due to the relatively small number of data samples, the relatively low reliability of the data quality, the high uncertainty of the decision-making system in the data information, gray clustering analysis has unique advantages. This method has been widely applied to the field of environmental quality assessment and the water quality analysis system. For example, Hu et al. (2012) applied the gray clustering model to evaluate the ambient air quality in Fuzhou city from 2004 to 2008, believing that improved gray clustering analysis evaluations are more objective and accurate. Zhu and Wang (2009) analyzed pollutant impact on indoor air quality, achieving gray evaluation in indoor air quality. Liu and Wang (2004) used gray clustering analysis to analyze the dump-leaching impact on groundwater quality. Lin et al. (2008) employed the gray decision-making method to evaluate green engineering and proposed a green ecological evaluation system for Taiwan. Hu et al. (2010) used the gray system to assess the quality of drinking water in Jiaozuo city, in which the method was simple and the operability was not bad and therefore achieved good results. Ip et al. (2009) applied the gray correlation degree to a water environmental quality assessment. Jiao and Ma (2010) comprehensively evaluated water in the Changjiang River based on gray-fuzzy clustering analysis. He et al. (2002) studied the application of the gray clustering decision in a comprehensive evaluation of water quality. Combining AHP and gray clustering analysis, Tang and Li (2011) created meteorological disaster post-assessment methods for highway traffic during flood seasons.

For the risk assessment system of flood loss in mainland China (excluding Hong Kong, Macao, and Taiwan), the indicators measured are relatively small: The risk assessment of disaster losses only includes a small number of measureable indicators, such as disaster losses, affected population, and affected areas; on the other hand, it often involves larger data samples and longer history disaster data (time series data). This paper tries to adopt the gray fixed weight cluster technique for risk analysis of disaster losses: national flood disaster loss risk assessment and zoning research involving 31 provinces, municipalities, and autonomous regions. The gray clustering techniques will help to explore the rainstorm and flood disasters losses based on a large-sample data classification problems.

We use disaster data from 2004 to 2009 of Y*earbook of Meteorological Disasters in China* and take 31 provinces, municipalities, and autonomous regions (except for Hong Kong, Macao, and Taiwan) as the clustering objects with seven disaster indicators, classifying the rainstorm flood losses of all 31 provinces, municipalities, autonomous regions (administrative divisions) by using a gray fixed weight cluster analysis. The trend of the future flood risk loss is predicted, which provides a scientific tool for decision-making in national disaster prevention and mitigation in disaster prevention and mitigation strategies research.

2 Gray fixed weight cluster analysis

2.1 Concept of gray fixed weight cluster (Liu et al. 2010)

Let x_{ij} be observations of indicators j about object i, and $f_j^k(\bullet)$ is the whitening weight function for the k subclass of the j indicator, $i \in N = \{1, \ldots, n\}$, $j \in M = \{1, \ldots, m\}$, $k \in S = \{1, \ldots, s\}$. If the weight η_j^k, $j \in M$, $k \in S$ of the k subclass of j indicator is irrelevant to k, that is, for any $k_1, k_2 \in S$, $\eta_j^{k_1} = \eta_j^{k_2}$, then we can remove k of η_j^k and denote η_j^k as η_j, $j \in M$ and take

$$\sigma_i^k = \sum_{j=1}^{m} f_j^k(x_{ij})\eta_j$$

as the gray fixed weight cluster coefficient with the object i belonging to the k gray class. According to the value of the weighted clustering coefficient, we can classify the clustering objects.

2.2 The steps of the gray fixed weight cluster analysis

Gray fixed weight cluster analysis is carried out according to the following steps:

Step 1: Construct the typical whitening weight function for the k subclass of j indicator $f_j^k(\bullet), j \in M, k \in S$.

A typical whitening weight function (Liu et al. 2010) generally includes three types, as follows:

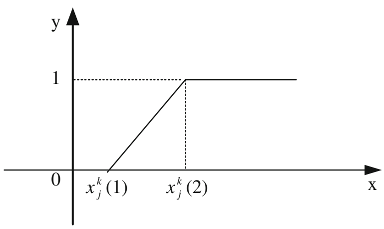
1. If the whitening weight function $f_j^k(\bullet)$ does not include the third and fourth turning point $x_j^k(3), x_j^k(4)$, as shown in Fig. 1, then we claim $f_j^k(\bullet)$ as the upper-limit measure of the whitening weight function, denoted as $f_j^k\left[x_j^k(1), x_j^k(2), -, -\right]$.
2. If the second and third turning point $x_j^k(2), x_j^k(3)$ of the whitening weight function $f_j^k(\bullet)$ coincide, as shown in Fig. 2, then we claim $f_j^k(\bullet)$ as the middle-limit measure of the whitening weight function, denoted as $f_j^k\left[x_j^k(1), x_j^k(2), -, x_j^k(4)\right]$.
3. If the whitening weight function $f_j^k(\bullet)$ does not include the first and second turning point $x_j^k(1), x_j^k(2)$, as shown in Fig. 3, then $f_j^k(\bullet)$ is considered to be the lower-limit measure of the whitening weight function, denoted as$f_j^k\left[-, -, x_j^k(3), x_j^k(4)\right]$.

Proposition 1 (Liu et al. 2010)

1. The upper-limit measure of the whitening weight function is as follows:

$$f_j^k(x) = \begin{cases} 0, & x < x_j^k(1) \\ \frac{x - x_j^k(1)}{x_j^k(2) - x_j^k(1)}, & x \in \left[x_j^k(1), x_j^k(2)\right] \\ 1, & x \geq x_j^k(2) \end{cases}$$

Fig. 1 The upper-limit measure of whitening weight function



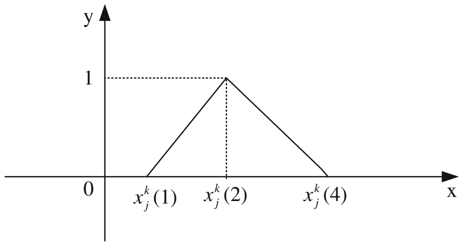


Fig. 2 The middle-limit measure of whitening weight function

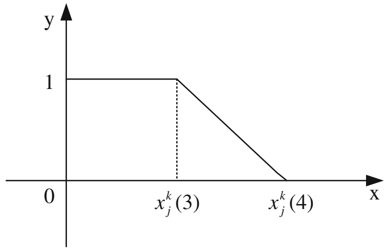


Fig. 3 The lower-limit measure of whitening weight function

And the image of this function is shown in Fig. 1.

2. The middle-limit measure of the whitening weight function is as follows:

$$f_j^k(x) = \begin{cases} 0, & x \notin \left[x_j^k(1), x_j^k(4)\right] \\ \frac{x - x_j^k(1)}{x_j^k(2) - x_j^k(1)}, & x \in \left[x_j^k(1), x_j^k(2)\right] \\ \frac{x_j^k(4) - x}{x_j^k(4) - x_j^k(2)}, & x \in \left[x_j^k(2), x_j^k(4)\right] \end{cases}.$$

And the image of this function is shown in Fig. 2.

3. The lower-limit measure of the whitening weight function is as follows:

$$f_j^k(x) = \begin{cases} 0, & x \notin \left[0, x_j^k(4)\right] \\ 1, & x \in \left[0, x_j^k(3)\right] \\ \frac{x_j^k(4) - x}{x_j^k(4) - x_j^k(3)}, & x \in \left[x_j^k(3), x_j^k(4)\right] \end{cases}$$

And the image of this function is shown in Fig. 3.

Step 2: Determine the clustering weight η_j, $j \in M$ of each indicator.

Step 3: Calculate the gray fixed weight cluster coefficient.

Using the whitening weight function $f_j^k(\bullet), j \in M, k \in S$, clustering weight η_j, $j \in M$, and $x_{ij}, i \in N, j \in M$, as observations on indicators j about object i, which is derived from Step 1 and Step 2, the gray fixed weight cluster coefficient $\sigma_i^k = \sum_{j=1}^{m} f_j^k\left(x_{ij}\right) \bullet \eta_j, i \in N, k \in S$ is calculated.

Step 4: Classify all the objects.

If $\max\limits_{1 \le k \le s}\left\{\sigma_i^k\right\} = \sigma_i^{k^*}$, then object i belongs to gray class k^*.

3 Gray fixed weight cluster of rainstorm and flood disasters losses in China

3.1 Steps of the gray fixed weight cluster of rainstorm and flood disasters losses in China

In this paper, the data are from *Yearbook of Meteorological Disasters in China* ("Yearbook") for the period of 2005–2010. We use the historical disaster data from 2004 to 2009 in "Yearbook" and seven affected indicators, which are affected area of crops (million ha), the area of no output (million ha), the affected population (million person-time), number of deaths including those missing (people), collapsed houses (million rooms), direct economic losses (billion RMB yuan), and we analyze the rainstorm and flood disaster losses in the Chinese mainland by the means of gray fixed clustering analysis. The steps of gray fixed weight clustering are as follows:

Step 1: Calculate the mean of each affected indicator

According to the statistical data of rainstorm flood affecting mainland China (excluding Hong Kong, Macao, and Taiwan) in 31 provinces, municipalities and autonomous regions from 2004 to 2009, and considering the regional area, population, economic development level, and other factors, we calculate the mean of each affected indicator in each administration. The results are shown in Table 1.

Step 2: Determine the whitening cut-off value

When determining the whitening weight function, it is important and critical to determine the cut-off value. The approximate golden section method to determine the cut-off value is adopted in the following section.

First, we sort the means of all administrations of rainstorm and flood disasters according to the seven indicators. Taking the area of affected crops as an example, we select the mean of the area of affected crops of the 31 provinces from 2004 to 2009 as the middle-whitening cut-off value (63.9, as shown in Table 2). We increase the middle-whitening cut-off value by 60 % (that is, $63.9 \times (1 + 60\ \%) = 102.2$), and then we regard this value as a high-whitening cut-off value (102.2, as shown in Table 2). Finally, we decrease the middle-whitening cut-off value by 60 % (that is, $63.9 \times (1 - 60\ \%) = 25.6$). We then regard this value as a low-whitening cut-off value (25.6, as shown in Table 2). Other indicators are handled likewise. The results are shown in Tables 2, 3:

Step 3: Determine the typical whitening weight function

Step 3.1: Construct whitening weight functions $f_j^k(\bullet)(j = 1, \ldots, 7;\ k = 1, 2, 3)$ for the 7 indictors and 3 gray classes:

$$f_1^1[63.9, 102.3, -, -], f_1^2[25.6, 63.9, -, 102.3], f_1^3[-, -, 25.6, 63.9]$$
$$f_2^1[8.9, 14.2, -, -], f_2^2[3.6, 8.9, -, 14.2], f_2^3[-, -, 3.6, 8.9]$$
$$f_3^1[336.1, 537.8, -, -], f_3^2[134.5, 336.1, -, 537.8], f_3^3[-, -, 134.5, 336.1]$$
$$f_4^1[36.4, 58.2, -, -], f_4^2[14.6, 36.4, -, 58.2], f_4^3[-, -, 14.6, 36.4]$$
$$f_5^1[2.7, 4.3, -, -], f_5^2[1.1, 2.7, -, 4.3], f_5^3[-, -, 1.1, 2.7]$$
$$f_6^1[6.8, 10.9, -, -], f_6^2[2.7, 6.8, -, 10.9], f_6^3[-, -, 2.7, 6.8]$$
$$f_7^1[21.7, 34.7, -, -], f_7^2[8.7, 21.7, -, 34.7], f_7^3[-, -, 8.7, 21.7]$$

Table 1 The losses mean of each administrative region according to seven indicators from 2004 to 2009

No.	Region	Crop disaster (million ha)		Population disaster		House affected (million rooms)		Direct economic losses (million RMB yuan)
		Affected area	Area of no output	Affected population (million person)	Death (person)	Collapse	Damage	
1	Beijing	0.8333	0.1000	1.6167	0.6667	0.0000	0.0333	0.4000
2	Tianjin	0.4000	0.0167	0.8833	0.5000	0.0000	0.0500	0.3167
3	Hebei	32.9667	3.9833	79.4000	8.8333	0.2167	0.8167	5.8833
4	Shanxi	26.6167	2.2000	92.9667	30.6667	1.8333	6.2167	9.8833
5	Inner Mongolia	55.6333	16.5500	66.2500	23.3333	0.6667	2.6500	12.9667
6	Liaoning	18.9167	1.7500	55.6000	9.5000	0.6500	2.5667	11.9000
7	Jilin	27.7500	2.9500	62.6833	2.3333	1.0167	9.3500	9.2333
8	Heilongjiang	95.9500	11.8667	122.2500	21.5000	0.8667	4.2333	20.4167
9	Shanghai	0.9167	0.1833	0.8167	1.1667	0.0000	0.0000	0.1000
10	Jiangsu	55.6167	7.2167	328.4330	4.8333	0.7667	3.2667	23.0500
11	Zhejiang	10.5500	0.8833	141.3170	5.5000	0.3000	0.6667	16.1833
12	Anhui	100.5170	18.2667	797.9670	9.5000	4.0167	7.5167	43.2333
13	Fujian	26.2500	1.8000	194.3500	30.3333	3.2833	3.9000	33.8667
14	Shandong	159.5830	17.7167	395.9830	11.8333	1.9667	6.8833	32.0333
15	Jiangxi	93.5000	10.4333	646.4170	18.1667	4.5833	11.2833	33.3333
16	Henan	178.9670	26.3500	561.0330	25.1667	4.6333	7.9667	30.9167
17	Hubei	213.3830	26.1500	1008.0200	63.3333	5.4000	13.0500	46.9833
18	Hunan	157.6330	29.6167	1066.1500	60.1667	8.3833	24.3333	69.9000
19	Guangdong	35.4833	3.9667	360.7830	36.0000	4.5167	4.2833	33.0833
20	Guangxi	145.3170	16.2500	801.2670	59.1667	7.9667	19.1667	53.4833
21	Hainan	3.7833	0.3167	54.4333	0.0000	0.0167	0.0333	1.7333
22	Chongqing	117.2330	15.2500	827.0330	83.1667	7.5167	18.9333	29.7167
23	Sichuan	174.7330	26.4000	1373.4800	192.0000	11.9833	22.9000	69.2000
24	Guizhou	65.5000	5.7167	458.1830	104.1670	1.5167	4.4833	15.3333
25	Yunnan	82.5833	10.7833	474.0830	199.5000	4.8667	11.7000	24.0167
26	Xizang	4.2167	0.6333	13.0000	7.3333	0.4667	1.2500	1.6333
27	Shanxi (Shaanxi)	50.0000	9.6333	269.6830	47.3333	3.1000	11.6500	19.5333
28	Gansu	23.9833	4.4833	114.0000	32.1667	1.0500	3.6000	14.0000
29	Qinghai	3.7000	0.3000	13.0667	6.5000	0.5500	2.1500	2.7000
30	Ningxia	6.7333	1.0500	15.7500	6.3333	0.3000	0.9500	1.2667
31	Xinjiang	2.1500	2.6500	23.5333	27.1667	1.7333	4.3833	5.9167

Step 3.2: Draw images of whitening weight function $f_j^k(\bullet)(j = 1, \ldots, 7;\ k = 1, 2, 3)$, as shown in Figs. 1, 2 and 3.

Now, take $f_1^1[63.9, 102.3, -, -]$,$f_1^2[25.6, 63.9, -, 102.3]$,$f_1^3[-, -, 25.6, 63.9]$ as an example to explain the meaning of the image corresponding to each whitening weight

Table 2 Sorting the means and determining whitening cut-off value

Affected area (million ha)	Whitening cut-off value	No output area (million ha)	Whitening cut-off value	Affected population (million person)	Whitening Cut-off value	Death population (person)	Whitening cut-off value
0.40		0.02		0.82		0.00	
0.83		0.10		0.88		0.50	
0.92		0.18		1.62		0.67	
3.70		0.30		13.00		1.17	
3.78		0.32		13.07		2.33	
4.22		0.63		15.75		4.83	
6.73		0.88		23.53		5.50	
10.55		1.05		54.43		6.33	
12.15		1.75		55.60		6.50	
18.92		1.80		62.68		7.33	
23.98		2.20		66.25		8.83	
26.25	25.57	2.65		79.40		9.50	
26.62		2.95		92.97		9.50	
27.75		3.97	3.55	114.00		11.83	
32.97		3.98		122.25		18.17	14.56
35.48		4.48		141.32	134.46	21.50	
50.00		5.72		194.35		23.33	
55.62		7.22		269.68		25.17	
55.63		9.63	8.89	328.43		27.17	
65.50	63.92	10.43		360.78	336.14	30.33	
82.58		10.78		395.98		30.67	
93.50		11.87		458.18		32.17	
95.95		15.25	14.22	474.08		36.00	
100.52		16.25		561.03	537.83	47.33	36.39
117.23	102.27	16.55		646.42		59.17	58.23
145.32		17.72		797.97		60.17	
157.63		18.27		801.27		63.33	
159.58		26.15		827.03		83.17	
174.73		26.35		1008.02		104.17	
178.97		26.40		1066.15		192.00	
213.38		29.62		1373.48		199.50	

function. The whitening weight function $f_1^1[63.9, 102.3, -, -]$ is shown in Fig. 1, and the location of $x_j^k(1)$ in Fig. 1 is 63.9, and the location of $x_j^k(2)$is 102.3. The whitening weight function $f_1^2[25.6, 63.9, -, 102.3]$ is shown in Fig. 2, and the location of $x_j^k(1)$ is 25.6, the location of $x_j^k(2)$ is 63.9, and the location of $x_j^k(4)$ is 102.3. The whitening weight function $f_1^3[-, -, 25.6, 63.9]$ is shown in Fig. 3, and the location of $x_j^k(4)$is 25.6 while the location of $x_j^k(3)$ is 63.9. Other figures of the whitening weight function are similar to the above.

Table 3 Sorting the means and determining whitening cut-off value

Collapsed house (million rooms)	Whitening cut-off value	Damaged house (million rooms)	Whitening cut-off value	Direct economic losses(million RMB yuan)	Whitening cut-off value
0.00		0.00		0.10	
0.00		0.03		0.32	
0.00		0.03		0.40	
0.02		0.05		1.27	
0.22		0.67		1.63	
0.30		0.82		1.73	
0.30		0.95		2.70	
0.47		1.25		5.88	
0.55		2.15		5.92	
0.65		2.57		9.23	8.67
0.67		2.65		9.88	
0.77		3.27	2.71	11.90	
0.87		3.60		12.97	
1.02		3.90		14.00	
1.05		4.23		15.33	
1.52	1.09	4.28		16.18	
1.73		4.38		19.53	
1.83		4.48		20.42	
1.97		6.22		23.05	21.68
3.10	2.72	6.88	6.78	24.02	
3.28		7.52		29.72	
4.02		7.97		30.92	
4.52	4.34	9.35		32.03	
4.58		11.28	10.85	33.08	
4.63		11.65		33.33	
4.87		11.70		33.87	
5.40		13.05		43.23	34.70
7.52		18.93		46.98	
7.97		19.17		53.48	
8.38		22.90		69.20	
11.98		24.33		69.90	

Step 3.3: Establish an expression of the whitening weight function. The whitening weight functions are, respectively, as follows:

$$f_1^1(x) = \begin{cases} 0, & x < 63.9 \\ \frac{x-63.9}{102.3-63.9}, & 63.9 \leq x < 102.3 \\ 1, & x \geq 102.3 \end{cases} \quad f_1^2(x) = \begin{cases} 0, & x \notin [25.6, 102.3] \\ \frac{x-25.6}{63.9-25.6}, & 25.6 \leq x < 63.9 \\ \frac{102.3-x}{102.3-63.9}, & 63.9 \leq x < 102.3 \end{cases}$$

$$f_1^3(x) = \begin{cases} 0, & \text{x} \notin [0, 63.9] \\ 1, & 0 \le x < 25.6 \\ \frac{63.9-x}{63.9-25.6}, & 25.6 \le x < 63.9 \end{cases} \quad f_2^1(x) = \begin{cases} 0, & x < 8.9 \\ \frac{x-8.9}{14.2-8.9}, & 8.9 \le x < 14.2 \\ 1, & x \ge 14.2 \end{cases}$$

$$f_2^2(x) = \begin{cases} 0, & x \notin [3.6, 14.2] \\ \frac{x-3.6}{8.9-3.6}, & 3.6 \le x < 8.9 \\ \frac{14.2-x}{14.2-8.9}, & 8.9 \le x < 14.2 \end{cases} \quad f_2^3(x) = \begin{cases} 0, & \text{x} \notin [0, 8.9] \\ 1, & 0 \le x < 3.6 \\ \frac{8.9-x}{8.9-3.6}, & 3.6 \le x < 8.9 \end{cases}$$

$$f_3^1(x) = \begin{cases} 0, & x < 336.1 \\ \frac{x-336.1}{537.8-336.1}, & 336.1 \le x < 537.8 \\ 1, & x \ge 537.8 \end{cases} \quad f_3^2(x) = \begin{cases} 0, & x \notin [134.5, 537.8] \\ \frac{x-134.5}{336.1-134.5}, & 134.5 \le x < 336.1 \\ \frac{537.8-x}{537.8-336.1}, & 336.1 \le x < 537.8 \end{cases}$$

$$f_3^3(x) = \begin{cases} 0, & \text{x} \notin [0, 336.1] \\ 1, & 0 \le x < 134.5 \\ \frac{336.1-x}{336.1-134.5}, & 134.5 \le x < 336.1 \end{cases} \quad f_4^1(x) = \begin{cases} 0, & x < 36.4 \\ \frac{x-36.4}{58.2-36.4}, & 36.4 \le x < 58.2 \\ 1, & x \ge 58.2 \end{cases}$$

$$f_4^2(x) = \begin{cases} 0, & x \notin [14.6, 58.2] \\ \frac{x-14.6}{36.4-14.6}, & 14.6 \le x < 36.4 \\ \frac{58.2-x}{58.2-36.4}, & 36.4 \le x < 58.2 \end{cases} \quad f_4^3(x) = \begin{cases} 0, & \text{x} \notin [0, 36.4] \\ 1, & 0 \le x < 14.6 \\ \frac{36.4-x}{36.4-14.6}, & 14.6 \le x < 36.4 \end{cases}$$

$$f_5^1(x) = \begin{cases} 0, & x < 2.7 \\ \frac{x-2.7}{4.3-2.7}, & 2.7 \le x < 4.3 \\ 1, & x \ge 4.3 \end{cases} \quad f_5^2(x) = \begin{cases} 0, & x \notin [1.1, 4.3] \\ \frac{x-1.1}{2.7-1.1}, & 1.1 \le x < 2.7 \\ \frac{4.3-x}{4.3-2.7}, & 2.7 \le x < 4.3 \end{cases}$$

$$f_5^3(x) = \begin{cases} 0, & \text{x} \notin [0, 2.7] \\ 1, & 0 \le x < 1.1 \\ \frac{2.7-x}{2.7-1.1}, & 1.1 \le x < 2.7 \end{cases} \quad f_6^1(x) = \begin{cases} 0, & x < 6.8 \\ \frac{x-6.8}{10.9-6.8}, & 6.8 \le x < 10.9 \\ 1, & x \ge 10.9 \end{cases}$$

$$f_6^2(x) = \begin{cases} 0, & x \notin [2.7, 10.9] \\ \frac{x-2.7}{6.8-2.7}, & 2.7 \le x < 6.8 \\ \frac{10.9-x}{10.9-6.8}, & 6.8 \le x < 10.9 \end{cases} \quad f_6^3(x) = \begin{cases} 0, & \text{x} \notin [0, 6.8] \\ 1, & 0 \le x < 2.7 \\ \frac{6.8-x}{6.8-2.7}, & 2.7 \le x < 6.8 \end{cases}$$

$$f_7^1(x)=\begin{cases}0, & x<21.7\\ \frac{x-21.7}{34.7-21.7}, & 21.7\le x<34.7\\ 1, & x\ge 34.7\end{cases}\quad f_7^2(x)=\begin{cases}0, & x\notin[8.7,34.7]\\ \frac{x-8.7}{21.7-8.7}, & 8.7\le x<21.7\\ \frac{34.7-x}{34.7-21.7}, & 21.7\le x<34.7\end{cases}$$

$$f_7^3(x)=\begin{cases}0, & \mathrm{x}\notin[0,21.7]\\ 1, & 0\le x<8.7\\ \frac{21.7-x}{21.7-8.7}, & 8.7\le x<21.7\end{cases}$$

Step 4: Gray fixed weight cluster analysis. The calculation process of the gray fixed weight cluster is as follows:

Step 4.1: Determine the clustering weight of each indicator $\eta_j, j\in M$. Since the cluster indexes have different meanings and dimensions, and furthermore, a great disparity in number, weights should be assigned to various cluster indexes in advance. The statistical loss data of the rainstorm and flood disasters include four aspects, namely, crop disaster situation (affected area, no output area), situation of population disaster (affected population, dead population), situation of house disaster (collapsed houses, damaged houses), and direct economic losses. Each aspect has equal weight. There are seven independent indicators, whose weights satisfy $\eta_1=\ldots=\eta_6=0.125, \eta_7=0.25$, where η_i is the weight of the $i-$th indicator, $i=1,2,\ldots,7$.

Step 4.2: According to 1,302 historical disaster data (the missing data are regarded as zero) in "Yearbook" and the formulation $\sigma_i^k=\sum_{j=1}^m f_j^k\left(x_{ij}\right)\bullet\eta_j$ for calculating the gray fixed weight cluster coefficient, the disaster losses can be classified as high, medium, and low gray classes.

When $i=1$,

$$\sigma_1^1=\sum_{j=1}^{7}f_j^1\left(x_{1j}\right)\bullet\eta_j=\left[f_1^1(3.8)+f_2^1(0.6)+f_3^1(2.9)+f_4^1(0)+f_5^1(0)+f_6^1(0.1)\right]$$
$$\times 0.125+f_7^1(0.6)\times 0.25=0$$

Similarly, $\sigma_1^2=0, \sigma_1^3=1$.So, $\sigma_1=\left[\sigma_1^1,\sigma_1^2,\sigma_1^3\right]=[0,0,1]$, where σ_1 represents the gray fixed weight cluster coefficient in the Beijing area in 2004. The gray fixed weight cluster coefficient in each area is calculated in the same way. The results are shown in Tables 4, 5, 6, 7, 8, 9.

Step 4.3: Determine the maximum of the gray fixed weight cluster coefficient.

The results of finding the maximum of the gray fixed weight cluster coefficient in each area from 2004 to 2009 are shown in Tables 4, 5, 6, 7, 8, 9.

Step 4.4: Classification.

According to the gray fixed weight cluster coefficient and its maximum value in Tables 4, 5, 6, 7, 8, 9, we assess the gray class for each administrative disaster loss, based on disaster losses of high, medium, and low gray classes. For example, by $\max_{1\le k\le 3}\left\{\sigma_1^k\right\}=\max_{1\le k\le 3}\{0,0,1\}=\sigma_1^3=1$, Beijing in 2004 can be judged to belong to the low-class area of disaster losses. Similarly, the disaster assessment of each area from 2004 to 2009 can be obtained, as shown in Tables 4, 5, 6, 7, 8, 9.

Table 4 Gray fixed weight cluster coefficient, maximum value and assessment of disaster in 2004

Area	Cluster coefficient of high class	Cluster coefficient of middle class	Cluster coefficient of low class	Maximum Value in 2004	Result of gray assessment
Beijing	0	0	1	1	Low
Tianjin	0	0	1	1	Low
Hebei	0.25	0.0177	0.7323	0.7323	Low
Shanxi	0.2122	0.3303	0.4575	0.4575	Low
Inner Mongolia	0.25	0.0883	0.6617	0.6617	Low
Liaoning	0	0.1116	0.8884	0.8884	Low
Jilin	0.1928	0.2651	0.5421	0.5421	Low
Heilongjiang	0.25	0.0596	0.6904	0.6904	Low
Shanghai	0	0	1	1	Low
Jiangsu	0.1816	0.0684	0.75	0.75	Low
Zhejiang	0	0	1	1	Low
Anhui	0.1887	0.1454	0.6659	0.6659	Low
Fujian	0.0645	0.0918	0.8438	0.8438	Low
Shandong	0.6374	0.2376	0.125	0.6374	High
Jiangxi	0.3233	0.4177	0.259	0.4177	Middle
Henan	0.875	0.0482	0.0768	0.875	High
Hubei	1	0	0	1	High
Hunan	1	0	0	1	High
Guangdong	0.1695	0.0996	0.7309	0.7309	Low
Guangxi	1	0	0	1	High
Hainan	0	0	1	1	Low
Chongqing	1	0	0	1	High
Sichuan	1	0	0	1	High
Guizhou	0.5	0.0606	0.4394	0.5	High
Yunnan	0.9782	0.0218	0	0.9782	High
Xizang	0	0.0669	0.9331	0.9331	Low
Shanxi (Shaanxi)	0.25	0.0828	0.6672	0.6672	Low
Gansu	0.156	0.219	0.625	0.625	Low
Qinghai	0	0	1	1	Low
Ningxia	0	0.0094	0.9906	0.9906	Low
Xinjiang	0.0472	0.2805	0.6723	0.6723	Low

3.2 The gray fixed weight cluster risk assessment of rainstorm and flood disaster losses in China

The assessment results of rainstorm and flood disaster losses in administrative districts of mainland China (except for Hong Kong, Macao and Taiwan) from 2004 to 2009 based on the gray fixed weight cluster could be obtained according to the gray fixed weight cluster coefficient, maximum value, and disaster assessment in Tables 4, 5, 6, 7, 8, 9. The results are shown in Tables 10, 11, 12, 13, 14, 15:

Table 5 Gray fixed weight cluster coefficient, maximum value, and assessment of disaster in 2005

Area	Cluster coefficient of high class	Cluster coefficient of middle class	Cluster coefficient of low class	Maximum value in 2005	Result of gray assessment
Beijing	0	0	1	1	Low
Tianjin	0	0	1	1	Low
Hebei	0	0	1	1	Low
Shanxi	0	0	1	1	Low
Inner Mongolia	0	0.1317	0.8683	0.8683	Low
Liaoning	0.2931	0.4078	0.2991	0.4078	Middle
Jilin	0.2936	0.2921	0.4143	0.4143	Low
Heilongjiang	0.6079	0.2274	0.1647	0.6079	High
Shanghai	0	0	1	1	Low
Jiangsu	0	0	1	1	Low
Zhejiang	0	0	1	1	Low
Anhui	0.875	0	0.125	0.875	High
Fujian	0.5436	0.1661	0.2903	0.5436	High
Shandong	0.3119	0.476	0.2121	0.476	Middle
Jiangxi	0.5	0.3472	0.1528	0.5	High
Henan	0.75	0.155	0.095	0.75	High
Hubei	0.96	0.04	0	0.96	High
Hunan	0.75	0.1889	0.0611	0.75	High
Guangdong	0.75	0.0291	0.2209	0.75	High
Guangxi	0.8231	0.138	0.0388	0.8231	High
Hainan	0	0	1	1	Low
Chongqing	0.375	0.4547	0.1703	0.4547	Middle
Sichuan	0.8545	0.129	0.0165	0.8545	Middle
Guizhou	0.125	0.1172	0.7578	0.7578	Low
Yunnan	0.125	0.1428	0.7322	0.7322	Low
Xizang	0	0	1	1	Low
Shanxi (Shaanxi)	0.4898	0.418	0.0922	0.4898	High
Gansu	0	0.1252	0.8748	0.8748	Low
Qinghai	0	0.0122	0.9878	0.9878	Low
Ningxia	0	0	1	1	Low
Xinjiang	0.0436	0.1903	0.7661	0.7661	Low

Results of the gray fixed weight cluster analysis can be obtained from Table 10: There were 9 areas belonging to the high-class loss areas of rainstorm and flood disasters in 2004, in which Shandong was the most typical one. Henan and Hubei were widely affected; Henan and Hunan were badly affected in the output areas; Hunan and Sichuan had a large affected population; Sichuan and Yunnan had relatively large casualties; buildings were damaged much more seriously in Chongqing and Sichuan; Sichuan and Hunan had more direct economic losses. Jiangxi was defined as medium-class loss area of rainstorm and

Table 6 Gray fixed weight cluster coefficient, maximum value, and assessment of disasters in 2006

Area	Cluster coefficient of high class	Cluster coefficient of middle class	Cluster coefficient of low class	Maximum value in 2006	Result of gray assessment
Beijing	0	0	1	1	Low
Tianjin	0	0	1	1	Low
Hebei	0	0	1	1	Low
Shanxi	0	0.0424	0.9576	0.9576	Low
Inner Mongolia	0.0092	0.2213	0.7696	0.7696	Low
Liaoning	0	0	1	1	Low
Jilin	0.0823	0.0677	0.85	0.85	Low
Heilongjiang	0.3346	0.2647	0.4007	0.4007	Low
Shanghai	0	0	1	1	Low
Jiangsu	0.7409	0.1026	0.1565	0.7409	High
Zhejiang	0	0.0346	0.9654	0.9654	Low
Anhui	0.2284	0.3621	0.4095	0.4095	Low
Fujian	0.7044	0.1138	0.1818	0.7044	High
Shandong	0	0.2916	0.7084	0.7084	Low
Jiangxi	0.6152	0.2036	0.1811	0.6152	High
Henan	0.0431	0.3343	0.6226	0.6226	Low
Hubei	0.0156	0.4757	0.5086	0.5086	Low
Hunan	0.8912	0.1088	0	0.8912	High
Guangdong	0.4415	0.1486	0.4099	0.4415	High
Guangxi	0.4451	0.2694	0.2855	0.4451	High
Hainan	0	0	1	1	Low
Chongqing	0	0.1974	0.8026	0.8026	Low
Sichuan	0.2656	0.2415	0.4929	0.4929	Low
Guizhou	0.125	0.336	0.539	0.539	Low
Yunnan	0.3783	0.3006	0.3212	0.3783	High
Xizang	0	0	1	1	Low
Shanxi (Shaanxi)	0	0.3376	0.6624	0.6624	Low
Gansu	0.1009	0.228	0.6711	0.6711	Low
Qinghai	0	0	1	1	Low
Ningxia	0	0	1	1	Low
Xinjiang	0.125	0.1607	0.7143	0.7143	Low

flood disasters, where the affected areas and population were relatively larger. Beijing and 20 other provinces were defined as the low-class loss areas of rainstorm and flood disasters.

Results of the gray fixed weight cluster analysis can be obtained from Table 11: There are 11 areas belonging to the high-class loss areas of rainstorm and flood disasters in 2005, in which Heilongjiang was the most typical one. Heilongjiang and Anhui had a very large affected area; Anhui and Hubei had a large zero-output area; Chongqing and Sichuan were much more seriously affected in the number of the population; Hunan and Sichuan had high casualties; collapsed and damaged buildings in Guangxi were more serious; Guangxi

Table 7 Gray fixed weight cluster coefficient, maximum value, and assessment of disasters in 2007

Area	Cluster coefficient of high class	Cluster coefficient of middle class	Cluster coefficient of low class	Maximum value in 2007	Result of gray assessment
Beijing	0	0	1	1	Low
Tianjin	0	0	1	1	Low
Hebei	0	0.2132	0.7868	0.7868	Low
Shanxi	0.6543	0.1819	0.1638	0.6543	High
Inner Mongolia	0	0.0263	0.9737	0.9737	Low
Liaoning	0	0	1	1	Low
Jilin	0	0	1	1	Low
Heilongjiang	0	0	1	1	Low
Shanghai	0	0	1	1	Low
Jiangsu	0.401	0.2584	0.3406	0.401	High
Zhejiang	0	0	1	1	Low
Anhui	0.875	0.1055	0.0195	0.875	High
Fujian	0	0.0963	0.9037	0.9037	Low
Shandong	0.4373	0.4208	0.1419	0.4373	High
Jiangxi	0.0305	0.4196	0.5499	0.5499	Low
Henan	0.9162	0.0838	0	0.9162	High
Hubei	1	0	0	1	High
Hunan	0.6651	0.2255	0.1094	0.6651	High
Guangdong	0.2038	0.5097	0.2865	0.5097	Middle
Guangxi	0.2294	0.5286	0.2421	0.5286	Middle
Hainan	0	0	1	1	Low
Chongqing	0.75	0.1758	0.0742	0.75	High
Sichuan	0.8694	0.1306	0	0.8694	High
Guizhou	0.5182	0.2507	0.2311	0.5182	High
Yunnan	0.7031	0.1668	0.1301	0.7031	High
Xizang	0	0.0263	0.9737	0.9737	Low
Shanxi (Shaanxi)	0.75	0.1309	0.0613	0.75	High
Gansu	0	0.2018	0.7982	0.7982	Low
Qinghai	0	0.0234	0.9766	0.9766	Low
Ningxia	0	0	1	1	Low
Xinjiang	0.1316	0.2749	0.5935	0.5935	Low

and Sichuan had much higher direct economic loss; Liaoning, Shandong and Chongqing belonged to the medium-class loss areas of rainstorm and flood disasters, Shandong and Chongqing had a larger affected population; the direct economic losses were greater in Liaoning. Beijing and 16 other areas belonged to the low-class loss areas of rainstorm and flood disasters.

Conclusion that can be drawn from Table 12: 7 areas were classified as high-class rainstorm and flood disaster losses, among which Jiangsu was representative. Heilongjiang and Jiangsu had more affected and non-output areas; Jiangsu and Hunan had a more affected population; the houses in Hunan were more seriously damaged; Sichuan, Guizhou,

Table 8 Gray fixed weight cluster coefficient, maximum value, and assessment of disaster in 2008

Area	Cluster coefficient of high class	Cluster coefficient of middle class	Cluster coefficient of low class	Maximum value in 2008	Result of gray assessment
Beijing	0	0	1	1	Low
Tianjin	0	0	1	1	Low
Hebei	0	0.0023	0.9977	0.9977	Low
Shanxi	0	0.094	0.906	0.906	Low
Inner Mongolia	0.1788	0.2792	0.5419	0.5419	Low
Liaoning	0	0	1	1	Low
Jilin	0	0	1	1	Low
Heilongjiang	0	0	1	1	Low
Shanghai	0	0	1	1	Low
Jiangsu	0	0	1	1	Low
Zhejiang	0.25	0.1151	0.6349	0.6349	Low
Anhui	0.1754	0.2146	0.61	0.61	Low
Fujian	0	0.0212	0.9788	0.9788	Low
Shandong	0	0.0213	0.9787	0.9787	Low
Jiangxi	0.5406	0.1692	0.2378	0.5406	High
Henan	0	0	1	1	Low
Hubei	0.7317	0.2136	0.0547	0.7317	High
Hunan	0.6381	0.2851	0.0768	0.6381	High
Guangdong	0.375	0.0916	0.5334	0.5334	Low
Guangxi	0.751	0.2184	0.0307	0.751	High
Hainan	0	0.0797	0.7953	0.7953	Low
Chongqing	0.1129	0.1389	0.6232	0.6232	Low
Sichuan	0.6463	0.1059	0.2477	0.6463	High
Guizhou	0.25	0.2142	0.5358	0.5358	Low
Yunnan	0.6083	0.1417	0.25	0.6083	High
Xizang	0	0	1	1	Low
Shanxi (Shaanxi)	0.0378	0.109	0.8532	0.8532	Low
Gansu	0	0.0308	0.9692	0.9692	Low
Qinghai	0	0	1	1	Low
Ningxia	0	0	1	1	Low
Xinjiang	0	0	1	1	Low

and Yunnan had more casualties; Jiangsu and Fujian had higher direct economic losses. There was no middle-class area of rainstorm and flood disaster losses. Twenty-four areas belonged to the low class of rainstorm and flood disasters losses, among which Beijing was considered typical.

Conclusions that can be drawn from Table 13: 12 areas belonged to the high class of rainstorm and flood disaster losses, among which Jiangxi is representative. The situation of disasters in 2007 was more severe, and there were 12 areas where rainstorms and floods caused very grave direct economic losses. The middle-lower Yangzi area, southwest China, Shanxi (Shaanxi), and Shanxi suffered major rainstorm and flood disaster

Table 9 Gray fixed weight cluster coefficient, maximum value, and assessment of disaster in 2009

Area	Cluster coefficient of high class	Cluster coefficient of middle class	Cluster coefficient of low class	Maximum value in 2009	Result of gray assessment
Beijing	0	0	1	1	Low
Tianjin	0	0	1	1	Low
Hebei	0	0	1	1	Low
Shanxi	0	0.1112	0.8888	0.8888	Low
Inner Mongolia	0	0.2874	0.7126	0.7126	Low
Liaoning	0	0	1	1	Low
Jilin	0	0	1	1	Low
Heilongjiang	0.5	0.123	0.377	0.5	High
Shanghai	0	0	1	1	Low
Jiangsu	0	0	1	1	Low
Zhejiang	0.1115	0.1784	0.7101	0.7101	Low
Anhui	0.3346	0.1394	0.526	0.526	Low
Fujian	0	0	1	1	Low
Shandong	0.4147	0.2621	0.3232	0.4147	High
Jiangxi	0.625	0.0705	0.3045	0.625	High
Henan	0	0	1	1	Low
Hubei	0.7161	0.2529	0.031	0.7161	High
Hunan	0.6628	0.1857	0.1514	0.6628	High
Guangdong	0	0.0254	0.9746	0.9746	Low
Guangxi	0.5213	0.1288	0.3499	0.5213	High
Hainan	0	0	1	1	Low
Chongqing	0.75	0.0232	0.2268	0.75	High
Sichuan	0.7607	0.211	0.0283	0.7607	High
Guizhou	0.0903	0.2811	0.6286	0.6286	Low
Yunnan	0.311	0.2848	0.4042	0.4042	Low
Xizang	0	0	1	1	Low
Shanxi (Shaanxi)	0	0.2241	0.7759	0.7759	Low
Gansu	0.2878	0.2197	0.4925	0.4925	Low
Qinghai	0	0.0078	0.9922	0.9922	Low
Ningxia	0	0.008	0.992	0.992	Low
Xinjiang	0	0	1	1	Low

implications. The affected areas in Anhui and Hubei were larger than other provinces; Anhui had more non-output areas; Anhui, Henan, Hubei, and Sichuan had more affected populations; Chongqing, Sichuan, Guizhou, and Yunnan had more casualties; collapsed houses were more serious in Anhui and Sichuan; damaged houses were more serious in Shanxi (Shaanxi) and Shanxi; Anhui and Sichuan had large, direct economic losses. Guangdong and Guangxi were the middle class of rainstorm and flood disaster losses, where there were more affected populations and casualties. Seventeen areas belonged to low class of rainstorm and flood disaster losses, among which Beijing was considered typical.

Table 10 Gray fixed weight cluster assessment of rainstorm and flood disasters in mainland in 2004

Assessment of disaster	Provinces
Damage of flood (High class)	Shandong, Henan, Hubei, Hunan, Guangxi, Chongqing, Sichuan, Guizhou, Yunnan
Damage of flood (Middle class)	Jiangxi
Damage of flood (Low class)	Beijing, Tianjin, Hebei, Shanxi (Shaanxi), Inner Mongolia, Liaoning, Jilin, Heilongjiang, Shanghai, Jiangsu, Zhejiang, Anhui, Fujian, Guangdong, Hainan, Xizang, Shanxi, Gansu, Qinghai, Ningxia, Xinjiang

Table 11 Gray fixed weight cluster assessment of and flood disasters in mainland in 2005 mainland

Assessment of disaster	Provinces
Damage of flood (High class)	Heilongjiang, Anhui, Fujian, Jiangxi, Henan, Hubei, Hunan, Guangdong, Guangxi, Sichuan, Shanxi (Shaanxi)
Damage of flood (Middle class)	Liaoning, Shandong, Chongqing
Damage of flood (Low class)	Beijing, Tianjin, Hebei, Shanxi, Inner Mongolia, Jilin, Shanghai, Jiangsu, Zhejiang, Hainan, Guizhou, Yunnan, Xizang, Gansu, Qinghai, Ningxia, Xinjiang

Table 12 Gray fixed weight cluster assessment of rainstorm and flood disasters in mainland in 2006 mainland

Assessment of disaster	Province
Damage of flood (High class)	Jiangsu, Fujian, Jiangxi, Hunan, Guangdong, Guangxi, Yunnan
Damage of flood (Middle class)	–
Damage of flood (Low class)	Beijing, Tianjin, Hebei, Shanxi (Shaanxi), Inner Mongolia, Liaoning, Jilin, Heilongjiang, Shanghai, Zhejiang, Anhui, Shandong, Henan, Hubei, Hainan, Chongqing, Sichuan, Guizhou, Xizang, Shanxi, Gansu, Qinghai, Ningxia, Xinjiang

Table 13 Gray fixed weight cluster assessment of rainstorm and flood disasters losses in mainland in 2007

Assessment of disaster	Provinces
Damage of flood (High class)	Shanxi (Shaanxi), Jiangsu, Anhui, Shandong, Henan, Hubei, Hunan, Chongqing, Sichuan, Guizhou, Yunnan, Shanxi
Damage of flood (Middle class)	Guangdong, Guangxi
Damage of flood (Low class)	Beijing, Tianjin, Hebei, Inner Mongolia, Liaoning, Jilin, Heilongjiang, Shanghai, Zhejiang, Fujian, Jiangxi, Hainan, Xizang, Gansu, Qinghai, Ningxia, Xinjiang

Table 14 Gray fixed weight cluster assessment of rainstorm and flood disasters losses in mainland in 2008

Assessment of disasters	Provinces
Damage of flood (High class)	Jiangxi, Hubei, Hunan, Guangxi, Sichuan, Yunnan
Damage of flood (Middle class)	–
Damage of flood (Low class)	Beijing, Tianjin, Hebei, Shanxi (Shaanxi), Inner Mongolia, Liaoning, Jilin, Heilongjiang, Shanghai, Jiangsu, Zhejiang, Anhui, Fujian, Shandong, Henan, Guangdong, Hainan, Chongqing, Guizhou, Xizang, Shanxi, Gansu, Qinghai, Ningxia, Xinjiang

Table 15 Gray fixed weight cluster assessment of rainstorm and flood disasters in mainland in 2009

Assessment of disaster	Provinces
Damage of flood (High class)	Heilongjiang,Shandong, Jiangxi, Hubei,Hunan, Guangxi, Chongqing, Sichuan
Damage of flood (Middle class)	–
Damage of flood (Low class)	Beijing, Tianjin, Hebei, Shanxi (Shaanxi),Inner Mongolia, Liaoning, Jilin, Shanghai, Jiangsu, Zhejiang, Anhui, Fujian, Henan, Guangdong, Hainan, Guizhou, Yunnan, Xizang, Shanxi, Gansu, Qinghai, Ningxia, Xinjiang

Conclusions that can be drawn from Table 14: 6 areas belonged to the middle class of rainstorm and flood disaster losses, among which Jiangxi was the typical one. Jiangxi and Hubei had more non-output areas; Hubei, Hunan, and Guangxi had more affected populations; Sichuan and Yunnan had more casualties; collapsed and damaged houses in Sichuan, Hunan, and Guangxi were more than those in other provinces; Hunan and Guangxi suffered large direct economic losses. Those areas that had no rainstorm and flood disaster losses belonged to the middle class. No rainstorm and flood disasters belonged to middle-class area. Twenty-five areas belonged to the low class, in which Beijing was the typical one.

Conclusions that can be drawn from Table 15: 8 areas belonged to the high class of rainstorm and flood disaster losses, in which Heilongjiang was the typical one. Heilongjiang and Hubei had larger affected and non-output areas; affected populations and casualties in Sichuan were more than other provinces; houses were more seriously damaged in Sichuan; Hunan and Sichuan had more direct economic losses. The areas that had no rainstorm and flood disaster losses belonged to the low class. Twenty-five areas belonged to the low class, in which Beijing was the typical one.

Overall, there are three main reasons for the high-level rainstorm and flood disaster losses: First, in some regions of China, the climate changes are abnormal, extreme weather events occur frequently, and meteorological disasters happen frequently and simultaneously, among which presents the characteristics of serious rainstorm and flood disasters. For example, the heavy rainstorm and flood disasters lasted in the Huaihe River Basin from June to July in 2007, leading to an affected crop area of 10,464,000 hectares, casualties of 1,467, and a direct economic loss of 84.47 billion RMB yuan, which could be defined as a year of serious rainstorm and flood disasters. Second, the remarkable monsoon climate in

Fig. 4 Zoning map of disaster risk assessment in 2004

China leads to the concentrated precipitation in the summertime, the obvious inter-annual variability, and the uneven seasonal distribution. For instance, in the summer of 2008, heavy rainstorm and flood disasters happened in the Pear River Basin and the upper reaches of the Xiangjiang River; in autumn of same year, the most powerful autumn rain in South China since 1951 caused a serious flood disaster which led to an affected crop area of 6,682,000 hectares, casualties of 915, and direct economic loss of 65.18 billion RMB yuan. Third, the strength and intensity of rainstorm and flood disasters have a direct relationship with factors like the regional climate, topography conditions, geological characteristics, the number and density of the population, and financial situations. In addition, in June of 2005, Guangdong, Guangxi, and Fujian suffered from heavy rainstorm and flood disasters due to the warm moist air and weak cold air, as well as the strong precipitation in South China and mid-south of Jiangnan. Influenced by this, severe floods, landslides, mudslides, and other disasters happened in some regions, which caused 117 casualties, a missing population of 66 and a direct economic loss of over 18 billion RMB yuan.

In short, the gray clustering analysis from 2004 to 2009 shows that the rainstorm and flood disasters in China have features that include wide range, high frequency, strong hazards, and severe loss due to the climate and geographical conditions as well as social-economic factors. Apart from natural factors, there are some other reasons for the rainstorm and flood disasters: the monsoon climate, high-intensity precipitation, long durations, uneven spatial and temporal distribution, unreasonable use of natural resources, low standards in flood control and water conservancy, population, and economic growth. The feature of flood distribution in China is high in the east and low in the west; high in the

Fig. 5 Zoning map of disaster risk assessment in 2005

coast and low in inland; high in lake and plain areas and low in plateau and hilly areas; high in the eastern and southern sides of mountains and low in western and northern.

3.3 Zoning map of the risk assessment of rainstorm and flood disasters in China

According to the results of the gray clustering assessment from 2004 to 2009 in China, we studied the dynamic zoning of rainstorm and flood disasters in various regions of mainland China, thus drawing a zoning map of the risk assessment of rainstorm and flood disasters. The high-class loss regions of rainstorm and flood disasters are shown in red, the middle-class loss regions in yellow, and the low-class loss regions in three colors: northwest China and Tibet in brown, eastern and southern China in light blue, and other areas in green. The zoning maps of the risk assessment of rainstorm and flood disasters in mainland China from 2004 to 2009 are, respectively, shown in Figs. 4, 5, 6, 7, 8, 9:

Conclusions from Fig. 4 to Fig. 9: Zoning maps of the risk assessment of the rainstorm and flood disaster losses dynamically show the severe impact of rainstorm and flood disasters in the Chinese mainland and also show the degree of influence of rainstorm and flood disasters losses suffered each year. For example, there are more red areas in 2005 and 2007, which intuitively represents that China suffered heavy rainstorm and flood disaster losses during those 2 years and relatively light rainstorm and flood disaster losses during the other 4 years, which are well consistent with historical disasters.

The research results show that rainstorm and flood disasters have aggravated hazards in most regions of the Chinese mainland; the results of rainstorm and flood disaster losses are

Fig. 6 Zoning map of disaster risk assessment in 2006

consistent with actual rainstorm and flood disasters in each administrative district. Facts have proven that the relevant departments attached great importance to disaster prevention and mitigation work. They have started “comprehensive national disaster prevention and mitigation strategies research” based on the disaster assessment data provided by relevant departments and therefore supply references for making prevention and mitigation decisions. Many positive and effective measures have been taken to reduce the disaster losses to ensure sustainable development of the national and provincial economies, and good results have also been obtained. Consequently, it is necessary to discuss systematically the future trends of rainstorm and flood disaster risks in every administrative district.

3.4 Future trends of rainstorm and flood disaster risks in China

Based on Tables 4, 5, 6, 7, 8, 9, we can get the frequency of high, middle, and low class of disasters from the assessment of rainstorm and flood disasters from 2004 to 2009. The results are shown in Table 16.

According to the frequency of high, middle, and low-class rainstorm and flood disasters from 2004 to 2009, we sort the frequency of the high-class rainstorm and flood disasters, as shown in Table 17. Then, we further analyze the high-class disaster areas, learning the most serious one, which is very helpful for focusing flood defending and fighting work.

Conclusions that can be drawn from Table 17: The frequency of rainstorm and flood disasters in Hunan is 6 times from 2004 to 2009, which is the most serious one in China. Hubei, Guangxi, Sichuan take the second place at 5 times; Jiangxi and Yunnan, 4 times;

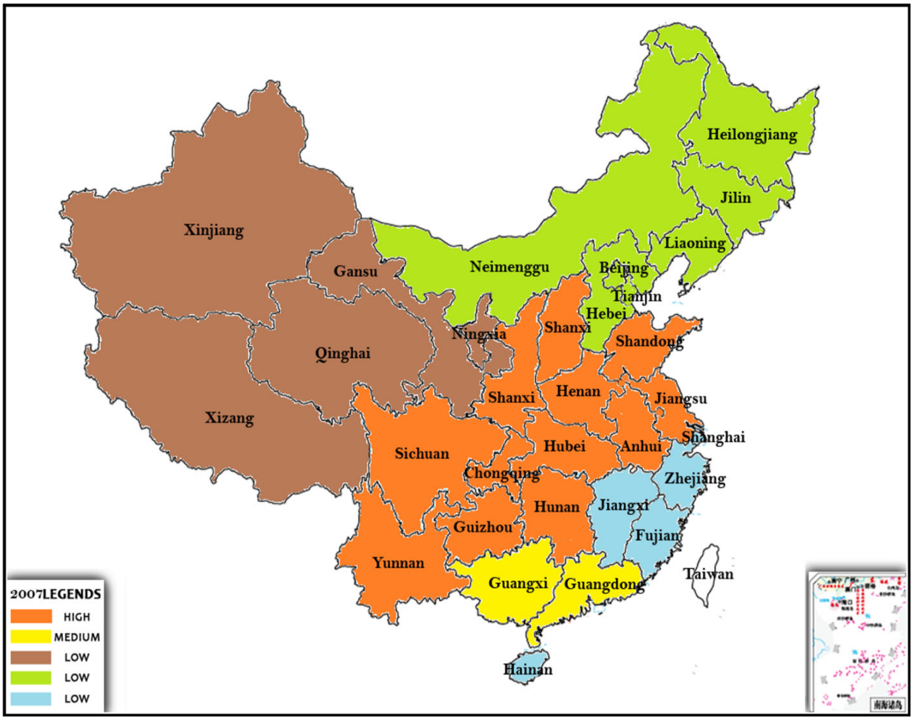


Fig. 7 Zoning map of disaster risk assessment in 2007

Shandong, Henan and Chongqing, 3 times; Heilongjiang, Jiangsu, Anhui, Fujian, Guangdong, Guizhou, and Shanxi (Shaanxi), 2 times; Shanxi, 1 time. This shows that rainstorm and flood disasters appeared in Hunan every year and that the situations are very grave. During 6 years, the disaster statistics are as follows: The crop-affected area is 9.458 million hectares; non-output area is 1,777 hectares; the affected population is 63.96.9 million, the casualties are 361, the number of collapsed houses is 503,000; the number of damaged houses is 146 million; the direct economic losses amount to 41.94 billion RMB yuan. Therefore, Hunan suffered the most serious disasters in China.

Through a comprehensive analysis of Tables 16 and 17, we can draw a conclusion that the rainstorm and flood disaster areas are relatively concentrated. Hereby, we can further determine the future flood risk trends as follows:

1. The rainstorm and flood disasters mainly concentrate in East China, Central China, South China and Southwest China; meanwhile, they appear less in the North, Northeast, and Northwest. East China, Central China, South China, and Southwest China are severely afflicted areas, followed by the Northeast and Northwest. North China is a light disaster area.
2. The provinces with a high frequency of 4–6 times of rainstorm and flood disasters are Jiangxi, Yunnan, Hubei, Guangxi, Sichuan, and Hunan, among which rainstorm and flood disasters happen most easily in Hunan, Hubei, Guangxi, and Sichuan. Therefore, they are always the most serious disaster areas, and the possibility of rainstorm and

Fig. 8 Zoning map of disaster risk assessment in 2008

flood disasters occurring in the future is the greatest, and the consequent disaster situations the most serious, too.

3. Those provinces, such as Shandong, Henan, and Chongqing, which have 3 times as high frequency of rainstorm and food disasters, the probability of rainstorm and flood disasters occurring is relatively small. But with increasingly serious global warming and all kinds of extreme weather and climate events occurring, severe rainstorm and flood disasters are very likely to happen due to factors like climate, natural geographic conditions, precipitation distribution in time and space, frequency of occurrence, etc.
4. As for those provinces, such as Heilongjiang, Jiangsu, Anhui, Fujian, Guangdong, Guizhou, and Shanxi (Shaanxi), which have 2 times as high frequency, the years of rainstorm and flood disasters fluctuate, but the trend of occurrence still exists. During the flood season especially, such disasters will happen much more easily in coastal areas.
5. In north, northeast and northwest China, where most parts have a dry climate and less rain, it is less probable for rainstorm and flood disasters to occur, but under the influence of an abnormal climate, strong rainfall is still likely to happen. Moreover, some long and large-scale continuous rain or frequent heavy rain will also cause rainstorm and flood disasters, which should not be neglected. For example, rainstorm and flood disasters have even occurred in Shanxi, Heilongjiang, and Shaanxi in history.

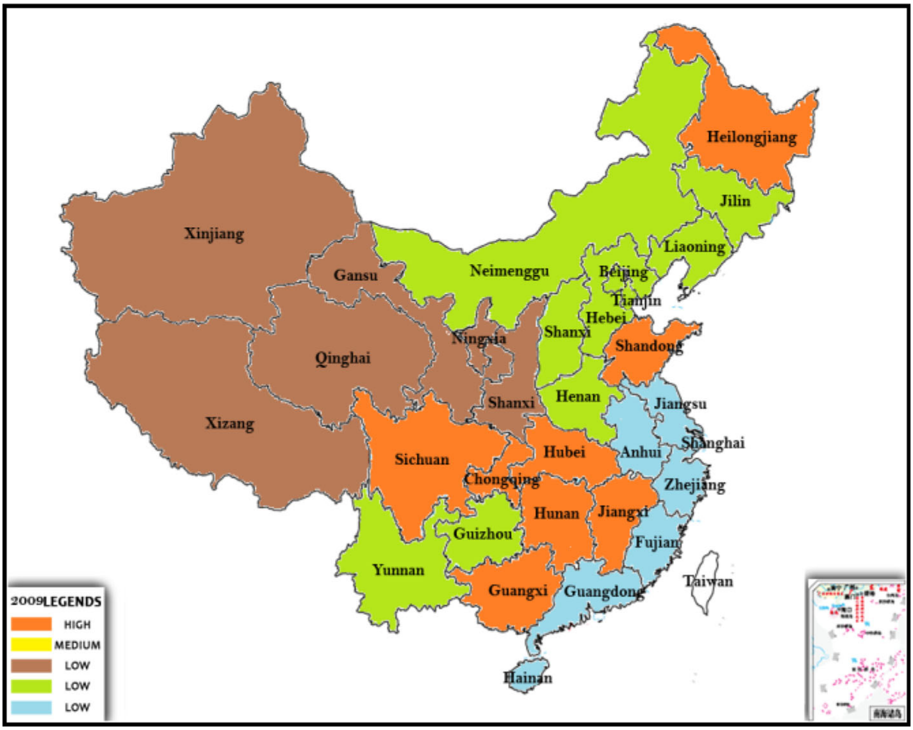


Fig. 9 Zoning map of disaster risk assessment in 2009

Table 16 The frequency of high, middle, low class of rainstorm and flood disasters from 2004 to 2009

No.	Area	Zoning	Frequency of high class	Year of high class disaster	Frequency of middle class	Frequency of low class
1	Beijing	North of China	0		0	6
2	Tianjin		0		0	6
3	Hebei		0		0	6
4	Shanxi		1	2007	0	5
5	Inner Mongolia		0		0	6
6	Liaoning	Northeast of China	0		1	5
7	Jilin		0		0	6
8	Heilongjiang		2	2005, 2009	0	4
9	Shanghai	East of China	0		0	6
10	Jiangsu		2	2006, 2007	0	4
11	Zhejiang		0		0	6
12	Anhui		2	2005, 2007	0	4
13	Fujian		2	2005, 2006	0	4

Table 16 continued

No.	Area	Zoning	Frequency of high class	Year of high class disaster	Frequency of middle class	Frequency of low class
14	Shandong		3	2004, 2007, 2009	1	2
15	Jiangxi		4	2005, 2006, 2008, 2009	1	1
16	Henan		3	2004, 2005, 2007	0	3
17	Hubei	Central of China	5	2004, 2005, 2007, 2008, 2009	0	1
18	Hunan		6	2004, 2005, 2006, 2007, 2008, 2009	0	0
19	Guangdong	South of China	2	2005, 2006	1	3
20	Guangxi		5	2004,2005,2006,2008, 2009	1	0
21	Hainan		0		0	6
22	Chongqing	Southwest of China	3	2004, 2007, 2009	1	2
23	Sichuan		5	2004, 2005, 2007, 2008, 2009	0	1
24	Guizhou		2	2004, 2007	0	4
25	Yunnan		4	2004, 2006, 2007, 2008	0	2
26	Xizang		0		0	6
27	Shanxi (Shaanxi)	Northwest of China	2	2005, 2007	0	4
28	Gansu		0		0	6
29	Qinghai		0		0	6
30	Ningxia		0		0	6
31	Xinjiang		0		0	6

Table 17 Ranking the frequency of high-class rainstorm and flood disasters in 2004–2009

Frequency of high class	Provinces
6	Hunan
5	Hubei, Guangxi, Sichuan
4	Jiangxi, Yunnan
3	Shandong, Henan, Chongqing
2	Heilongjiang, Jiangsu, Anhui, Fujian, Guangdong, Guizhou, Shanxi (Shaanxi)
1	Shanxi

4 Conclusions

This paper takes flood disaster data for 31 regions of mainland China of the past 6 years from 2004 to 2009, attempting to apply the improved gray fixed weight clustering evaluation results to the economic loss assessment of floods. The results show that rainstorm and flood disaster losses in each administration are in accordance with actual flood disaster losses and that according to the clustering results of the flood disaster losses, drawing a zoning map of the flood disaster assessment in mainland China dynamically shows the condition of flood disaster losses, and the map is intuitively clear and has a good effect. By providing a more intuitive reference for the economy and for prevention and mitigation of the region, there is potential value in the risk assessment of meteorological disasters.

The gray fixed weight cluster theory is an effective method to assess rainstorm and flood disaster losses, and the method could be commonly used in the assessment of meteorological disasters, but in order to improve the accuracy of loss evaluation results of rainstorm and flood disasters, it still needs to be explored further in some respects. For example, accurately determining affected index weights and rationally selecting cut-off values for whitening, etc., are for future study.

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