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EDITED BY
Hema Achyuthan,
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REVIEWED BY
Huasheng Peng,
China Academy of Chinese Medical Sciences, China
David Zhang,
Guangzhou University, China

*CORRESPONDENCE
Li Wu,
jedi-wuli@163.com

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Spatial–temporal variations in natural disasters during the Ming and Qing dynasties (1368–1911 AD) in the ancient Huizhou region, eastern China

Shuguang Lu[1], Li Wu[1,2]*, Xianfu Cheng[1], Guanglai Xu[1], Fei Shen[1], Chenchen Li[1], Xiaosi Hu[1,2], Baodong Yang[1], Hongmei Zhang[1] and Xiaoxue Li[1]

[1]Provincial Key Laboratory of Earth Surface Processes and Regional Response in the Yangtze-Huaihe River Basin, School of Geography and Tourism, Anhui Normal University, Wuhu, China, [2]State Key Laboratory of Lake Science and Environment, Institute of Geography and Limnology, Chinese Academy of Sciences, Nanjing, China

The Little Ice Age (LIA) during the Ming and Qing dynasties was the most abnormal climate event in China for nearly 2,000 years. During this period, the climate was relatively cold and various natural disasters frequently took place. By locating and compiling related historical documents, we aimed to quantitatively and systematically analyze the spatial–temporal variations in the natural disasters in the ancient Huizhou region (hereinafter referred to as Huizhou region or Huizhou) during the Ming and Qing dynasties (1368–1911; all dates are in AD, unless otherwise mentioned). The results show that (1) flood and drought disasters, the major types of disasters in this area during the Ming and Qing dynasties, occurred 422 times, accounting for 79.6% of the natural disasters, (2) there was a significant correlation of occurrence frequency of flood plus drought disasters and the total natural disasters on a certain time scale. In addition to flood and drought disasters, other disasters (hailstorms, windstorms, frosts, and earthquakes) occurred more frequently in the Qing dynasty (1644–1911) than in the Ming dynasty (1368–1644). The occurrence frequency of natural disasters had a fluctuant variation pattern over time, with peaks emerging about once a century. The peaks of natural disasters were mainly concentrated at 1471–1490, 1571–1590, 1671–1690, 1751–1770, and 1851–1870, which is supported by the wavelet analysis, (3) the most frequent natural disasters took place in Wuyuan, followed by Jixi, Shexian, Xiuning, Qimen, and Yixian. More droughts occurred in Jixi and Yixian, while more floods occurred in Wuyuan, Shexian, and Qimen, more hailstorms occurred in Wuyuan and Jixi, more frost disasters occurred in Wuyuan, Jixi, and Qimen, and more earthquakes occurred in Wuyuan and Jixi. The occurrence frequency of wind disasters was not high in any of the counties, (4) flood and drought disasters in the Huizhou region exhibited obvious stage characteristics during the Ming and Qing dynasties, and they changed gradually from droughts to floods, among which the transition from slight drought to slight flooding was the most obvious during 1811–1911, and (5) overall, slight flooding and slight drought situations accounted for the largest percentage of drought and flood disasters in this area during the Ming and Qing dynasties. Among these, slight flooding mainly occurred in Shexian and Qimen; severe flooding mainly occurred in Wuyuan; slight drought mainly occurred in Yixian; and severe drought mainly occurred in Jixi.

KEYWORDS

natural disasters, spatial–temporal variations, Mt. Huangshan area, Huizhou region, Ming and Qing dynasties, Little Ice Age

Introduction

Disasters are one of the most serious global issues and are recognized throughout the world. Natural disasters destroy roads and housing facilities, threaten lives and property, destroy crops, and trigger epidemics, thus causing physical and psychological damage to humans, causing massive economic losses to the country, and jeopardizing the safety and stability of society. With its vast territory, complex geographical environment, poor climate stability, and fragile ecological environment, China has experienced various types and high frequencies of natural disasters, and it is one of the countries with the most serious natural disasters in the world (Wang et al., 2006). China has had a tradition of recording natural disasters since ancient times, which has the significance of learning from history and preventing them (Chen, 1987). The formation of natural disasters is primarily determined by natural variations in factors and the vulnerability of the victims. Although the occurrence of individual disasters is uncertain, the occurrence of a large number of disasters is inevitable, so the occurrence of natural disasters follows a certain law (Liang and Zhou, 2010; Li et al., 2011). It is of great importance to understand this law in order to improve regional disaster relief and mitigation.

Natural disasters are closely related to climate. According to Ge et al. (2013a, 2013b, 2014, 2015), Zheng and Wang (2005), 2010), and Fang et al. (2014), regional temperature and humidity changes have had a great impact on precipitation over the past 2,000 years. In particular, during the Ming and Qing dynasties, China's climate has been unstable, and floods and droughts have occurred alternately throughout the country (Wan et al., 2018). The Ming and Qing dynasties (1368–1911), also known as the cosmic period of the Ming and Qing dynasties or the Little Ice Age (LIA), existed during an unusually cold period in Chinese history, with various natural disasters occurring frequently since the end of the warm period during the Tang and Song dynasties (Cao et al., 2014). In addition, writing local chronicles was popular during this period, and a large number of local chronicles and other materials have been maintained. These historical materials have a high degree of credibility because they are characterized by the fact that the more recent the time is, the more realistic is the account. Official and local records of disasters that occurred during this period were also abundant, which provides more detailed and reliable historical data sources and references for disaster studies.

At present, several achievements have been made in the study of natural disasters during the Ming and Qing dynasties. Wu et al. (2018) found that floods and droughts were the main natural disasters in the Chaohu Lake Basin during the Ming and Qing dynasties, by collecting and sorting historical documents, and they pointed out that the spatial differentiation of the occurrences of natural disasters was related to the landforms in the river basin. Wan et al. (2018) used the moving average, accumulated anomaly, and wavelet analysis methods to determine that the drought and flood disasters in the Baoji region occurred alternately during the Ming and Qing dynasties, and the disaster chain corresponded well with the global climate changes. Pei et al. (2015) was the first to quantitatively assess and verify the mechanism of the "climate change-economy-epidemic" in the Ming and Qing dynasties using statistical methods, including correlation analysis, Granger causality analysis, autoregressive with exogenous terms (ARX), and Poisson-ARX modeling. They confirmed that climate change could only fundamentally lead to the spread and occurrence of epidemics, and the depressed economic well-being was the direct trigger of the spread and occurrence epidemics on national and long-term scales in historical China. Xiao et al. (2014) divided the succession of flood and drought disasters on the North China Plain during the Qing dynasty into four stages, namely, the cropland expansion stage (1644–1720), the governmental disaster relief stage (1721–1780), the increasing number of climate refugees stage (1781–1860), and the revolt and emigration stage (1861–1911), based on the social response behaviors and measures of human society in response to flood and drought disasters. They found that the multi-stage evolution of the social response was affected by various natural and social factors, including population, food, economy, government policies, and climate change. In addition, Zhang et al. (2014) conducted a comparative analysis of the evolution characteristics of flood and drought disasters at the national scale during the Ming and Qing dynasties in China and found that the floods and droughts mainly occurred in the middle and lower reaches of the Yangtze River and the Huang-Huai River. Moreover, the areas with high incidences of flooding were distributed in a block pattern in the north–south direction, while the droughts were distributed in a zonal pattern in the east–west direction. Yan (2009), Zhu (2012), Zhang and Zhao (2018), Ma and Yang (2013), Wang (2016), and Gu et al. (2013) studied Guizhou Province, the Liangshan region in Sichuan Province, Fenhe River Basin, and Jialing River Basin, respectively, and discussed the temporal and spatial characteristics of flood and drought disasters. In addition to floods and droughts, hail disasters (Qu et al., 2015; Wang et al., 2018), locust disasters (Li et al., 2015; Kong et al., 2017), and other types of disasters (Cheng et al., 2009; Kong et al., 2016) have been studied. According to the existing research results, the natural disasters during the Ming and Qing dynasties were studied either at the national scale or in larger river basins, while studies in typical local areas and small basins were somewhat inadequate.

The ancient Huizhou region (hereinafter referred to as Huizhou region or Huizhou) is one of the regions with the most complete and abundant traditional Chinese villages. Xidi and Hongcun in this area were included as World Cultural Heritage sites in 2000. In 2008, the Huizhou region was listed as the first eco-cultural preservation experimental area in the administrative regions of China (Lu et al., 2018). The study of natural disasters in this area is of great significance to the protection of traditional Chinese villages and cultural inheritance and to monitoring of the natural environment in cultural heritage sites. In addition, this area is one of a typical representative of the northern subtropical mountainous area in southeastern China. By studying the natural disasters in this area, the law of these natural disasters in the middle mountainous and hilly areas on the north margin of the subtropical zone in China can be determined. In addition, it has a certain practical significance to regional disaster prevention and mitigation, sustainable economic development, social harmony, and stability. However, previous studies of disasters in the Huizhou region (Tian, 2015; Luo, 2018) have mainly focused on the literature sorting and qualitative statistical analysis of a single type of disaster or drought and flood disasters, while comprehensive quantitative researches on various natural disasters and analyses of their spatiotemporal differentiation characteristics are insufficient. To this end, based on previous studies, in this study the pure text narratives and descriptions in historical documents were quantitatively processed to study the spatial and temporal variations in the natural disasters in the Huizhou region during the Ming and Qing dynasties. The results of this study have a significant reference value for discussing the current law of natural disaster formation and evolution, disaster mitigation and prevention measures, environmental monitoring of heritage sites, and sustainable social and economic development.

Geographic setting

The ancient Huizhou region (29°01′ to 30°18′N and 117°11′ to 118°56′E) included six counties during the Ming and Qing dynasties (Figure 1), including Shexian, Yixian, Xiuning, Qimen, Jixi, and Wuyuan counties. The political districts of the six counties have maintained long-term stability during the historical period, and their spatial scopes were roughly equivalent to those of the six counties with the same names in southern Anhui and northern Jiangxi today. According to the history of the Huizhou region, apart from Taiping County (now the Huangshan District), the ancient Huizhou region roughly included the Huizhou District, Tunxi District, Yixian County, Shexian County, Xiuning County, and Qimen County in Huangshan City in Anhui, Jixi County in Xuancheng City, and Wuyuan County in Shangrao City in Jiangxi (Lu et al., 2018). In consideration of the consistency of the historical documents and data statistics, in this study, these six counties were used as the unit for the disaster statistics. Tunxi District was classified as Xiuning County, and Huizhou District was classified as Shexian County, while the other counties were not changed.

The Huizhou region is located in the subtropical humid monsoon climate zone, with four distinctive seasons and a mild and rainy climate. The terrain of this area is complicated, mainly consisting of low mountains and hills surrounded by high mountains, with valley plains or basins in the central part. The special topographic structure and humid climate have led to the development of water systems and dense river networks in this area. Due to the instability of the intensity and duration of the summer and winter monsoons and the complex topography, hydrology, and other natural geographical features in this region, floods and droughts, and hailstorms, frosts, windstorms, and other natural disasters, occur frequently in this area.

Materials and methods

Data sources

To make the statistical results more complete, reasonable, and credible, the data for the various natural disasters were mainly obtained from local chronicles and gazetteers (Ling, 1911; Hu, 1925; Liao and Wang, 1970; Ding et al., 1975; Dong and Wang, 1975; Huang, 1975; Huang and Zhu, 1975; Jiang, 1975; Jin et al., 1975; Lao and Shen, 1975; Peng and Zhang, 1975; Su and Cao, 1975; Wang and Gui, 1975; Wang and Wu, 1975; Yu and Pan, 1975; Zhang and Liu, 1975; Peng and Wang, 1982; Ge and Wang, 1988; Place Names Office of Jixi County, 1988; Shi et al., 1988; Chorography Compilation Committee of Qimen County, 1990; Chorography Compilation Committee of Xiuning County, 1990; Chorography Compilation Committee of Shexian County, 1995; Wu D. H. et al., 1998a; Wu K. J. et al., 1998b; Chorography Compilation Committee of Anhui, China, 1998; Chorography Compilation Committee of Jixi County, 1998; He and Fang, 1998; Lv and Zhan, 1998; Ma, 1998; Ni, 1998; Qing and Xi, 1998; Xie et al., 1998; Zhou and Wang, 1998; Cheng, 2000; He and Wang, 2000), and from *Drought Disasters during Past Dynasties in Anhui* (Disasters Collection Group of Research

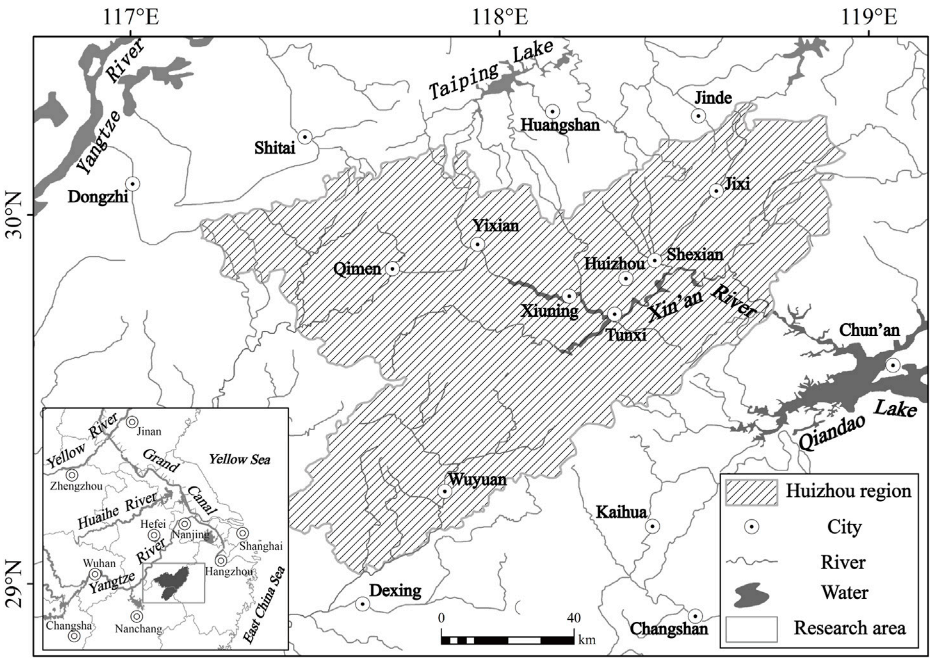

FIGURE 1
Geographic location of the Huizhou region during the Ming and Qing dynasties (1368–1911)

Institute of Culture and History in Anhui, 1957), *Preliminary Systematic Records of Earthquakes in Anhui* (Disasters Collection Group of Research Institute of Culture and History in Anhui, 1959b), *Preliminary Systematic Records of Wind, Hail, Snow and Frost Disasters in Anhui* (Disasters Collection Group of Research Institute of Culture and History in Anhui, 1959a), *Preliminary Systematic Records of Flood disaster in Anhui* (Disasters Collection Group of Research Institute of Culture and History in Anhui, 1960), and *Famine Time Scale in Modern China* (Li, 1994), in addition to other related sources of information. Moreover, the statistical processing and natural disaster classification methods mentioned in the *Study on Data Distribution of Drought and Waterlogging Disasters in Historical Period* (Man, 2000), *Yearly Charts of Dryness/Wetness in China for the Last 500 Years Period* (Central Meteorological Administration, Chinese Academy of Meteorological Sciences, 1981), and *Disasters and Social Countermeasures in Huizhou Region during Ming and Qing Dynasties* (Wu, 2014) were used to quantitatively discuss the spatial and temporal variations of natural disasters in the Huizhou region, eastern China.

Data processing methods

The disaster grade is an important indicator of the losses caused by natural disasters. The purpose of this classification is to indicate the degree of damage caused to human beings and their living space by a natural disaster and to serve as the basis for human rescue operations. In addition, it serves as an index to assess the disaster recovery capability and disaster management methods (Guo et al., 1996). In this study, quantitative statistics on the pure text description of natural disasters that occurred in the Huizhou region during the Ming and Qing dynasties were obtained. Among these, the records of hail, frost, wind, and earthquake disasters were relatively brief, for example, "hailstorm in March," "earthquake in July," and "windstorm in March." Even when there were detailed descriptions, the records were shorter, and the statistical significance of the classification was not high, so these disaster types were not graded in this study. We only recorded their frequencies. In contrast, the records concerning flood and drought disasters are detailed and abundant, which is convenient for the classification, and the methods of classifying floods and droughts are more mature. Therefore, in this study, the classification statistics and analysis of the flood and drought disasters were conducted.

At present, the levels of flooding and droughts in the historical data mainly adopted the method from *Yearly Charts of Dryness/Wetness in China for the Last 500 Years Period* (Central Meteorological Administration, Chinese Academy of Meteorological Sciences, 1981). In our study area, the disaster-rating standard can only be determined after comparison of the disaster situation at the time. By comparison and sorting, the following indicators were adopted in this study to classify flood and drought disasters in the study area (Guo et al., 1996). (1)

Severe drought: the criterion for severe drought was that the drought disaster lasted for a long time and greatly changed the society. In addition, the drought caused serious secondary disasters, and great disaster relief efforts were made: "no rain in 2 months during summer and autumn; no rain from June to July," "men feed on the soil," "the dead were all over the road," "droughts were followed by famine and tigers," and "a place was set up to cook porridge and relieve hunger." (2) Slight drought: the criterion for slight drought was that the drought disaster lasted longer and had a certain impact on the society. Secondary disasters were triggered by the drought to some degree, and the relief efforts were relatively strong: "no rain for a long time, the wheat harvest was decreased by half," "the drought was followed by a flood," and "the government relieved the hunger." (3) Slight flooding: the judgment criterion for slight flooding was that the flood disaster had a slightly longer duration and had a certain influence on society. Secondary disasters were caused by the flood to a certain extent, and the relief efforts were relatively strong: "rain for months," "the heavy rain damaged the fields and roads," and "the government relieved the hunger." (4) Severe flooding: the criteria for severe flooding were that the flood disaster occurred for a long time, the degree of damage was high, the society was greatly influenced by the flood, the secondary disasters caused by the flooding were serious, and the disaster relief efforts were great: "rain for seasons," "the fields were covered by water, and the insects damaged the crops so that many crops failed," "the floods were followed by an epidemic in autumn and winter," "people drifted with their houses," and "a place was set up to cook porridge to relieve the hunger."

The following facts about the grading need to be explained (Wu, 2014). (1) The three seasons, spring, summer, and autumn recorded in historical documents refer to the first to third, fourth to sixth, and seventh to ninth months in the lunar calendar, respectively. (2) The term continuous seasonal natural disasters does not mean that the disasters lasted for several months, but rather that the disasters spanned multiple seasons, including two consecutive seasons, three consecutive seasons, and four consecutive seasons, such as spring–summer, summer–autumn, and summer–autumn–winter. (3) Droughts in summer and autumn have more crucial influence on crop growth and maturity in continuous seasons than in spring and autumn because the crop needs rich water to grow and be harvested during this period. Therefore, drought in spring and summer is designated as slight drought, and drought in summer and autumn is designated as severe drought. (4) If a drought disaster occurred after a flood disaster in the same year, it was recorded as a severe drought because the drought had a greater impact on the crops than the flooding. If there was a drought in spring and a flood in summer, or a drought in summer and a flood in autumn, the classification would depend on the summer conditions. (5) For the disaster relief records, if the reasons for the disaster relief were not known, the data were discarded. (6) If a flood or drought disaster caused secondary disasters, it was classified as a severe flood or a severe drought, such as "the plague in autumn and winter was followed by a flood in the summer." (7) It should be noted that once the disaster was extremely serious in the first year, the second year would maintain the emergency relief even though the level may be slight in the second year. By the same token, the emergency relief would be recorded in the third year if the disaster was severe in the second year, but no disaster was recorded for more than 3 years in the Huizhou region during the Ming and Qing dynasties. Therefore, we think that if emergency relief was provided for successive years, the first year was designated as a severe drought or a severe flood, and the second year was designated as a slight drought or slight flood. (8) If the record in the local chronicles was confirmed by the official history, it was designated as a severe flood or severe drought. For example, in 1448, Shexian County was identified as having experienced severe flooding, which was recorded in *the Wuxingzhi of the Ming History*. (9) If natural disasters took place in multiple counties simultaneously, the occurrence frequency of these disasters was counted in all of the counties.

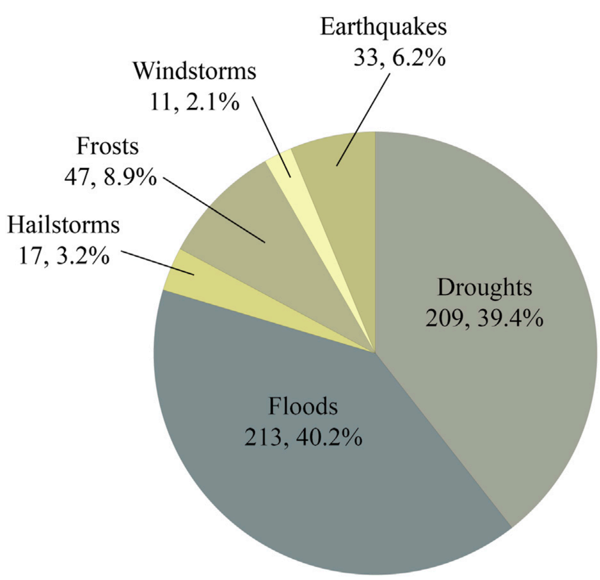

FIGURE 2
Frequency chart of the natural disasters in Huizhou during the Ming and Qing dynasties.

Results

Occurrence frequency of natural disasters

As can be seen from Figure 2, there were 530 natural disasters in the Huizhou region during the Ming and Qing dynasties (1368–1911), mainly including droughts, floods, hailstorms, frosts, windstorms, and earthquakes. They

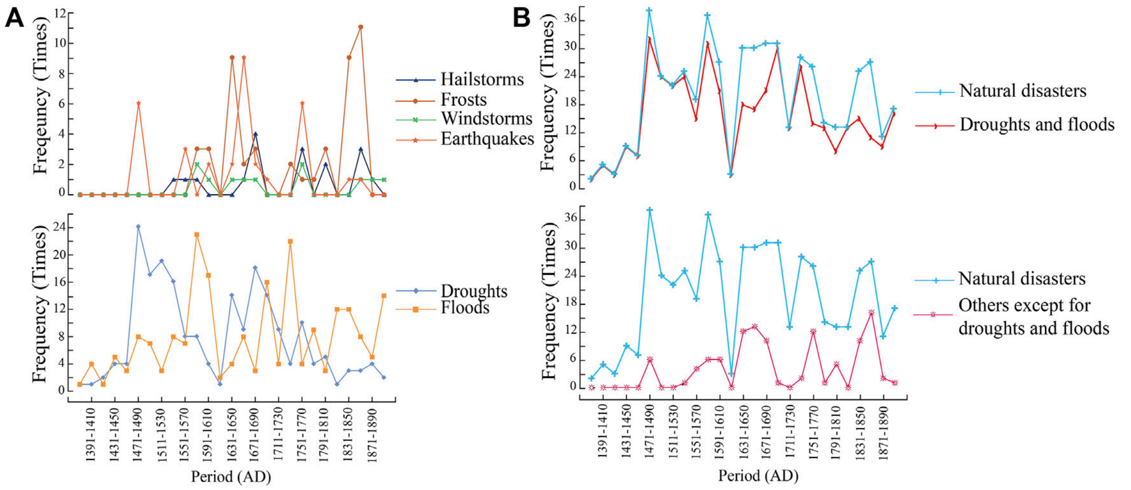

FIGURE 3
Frequency curves of the natural disasters in the Huizhou region during the Ming and Qing dynasties. **(A)** Inter-annual frequency variation of the natural disasters. **(B)** Comparison of the inter-annual frequency variation of floods, droughts with natural disasters, and other disasters with natural disasters.

occurred every 1.03 years on average. Among the natural disasters with clear records, there were 213 floods, accounting for 40.2% of the total number of various disasters, with an average of once every 2.55 years. The droughts were second only to the floods, and 209 droughts occurred, accounting for 39.4%, with an average of once every 2.6 years. Flood and drought disasters occurred 422 times in total, accounting for 79.6% of the natural disasters. On average, one flood disaster or drought disaster occurred every 1.3 years, and they were the two main natural disasters in this area during the Ming and Qing dynasties. The other four types of natural disasters accounted for 20.4%, and the occurrence frequencies of these types of natural disasters were much lower than those of the flood and drought disasters. Among them, there were 47 frost disasters, accounting for 8.9% and occurring once every 11.57 years on average. There were 33 earthquakes, accounting for 6.2% and occurring once every 16.48 years on average. The frequencies of the hailstorms and windstorms were 17 and 11 times, respectively, accounting for 3.2 and 2.1%, with averages of once every 32 years and once every 49.45 years, respectively. The fact that the numbers of flood and drought disasters were much higher than those of the other types of disasters related to the climate, hydrology, and geomorphology of the study area. The Huizhou region has a typical subtropical humid monsoon climate, with high precipitation variability. The middle-low mountains are widely distributed in this area, and the villages were mainly distributed in the intermontane basins. Once too much water was produced, and the water could not easily drain out because the surrounding terrain was very steep, so the water was collected rapidly, and thus, floods formed easily. In addition, it was not easy to save water in the mountainous area, and thus, this area was prone to droughts in dry seasons.

Inter-annual variations in natural disaster occurrences

Given the law of disasters is terrible if fewer years were taken as the time unit, 20 years were taken as the statistical unit, which can reflect the tendency well. The situation is shown in Figure 3. The figure and statistical data suggest that (1) there was a significant correlation between the occurrence frequency of flood plus drought disasters and total number of natural disasters on the chosen time scale. However, the occurrence frequencies of hailstorms, windstorms, frosts, and earthquakes were less compatible with the total occurrence frequency of the natural disasters. This confirms the aforementioned conclusion that flood and drought disasters were the main disasters and indicates that the variation in the flood and drought disasters had an important directional effect on the variations in the various natural disasters, (2) the lowest natural disaster frequencies occurred during dynastic transition periods (Figures 3A,B). In fact, the occurrence of natural disasters was one of the important reasons leading to the decline of a dynasty (Xiao et al., 2014). For example, droughts took place frequently and severe droughts caused numerous people to die in the late Ming dynasty, but the Ming government shirked its obligation to provide social assistance, which triggered social unrest. Coupled with the rapid increase in Manchu power, these factors accelerated the collapse of the Ming dynasty (Mote and Twitchette, 1998). It is clear that the frequency of natural disasters during dynastic

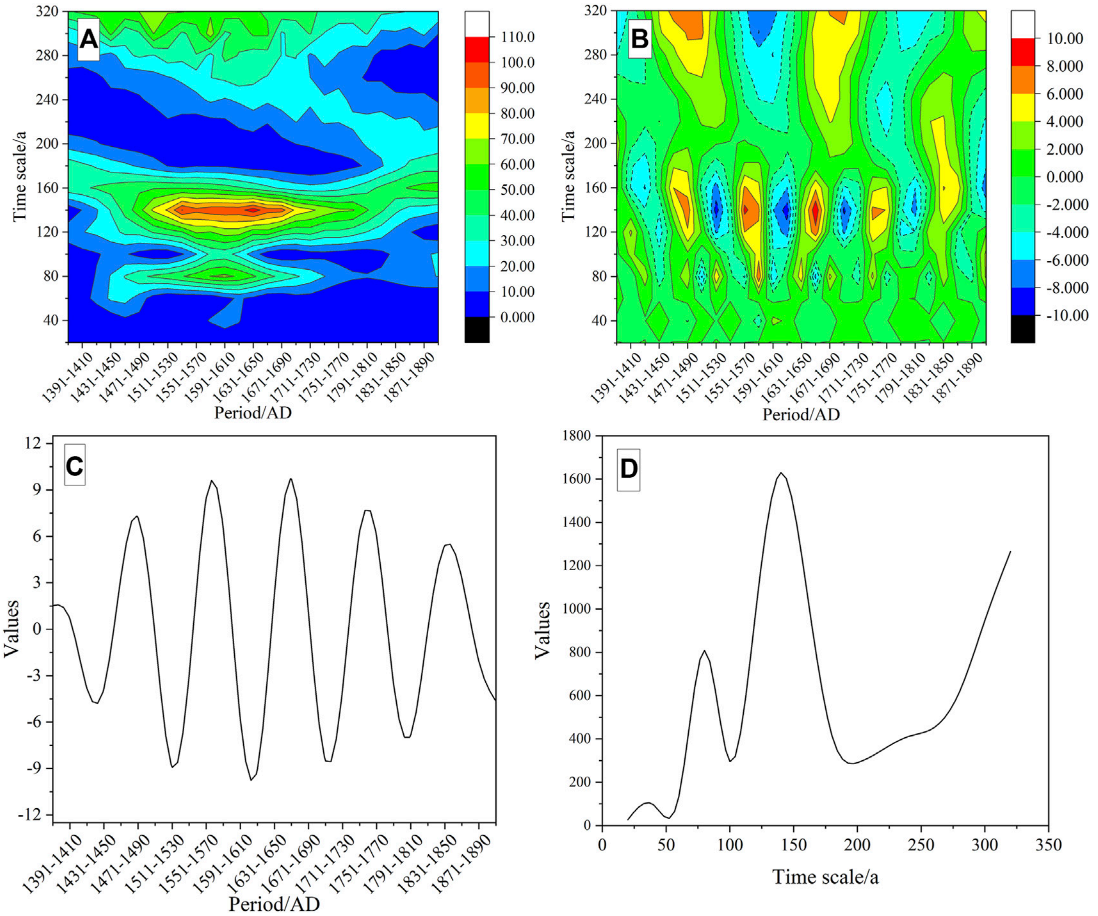

FIGURE 4
Wavelet analysis of natural disasters in Huizhou during the Ming and Qing dynasties. **(A)** Contour map of modulus square wavelet coefficient, indicating a main cycle of 140 years. **(B)** Real part wavelet coefficient contour map, indicating a periodic change of 80–100 years on the time scale of 140 years. **(C)** Real values curve of wavelet coefficient at the time scale of 140 years, supporting the point of Figure 4B. **(D)** Variance curve of natural disasters at different time scales, supporting the point of Figure 4A.

transition periods was not that low (Figures 3A,B), and it is the result of the absence of historical records caused by war and political chaos. It should be noted that natural disasters occurred more frequently during the late Qing dynasty and the early Republic of China (1911–1949) compared with the late Yuan and the early Ming dynasties and the late Ming and early Qing dynasties. This is because the local chronicles were quite mature in the Qing dynasty, (3) in addition to floods and droughts, other natural disasters occurred more frequently during the Qing dynasty than during the Ming dynasty (Figure 3A). For example, a total of 17 hailstorms were recorded, with 14 in the Qing dynasty and 3 in the Ming dynasty. A total of 47 frosts were recorded, with 37 in the Qing dynasty and 10 in the Ming dynasty. A total of 11 windstorms were recorded, with 8 in the Qing dynasty and 3 in the Ming dynasty. A total of 33 earthquakes were recorded, with 25 in the Qing dynasty and 8 in the Ming dynasty. Undoubtedly, this may be attributed to the fact that more historical materials survived in the Qing dynasty than in the Ming dynasty. More importantly, it is a phenomenon rarely seen elsewhere in China. For example, the hailstorms and frosts took place more frequently in the Qing dynasty than in the Ming dynasty; however, the frequency of windstorms was higher in the Ming dynasty than in the Qing dynasty in Jiangxi Province, China (Shi, 2000). Similar to Jiangxi, the natural disasters in Heihe River Basin during the Ming and Qing dynasties did not follow the pattern of Huizhou (Shi and Dong, 2018). This suggests that Huizhou was more affected by the LIA that reached the maximum in the Qing dynasty than elsewhere in China, (4) the occurrence frequency of natural disasters exhibited a fluctuant variation with time, which was related to the contingency of the natural disasters, so there were more in some years and less in others. Although the frequencies of the various natural disasters were different, the peaks

TABLE 1 Frequencies of the natural disasters in different seasons in the Huizhou region during the Ming and Qing dynasties.

Season	Natural disaster					
	Drought	Flood	Hailstorm	Frost	Windstorm	Earthquake
Spring	1	7	5	10	3	4
Summer	33	110	6	2	3	9
Autumn	15	17	2	1	0	5
Winter	6	13	0	25	0	7
Spring–summer	1	0	0	0	0	0
Summer–autumn	19	0	0	0	0	0
Autumn–winter	2	0	0	0	0	0
Summer–autumn–winter	2	0	0	0	0	0

were roughly the same. Taking 20 years as the statistical unit, the occurrence peaks of the natural disasters were mainly concentrated at 1471–1490, 1570–1590, 1671–1690, 1751–1770, and 1851–1870, with a peak appearing approximately every 100 years. This idea is supported by the wavelet analysis. Both variance and modulus square of wavelet coefficient indicate the 140-year main cycle of the occurrence frequency of natural disasters in Huizhou (Figures 4A,D). Moreover, the real values of wavelet coefficient show that there is a periodic change of 80–100 years at the time scale of 140 years (Figures 4B,C), which is generally consistent with the earlier conclusion (Figure 3). Various disasters frequently occurred in the late Ming and early Qing dynasties. This is consistent with the "Group Occurrence Period of Natural Disasters in the Ming and Qing Dynasties" (Wang, 1963).

Seasonal variations in natural disasters

During the Ming and Qing dynasties, 530 natural disasters occurred in the study area, 222 of which occurred in unknown seasons, accounting for 41.9% of the total. There were 308 recorded natural disasters in clear seasons, accounting for more than half of the total (58.1%) (Table 1). The natural disasters mainly occurred in a single season, with a few occurring during two consecutive or three consecutive seasons, but none extended over four consecutive seasons. Of the 308 disasters with clear season records, 254 occurred in summer, winter, and autumn, accounting for 82.5% of the total clear season records. As can be seen from Table 1, in a single season, the most frequent natural disasters took place in summer (163 disasters), accounting for 52.9%. Among the 163 natural disasters, 113 were recorded in specific months, accounting for 69.3% of the natural disasters in summer. Among which, 71 occurred in May, accounting for 62.8% of the clear season records in summer. In addition, some of the natural disasters lacked specific month records in May, so the natural disasters in summer were mainly concentrated in May, followed by winter and autumn, with 51 and 40 disasters, respectively, accounting for 16.6 and 13%. In addition, 30 natural disasters occurred in spring, accounting for 9.7%. In consecutive seasons, they were mainly concentrated in summer–autumn (19 disasters), accounting for 6.2%. However, the frequencies of natural disasters in autumn–winter (two disasters), summer–autumn–winter (two disasters), and spring–summer (one disaster) were very small (1.6% in total).

Summer and autumn were the high-occurrence seasons of flood and drought disasters in the study area during the Ming and Qing dynasties. A total of 194 floods and droughts occurred in these two seasons, accounting for 63% of the total clear season records. There were 13 hailstorms in this region, mainly in spring, summer, and autumn (five in March, one in April, one in May, two in June, two in September, and two in unknown months in summer), and there were no records in winter. March to August of the lunar calendar was the main occurrence period of hailstorms in China, while these storms were rare in winter (Wu, 1997), which is consistent with the climate of the study area. Frost disasters occurred 35 times in spring and winter, accounting for 92.1% of the total. All six wind disasters occurred in spring and summer because during this period, the air convection in the Huizhou region was strong, and it was prone to generate cyclones, causing damage to buildings and crops and leading to wind disasters. In addition, 25 earthquakes occurred throughout the year, with more in summer.

In general, during the Ming and Qing dynasties, the natural disasters in the Huizhou region mainly occurred in summer and autumn (203 disasters), accounting for 65.9%, especially in summer, and the highest frequency was in May. This is mainly because this period was the high-incidence period of flood and drought disasters, and the high frequency of flood and drought disasters caused the high frequency of the total natural disasters to occur in summer and autumn.

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TABLE 2 Frequencies of the natural disasters in different counties in the Huizhou region during the Ming and Qing dynasties.

Natural disaster	Counties in Huizhou region					
	Shexian	Jixi	Qimen	Wuyuan	Xiuning	Yixian
Droughts	31	43	30	31	34	40
Floods	39	31	38	43	33	29
Hailstorms	2	4	1	8	2	0
Frosts	7	9	8	13	7	3
Windstorms	3	1	1	1	5	0
Earthquakes	4	9	4	10	4	2

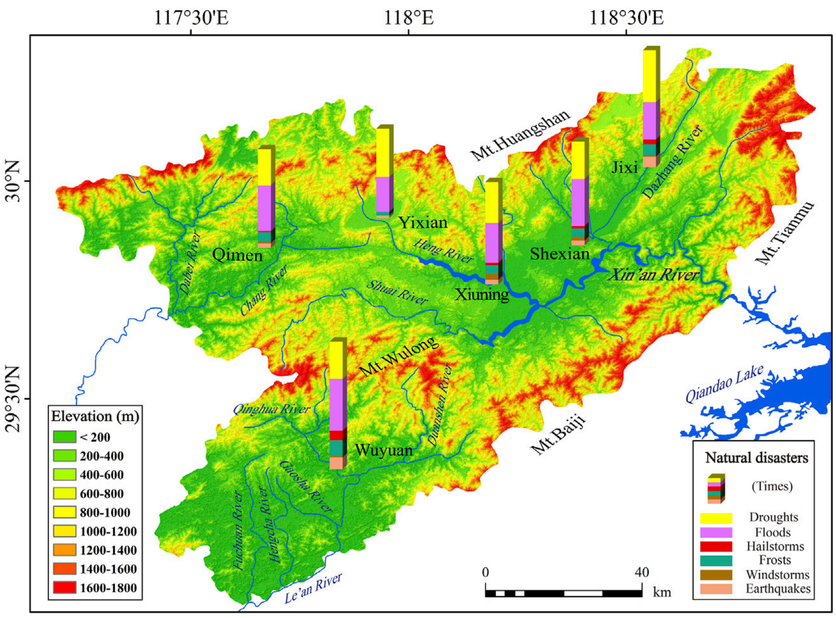

FIGURE 5
Spatial distributions of the various natural disasters in Huizhou during the Ming and Qing dynasties.

Spatial distribution of natural disasters

Among the counties in the study area (Table 2; Figure 5), the most frequent natural disasters occurred in Wuyuan (106), followed by Jixi (97), Shexian (86), Xiuning (85), Qimen (82), and the least occurred in Yixian (74). Of all the ancient villages in Yixian County, there are 44 state-level villages, such as Xidi and Hongcun, which are world cultural heritage sites. This not only reflects the low frequency of natural disasters but also proves the reliability of recorded data of natural disasters because ancient villages would be destroyed by natural disasters such as floods and hailstorms.

The frequency of flood and drought disasters exhibited certain spatial differences. For droughts, the most occurred in Jixi (43), followed by Yixian (40), and the other counties (34 in Xiuning, 31 in Shexian, 31 in Wuyuan, and 30 in Qimen). In contrast to droughts, the fewest floods occurred in Yixian (29), Jixi (31), and Xiuning (33), while Wuyuan (43), Shexian (39), and Qimen (38) had more floods. For the other natural disasters, the most hailstorms took place in Wuyuan (8), accounting for nearly half of the 17 hailstorms. Wuyuan (13), Jixi (9), and Qimen (8) experienced more frost disasters, while Yixian (3) experienced the least since it was encircled by mountains, and the cold air was blocked. Xiuning and Shexian experienced five and three

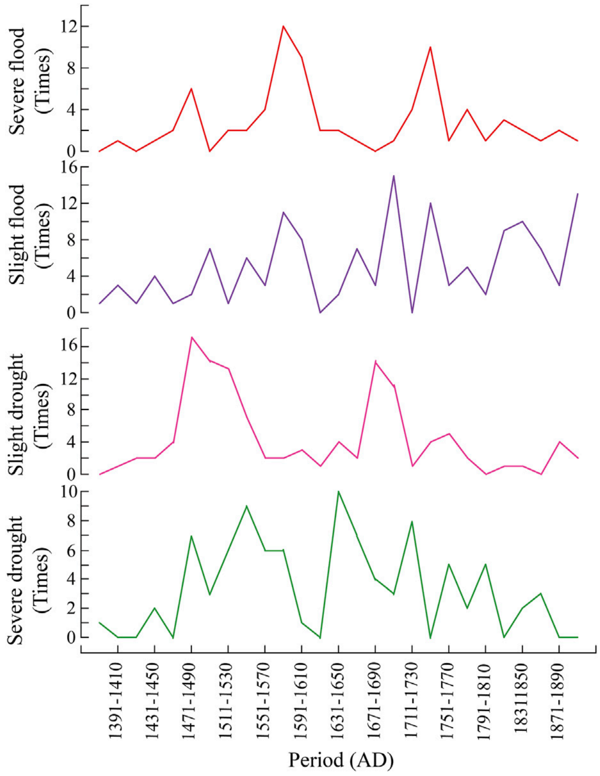

FIGURE 6
Frequency curves of the different grades of floods and droughts in the Huizhou region.

windstorms, respectively; Jixi, Qimen, and Wuyuan only experienced one storm each; and there were no windstorms in Yixian. Wuyuan, Jixi, Shexian, Qimen, Xiuning, and Yixian experienced 10, 9, 4, 4, 4, and 2 earthquakes, respectively. The reason for so few earthquakes in this region is that Huizhou is not located in an active earthquake zone. The seismic activity in Anhui is mainly concentrated along the northern foot of Dabie Mountain and in the Tan–Lu Fault Zone (the Anhui section starts in Suqian County in the north, passes southward through Sihong, Wuhe, Mingguang, Feidong, Lujiang, Taihu, Susong, and Huangmei Counties, and ends near Guangji County in Hubei Province) and in northeastern Anhui Province (Zhang et al., 2004; Ni et al., 2013).

Discussion

From the aforementioned analysis, we know that flood and drought disasters were the main types of natural disasters, with 422 events accounting for 79.6% of the total, and there were only 108 other natural disasters, accounting for 20.4%. Based on this, in this section, we focus on the spatial–temporal variations in the different grades of flood and drought disasters.

Occurrence frequency of all grades of floods and droughts

During the Ming and Qing dynasties, there were obvious differences in the grades of flood and drought disasters in the Huizhou region. The frequencies of slight droughts and slight floods were 119 and 139, respectively, accounting for 28 and 33%, with a total of 258 floods and droughts, accounting for 61% of all of the flood and drought disasters. There were 90 severe droughts and 74 severe floods, accounting for 21 and 18%, respectively, with a total of 164 severe floods and droughts, accounting for 39%. Therefore, the flood and drought disasters in this area were mainly slight droughts and slight floods during the Ming and Qing dynasties.

Inter-annual variations in all grades of floods and droughts

Taking 20 years as the statistical unit to calculate the inter-annual variations in the flood and drought disasters at all levels (Figure 6), the flood and drought disasters were divided into four stages. (1) In 1368–1470, slight droughts and slight floods were the main classifications of flood and drought disasters, accounting for 73.1% of the total. During this period, the occurrences of floods and droughts of all grades were relatively low, with a total of 26 events and an average of one every 3.92 years, which was far lower than the average of one every 1.29 years. The reason for this is the same as the situation mentioned earlier for the low frequency of natural disasters during the dynastic transition periods. (2) 1471–1630 was the first high-incidence period of flood and drought disasters, with 172 events and an average of 1.08 events per year, which is higher than the average value of 1.29 events per year. During this stage, there were more droughts than floods, and the droughts were mainly slight droughts. There were 17 slight droughts recorded in 1471–1490. (3) 1631–1810 was the second high-incidence period of flood and drought disasters, with 160 events and an average of one every 1.13 years. During this period, droughts were still the main disaster, but the proportion of floods began to increase. Slight droughts, severe droughts, and severe floods mainly occurred. (4) In 1811–1911, the flood and drought disasters decreased overall, but the floods began to surpass the droughts. The frequencies of slight floods and severe floods were much higher than those of the slight droughts and severe droughts. Unlike in the previous stages, the number of slight floods in this stage was much higher than those of the other grades, with a total of 42 slight floods, accounting for 65.6%. In addition, although there were some fluctuations during this period, the occurrence frequency of floods began to exceed that of droughts, and the trend in which floods were dominate becomes obvious.

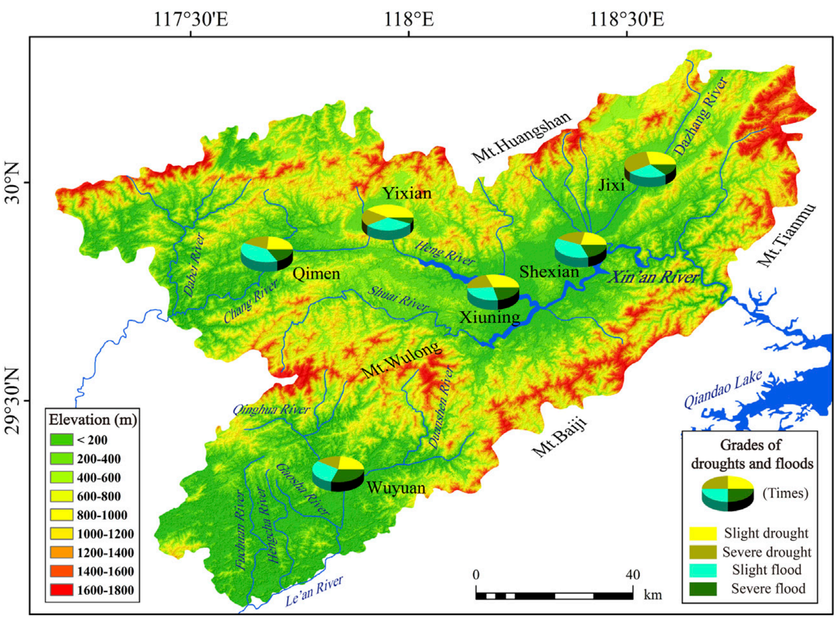

FIGURE 7
Spatial distributions of different grades of floods and droughts in the counties.

TABLE 3 Frequencies of different grades of floods and droughts in different counties in the Huizhou region during the Ming and Qing dynasties.

County	Grades of flood and drought			
	Severe drought	Slight drought	Slight flood	Severe flood
Shexian	16	15	26	13
Jixi	22	21	22	9
Qimen	14	16	27	11
Wuyuan	14	17	20	23
Xiuning	13	21	19	14
Yixian	11	29	25	4

Spatial distributions of all of the grades of droughts and floods

As can be seen from Figure 7 and Table 3, the different grades of flood and drought disasters exhibited obvious spatial variations. In terms of the administrative divisions, they occurred most frequently in Jixi (74) and Wuyuan (74), accounting for 17.5%, respectively; followed by Shexian (70), accounting for 16.6%; Yixian (69), accounting for 16.4%; Qimen (68), accounting for 16.1%; and Xiuning (67), accounting for 15.9%. Among them, the most droughts occurred in Jixi (43) and Yixian (40), and the most floods occurred in Wuyuan (43), Shexian (39), and Qimen (38).

Based on the grades of drought and flood disasters in each county, Shexian, mainly experienced slight floods (26), accounting for 37.1% of the total flood and drought disasters. The frequencies of the other grades were only slightly different, with 16 severe droughts, 15 slight droughts, and 13 severe floods. In Jixi, except for the number of severe floods (9) being the lowest, all the other three grades exceeded 20 events, including 22 severe droughts, 21 slight droughts, and 22 slight floods. Similar to Shexian, Qimen also had the highest frequency of slight floods (27), accounting for 39.7%. The other three grades were only slightly different and were less than 20 events. The numbers of slight droughts, severe droughts, and severe floods were 16, 14, and 11 in Qimen, respectively. Wuyuan was dominated by floods, and the frequencies of severe floods and slight floods were 23 and 20, respectively, with 43 in total, accounting for 58.1% of those in Wuyuan; whereas the numbers of slight droughts and severe droughts were less than 20, that is, 17 and 14, respectively. There were few floods and droughts in Xiuning, and those that occurred were mainly slight droughts (21) and slight floods (19), while fewer severe floods (14) and severe droughts (13) occurred. Yixian was similar to Xiuning, but the grade difference was greater (29 slight droughts and 25 slight floods), with a total of 54 events, accounting for 78.2%. A total of 15 severe droughts and severe floods occurred, and only half of the occurrences were slight droughts.

Relationships between the natural disasters and geographical environment

Due to the different disaster-prone environments, there were also differences in the spatial and temporal patterns of the natural disasters. The climate, topography, hydrology, and other natural geographical factors in the Huizhou region were closely related to the formation of temporal–spatial variations in floods, droughts, hailstorms, frosts, and others.

In terms of climate, the changes in temperature played an important indicative role in the frequencies of flood and drought occurrences. It is generally recognized that more floods took place in the warm period, while droughts took place in cold periods (Jia et al., 2012; Tang and Hu, 2017). The frequency of droughts was supposed to exceed that of floods because the LIA during the Ming and Qing dynasties was a relatively long cold period in the climate history of China. In contrast, the frequency of droughts was lower than that of floods, even though droughts were frequent in the study area. Of course, this may be partially due to the lack of historical records, but it was more affected by climate. The Huizhou region is located in the subtropical humid monsoon climate zone. This climate is generally wet and experiences more precipitation, which leads to fewer droughts. This is confirmed by the occurrence of more slight floods and slight droughts than severe floods and severe droughts. However, this does not mean that the climate change during the LIA had no impact on the Huizhou region. A previous study reported that 1650–1700 was the coldest period in the middle and lower reaches of the Yangtze River, and the number of droughts in the Huizhou region was significantly higher than the number of floods during this period, indicating that the climate during the LIA still had a great impact on the study area (Wang et al., 2003). In addition, the influence of the LIA reached its greatest degree during the Qing dynasty. The various meteorological disasters that occurred during the Qing dynasty were more frequent in the Ming dynasty (He and Yang, 2017). Affected by the LIA, the frost disasters in Huizhou were mainly concentrated in the late Ming and early Qing dynasties, and the frequency of frosts in the Qing dynasty was generally higher than that in the Ming dynasty. Judging from the differences between seasons, the temperature was the leading factor causing the occurrence of frosts. The low temperatures in winter and spring led to a high incidence of frost disasters. In addition, two frosts also occurred in early summer. At this time, the temperature was still not high, and there was the possibility of a sharp temperature drop. Moreover, crop growth was vigorous during this period, but the impact of severe cooling on crops would have been more serious (He and Yang, 2017).

In terms of the terrain, the Huizhou region is dominated by middle-low mountains and hills, including Huangshan Mountain, Baiji Mountain, Wulong Mountain, Tianmu Mountain, and many hills. The Xin'an River Basin is surrounded by high mountains, and the valley plains and basins in the center are narrow and flat. If heavy rainfall supplied too much water to the upstream area, mountain torrents would flow downstream, and the river would not be able to discharge the torrents in a timely manner, which easily caused floods. Wuyuan County is backed by Wulong Mountain and faces the Poyang Lake plain. The southeast monsoon in summer is blocked by the mountain, and precipitation is prone to occur on the windward slope. The low and flat terrain and the weak flood releasing capacity resulted in a high frequency of floods in Wuyuan County. The droughts were mainly distributed in the vast mountainous areas of western Huangshan Mountain, northern Huangshan Mountain, and northwestern Tianmu Mountain. The cultivated slope land in the mountainous area was dry, with a shallow soil layer and poor structure. In particular, the eroded soil was characterized by less organic matter, sandy soil, and a poor water and fertilizer conservation ability, leading to frequent droughts (Wu, 2014). Because of the steep terrain, it was difficult to use river water for irrigation, which aggravated the droughts. The formation of hailstorms requires precipitation conditions, that is, sufficient water vapor, lifting force, and unstable stratification, and special conditions for hailstorms. Huizhou is surrounded by mid latitude mountains, and the undulation of the terrain causes the ground to be unevenly heated, forming local thermal circulation. Under this complex climate system, hail disasters easily occurred (Qu et al., 2015). Among the counties, hail disasters occurred most frequently in Wuyuan. Located to the south of Wulong Mountain, Wuyuan is on the windward slope of the southeast monsoon. The high mountain performs the functions of restricting, uplifting, and heating of the air currents above the leeward slope, which is conducive to the formation of hail clouds and the occurrence of hail disasters (Wen, 2008; Zheng et al., 2010; Qu et al., 2015).

From a hydrological point of view, there were more flood disasters in the river gathering areas than in the areas where a single river passed through. Wuyuan has a well-developed water system and a dense network of rivers, including the Qinghua River, Duanshen River, Gaosha River, and Le'an River, which is one of the main tributaries of the Raohe River. There are many tributaries in the Xin'an River Basin, two of which are the main tributaries, namely, the Shuai River in the south and the

Hengjiang River in the north. The rainy season came at the same time for all of the rivers, and flooding of the confluence of the main stream easily occurred in a short time period. Therefore, the floods in Wuyuan County and the Xin'an River Basin were serious. The water in the Xin'an River Basin was eventually injected into Qiandao Lake through Jiekou Town in Shexian County, which reduced the drainage pressure in the basin. As a result, the floods in the Xin'an River Basin were mainly slight floods. However, Jixi and Yixian, in which a single river flows through, experienced less frequent floods, especially severe floods, that is, only nine and four in 544 years, respectively.

Conclusion

The historical documents of the Huizhou region in the Ming and Qing dynasties were collected to explore the law of natural disasters. It is found that there were some spatial–temporal variations in the Huizhou region during the Ming and Qing dynasties, related to the geographical environment. More detailed conclusions are as follows.

(1) Flood and drought disasters, the major types of disasters in the Huizhou region during the Ming and Qing dynasties, were significantly correlated with the natural disasters on the time scale of the study; however, the others (windstorms, frosts, hailstorms, and earthquakes) were less.
(2) Apart from floods and droughts, the other disasters occurred more frequently in the Qing dynasty (1644–1911) than in the Ming dynasty (1368–1644). The occurrence frequency of natural disasters had a fluctuant variation pattern over time, with peaks emerging about once a century. Taking 20 years as the statistical unit, the peaks of natural disaster occurrence were mainly concentrated at 1471–1490, 1571–1590, 1671–1690, 1751–1770, and 1851–1870, which is supported by the wavelet analysis. The natural disasters in this area mainly occurred in summer and autumn. The flood and drought disasters exhibited obvious four stages of 1368–1470, 1471–1630, 1631–1810, and 1811–1911, and they changed gradually from more droughts to more floods.
(3) The most frequent natural disasters took place in Wuyuan, followed by Jixi, Shexian, Xiuning, Qimen, and Yixian. More droughts occurred in Jixi and Yixian; while more floods occurred in Wuyuan, Shexian, and Qimen; more hailstorms occurred in Wuyuan and Jixi; more frost disasters occurred in Wuyuan, Jixi, and Qimen; and more earthquakes occurred in Wuyuan and Jixi. The occurrences of wind disasters were not high in any county. Among the floods and droughts, slight floods mainly occurred in Shexian and Qimen; severe floods mainly occurred in Wuyuan; slight droughts mainly occurred in Yixian; and severe droughts mainly occurred in Jixi.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material; further inquiries can be directed to the corresponding author.

Author contributions

SL and LW drafted the initial manuscript after several days of discussion with XC, GX, and FS. CL, XH, BY, HZ, and XL jointly produced the figure. All co-authors equally edited the manuscript and provided suggestions, references, and improvements.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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