

China's regional meteorological disaster loss analysis and evaluation based on grey cluster model

Naiming Xie · Jianghai Xin · Sifeng Liu

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Abstract To evaluate the regional meteorological disaster loss of China, this paper analyzed the different types of meteorological disasters, including droughts, floods, tropical storms, snowstorms and hail disasters. Based on the analysis about Chinese geographical features, the historical characteristics of different meteorological disasters are analyzed. In particular, these meteorological disasters influence to agriculture production are discussed. According to the analysis of data from 2004 to 2010, we know that the distribution characteristics are very different about different disasters. Provinces like Heilongjiang, Liaoning, Jilin, Inner Mongolia, Gansu, Shanxi and Yunnan are serious affected areas of drought influence. And Anhui, Shandong, Jiangsu, Henan, Jiangxi, Hubei, Hunan, Guangxi, Sichuan and Heilongjiang are serious affected areas by floods and heavy rain. While Guangdong, Fujian, Zhejiang, Shanghai, Jiangsu and Shandong are mainly affected by tropical storms, Henan, Hebei, Hunan and Hubei are serious affected by snowstorms and hail disasters. Then, a novel method based on grey cluster model is constructed and combined with the regional meteorological disaster loss evaluation index system. A total of 31 provinces are considered to evaluate the integrated meteorological disaster losses. The results indicated that Beijing, Tianjin, Shanghai, Xizang, Qinghai and Ningxia belong to the lighter loss grey class. Jiangxi, Hubei, Hunan, Hainan, Sichuan and Gansu belong to the serious loss grey class. Other regions belong to the general loss grey class that the influence caused by meteorological disasters not better than the lighter loss grey class and not worst than the serious loss grey class.

N. Xie (✉) · S. Liu

Institute of Grey System Studies, Nanjing University of Aeronautics and Astronautics, Nanjing, Jiangsu, People's Republic of China
e-mail: xienaiming@nuaa.edu.cn

S. Liu

e-mail: sflu@nuaa.edu.cn

J. Xin

Department of Vehicle Engineering, Nanjing University of Technology, Nanjing, Jiangsu, People's Republic of China
e-mail: nuaaxjh@nuaa.edu.cn

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1 Introduction

Meteorological disasters are some kinds of meteorological phenomena or activities, like heavy rain, drought and typhoon, take actions on human society and socioeconomic system. These disasters not only harm to human beings safety and social production activities, but also produce systemic chain reactions. One meteorological disaster events may lead to some other natural disaster events. For example, heavy rainfall maybe induce landslides mudslides and floods, typhoon maybe trigger the storm surges, earthquake maybe induce tsunami, drought maybe induce fires of forests or grasslands. These disaster events generally embody the characteristics of heavy harmful, wide range, high frequency, long duration and chain diffusivity so that these disasters produce more and more negative influences on the national economics and human beings' life. According to the statistic results of World Meteorological Organization, meteorological disasters occupy about 70 % of the total natural disasters. According to climate bulletins of the China Meteorological Administration in recent years, the frequency of meteorological disasters is increasing and the negative influences of meteorological disasters to the development of the national economy are rapidly growing on the background of global warming.

China has a vast, complex terrain, a huge difference of the height, variety of land and sea, and other natural disaster conditions, which result in extremely complex weather and climate conditions in China. Variety of meteorological disasters and frequent destruction of human activities act on the ecological environment has exacerbated these disasters, and even produce some new meteorological disasters, such as air pollution, acid rain. Therefore, China is one of the few countries in the world that encountered with many kinds of meteorological disasters and severe damages. To study the regional meteorological disaster in China is benefit to know the meteorological disaster distribution characteristic and put forward strategy to cope with such disasters. Existent literatures focused on meteorological disasters are mainly divided in three types. The first type is to analyze and forecast the changes in special cases of meteorological disasters. Second type is to research the risks of meteorological disasters and provide some response measures. Third one is to evaluate the meteorological disasters, focused on resources collection, allocation and provide some emergency disaster relief programs. We take the view that even the occurrence of meteorological disasters is mainly influenced by nature, while the rescue human beings and relief the loss of meteorological disasters are mainly rely on government or other forces. So to evaluate the loss of meteorological disasters in regional areas is meaningful and it is helpful to formulate plans by government. The original ideas of this paper are to combed the history of meteorological disasters happening which is helpful to prepare the preventions, to evaluate the regional meteorological disaster grades and distribution characteristics which is better for allocating resources and to construct novel meteorological disaster evaluation models.

This paper is structured as follows. In the next section, the main progress in meteorological disaster evaluation and grey cluster evaluation will be summarized. Section 3 will analyze Chinese geographical features and different kinds of meteorological disasters in China. Section 4 will create a novel regional meteorological disaster loss dynamic evaluation method based on grey cluster model. In Sect. 5, the index system on regional

meteorological disaster loss evaluation will be discussed, and the grey cluster evaluation model will be applied to the cases. Finally, Sect. 6 comes to the conclusions of the paper.

2 Literature review

Natural disasters, especially meteorological disasters, have frequently occurred all over the world, and these disasters resulted in enormous losses of life and property. And the disasters seriously affected on the human beings production and life (Xiao and Xiao 2010). Scholars pay more attention on analyzing disasters, evaluating the results, forecasting the changes and providing solutions. To analyze and to evaluate the influences of meteorological disasters, existent literatures mainly focused on analysis and forecast the changes, evaluating the risks of disasters. To study the measures to relief losses, a storm surge prediction system has been set up at the Centre for Coastal Ocean Design and Prediction Systems. With the system and appropriate forecasting models, the actual curvilinear geometry of the shoreline can be simulated and finer resolution in the shallow seas of the eastern seaboard can be provided (Dube and Gaur 1995). Haque examined the process that warning of the impending disastrous cyclone by the local communities and disseminated throughout the coastal regions of Bangladesh. The results indicated it is successful to identify the threatening condition due to atmospheric disturbance, monitor the hazard event and disseminate the cyclone warning (Haque 1995). Chang constructed a forecasting model to assess the overall usefulness and limitation of numerical weather prediction models in quantitative precipitation forecasting for this flash flood event. He combined the model with the case of the Enid, Oklahoma flood of October 10–11, 1973. The results reveal that the broad-scale precipitation patterns associated with the front and cyclone are well predicted, but the maximum rainfall amounts around Enid are under predicted (Chang 1998). Boswell et al. created a multivariate model developed through multiple regression analysis of an array of independent variables that measure meteorological, socioeconomic and physical conditions related to the landfall of hurricanes. They utilized a case in Florida, USA, to explain the validity of the model and gave out several suggestions (Boswell et al. 1999). A case for a reassessment of the risks of extreme hydrological hazards in the Caribbean is discussed, and an examination of predictive methodologies was presented for the assessment of long-term risks of hydrological hazards (Sisson et al. 2006). The case of the weather-related losses in Australia is used to estimate the insured loss, and the success of improved building standards in reducing tropical cyclone wind-induced losses was evidence that important gains can be made through disaster risk reduction (Crompton and Mcaneny 2008). The drought risk index was established with drought disaster frequency, drought severity, production and extent of irrigation. With the index, the drought risk for world crop production was evaluated under current and future climatic conditions by using an integrated approach to analyze the correlation between historical crop yield and meteorological drought (Li et al. 2009). Multivariate geo-statistical methods are implemented by combining information from 1,180 rain gauges covering the period 1950–2005 in Colombia, and four new annual average precipitation fields are estimated. These improved fields are applied in water resources, agriculture, hydropower generation, human health, risks and disaster prevention, etc (David et al. 2011). Monthly rainfall and mean air temperature from the surface observations of Bangladesh are utilized to analyze the meteorological drought events by calculating Standardized Precipitation Index (SPI) and Palmer Drought Severity Index (PDSI) for the period 1961–1990. Results reflected that regional information is better in drought diagnosis compared to the point information

(Dash et al. 2012). The paper presents a framework for the nation-wide assessment of natural hazards, vulnerability and risk for the Republic of Georgia. Database, hazard maps, economic losses and novel approach were considered to calculate the overall vulnerability value for each individual hazard type by using the Gross Domestic Product per unit area. The spatial distribution of general vulnerability was assessed, and the expected maximum economic loss was calculated as well as a multi-risk map was set up (Varazanashvili et al. 2012). A new method for spatial, geo informatics-based assessment of agricultural, meteorological and hydrological drought hazard is proposed and applied in Palamu district of Jharkhand. The framework for the derivation of an agricultural, meteorological, and hydrological drought hazard map was constructed through the development of a numerical weighting scheme to evaluate the drought potential of the classes. The area with different severity of drought hazards under cumulative drought hazards scenario revealed high drought proneness of the area and the usefulness of geo informatics in better spatial prognosis of drought hazards (Pandey et al. 2012). Global precipitation variation monitoring product based on the Climate Anomaly Monitoring System–Outgoing Long-wave Radiation Precipitation Index (CAMS-OPI) data provided by the APEC Climate Center (APCC) is used to monitor large-scale precipitation variability in East Asia. The results showed that the index is effective to monitor the rainfall (Sohn et al. 2012). An empirical tree-based model is applied to estimate quantitatively about the risk of future drought and winter disasters in Mongolia, the results indicated that drought is the dominant factor for high livestock mortality, and the frequency of meteorological disasters leading to high livestock mortality in the future will be lower than that during 1940–2003 (Tachiiri and Shinoda 2012). According to the above-mentioned literatures, the existent literatures about meteorological disasters are mainly concerned on the special case analysis and evaluation, especially on rainfalls and droughts. The contents are mainly on the risk analysis of different disasters.

In the area of China, meteorological disasters are variety and complex. Many scholars concerned about the area and research on some special meteorological disaster cases in China. Weidinger et al. (2001) focused on geo-analytical hazard analysis, studied the preexisting structures and preparatory causal factors of the landslides, compared the analysis results with Gansu, China, and found that climatologically meteorological conditions, earthquakes and human impact concerning the rapidly happening disasters. A new model for risk analysis and assessment of drought disaster to agricultural production was presented and applied in the maize-growing area of Song liao Plain of China based on Geographical Information Systems. The results showed the model can provide the basis for developing strategies to mitigate drought and reducing the losses to ensure agricultural sustainable development (Zhang 2004). The linear relationship between satellite-generated brightness temperatures and in situ observation temperature and that land surface temperature is largely influenced by vegetation cover conditions. The model is combined with the case of southern China during the strong snow disaster in 2008. The results indicated that the simulation models were more effective for producing land surface temperature (Chen et al. 2011). Annual extremes in temperature and precipitation in the Zhujiang River Basin were discussed, and the high station density and data quality are very useful for spatially assessing change-points of climatic extreme events. The relation of the change-points to large-scale oscillation can provide valuable data for planning adaptation measures against climate risks (Fischer et al. 2012). The paper analyzes the characteristics of high-impact weather events based on available data in Shanghai, China, during 1960–2009, including the frequency and extreme value of rainstorm, typhoon, thunderstorm, strong wind, tornado, fog, haze and hot days. The results revealed that Shanghai has become more

vulnerable to high-impact weather and meteorological disaster, especially high temperature, haze and typhoon with global climate change, urbanization and rapid economic development (Shi and Cui 2012). A risk analysis method based on information diffusion theory was applied to create a new drought risk analysis model, and the model was combined with the historic drought disaster data from 583 agro-meteorological observations of China in 1991–2009. Drought risk presented clear zonal differentiation that may be result from stepped topography, different precipitation and hazard-affected bodies (Hao et al. 2012). The observation records of meteorological stations distributed in the middle Inner Mongolia were analyzed, and the results revealed that annual mean air temperature obviously rose, while precipitation slightly decreased due to fluctuation in the study area. So some effects and potential problems of adaptation strategy made by regional government need to be comprehensively assessed further in longer time scales and aimed at different sub-regions (Liu and Wang 2012). Meteorological observation data, soil moisture data and remote sensing data from 30 meteorological stations in Inner Mongolia, China, from 1985 to 2006 were used to risk analysis and assessment of severe dust storm disaster. The results revealed that the risk decreased from west to east across Inner Mongolia and the results can support local and national government agencies to make decision on resource allocation, high-level planning and raise public awareness of severe dust storm risk (Liu et al. 2012). A case about snowfall of China for the period 1953–2008 is discussed, and the results indicated that the extreme snowfall weather over central-eastern China is closely associated with the Asian atmospheric cold source. Compared with the El Nino-Southern Oscillation and Arctic Oscillation during winter, the thermal condition over the Asian continent has a closer relationship with the occurrence of the heavy snowfall weather over central-eastern China (Nan and Zhao 2012). A case of dust storms in north China is applied to analyze the IAP Sandstorm Prediction System and more recent version. The results showed in the integrated sandstorm management system that improved land surface modeling affects modeling of sandstorms. The specific mechanisms by which land surface processes affect dust storm modeling and further improvements to numerical dust storm simulations were discussed (Lin et al. 2012). According to the above-mentioned Chinese cases, literatures mainly focused on special cases and risk assessment. The areas mainly focused on dust storm, strong snowfall, drought and rainfall. The contents mainly focused on risk analysis loss of agriculture production and some precautions for these disasters.

Considering the information people could collect is very limited, many different evaluation methods are applied in analyzing and assessing the disasters problems. Statistic method is applied in evaluation of drought in a tropical setting, and the results indicated that relationships between drought indicators and relief payments point to the potential utility of meteorological drought assessments for disaster risk management are statistically significant in the case study (Lyon et al. 2009). Fuzzy analysis is utilized in meteorological disaster analysis and evaluation, Such as intuitionistic fuzzy analysis method was applied to simulate the unknown relations between a set of meteorological and hydrological parameters (Kalayathankai et al. 2011). Triangular fuzzy numbers were used to express the uncertainty information in meteorological disasters and applied in risk evaluation of China's nature disaster systems (Jin et al. 2012). Grey system theory is a new uncertainty system analysis theory proposed by Professor Deng Julong, and grey numbers are used to characterize information partially known and limited observation samples (Deng 1982). Grey cluster method is one of the main grey models in grey system theory. To compare with other evaluation methods, grey cluster model can get better results and the evaluation information can be traced. On the other words, when the final evaluation result of an object

is best could not state that each sub-index is the best, that is to say some sub-indexes still can be progressed. While other evaluation methods maybe lose some information and the results could not effectively traced, Grey cluster evaluation method has been applied in all kinds of evaluation cases. For example, the method was applied to evaluate the development of an organization (Fariborz et al. 2011). Grey cluster evaluation method was used to evaluate real-time bird-strike risk, and new bird-strike risk assessment system was constructed to avoid the aviation accident (Wang et al. 2012). Hierarchical grey relation clustering analysis was created to analyze the geographical position of hospitals, and results can inform hospitals of their competitors and help them to develop appropriate responses (Wu et al. 2012).

Grey cluster method has widely used in analyzing and evaluating different cases, and the results indicated the model could obtained better conclusion than other uncertainty methods, while the existent literatures showed that grey cluster evaluation method has not been used in analyzing and evaluating meteorological disaster. In following sections, grey cluster method will be applied to analyze meteorological disaster loss in China and classify different regions in China to help the regional and national government to make more useful policies for prevention of different kinds of meteorological disasters.

3 Chinese geographical features and historical analysis of meteorological disaster in China

3.1 Analysis of meteorological disaster type

There are a wide variety of meteorological disasters. We can even say that all of the weather-related disasters can be called meteorological disasters. Up to present, there is not a unified division about meteorological disasters. In this paper, we divide meteorological disasters into different types mainly on the consideration that the causes, properties and harm to human beings. We also consider the information that can be collected. Therefore, we analyze the meteorological disaster types, phenomenon, harm and secondary disasters that produced by normal meteorological disasters. The detail information is given in Table 1.

3.2 Chinese geographical features and meteorological disaster analysis

The terrain of China is very complex. Generally, it is higher in west and lower in the east, formed three steps gradually from the west to the east. The southwest is the first step where is named “roof of the world.” The average highest plateau of the world, the Tibetan Plateau, is located in this area. From the area to the east and north, there are a lot of plateaus and basins where is viewed as second step. The rest regions almost belong to the coastal areas, mainly plains and hills, viewed as the third step. Due to the difference of terrain, the temperatures, rainfalls and climates in different regions of China change very much. This is the main reason that causes meteorological disasters in China have many types, complex circumstances and different in different regions. So it is very difficult to make appropriate plans to relief the losses of meteorological disasters. Every year about twenty thousands of people died because of all kinds of meteorological disasters. And these disasters resulted in almost 200 billion RMB direct economic losses. In particular, they resulted in serious negative influence on agriculture production. The most frequency disasters are drought, tropical storms, floods and heavy rain.

Table 1 Different type of meteorological disasters

Meteorological disasters	Meteorological phenomena	Major impact and harm	Secondary disasters
Drought	Air and soil drying High temperature Dry hot wind Vatican wind	Drinking water problems Crop failure or total destruction Disease (heat stroke, etc.)	Forestry disasters (forest and grassland fires, pests and diseases) Famine Geological disasters (desertification)
Floods and heavy rain	Heavy rain Even the rainy	Flash floods River flooding Water logging Destruction of crops, buildings, supplies Human and animal casualties Crop failure or crops Affect crop growth and development, materials mildew Transportation, communication is blocked	Forestry disasters (pest) Geological disasters (avalanches, landslides, mudslides) Hydrosphere disasters (floods, water logging)
Tropical storms (typhoons)	Strong winds Heavy rain	Flash floods River flooding Waterlogging Destruction of crops, buildings, supplies Human and animal casualties Crop failure or crops Affect crop growth and development, materials mildew Transportation, communication is blocked	Forestry disasters (pest) Geological disasters (avalanches, landslides, mudslides) Hydrosphere disasters (floods, water logging, waves, storm surges)
Cryogenic freezing and snowstorms	Frost, snow (the snowstorm or white disaster) Blowing snow (or white hair wind) Freezing rain (glaze) Gale Cold damage (the cold dew wind)	Crop failures Crops, trees, people and livestock frost damage Ranch snow The death of livestock Avalanche Wire, road icing Transportation, communications blocked traffic accidents	Forestry disasters (crops, trees, frost damage) Hydrosphere disasters (river, lake, river, sea icing, ice flood)
Wind and hail disaster	Hail Strong winds (hurricane) Rainstorm Thunder Tornado Downburst	Destruction of crops, buildings, supplies Human and animal casualties Flash floods Transportation, communication is blocked Traffic accidents, air crashes, fires	Forestry disasters (forest, grassland fires)

Table 1 continued

Meteorological disasters	Meteorological phenomena	Major impact and harm	Secondary disasters
Others	Fog Smoke Sandstorm Acid rain Air pollution The low-level wind shear Empty turbulence	Transportation, communication is blocked Traffic Accidents Plane crash Disease Construction, materials corrosion	Agriculture and forestry the disaster (crop, forest disease) Disasters of the hydrosphere (water pollution) Geological disasters (desertification)

3.2.1 Drought

Most areas of China belong to the mainland Asian monsoon region. The eastern and the central areas of China are concentrated occur region of agricultural drought. The imbalance between soil and water resources also contributed to the drought and lack of water resource in Chinese mainland. Precipitation from southeast coast to the northwest region of the Chinese mainland is gradually decreased. A lot of precipitation in the southeast and the seasonal distribution of rainfall are very uneven. North China, Northwest China, Yangtze River and the Huaihe River, South China and the Yunnan province are the areas where more severe drought occurred. In north of the Huaihe River, the more frequently occurring drought disaster is spring drought. In the middle and downstream areas of the Yangtze River, more of late summer drought occurred. In the southwest of China, the more frequent drought is winter and spring drought.

3.2.2 Floods and heavy rain

The main reason of flood disaster in mainland China is floods and heavy rain, while the small proportion of the disasters is caused by melting ice and melting snow. In eastern China, there are about 740,000 km² of land threat by floods. It occupies the 40 % of the country's population, 35 % of the arable land and 60 % of the fixed assets of total china. Rainstorm prone areas are concentrated in the eastern part of China. From southeast coast to Guangxi area, including Taiwan and Hainan, high-strength rainstorm sometimes is over 500 mm in 1 day. From Liaodong Peninsula to the Haihe, Yellow, Huaihe rivers, and middle and downstream of the Yangtze River region, rainstorm occurs more than 400 mm in 1-day rainstorm. More than 300 mm of day rainstorm frequently occurs in Sichuan Basin.

3.2.3 Tropical storms (typhoons)

China is one of the world's few countries seriously affected by the typhoon. Annually from the Northwest Pacific, typhoon generated an average of seven landed influence to mainland China and reached up to 12 in extremely years. The landing time is occurred in May–October each year. With the economic development of coastal areas in the Chinese mainland, the more economically developed areas, like Guangdong, Zhejiang, Jiangsu, Shandong, are concentrated in the coastal areas. The losses caused by tropical storm disasters grow rapidly.

According to the statistic information of 2004–2010 in Table 2, agriculture production is mainly influenced by drought, floods and heavy rain, wind and hail disaster, tropical storms, cryogenic freezing and snowstorms. As shown in Figs. 1 and 2, the average influence on agriculture production of China is mainly caused by drought, floods and heavy rain which occupied over 70 % of the total amount. Proportion of average affected agriculture area of China that caused by drought, floods and heavy rain is about 71.7 %, while proportion of average failure agriculture area of China that caused by drought, floods and heavy rain is about 73.1 %. However, proportion of each meteorological disaster is not even stable, such as proportion of drought affected to agriculture production occupies about 62 % in 2009, while it occupies only 30.3 % in 2008. Similarly, proportion of drought failure to agriculture production occupies about 66.5 % in 2009, while it occupies only 20.1 % in 2008. Additionally, the relationship between drought and floods and heavy rain embodies negative correlation each other. In 2006, 2007 and 2009, the proportion of drought occupies high level and it occupies low level in 2010, while the proportion of floods and heavy rain occupies low level in 2006, 2007, 2009 and high level in 2010.

3.3 Historical analysis of drought disaster influence

China is located in East Asia, and the monsoon climate from Pacific Ocean affects China very much. The instability of monsoon resulted in the frequent occurrence of drought in different years. Drought has become the most serious meteorological disasters that affect agricultural production of China. According to the statistic information in Figs. 3 and 4, total farmland affected area by drought of China is about 21.56 million ha which occupies about 60 % of the total amount of all kinds of meteorological disasters. The total farmland inundated area by drought of China is about 9.62 million ha which occupies 44.6 % of the total farmland affected area by drought of China. In particular, between 2000 and 2010, the total farmland affected area by drought of China is about 24 million ha which is 10 % higher the average level between 1950 and 2010. The total farmland inundated area by drought of China between 2000 and 2010 is about 13.97 million ha which occupies the 58.2 % of the total farmland affected area by drought of China which is also higher than the average level between 1950 and 2010 in the same index. These data indicated that the agricultural production is more and more severely affected by drought disaster.

Considering the disaster's difference in different provinces, we divided the drought areas of China into serious affected area, middle affected area, less affected area and no affected area. In this paper, 31 provinces in mainland China are considered, while Taiwan, Hong Kong, Macau and south China sea region are not included because there is no collected information in above regions. Similar with Sect. 3.2, we collected the drought disaster affected agriculture production from 2004 to 2010. Consider the data are instable and changed a lot in different years. We utilize the average affected area of agriculture production as the index to analyze the influence by drought. The value range between 0 and 5 is viewed as no affected area. The value range between 5 and 50 is viewed as less affected area. The value range between 50 and 100 is viewed as middle affected area, while the value range more than 100 is viewed as serious affected area. As is shown in Fig. 5, North and Northeast China regions, including Heilongjiang, Liaoning, Jilin, Inner Mongolia, Gansu, Shanxi and Yunnan, are serious affected areas from 2004 to 2010, while Hebei, Shandong, Henan, Shaanxi, Hubei, Hunan, Guangxi and Sichuan better than above serious regions. Other regions are less affected areas.

Table 2 Agriculture influence area by different disasters of China in 2004–2010

Year	Total amount		Drought		Floods and heavy rain		Wind and hail disaster		Tropical storms (typhoons)		Cryogenic freezing and snowstorms	
	Affect	Failure	Affect	Failure	Affect	Failure	Affect	Failure	Affect	Failure	Affect	Failure
2004	3,710.7	435.8	1,725.3	167.7	745.9	104.5	597.7	76.3	69.1	7.2	371.1	52.9
2005	3,881.8	459.7	1,602.8	188.9	1,093.2	146.6	297.7	46.3	445.3	50.1	442.8	27.8
2006	4,109.1	540.9	2,073.8	229.5	810.2	142.6	438.7	70.5	295.2	47.9	491.3	50.4
2007	4,899.2	574.7	2,938.6	319.0	1,046.3	164.2	298.6	43.0	208.6	21.3	407.2	27.1
2008	3,999.0	403.2	1,213.7	81.2	647.7	75.6	418.0	47.5	231.0	14.5	1,469.6	182.8
2009	4,721.4	491.8	2,925.9	326.9	764.4	78.1	549.3	53.5	114.6	8.1	367.3	25.2
2010	3,742.6	486.3	1,325.9	267.2	1,752.5	165.8	218.0	28.0	34.2	1.2	412.1	24.1
Average	4,152.0	484.6	1,972.3	225.8	980.0	125.3	402.6	52.1	199.7	21.5	565.9	55.8

Source Ministry of Chinese Civil Affairs

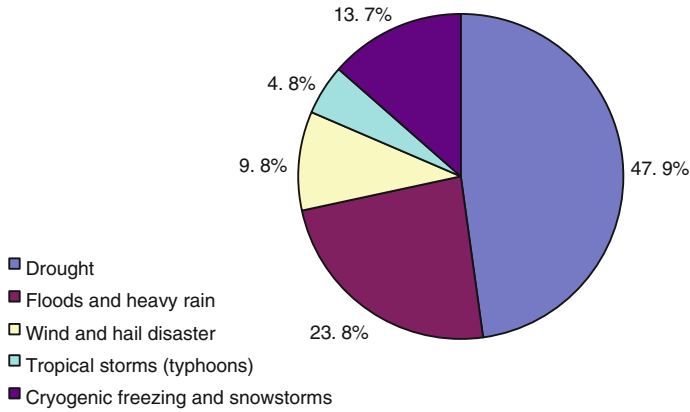


Fig. 1 Proportion of average affected agriculture area of China in 2004–2010

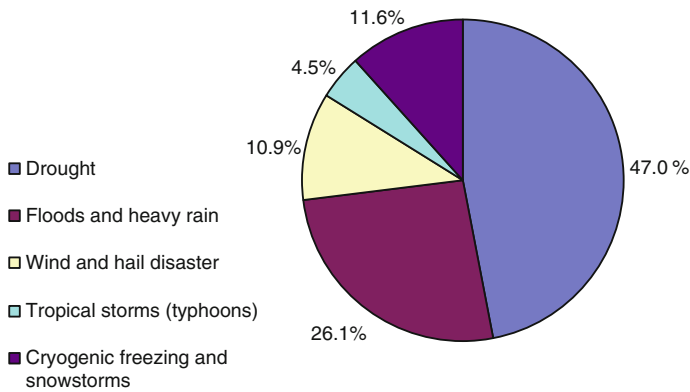


Fig. 2 Proportion of average failure agriculture area of China in 2004–2010

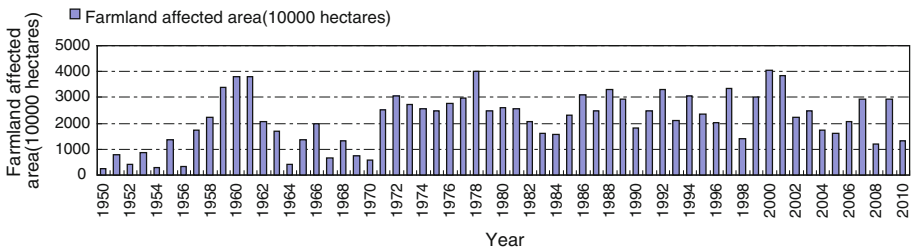


Fig. 3 Total farmland affected area of China by drought in 1950–2010

3.4 Historical analysis of floods and heavy rain disaster influence

Floods and heavy rain disaster are another serious influence disaster to agriculture production. According to the statistic information in Figs. 6 and 7, total farmland affected area by floods and heavy rain of China is about 9.58 million ha which occupies about 20 % of the total amount of all kinds of meteorological disasters. The total farmland inundated area

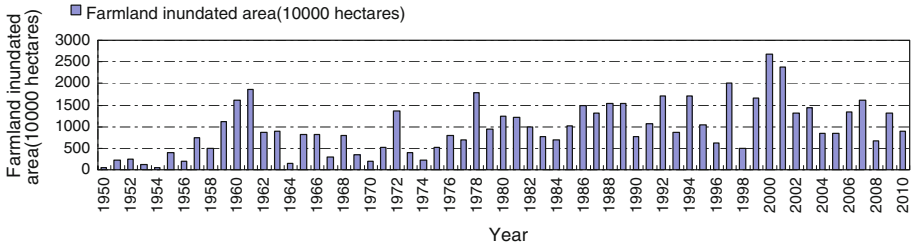


Fig. 4 Total farmland inundated area of China by drought in 1950–2010

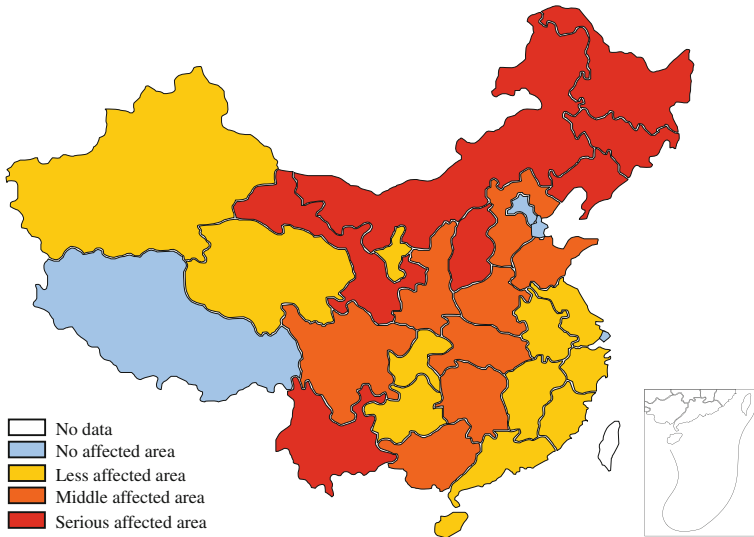


Fig. 5 Classification of agriculture production influence by drought in China

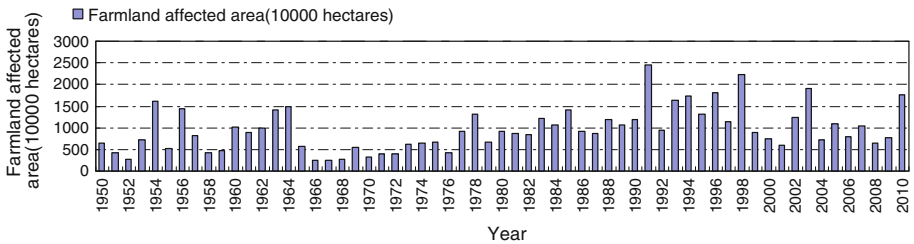


Fig. 6 Total farmland affected area of China by floods and heavy rain in 1950–2010

by floods and heavy rain of China is about 5.34 million ha which occupies 55.8 % of the total farmland affected area by floods and heavy rain of China. Similar analysis with the drought disaster between 2000 and 2010, the total farmland affected area by floods and heavy rain of China is about 10.3 million ha which is 9 % higher the average level between 1950 and 2010. These data also indicated that the agricultural production is more and more severely affected by floods and heavy rain disaster.

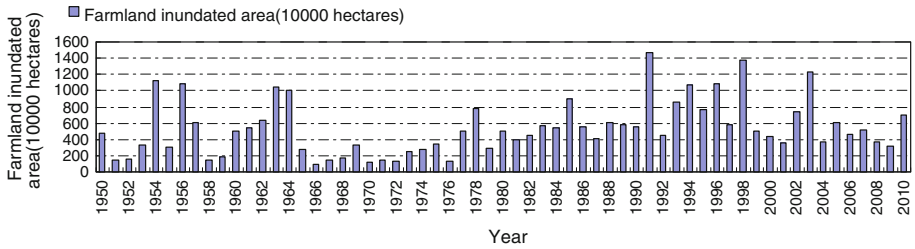


Fig. 7 Total farmland inundated area of China by floods and heavy rain in 1950–2010

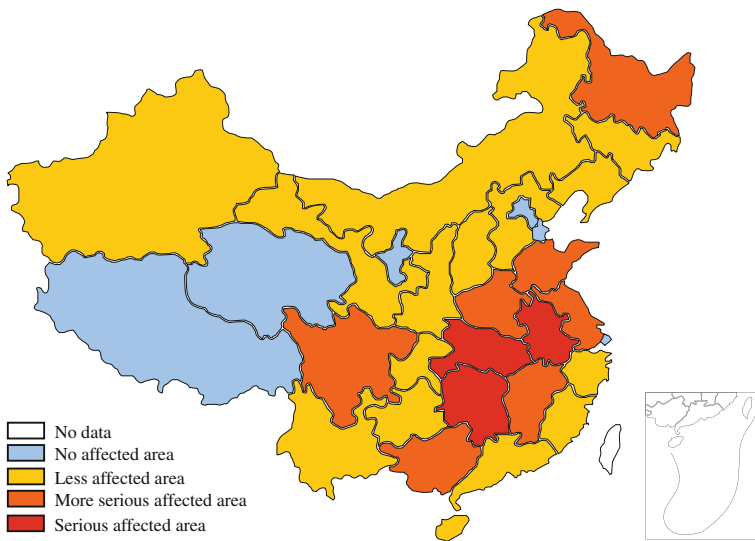


Fig. 8 Classification of agriculture production influence by floods and heavy rain in China

Similar to drought disaster analysis, to analyze the floods and heavy rain influence to agriculture production, we also divided the drought areas of China into serious affected area, middle affected area, less affected area and no affected area. Because there is no collected information, 31 provinces in mainland China are considered, while Taiwan, Hong Kong, Macau and South China Sea region are not included. The information that floods and heavy rain affected agriculture production from 2004 to 2010 is used to analyze the difference of different provinces. We also utilize the average affected area of agriculture production as the index to analyze the influence by floods and heavy rain. The value range between 0 and 5 is viewed as no affected area. The value range between 5 and 40 is viewed as less affected area. The value range between 40 and 80 is viewed as middle affected area, while the value range more than 80 is viewed as serious affected area. As is shown in Fig. 8, east and southeast China regions, including Anhui, Shandong, Jiangsu, Henan, Jiangxi, Hubei, Hunan, Guangxi, Sichuan and Heilongjiang, are serious or more affected areas in 2004–2010, while Beijing, Shanghai, Tianjin, Xizang, Qinghai and Ningxia almost not be affected by floods and heavy rain in 2004–2010. Other regions are less affected areas.

3.5 Analysis of tropical storms, snowstorms and hail disasters influence

Tropical storms, snowstorms and hail disasters also frequently occur in mainland China. But these three kinds of disasters are different from each other. The tropical storms or typhoon that impact mainland China is mainly formed in the western Pacific Ocean. So the affected regions are mainly concentrated in the east coast of China, such as Guangdong, Fujian, Zhejiang, Shanghai, Jiangsu, Shandong. Sometimes the strong tropical storms maybe affect Liaoning, Tianjin and Hebei, etc. As shown in Table 2, the tropical storms affected not very serious on agriculture production compare with the drought and floods. It is because the tropical storms are formed and affected in very short time, while the drought and floods disasters maybe last in a long time. In fact, tropical storms destroy more fixed assets and cause more economic losses because it has strong damaging effects. Snowstorms and hail disasters are both caused by cold weathers. So we analyze their influences together. Similarly, 31 provinces in mainland China are considered, while Taiwan, Hong Kong, Macau and South China Sea region are not included in analysis process. We collected the snowstorms and hail disasters affected agriculture production from 2004 to 2010 and divided the drought areas of China into serious affected area, middle affected area, less affected area and no affected area. We also utilized the average value of total snowstorms and hail disasters affected agriculture production as the index. The value range between 0 and 5 is viewed as no affected area. The value range between 5 and 30 is viewed as less affected area. The value range between 30 and 60 is viewed as middle affected area, while the value range more than 60 is viewed as serious affected area. As shown in Fig. 9, Henan, Hebei, Hunan and Hubei are serious affected areas in 2004–2010, while Liaoning, Jilin, Beijing, Tianjin, Shanghai, Fujian, Zhejiang, Guangxi, Guangdong, Xizang, Qinhai, Chongqing and Ningxia are affected less by snowstorms and hail disasters. Other regions are between the above two classes.

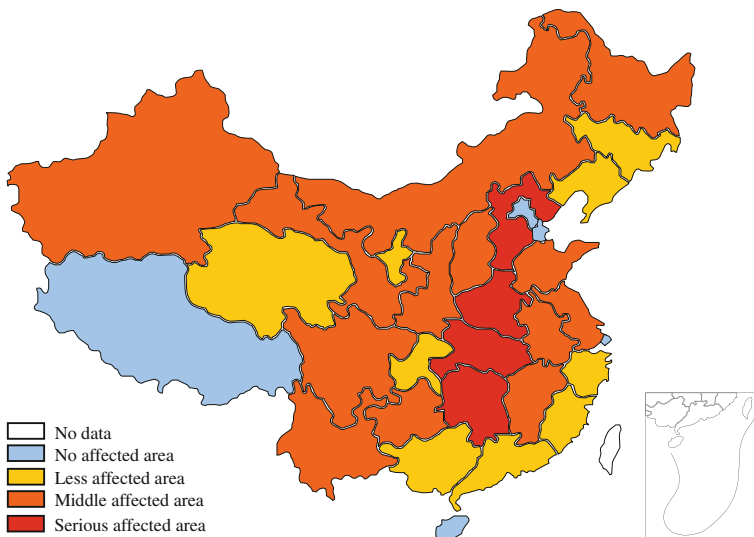
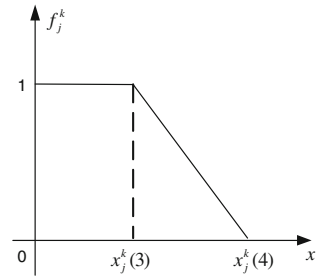


Fig. 9 Classification of agriculture production influence by snowstorms and hail disasters in China

Fig. 10 Lower whitenization weight function



In this section, we analyzed the five different meteorological disasters. Because of the lack of information, we mainly focused on analyzing different meteorological disasters affected agriculture production, and we use the absolute value of the disaster areas. However, as the size of different provinces and the arable land areas also differ from each other, the results should be progressed when the enough information is provided.

4 A novel regional meteorological disaster loss evaluation method: grey cluster model

Grey fixed weight clustering method is an effective method to classify different objects. The main idea of grey fixed weight clustering is to take the gathered provinces’ loss information caused by meteorological disasters. These provinces are viewed as clustering objects while the collected information will be expressed as different indexes. Give m clustering indexes based on the evaluating index system, set s grey classes, put the object i into class $k(k = 1, 2, \dots, s)$ according to the observation $x_{ij}(i = 1, 2, \dots, n; j = 1, 2, \dots, m)$ of object i about index $j(j = 1, 2, \dots, m)$, thus the advantageous order of losses of different provinces is acquired through analyzing their clustering coefficient of different grey classification.

The steps of grey fixed weight clustering method are as follows:

Step 1 Divide classification s according to the evaluation requirements.

Step 2 Transfer the data form according to the polarity of different indexes. If the result is better when the value of index is larger, then we can normalize the value between 0 and 1. That is for the index $j(j = 1, 2, \dots, m)$, we have different observation values of each object $y_{ij}(i = 1, 2, \dots, n)$, and we can get the maximum value y_M and minimum value y_m of y_{ij} , then the index value is normalize as

$$x_{ij} = \frac{y_{ij} - y_m}{y_M - y_m} \tag{1}$$

If the result is better when the value of index is smaller, then we can normalize the index as

$$x_{ij} = \frac{y_M - y_{ij}}{y_M - y_m} \tag{2}$$

Step 3 Set the whitenization weight functions of each index according to its value range. In grey fixed weight clustering method, the whitenization weight function of sub-class k of index j generally is set as $f_j^k(\cdot)(j = 1, 2, \dots, m; k = 1, 2, \dots, s)$

(1) Lower whitenization weight function (Fig. 10) as $[-, -, x_j^k(3), x_j^k(4)]$, i.e.

Fig. 11 Moderate whitenization weight function

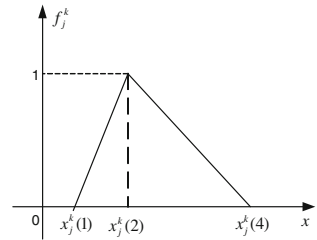
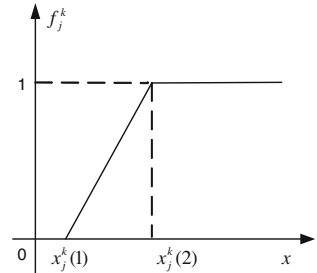


Fig. 12 Upper measure whitenization weight function



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

(2) Moderate whitenization weight function (Fig. 11) as $[x_j^k(1), x_j^k(2), -, x_j^k(4)]$, i.e.

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

(3) Upper whitenization weight function (Fig. 12) as $[x_j^k(1), x_j^k(2), -, -]$, i.e.

$$f_j^k(x) = \begin{cases} 0, & x \notin [x_j^k(1), 7] \\ \frac{x - x_j^k(1)}{x_j^k(2) - x_j^k(1)}, & x \in [x_j^k(1), x_j^k(2)] \\ 1, & x \in (x_j^k(2), 7] \end{cases} \quad (5)$$

Step 4 Determine the clustering weight $\eta_j (j = 1, 2, \dots, m)$ of each index. Generally, when there is no enough information, the weight can be set as $\eta_j = \frac{1}{m}$.

Step 5 With the function $f_j^k(\cdot) (j = 1, 2, \dots, m; k = 1, 2, \dots, s)$ in step 3, the weight $\eta_j (j = 1, 2, \dots, m)$ in step 4 and observation $x_{ij} (i = 1, 2, \dots, n; j = 1, 2, \dots, m)$ of object i about index $j (j = 1, 2, \dots, m)$, calculate the grey fixed weight clustering coefficient

$$\sigma_i^k = \sum_{j=1}^m f_j^k(x_{ij}) \cdot \eta_j, \quad (i = 1, 2, \dots, n; k = 1, 2, \dots, s) \tag{6}$$

Step 6 Calculate the clustering weight vector according to the fixed weight coefficient of each class

$$\sigma_i = (\sigma_i^1, \sigma_i^2, \dots, \sigma_i^s) = \left(\sum_{j=1}^m f_j^1(x_{ij}) \cdot \eta_j^1, \sum_{j=1}^m f_j^2(x_{ij}) \cdot \eta_j^2, \dots, \sum_{j=1}^m f_j^s(x_{ij}) \cdot \eta_j^s \right) \tag{7}$$

Step 7 Calculate the clustering coefficient matrix

$$\Sigma = (\sigma_i^k) = \begin{bmatrix} \sigma_1^1 & \sigma_1^2 & \cdots & \sigma_1^s \\ \sigma_2^1 & \sigma_2^2 & \cdots & \sigma_2^s \\ \vdots & \vdots & \ddots & \vdots \\ \sigma_n^1 & \sigma_n^2 & \cdots & \sigma_n^s \end{bmatrix} \tag{8}$$

Step 8 Determine the class that certain object belongs to according to the clustering coefficient matrix. Object i belongs to class k^* if

$$\max_{1 \leq k \leq s} \{ \sigma_i^k \} = \sigma_i^{k^*} \tag{9}$$

Step 9 Determine the priority orders of objects according to the class and value of clustering coefficient.

5 Regional meteorological disaster losses evaluation based on grey cluster model

To measure the losses caused by different kinds of meteorological disasters to classify the different regions, we plan to use grey fixed weight clustering method to evaluate the losses of different regions. Regional meteorological disaster losses are affected by many factors, such as the area of each region, the amount of disaster people, the economic losses. However, considering the size difference of different province and the arable land areas also different from each other, the results should be progressed when the enough information is provided. So except the absolute amount indexes, some of the relative amount indexes should be considered. Therefore, the total index system is very complex and the indexes are various in different magnitudes of the whole index system. Considering the data can be collected and simplify the analysis process, we constructed the index system with six different indexes, including three absolute amount indexes and three relative amount indexes as shown in Table 3. The index system covered the losses of agriculture productions, the affected populations and direct economic losses.

With regard to the data of different indexes and objects, 31 provinces in mainland China are considered, while Taiwan, Hong Kong, Macau and South China Sea region are not included because there is no enough statistic information in these regions. Considering the indexes X_2 , X_4 and X_6 are relative indexes and could not be given in the statistic resources.

Table 3 The indexes system of comprehensive evaluation of regional meteorological disaster losses

Symbol	Name of index	Explanation about the index
X_1	Affected area of agriculture production	It is an absolute amount index which is caused by meteorological disaster, no matter the disaster types, just sum of the total area affected by drought, floods, tropical storms, snowstorms and hail disasters
X_2	Proportion of affected area occupies the total arable land	It is an relative amount index which is used to measure the affected degree of agriculture production in the region
X_3	Affected population	It is an absolute amount index which is caused by meteorological disaster, no matter the disaster types, just sum of the total amount of population
X_4	Proportion of affected population occupies the total population	It is an relative amount index which is used to measure the affected proportion of population in the region
X_5	Direct economic losses	It is an absolute amount index which is caused by meteorological disaster, no matter the disaster types, just sum of the total amount of losses
X_6	Proportion of direct economic losses occupies the regional gross development production	It is an relative amount index which is used to measure the affected proportion of economic condition in the region

We collected the information of affected area of agriculture production, affected population, direct economic losses, total arable land, total population and gross development production as shown in Table 4. Considering the meteorological disasters occur suddenly and accidentally, we use the average value of each index from 2004 to 2010 as shown in Table 4. The value of indexes can be calculated with the provided data.

Considering X_1 – X_6 are all negative direction indexes, i.e., the result is better when the value of index is smaller. According to the methods to determine whitenization weight functions in Eqs. (3), (4) and (5), in combination with the distribution value of each index, we divided each index into three grey classes, i.e. serious loss class, general loss class and lighter loss class. The serious loss class is the worst status of the value range; it sets as the upper whitenization weight function. The lighter loss class is best status of the value range which means the region is affected lighter by all of the disasters and the class is set as lower whitenization weight function. The general loss class is the status between the serious loss class and lighter loss class, so it is set as moderate whitenization weight function. The different whitenization weight functions of different indexes are set as Table 5.

According to the whitenization weight functions of different indexes in Table 5, substitute the real value in Table 4 into each whitenization weight function of each grey class of each meteorological disaster evaluation index. We can get the whitenization weight coefficient of each object to each index formed like $f_j^k(\cdot) (j = 1, 2, \dots, m; k = 1, 2, \dots, s)$. Then considering the each index is equal weight $\eta_j = \frac{1}{m}$, we can get the integrated grey cluster coefficient of each object to each grey class as show in Table 6.

In fact, the results in Table 6 are composed of the clustering coefficient matrix in Eq. (8), and then we can determine the certain class that each object belongs to the Eq. (9). According to the results in Table 6, we know that Beijing, Tianjin, Shanghai, Xizang,

Table 4 Average value of different indexes from 2004 to 2010

Region	Affected area (10,000 ha)	Affected population (10,000 people)	Direct economic losses (100 millions)	Total arable land (10,000 ha)	Total population (10,000 people)	Gross development production (100 millions)
Beijing	4.2	38.3	4.3	23.2	1,961	9,756.1
Tianjin	7.6	27.0	2.9	44.1	1,294	5,712.8
Hebei	182.8	1,962.0	78.6	631.7	7,185	13,898.6
Shanxi	164.3	1,163.0	79.4	405.6	3,571	6,075.5
Inner Mongolia	304.1	831.5	124.2	714.7	2,471	6,887.5
Liaoning	131.6	703.4	94.4	408.5	4,375	11,784.0
Jilin	168.4	571.3	130.2	553.5	2,746	5,524.9
Heilongjiang	386.7	930.7	89.7	1,183.0	3,831	7,264.0
Shanghai	2.1	23.0	3.2	24.4	2,302	12,367.9
Jiangsu	119.2	1,033.8	59.8	476.4	7,866	26,847.8
Zhejiang	72.5	1,796.7	194.5	192.1	5,443	18,819.2
Anhui	174.1	2,233.4	113.8	573.0	5,950	7,840.2
Fujian	56.9	931.9	125.2	133.0	3,689	9,565.9
Jiangxi	156.1	2,257.8	177.9	282.7	4,457	6,030.2
Shandong	189.2	1,928.6	115.8	751.5	9,579	26,459.4
Henan	193.8	1,852.1	89.2	792.6	9,402	15,301.1
Hubei	248.7	2,573.7	116.4	466.4	5,724	9,908.8
Hunan	239.4	3,140.1	179.3	378.9	6,568	9,990.6
Guangdong	98.9	1,398.5	133.2	283.1	10,430	31,698.3
Guangxi	161.0	2,508.5	121.3	421.8	4,603	6,061.3
Hainan	28.8	474.1	43.2	72.8	867	1,316.3
Chongqing	82.2	1,630.8	66.2	223.6	2,885	4,942.3
Sichuan	206.9 ^a	3,795.9 ^a	184.8 ^a	594.7	8,042	10,993.6 ^a
Guizhou	103.1	2,157.1	82.4	448.5	3,475	2,993.8
Yunnan	186.3	2,248.2	124.0	607.2	4,597	4,914.5
Xizang	4.2	49.1	4.4	36.2	300	349.6
Shaanxi	137.2	1,465.2	123.3	405.0	3,733	6,137.1
Gansu	176.0	1,641.0	156.0	465.9	2,558	2,753.8
Qinghai	16.2	217.5	45.8	54.3	563	843.7
Ningxia	49.1	235.3	15.1	110.7	630	1,005.0
Xinjiang	109.5	357.9	46.2	412.5	2,181	3,611.3

Sources (1) Ministry of Chinese Civil Affairs, (2) Chinese Statistical Yearbook 2005–2011

Total arable land and total population adopt the census data in 2,009, not the average value from 2004 to 2010

^a Sichuan province is considered the Wenchuan Earthquake in 2008, it is seriously emergency disaster. So the index of Sichuan is calculated from 2004 to 2010 but exclude 2008

Qinghai and Ningxia belong to the lighter loss grey class. Jiangxi, Hubei, Hunan, Hainan, Sichuan and Gansu belong to the serious loss grey class. Other regions belong to the general loss grey class that the influence caused by meteorological disasters not better than the lighter loss grey class and not worst than the serious loss grey class.

Table 5 Whitenization weight functions of different indexes

Symbol	Name of index	Lighter loss class	General loss class	Serious loss class
X_1	Affected area of agriculture production	$[-, -, 20, 135]$	$[20, 135, -, 250]$	$[135, 250, -, -]$
X_2	Proportion of affected area occupies the total arable land	$[-, -, 0.1, 0.3]$	$[0.1, 0.3, -, 0.5]$	$[0.3, 0.5, -, -]$
X_3	Affected population	$[-, -, 50, 1,350]$	$[50, 1,350, -, 2,700]$	$[1,350, 2,700, -, -]$
X_4	Proportion of affected population occupies the total population	$[-, -, 0.05, 0.32]$	$[0.05, 0.32, -, 0.58]$	$[0.32, 0.58, -, -]$
X_5	Direct economic losses	$[-, -, 5, 95]$	$[5, 95, -, 185]$	$[95, 185, -, -]$
X_6	Proportion of direct economic losses occupies the regional gross development production	$[-, -, 0.001, 0.016]$	$[0.001, 0.016, -, 0.030]$	$[0.016, 0.030, -, -]$

Table 6 The integrated grey cluster coefficient of each province to different grey class

Region	Lighter loss class	General loss class	Serious loss class	Region	Lighter loss class	General loss class	Serious loss class
Beijing	0.932	0.068	0	Hubei	0.047	0.347	0.605
Tianjin	0.939	0.061	0	Hunan	0	0.236	0.764
Hebei	0.183	0.672	0.145	Guangdong	0.298	0.584	0.118
Shanxi	0.085	0.781	0.134	Guangxi	0.000	0.514	0.486
Inner Mongolia	0.066	0.575	0.358	Hainan	0.362	0.246	0.391
Liaoning	0.276	0.706	0.018	Chongqing	0.159	0.593	0.248
Jilin	0.169	0.630	0.201	Sichuan	0	0.416	0.584
Heilongjiang	0.152	0.659	0.189	Guizhou	0.128	0.478	0.394
Shanghai	1.000	0	0	Yunnan	0	0.544	0.456
Jiangsu	0.440	0.560	0	Xizang	0.787	0.213	0
Zhejiang	0.153	0.554	0.293	Shaanxi	0	0.806	0.194
Anhui	0.016	0.744	0.239	Gansu	0	0.393	0.607
Fujian	0.241	0.597	0.163	Qinghai	0.405	0.386	0.209
Jiangxi	0	0.268	0.732	Ningxia	0.427	0.419	0.154
Shandong	0.243	0.569	0.188	Xinjiang	0.415	0.585	0
Henan	0.246	0.607	0.147				

According to the Fig. 13, we know that the middle of china is serious influenced by meteorological disasters. In fact, almost all kinds of meteorological disasters occurred in these regions and the losses of the area are very serious. Although most of the provinces are divided into general grey class, the status is definitely different. For example, Shaanxi, Shanxi, Anhui, Liaoning, Hebei, Heilongjiang, Jilin and Henan belong to general grey class, while the integrated grey cluster coefficients of these areas are very high which indicated that these areas are very close to the serious loss grey class. So these areas should

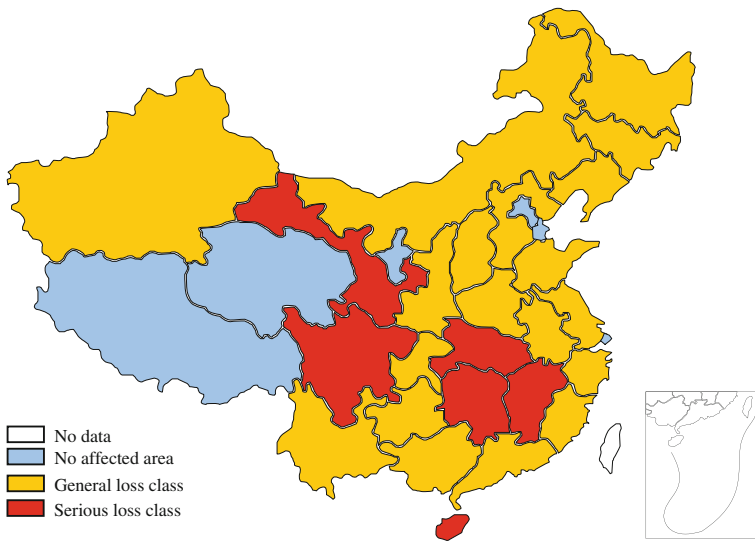


Fig. 13 Classification of regional influence by all kinds of meteorological disasters in China

not be excessively concerned, but they also should not be neglected. While Jiangsu, Shandong, Zhejiang belong to the general grey class, although the tropical storms and floods are frequently occurred in these provinces, they are not serious because of the gross development products are very high and the losses occupy only very small proportions of the total gross development products. Therefore, we still should discriminate the different regions in the same grey class.

6 Conclusions and future remarks

The paper mainly focused on analyzing and evaluating the losses of different meteorological disasters of different region in China. Considering the complex features of China, we divided meteorological disasters into drought, floods, tropical storms, snowstorms and hail disasters. According to the analysis results of historical data, the main destroy to agriculture production is by drought and floods almost in every year. Heilongjiang, Liaoning, Jilin, Inner Mongolia, Gansu, Shanxi and Yunnan are serious affected areas of drought influence from 2004 to 2010. Anhui, Shandong, Jiangsu, Henan, Jiangxi, Hubei, Hunan, Guangxi, Sichuan and Heilongjiang are serious affected areas by floods and heavy rain. Guangdong, Fujian, Zhejiang, Shanghai, Jiangsu, Shandong are mainly affected by tropical storms. Henan, Hebei, Hunan and Hubei are serious affected by snowstorms and hail disasters. We constructed a novel regional meteorological disaster loss evaluation method based on grey cluster model and give out the detailed steps of the methods. Then, the method was used to evaluate the regional meteorological disaster losses. In the integrated analysis conclusions, Beijing, Tianjin, Shanghai, Xizang, Qinghai and Ningxia belong to the lighter loss grey class. Jiangxi, Hubei, Hunan, Hainan, Sichuan and Gansu belong to the serious loss grey class. Other regions belong to the general loss grey class that the influence caused by meteorological disasters not better than the lighter loss grey class and not worst than the serious loss grey class.

The results of the paper are benefit to combed the history of meteorological disasters happening which is helpful to prepare the preventions, to evaluate the regional meteorological disaster grades and distribution characteristics which is better for allocating resources, and to construct novel meteorological disaster evaluation models. However, the paper mainly relies on the data of statistical yearbooks and other public statistic resources but lack the specific meteorological disaster data. Additionally, we mainly evaluate the overall loss of different regions, while we did not analyze the difference of sub-regions and did not analyze unbalanced losses of the inter-annual and different month in 1 year. These problems will be further discussed in the future works.

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