Characteristic analysis of rainstorm-induced catastrophe and the countermeasures of flood hazard mitigation about Shenzhen city

Lei Zhou\textsuperscript{a}, Xianhua Wu\textsuperscript{b}, Zhonghui Ji\textsuperscript{c} and Ge Gao\textsuperscript{d}

\textsuperscript{a}School of Applied Meteorology, Nanjing University of Information Science & Technology, Nanjing, China; \textsuperscript{b}Collaborative Innovation Center for Forecast and Evaluation of Meteorological Disasters, School of Economics and Management, Nanjing University of Information Science & Technology, Nanjing, China; \textsuperscript{c}School of Economics and Management, Nanjing University of Information Science & Technology, Nanjing, China; \textsuperscript{d}Collaborative Innovation Center for Forecast and Evaluation of Meteorological Disasters, National Climate Center, Beijing, China

ABSTRACT
Based on the statistical data of rainstorm-induced catastrophe about Shenzhen city during 1980–2014, this paper constructs a calculation model of disaster magnitude, which includes three influence factors: death toll, direct economic loss and disaster affected population. At the same time, the relationship between the disaster magnitude and the temporal, spatial and cause of the rainstorm-induced catastrophe about Shenzhen city is analysed. The results show that (1) The classification of catastrophe risk is carried out by the result of the disaster magnitude model. (2) The region where the disaster occurs frequently and seriously is located in the Midwest, and the disaster occurs infrequently and lightly is located in the south-east. (3) The rainstorm-induced catastrophe about Shenzhen City is mostly caused by persistent short-time heavy rainfall. While it occurs most frequently in July, and the most serious in September affected by the typhoon. (4) The main reasons for the occurrence of rainstorm-induced catastrophe about Shenzhen City are flood, waterlogging, tide and typhoon, of these factors waterlogging is the primary one. Finally, this paper puts forward the corresponding countermeasures of flood hazard mitigation in Shenzhen City.

1. Introduction
China’s urban environments are particularly vulnerable to typhoons, rainstorm, floods and other meteorological disasters because of the global climate change and rapid urbanization; with the global climate changing, the intensity and frequency of extreme meteorological events have been increased. At the same time, rapid urbanization amplifies the adverse effects of flood disaster due to the lag of city drainage infrastructure construction and the lack of emergency management ability. Flood disasters, have a great impact on the people’s lives and property, causing the serious concern in the community. In recent years, frequent extreme weather events and increased flood risks in cities have become the focus of the public because the intensity and frequency of floods and the vulnerability of society and economy in cities are all increasing quickly.

The primary methods for flood risk assessment are divided into four types, including index system assessment (Messner and Meyer 2005; Yin et al. 2013), historical data assessment (Benito et al. 2004; Diakakis et al. 2012), GIS and remote sensing assessment (Li et al. 2003; Ding 2004), and
scenario simulation assessment (Liu 2011; Wu et al. 2016). All these methods have both advantages and disadvantages. The index system assessment is simple and convenient but the certain subjectivity exists in index selection and weight assignment. Historical data assessment is also convenient but needs a lot of data. GIS and remote sensing assessment can provide real-time hazard maps with the constraint of the spatial resolution of remote sensing images. Scenario simulation assessment can offer more accurate results with different probabilities of occurrence, but it is dependent on the accessibility of data.

So far, many researches carried on risk assessment of flood disaster based on historical flood assessment. However, these researchers often focus on flood disaster without the special research on the risk of extreme disaster, for example, the rainstorm-induced catastrophe. They often focus on one flood type and do not analyse flood risk in an integrated framework. What is more, some neglected its spatial–temporal characteristics. These limitations of previous studies cannot make them provide more accurate information for the local government to improve extreme flood risk governance.

Located in the south of the Tropic of cancer, Shenzhen City belongs to subtropical marine monsoon climate. Influenced by coastal mountain topography and frequent typhoon on low latitude, the flood and waterlogging, storm surges and other disasters occur frequently, and especially the rainstorm-induced catastrophe has seriously restricted the comprehensive, coordinated and sustainable development of the economy and society. According to statistics, Shenzhen City is particularly vulnerable to extreme weather such as rainstorm-induced catastrophe. However, it has not been thoroughly studied in the disaster magnitude in disaster classification to quantitative assessment. Moreover, there is no systematic study in the relationship between the disaster magnitude and the temporal, spatial and cause of the rainstorm-induced catastrophe. So it is of profound significance to the evaluation method of rainstorm-induced catastrophe in Shenzhen area and built criteria of catastrophe risk rank.

This study has three contributions. First, based on the comprehensive evaluation of the total 40 times rainstorm-induced catastrophe from 1980 to 2014 about Shenzhen city, the classification of catastrophe risk is carried out by the result of the disaster magnitude model. Second, the temporal–spatial distribution pattern of catastrophe studied through the relationship between the disaster magnitude and the temporal, spatial and cause of the rainstorm-induced catastrophe about Shenzhen City. Last but not the least, this paper puts forward the corresponding countermeasures of catastrophe risk mitigation about Shenzhen City, to provide some reference for the catastrophe risk management of rainstorm disaster.

2. About Shenzhen City

Shenzhen City was established in 1979, and the Special Economic District was set up in 1980. The main driving force of economic development lies in the process of extensive industrialization and urbanization. Shenzhen City (22°12’60″–22°15’10″ N, 113°14′50″–114°13′70″E) is located in the South of the Guangdong Province, China. Its North is adjacent to Huizhou and Dongguan Cities, and the south to Hong Kong, facing the Dapeng Bay and Daya Bay on the east and Lingding ocean on the west. The administration area of Shenzhen is 1996.85 km² according to the detailed survey of land resources, which is narrow and long in shape, wide in the East-West and narrow in the South-North. Its topography is relatively high in the South-east and low in the North-west, including various kinds of landforms, and among them, the hills area is the largest one, and the plains area is the second. At present, Shenzhen City has 10 administration districts, namely, Luohu District, Futian District, Yantian District, Baoan District, Nanshan District, Longgang District, Pingshan District, Longhua New District, Guangming District and Dapeng New District.

According to the statistics of Shenzhen Reservoir Station for many years, the area is abundant in rainfall, and concentrated in 4–9 months, accounting for 85.3% of the whole year. Heavy rain often appears in 4–6 months due to the cross influence of the low trough in India ocean and Pacific
Subtropical High, leading to the south-west monsoon precipitation and the north cold air hitting the formation of cold front. Six to nine months rains often resulted in strong precipitation, mainly affected by the typhoon of tropical circulation system. In addition to precipitation, some areas of Shenzhen are influenced by tidal level because part of the tidal area is lower than the design flood level, and also the tidal effects are difficult to exclude for a long time.

3. Data and methodology

3.1. Data descriptions

Disaster information data were collected through from the Shenzhen city drainage waterlogging comprehensive planning department and the rainfall data were derived from the meteorological observation data of the national weather station and the local weather station. On the basis of these data, a total of 40 times of rainstorm-induced catastrophe and flood disaster data in 1980–2014 were collected, and the database of rainstorm and flood disaster about Shenzhen city was constructed, including the time, place, 126 rainfall, direct economic loss, the death toll and the main cause of the rainstorm disaster. In recent years, the Ministry of Civil Affairs of China uses the death population, the affected population, crops affected area, houses collapsed and direct economic losses as the main content of natural disaster statistics. Because of the high urbanization rate in Shenzhen and the limited agricultural planting area, there was almost no effect on housing collapse caused by disasters about Shenzhen City. Therefore, in this paper, we use these factors above as the evaluation index of disaster about Shenzhen City.

A total of 40 rainstorm-induced catastrophes occurred in Shenzhen from 1980 to 2014 (Table 1), where the death of 120 people and the affection on 5 million 209 thousand people. Direct economic losses were more than RMB 4 billion 700 million. On average, one rainstorm-induced catastrophe caused 3.4 deaths and the affection on 149,000 people, with the average direct economic loss of each catastrophe being more than RMB 136 million.

3.2. Extreme disaster risk threshold analysis

The existing approaches to disaster risk threshold assessment can be divided into two categories. The first is to determine the hazard level by the threshold range of key factors. The other is to quantify the disaster risk using the comprehensive disaster index. For example, the method for chromatography analysis is used to evaluate the weight of the index. The former method is difficult to meet the threshold interval of each factor, and the latter is more subjective to determining the index and their weights. In this paper, the concept of disaster magnitude is introduced, and the threshold value of extreme rainstorm disaster is analysed. The disaster magnitude is the key to disaster assessment and disaster classification. According to the actual situation of natural disasters in China, Ma et al. (1988) put forward the concept of disaster magnitude, which was used to measure social damage of disasters. The disaster magnitude provided a clear quantitative assessment of disaster and a scientific basis for disaster management, and it has been endorsed by disaster researchers. Yu (1993), Sun et al. (2006) and Gao (2008) widely studied and discussed, Yu (1993) determined of

| Statistics data                              | Gross statistics | Annual average | Maximum and occurrence time | Minimum and occurrence time |
|----------------------------------------------|------------------|----------------|-----------------------------|-----------------------------|
| Death populations/people                     | 120              | 3.4            | 22 (2 September 2003)       | 0 (1980, 1981, 1988, 1996, 1997, 1999, 2001, 2009, 2011) |
| Disaster-affected populations/thousand people | 5209             | 149            | 320 (13 June 2008)         | 1 (19 July 1988)            |
| Direct economic loss/RMB Billion             | 47.74            | 1.36           | 12 (13 June 2008)          | 0.01 (17 June 2011)         |
critical criteria for disaster magnitude in natural disasters; Sun et al. (2006) established comprehensive evaluation model of disaster magnitude model by combine matter-element extension method and flood damage intensity index with analytic hierarchy process. Gao (2008) use the disaster magnitude model applied to all types of natural disasters, and it has been a better development, Xu et al. (2012) analysed the dual attributes of disaster, including natural attribute and social attributes, he considered that disaster magnitude was a quantitative description of the social attribute of disaster, and put forward the disaster magnitude model based on the indexes of death population, disaster-affected population and direct economic loss, with the disaster magnitude model calculated by the following formula:

\[ D = \log_{10} (P + 1) + 10^{\frac{E}{GDP}} + \log_{10} K \]  

(1)

where \( D \) is the disaster magnitude, \( P \) is the death population, \( k \) is the disaster-affected population and \( E \) is the direct economic loss, and GDP is the gross national product of the year disaster occurred. Using \( \log_{10}(P + 1) \) to represent the impact factor of death population, the value will be between 0 and 10. \( P + 1 \) is used to eliminate the 0 death on the logarithmic meaningless, leading to the fact that the formula cannot be worked out. Using \( 10^{E/GDP} \) to express the impact factor of the direct economic loss, and the direct economic loss is converted to the relative value compared with GDP, with the value between 0 and 10. Using \( \log_{10}K \) to express the impact factor of the disaster-affected population, the value between 0 and 10. Therefore, the final value of the disaster magnitude value ranges from 0 to 30, and the greater the value, the more serious the disaster will be.

Sheng et al. (2015) modified the above model by adding the index of the crops affected area to the severity of the disaster. Crops affected area accounted for the proportion of agricultural area, which is due mainly to the great differences between different times and regions. The disaster magnitude model is calculated by the following formula:

\[ D = \log_{10} (P + 1) + 10^{\frac{E}{GDP}} + \log_{10} K + 10^{\frac{S_D}{S_A}} \]  

(2)

where \( S_D \) is the crop disaster area and \( S_A \) is the agricultural area.

This paper refers mainly to the above models, considering that Shenzhen as one of the special economic zones in China. It has been growing rapidly from rural land to an industrial city since the 1980s. In the process of urbanization and the rapid expansion of population, the number of people affected by the rainstorm-induced catastrophe varies considerably in different years and areas; so this paper uses the affected population to account for the total population as the model factor. The disaster magnitude model is modified in the following formula:

\[ D = \log_{10} (P + 1) + 10^{\frac{E}{GDP}} + 10^{\frac{k_d}{k_A}} \]  

(3)

where \( k_d \) is the disaster-affected population and \( k_A \) is the total population.

4. Results

According to the model of flood disaster magnitude, a total of 40 rainstorm-induced catastrophes in Shenzhen from 1980 to 2014 were calculated; and the relative contribution rate of each influence factor to the disaster magnitude is analysed, including death population, disaster-affected population and direct economic loss, with the classification of catastrophe risk made by the result of the disaster magnitude model.
The disaster magnitude of each disaster was calculated based on Equation (3), and the contribution rate of each influence factor to the disaster magnitude was calculated. The results showed that the contribution rate of direct economic 192 loss impact factor to disaster magnitude was 44.7%, and that the disaster-affected population was 42.9%. However, the death population was as low as 12.4%. The direct economic loss made the greatest contribution on disaster magnitude, which is the most important factor, followed by disaster-affected population, but death population was the lowest contribution rate.

How is the difference between the three influence factors on disaster magnitude treated? Is there a need to weigh the different factors in formula (3) in order to achieve the same contributions? The answer is No. In this paper, it is considered that the weight of each influence factor is 1, which is not needed to be adjusted, because of people giving an increasing attention to life. The impact on the human should be put in the first place, so the death population should occupy an important position. It is better to reflect the ‘human-oriented’ concept of the disaster magnitude calculation from formula (3).

The disaster magnitude of 40 rainstorm-induced catastrophe samples in Shenzhen ranged from 2 to 3.4, with the average 2.4 (Figure 1). There are seven disaster magnitudes greater than 3, accounting for 17.5% of the total. They are as follows: 20 May 1987, 7 September 1992, 6 August 1994, 22 July 1994, 24 May 1998, 14 April 2000 and 30 August 2013. The other 33 samples of disaster magnitude were between 2 and 3, accounting for 82.5% of the total. Based on the death population, the disaster-affected population and direct economic losses from rainstorm-induced catastrophe, the Gradation criterion of catastrophe risk is carried out by the disaster magnitude model shown in Table 2.

4.1. Analysis of temporal characteristics of rainstorm-induced catastrophe in Shenzhen City

From the yearly change of accumulative and average disaster magnitude values from rainstorm-induced catastrophe in Shenzhen City from 1980 to 2014 (Figure 2), we can see that 1993 is the most serious year, with several severe floods occurring in the Shenzhen City, for example, the long duration of plum rains in 16 June 1993 and the typhoon rainstorms in 26 September 1993. In the rainstorm of ‘6.16’ centre in Buji Town, from 9 am to 2 pm, 5 h of rainfall is up to 256 mm, the water
level of Buji Town dramatically rose to about 2 m, and the inundated area was 13.2 km², resulting in 11 deaths, and RMB 737 million of direct economic losses. The rainstorm of ‘9.26’ affected by typhoon resulted in the fact that the water storage of 8 reservoirs in Shenzhen City is higher than flood limited. The dam was in danger because of the rising flood. The inundated area was 12.4 km², leading to 14 deaths, and RMB 764 million of direct economic losses; also the train lines were flooded out.

From 2012 to 2014, rainstorm-induced catastrophes in Shenzhen City were serious due to a high frequency as well as the high direct economic loss. Rainstorm-induced catastrophes occurred in 19 April, 29 April, 25 July, in 2012, and 13 August, 30 August, 26 May, in 2013, and 30 March, 11 May, 20 May, in 2014.

The monthly change of accumulative and average disaster magnitude values of rainstorm-induced catastrophe in Shenzhen City from 1980 to 2014 can be seen from (Figure 3). Disaster magnitude value is concentrated in March–September, which is basically in line with the flood season about Shenzhen City from April to September. Affected by the typhoon in September, huge amounts of rainfalls are dumped, and the average disaster magnitude value of rainstorm-induced catastrophe is the largest. Accounting for nearly one-fourth of the total, July is the season when most frequent flood disasters happen, with the cumulative disaster magnitude value reaching a peak value of 23.6. From the Shenzhen urban meteorological monitoring report, local heavy rainfall occurred in July.

| Disaster magnitude | Gradation criterion of rainstorm-induced catastrophe in Shenzhen City |
|--------------------|--------------------------------------------------|
| $D < 2$            | Level 1 – general disaster                        |
| $2 \leq D < 3$     | Level 2 – normal catastrophe                      |
| $D > 3$            | Level 3 – abnormal catastrophe                    |

Table 2. Gradation criterion of rainstorm-induced catastrophe in Shenzhen City.
seriously, and the results are the same as that made in the research by Zhang (2001) and Wu and Li (2009). In Zhang (2001), severe and continuous rainstorms mostly occurred in Shenzhen in July in the past 47 Years. In Wu and Li (2009), the statistical analysis of meteorological disasters in Shenzhen in 2000–2007 years, it is found that heavy rains and typhoon disasters occurred more frequengly in July, It which is consistent with the actual situation about Shenzhen City.

4.2. Analysis of spatial characteristics of rainstorm-induced catastrophe in Shenzhen City

From the district change of accumulative and average disaster magnitude values of rainstorm-induced catastrophe in Shenzhen City from 1980 to 2014 (Figure 4), we can see that the region

![Figure 3. Monthly change of accumulative and average disaster magnitude values of rainstorm-induced catastrophe in Shenzhen City from 1980 to 2014.](image)

![Figure 4. District change of accumulative and average disaster magnitude values of rainstorm-induced catastrophe in Shenzhen City from 1980 to 2014.](image)
where the disaster occurs frequently and seriously is located in the Midwest; for example, Baoan Dis-

trict is the place where heavy rains occur frequently. While the regions where the disasters occur

infrequently are located in the south-east, for example, such as the Dapeng New District. The serious

impact of the average disaster is on the central areas, namely Longgang District and Luohu District.

From Figure 5, we can obviously see that the colour variations show that the accumulative magni-

tude value varying from different administrative regions in Shenzhen City. The accumulative disaster

magnitude value is between 10 and 20 is marked in green on the map; the accumulative disaster

Figure 5. Administrative district distribution of accumulative disaster magnitude values of rainstorm-induced catastrophe in Shenzhen City from 1980 to 2014.

Figure 6. Administrative district distribution of average disaster magnitude values of rainstorm-induced catastrophe in Shenzhen City from 1980 to 2014.
magnitude value between 20 and 30 is marked in blue on the map; the accumulative disaster magnitude value between 30 and 40 is marked in yellow on the map; the accumulative disaster magnitude value greater than 40 is marked in red on the map. As can be seen from the figure, Baoan District is the most serious region. From Figure 6, we can obviously see that the colour variations show that the average magnitude value varying from different administrative regions in Shenzhen City. In the same way, we also use the four colours to mark the average magnitude value, which is displayed directly on the map; the average disaster magnitude value between 2.2 and 2.3 is marked in green on the map; the average disaster magnitude value between 2.3 and 2.4 is marked in blue on the map; the average disaster magnitude value between 2.4 and 2.5 is marked in yellow on the map; the average disaster magnitude value greater than 2.5 is marked in red on the map. As can be seen from the figure, the average magnitude values in Nanshan District and Futian District are great.

4.3. Analysis of reasons for rainstorm-induced catastrophe in Shenzhen City

The main reasons for the occurrence of rainstorm-induced catastrophe in Shenzhen City are flood, waterlogging, tide and typhoon. First, this paper defines and distinguishes these concepts, and adequately explain why rainstorm-induced catastrophes in Shenzhen City are affected by these factors.

The flood had been caused by unprecedented rainfall, causing the mountain torrents rushing down, and urban infrastructure destroyed, threatening the urban ecological safety. Urban waterlogging refers to those in the urban area, due to the fact that the short-time rainfall intensity is large great, the urban surface area of infiltration capacity is impervious, and the moisture-holding capacity is weak, so it is of short intense rainfall when surface runoff formation is under a regional flood disaster. Tide describes the periodic movement of water associated with the rise and fall; there are some tidal rivers in Shenzhen City, and the water is coming up to the bank in the flood season. For example, part of the old city ground elevation is only 2 m in the west of Baoan District, and when it rains in most flooded areas because of tidal backwater. Typhoon occurring over tropical oceans, as a kind of strong warm cyclonic storms is strongly destructive and disastrous with Shenzhen being one of the most typhoon-stricken cities.

According to the actual statistics (Figure 7), waterlogging is the primary of these factors. As an integral part of the urban infrastructure construction, the municipal sewer system plays a very important part in the urban construction and development. At present, Shenzhen city has been in accordance with the planning and implementation. However, in the new urban areas such as Guangming New District, Longhua New district, the planning, design and the operation and

![Figure 7. Accumulative and average disaster magnitude values of different types of rainfall.](image-url)
management manner of traditional drainage network gradually are unable to satisfy the requirement for the current construction of drainage facilities.

4.4. Analysis of precipitation characteristics of rainstorm-induced catastrophe in Shenzhen City

This paper mainly collects the duration of disaster, the maximum rainfall intensity and the maximum 24 h precipitation to analyse the precipitation characteristics (Figure 8). The maximum rainfall intensity of the rainstorm-induced catastrophe occurred in the range of 12.7–85.5 mm, which is mainly concentrated in the 20–43 mm. The maximum 24 h precipitation in the range of 46–631 mm, and mainly concentrated in 100–300 mm. Precipitation time mainly concentrated in 2–5 h. It can also be seen from Figure 8 that the rainstorm-induced catastrophe in Shenzhen City is mostly caused by persistent short-time heavy rainfalls, which concentrated for about 3 h.

In this paper, the relationship between precipitation and disaster magnitude is considered. From Figure 9, we cannot directly see the positive and negative correlations of linear relationship between
precipitation and disaster magnitude. What are considered may be the natural factors of rainfall, the terrain, the underlying surface, as well as economic, demographic and other social factors. In 1980, under the initiative of Mr Deng Xiaoping, China’s first special economic zone was set up in Shenzhen. Great changes have taken place in Shenzhen for these years, including the underlying surface condition and the population explosion and economic development, because the data are large and cannot be partly obtained. It is difficult to consider the influence of these social factors on disaster magnitude. However, these factors will be taken into account in future research.

5. Conclusions

A more comprehensive understanding of the rainstorm-induced catastrophe occurring in Shenzhen City through helps to analyze the relationship between the disaster magnitude and the temporal, spatial and cause of the rainstorm-induced catastrophe in Shenzhen city from 1980 to 2014. This paper constructs a calculation model of disaster magnitude, which includes three influence factors: death toll, direct economic loss and disaster affected population, and describes the application of disaster magnitude in disaster classification to the quantitative assessment of social attributes of disasters. The main conclusions are as follows:

(1) The classification of catastrophe risk is carried out by analyzing the result of the disaster magnitude model, and when the disaster magnitude value is less than 2, it is classified as a general disaster; when the disaster magnitude value is between 2 and 3, it is classified as normal catastrophe; when the disaster magnitude value is larger than 3, it is classified as an abnormal catastrophe.

(2) The region where the disaster occurs frequently and seriously is located in the Midwest; for example, Baoan District is the most vulnerable to heavy rains. While the regions where the disaster occurs infrequently and lightly are located in the southeast; for example, such as Dapeng New District.

(3) The rainstorm-induced catastrophe occurring in Shenzhen City is caused mainly by a persistent short-time heavy rainfall. While it occurs most frequently in July, the affection by the typhoon is most serious in September.

(4) The main reasons for the occurrence of rainstorm-induced catastrophe in Shenzhen City are flood, waterlogging, tide and typhoon; and of these factors, waterlogging is the primary one. Finally, this paper puts forward the corresponding countermeasures of flood hazard mitigation in Shenzhen City. The main countermeasures for flood hazard mitigation are as follows:

(1) The construction of drainage to reduce waterlogging should be strengthened, with the remake of combined sewer system being a key link with old city proper remake and water environmental protection in city, also the set-up of rain inlet on circularity crossing is of importance in the design and building of city roads drain system. The deficiencies of traditional urban canalization system should be compensated, to relax the unfortunate effect of urban construction to water system and to assure the sustainable development of the city. Meanwhile, for the tidal zone, especially the moisture in the key area in Maozhou River, Guanlan River and Longgang River, both engineering and non-engineering measures should be studied to improve their damp proof criterions and to eliminate flood and tide damage.

(2) There is a new upsurge in the construction of flood prone areas and water points in each community because it brings a lot of inconvenience to people’s production and life in the flood season. It is suggested that the local government compiles risk map of different rainfall intensities should be made to lower the public grasp the hazard level and raise their risk awareness. Besides, emergency measures and schemes for temporarily evacuating residents should be worked out in advance to reduce flood disaster loss.

(3) The competent meteorological departments at different levels and the meteorological offices and stations subordinated to them shall issue public meteorological forecasts and severe weathers warning with improved accuracy, timeliness and service. The key factors
of early warning plan for meteorological hazards in digital city are real-time and in continuous monitoring, small area forecasting, delivery diversity and individuality service, thus providing meteorological services for decision-makers on emergent meteorological disasters and other environmental disasters.

(4) The best and the economical way to save, dispose, utilize and display the disasters information is the establishment of historical data base and background data base for disasters. The structure of the information system composed covers death population, affected population, direct economic loss, disaster magnitude, disaster cause and correlative synthetic management, serving as a reference for practice activities.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was supported by the National Natural Science Foundation of China [grant number 71373131], [grant number 41501555], [grant number 91546117]; National Social Science Foundation [grant number 16ZDA047]; Top-notch Academic Programs Project of Jiangsu Higher Education Institutions, TAPP [grant number PPZY2015A072].

References

Benito G, Lang M, Barriendos M, Llasat MC, Francés F, Ouarda T. 2004. Use of systematic, palaeo flood and historical data for the improvement of flood risk estimation, review of scientific methods. Nat Hazards. 31(3):623–643.

Daiakasis M, Mavroulis G, Deligiannakis G. 2012. Floods in Greece, a statistical and spatial approach. Nat Hazards. 62 (2):485–500.

Ding ZX. 2004. A study on the technology and method of flood and waterlogging disaster loss assessment based on RS and GIS [dissertation]. Beijing (BJ): China Institute of Water Resource and Hydroelectric Research.

Gao JG. 2008. A quantitative value of the disasters on the social impact and the size of loss. China Popul Res Environ. 18:588–590.

Li J, Ding ZX, Huang SF, Hu YL. 2003. Research of flood and waterlogging loss assessment model based on spatial distribution social-economic database. J Chin Inst Water Res Hydropower Res. 1(2):104–110.

Liu YL. 2011. Multi-scale natural disaster scenarios’ risk assessment and zoning–A case study of Wenzhou city, Zhejiang Province. Shanghai [dissertation]. Shanghai (SH): East China Normal university.

Ma ZJ, Li YC, Zhu SL. 1988. Progress and prospect of seismological work in China in recent years. Earthquake Res. China. (2):115–119.

Messner F, Meyer V. 2005. Flood risk management-hazards, vulnerability and mitigation measures. Berlin (BE): Springer.

Sheng C, Sun Y, Yin DP, Bao J. 2015. Characteristic analysis 389 of rainstorm-induced flood disaster in Jiangsu Province. J Nat Disaster. 24(02):203–212.

Sun XL, Zhou YX, Cao AL, Xu YD. 2006. Comprehensive evaluation model and application for flood damage intensity. J Shandong Univ Eng Sci. 36(6):87–90.

Wu XH, Zhou L, Gao G, Ji ZH, Guo J. 2016. Flood depth-damage curves for urban properties considering disaster prevention and mitigation capabilities: evidence from Lizhong Town, Lixiahe region, China. Progress in Geography. 35(2):223–231.

Wu YL, Li H. 2009. Meteorological disasters and their risk assessment since 2000 in Shenzhen City. Guangdong Meteorol. 31(3):43–46.

Xu JH, Nie GS, Li ZQ, Zhu DW. 2012. Disaster magnitude based Asian catastrophe criterion for classification. J Nat Disasters. 21(3):64–69.

Yin J, Yin Z, Xu S. 2013. Composite risk assessment of typhoon-induced disaster for China’s coastal area. Nat Hazards. 69(3):1423–1434.

Yu QD. 1993. Limitation of disaster grade classification method and its improvement. J Nat Disasters. 02(02):8–11.

Zhang XL. 2001. Severe meteorological disasters and their variations in the past 47 years in Shenzhen. Guangdong Meteorol. 02:27–28.