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EDITED BY
Zhuolun Li,
Lanzhou University, China

REVIEWED BY
Yinzhou Huang,
Lanzhou University, China
Wei Pan,
Yunnan University, China

*CORRESPONDENCE
Gang Li,
liglzu@gmail.com

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Spatio-temporal evolution, climatic response and social impacts of locust breeding areas from 618 to 1949 in Cangzhou, Hebei, China

Chenxi Feng[1], Gang Li[1,2,3,4]*, Wei Xu[3], Shuo Wang[1], Xingxing Wang[1] and Xing Gao[1]

[1]College of Urban and Environmental Sciences, Northwest University, Xi'an, China, [2]Shaanxi Key Laboratory of Earth Surface System and Environmental Carrying Capacity, Northwest University, Xi'an, China, [3]State Key Laboratory of Earth Surface Processes and Resource Ecology, Beijing Normal University, Beijing, China, [4]State Key Laboratory of Loess and Quaternary Geology, Institute of Earth Environment, CAS, Xi'an, China

Recent years have seen a significant increase in natural disasters and vicissitudes of the environment, making it imperative to investigate their spatio-temporal dynamics. Using records extracted from historical documents and focusing on a typical hazardous area—Cangzhou, this study reconstructed databases of locust plagues and related disasters from 618 to 1949 to analyze the spatio-temporal evolution of the locust plagues as well as the locust breeding areas under the influence of patterns of water environment, and to clarify the climatic system and the social response to the locust plagues. The results suggested that: 1) Locust plagues occurred chiefly from March to June, while frequency and grades of the locust plagues rose in volatility, with mainly slight or moderate locust plagues becoming severe or catastrophic, the impact of the locust plagues increasing significantly from the Ming Dynasty to the Republic of China and the 17th century was the peak. 2) Locust plagues were widespread throughout Cangzhou, frequently occurring in densely hydrographic networks with significant hydrophilia. The locust breeding areas were divided into four main types: the eastern sea coast locust breeding areas, the central river flood locust breeding areas, the northwestern lake shore locust breeding areas, and the southwestern internal plain flood locust breeding areas. 3) There was no significant correlation between the locust plagues and temperature, while precipitation was closely related to the locust plagues. Locust plagues were misaligned with river floods and synchronized with droughts. 4) Locust plagues were formed by combination of climatic and social influences and act as mediums for transmitting negative impacts to social systems, resulting in social impacts and responses.

KEYWORDS

locust plague, locust breeding area, spatio-temporal evolution, climatic response, social impact, cangzhou

1 Introduction

Locust plagues, floods, and droughts were the three major natural disasters in ancient China had substantial impacts on the people's livelihood, society's stability, and the country's prosperity. In records from the last 2000 years, the locust plagues were described in many scenarios, including those detailing locusts consuming all available food and resulting in cannibalism. Furthermore, the connections between the locust plagues and other natural disasters were described as coinciding with floods or droughts, with hydrophilia and spatial distribution of the locust plagues being described as more widely distributed on both sides of the river.

In the world, China had the longest locust plague record, the most extensive spatial impact, and the greatest locust plague damage (Li, 2014). Since the 20th century, studies of the historical locust plagues have increased, and researchers in multi-disciplinary fields have conducted many pieces of research. Much attention was being paid to spatio-temporal distributions, migrations, and factors of the locust plagues. With the Huanghuaihai Plain as a case, The spatio-temporal characteristics of locust plagues and the factors that influenced them, identifying five peak locust plague periods and five major locust plague events (Zou, 1993). Locusts migrated from Shandong, Henan, and Huabei Provinces to North and South China (Zheng, 1990). While the North China Plain was the primary source of historical locust plague outbreaks, and Hebei Province was one of the most affected areas (Kong et al., 2017; Wang et al., 2017). Various results of studies on the relationship between the historical locust plagues and climate changes in China remain highly contentious. Locust plagues were closely related to droughts (Li, 1996). Based on the spatio-temporal distribution of locusts, 41° north latitude was the northern boundary of their occurrence (Zhang and Chen, 1998). Locust plagues were not significantly correlated with the winter temperature but negatively correlated with summer precipitation (Li, 2008; Li et al., 2010; Li, 2014).

As above, it was evident that the spatio-temporal distribution of the locust plagues was closely tied to natural habitats, forming studies that examined locust breeding areas. "Locust breeding area" referred to the ecogeographic areas suitable for locust breeding and habitat, and divided it into four primary types: sea coast locust breeding areas, river flood locust breeding areas, lake shore locust breeding areas and internal plain flood locust breeding areas (Ma, 1960). The locust breeding areas were classified into three occurrence sites: base occurrence sites, general occurrence sites, and temporary occurrence sites (Chen, 2007). Furthermore, locust plagues had adverse effects on society, with scholars focusing on the prevention and control, and social response of locust plagues. Unreasonable agricultural practices and misconceptions of the ancients contributed to outbreaks of Zhang (1996) as the locust plagues severely affected people's lives and national politics during the Tang Dynasty, which was a significant factor in peasant uprisings (Yan, 2003). Locust plagues could produce phenomena such as severe epidemics, plummeting populations, and frequent wars, seriously affecting social stability (Li, 2014; Liu et al., 2018). As shown, it was evident that the locust plagues negatively affected social systems in the locust breeding areas.

Most of the above studies focused on the spatio-temporal evolution of locust plagues and locust breeding areas, with the connections between locust plagues and climate, as well as their social impacts and responses, which provided a basis for this study. Meanwhile, it was found that studies of historical locust plagues and locust breeding areas in the North China Plain were limited, and their spatio-temporal evolution from 618 to 1949 at the micro-municipal level was less explored. Hence, this paper focused on the spatio-temporal evolution of the locust plagues and locust breeding areas concerning climate that occurred in 618–1949 and explored the response mechanisms ("locust-river", "locust-lake", "locust-sea" etc.), revealing the evolutionary processes and mechanisms of natural and humanistic systems.

2 Materials and methods

2.1 Study area

Cangzhou is located in the southeastern of Hebei Province and the eastern of the Hebei Plain in the Heilonggang River Basin, bordering the Bohai Sea to the east, Tianjin Province to the north, Shandong Province to the south, and Hengshui and Baoding Provinces to the west (Figure 1). Cangzhou, as the prefecture-level city, was composed of Cangzhou District (including Xinhua, Yunhe Districts, and Cang County), Botou, Renqiu, Huanghua, Hejian County-Level Cities (Botou, Renqiu, Huanghua, Hejian), Qing, Dongguang, Haixing, Yanshan, Suning, Nanpi, Wuqiao, Xian Counties (Qing, Dongguang, Haixing, Yanshan, Suning, Nanpi, Wuqiao, Xian), and Meng Village Hui Autonomous County (Meng Village). It is a typical subtropical region that experiences humidity and monsoons, with sufficient light sources, precipitation, and heat, frequently occurring disastrous events such as spring droughts and summer floods. It is low-lying, with the alluvial fan edge in front of

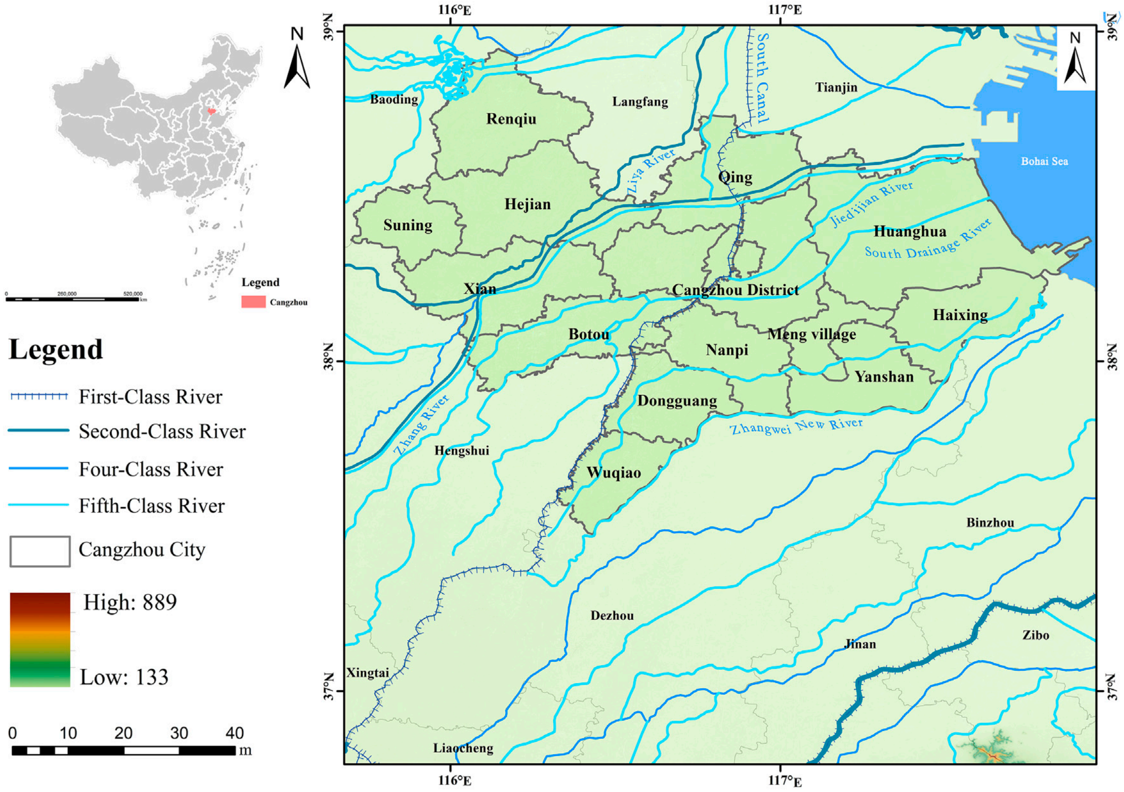

FIGURE 1
Map of the study area.

the Taihang Mountains in the west, the vast plains formed by the alluvial flow of the Yellow River, Zhang River, Hutuo River, and Tang River in the center, and the coastal alluvial of the Bohai Sea in the east (Figure 1). As part of the Haihe River Basin, the coastline is 95.3 km, and the territory is rich in wetland resources, such as Nandagang, Haixing, and Baiyangdian wetlands. Cangzhou's unique geographical location, climate, topography, and hydrological conditions provided the environmental basis for the formation of locust plagues and locust breeding areas, which are among the most famous historical locust breeding areas in China (Zhang et al., 2018), so Cangzhou is highly representative and typical in research.

2.2 Materials

Source of data. The data on locust plagues was derived from "A Compendium of Chinese Meteorological Records of the Last 3,000 Years" (Zhang, 2013) and constructing a database of locust plagues from the Tang Dynasty to the Republic of China, which included the time (season, month), generation, county, descriptions and sources, with a total of 497 documents. Meanwhile, to study the spatio-temporal evolution of the historical locust breeding areas, databases on river floods, internal plain floods and sea tides were established from A Compendium (Zhang, 2013), "Historical Materials on Natural Disasters in the Haihe Basin" (Research Group of Drought and Flood Forecasting in Hebei Province, 1985) and "The Historical Data of Tide Disasters" (Lu, 1984), with "Table of Natural and Humanistic Disasters in China" (Chen, 1939) as an essential supplement. Besides, data on famine, epidemics were obtained from "A Compendium" (Zhang, 2013) and "Annals of Epidemics in China over the Past 3,000 Years" (Gong, 2019) to explore social effects of the locust plagues.

Structures of the locust plague and related disaster databases. It should be noted that historical records often "recorded differences, but not the norm" (Li et al., 2015), with years without the locust plagues and related disaster records regularly being considered normal or less likely to experience massive and severe locust plagues. Among the historical sources, 16 percent of the locust plague data came from official records such as "The New and Old Book of the Tang Dynasty", "The History of the Song Dynasty",

TABLE 1 Grade standards.

Description	Locust occurred without damage	Locust/Slight damage	Locust/Reduce half/Famine appear/ Delay tax	Serious locust/ Without harvest/Heavy damage to agriculture/ Relive tax
Local/One generation	I	II	II or III	IV
Local/Two generation	-	II or III	III or IV	IV
Local/Many years	-	II	III or IV	IV
Regional/One or two generations	I or II	II or III	III or IV	IV
Regional/Many years	-	II or III	III or IV	IV

"The History of the Jin Dynasty", "The History of the Yuan Dynasty", "The History of the Ming Dynasty" and "Archives of the Qing Dynasty", while 74% came from local chronicles, and the materials of related disasters had similar compositions. From the accuracy of records, official records were the most accurate, followed by local chronicles and private journals, so the research data was scientific and reliable.

Spatio-temporal scales of the locust plague and related disaster data. The temporal resolution of the locust plagues and related disaster data was 1a, and it was feasible to use 1a as the temporal resolution. Over the centuries, China's administrative units have changed frequently, with the county-level remaining relatively stable (Ge and Zhang, 1990). Locust plague database contained 469 entries (94.37%) that were accurate to the county-level, suggesting that spatial scale accurate to the county was reliable. As a particular example, the locust plague was widespread in the "Hebei" in the Tang Dynasty (715), so the location of the locust plague was identified as the entire territory of Cangzhou. In the Song Dynasty (991), the locust plague occurred in the "Qianning Army", and the army's jurisdiction was equivalent to Qing in Cangzhou. Using the 1a and county as the primary temporal and spatial units, the 10a frequency and 1a counties series were plotted to analyze the spatio-temporal dynamic characteristics of the locust plagues and locust breeding areas. The data were compared and overlaid with related disaster data to reveal the spatio-temporal dynamics of the locust plagues, locust breeding areas, and the relation with climate to reflect their social impacts and response mechanisms.

2.3 Methods

Frequency of the locust plagues and river floods. Referring to definitions of rainy soil year and rain soil frequency (Zhang, 1984), every year that suffered the locust plagues and river floods was called a locust plague year and river flood year, respectively. The number of locust plagues and river floods per 10a was defined as "10a frequency of the locust plagues" and "10a frequency of river floods".

Counties of the locust plagues. Ignoring the duration, scope, and spread of the locust plagues defined as the number of counties where the locust plagues occurred within the specific temporal (1a) and spatial unit (Cangzhou).

Series of the locust plagues. A time series arranged in chronological order based on consistent information on locust plague data, with 1a as (618–1949) and county as (Cangzhou).

Classification of grades. Based on the classification of historical droughts and floods into five grades from "Atlas of the Last 500 Years of Drought and Flood Distribution in China" (Chinese Academic of Meteorological Sciences, China Meteorological Administration, 1981), and locust plague classification (Zhang, 2008a), the locust plagues were classified into slight locust plague, moderate locust plague, severe locust plague and catastrophic locust plague (I, II, III, IV) based on the occurrence and duration, scope, social impacts and responses (disaster relief, locust management, rite and morality order) of the locust plagues.

3 Results

3.1 Temporal dynamics of locust plagues

Based on the above analysis, this study explored the temporal evolution of the locust plagues. Meanwhile, this research revealed in depth the temporal dynamics of the locust breeding areas based on the temporal evolution of typical locust events.

3.1.1 Month and generation patterns of locust plagues

The locust plague months were counted to establish the month distribution of the locust plagues in Cangzhou. Figure 2A showed that the locust plagues mainly occurred from March to September

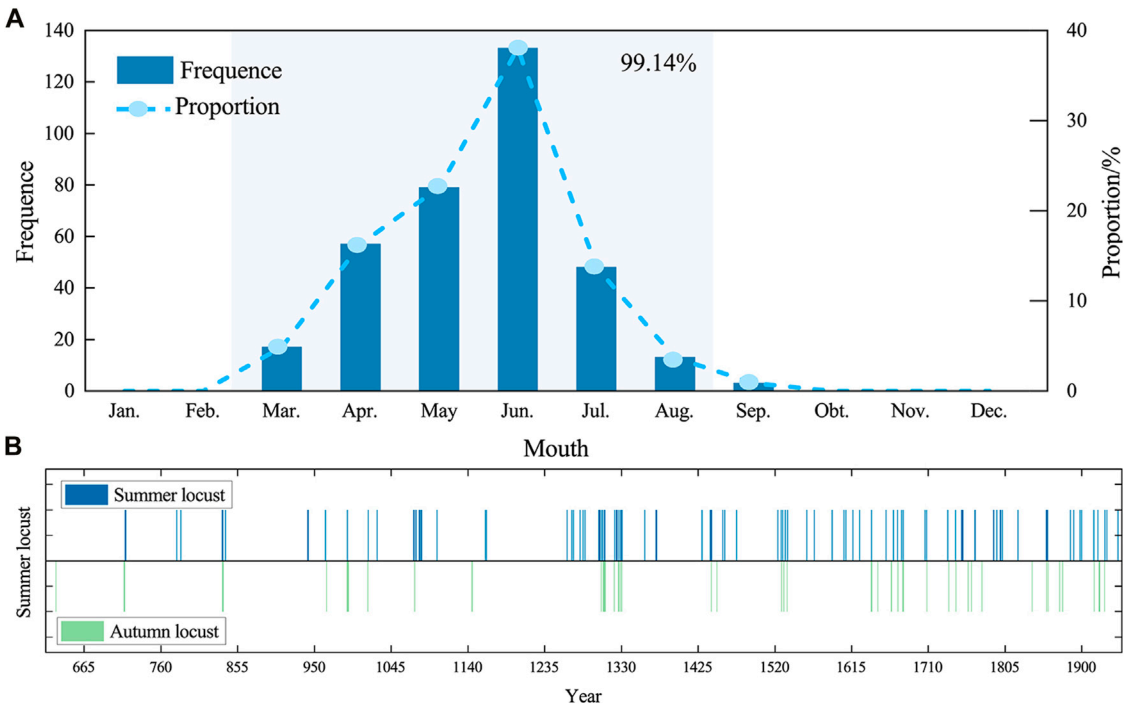

FIGURE 2
Month and generation distribution of the locust plagues in Cangzhou from 618 to 1949. **(A)** Month distribution of the locust plagues. **(B)** Generation distribution of the locust plagues.

TABLE 2 Locust generations in cangzhou from 618 to 1949.

Locust generation	Summer locusts	Autumn locusts	Summer and autumn locusts	Third generation locusts
Years/a	80	46	5	1
Proportion/%	60.6	34.8	3.8	0.8

and peaked from April to July, which accounted for 99.1% and 90.6%, respectively, followed by March, August, and September, accounting for 9.43%, and October to February was less frequent. Generally, locusts prefer temperatures between 28 and 34°C, and the minimum temperature for locust eggs to hatch in 15 to 20°C, so growth must last at least 30 days, and the average daily temperature must be over 25°C (Chen, 2007). It was found that summer locusts and autumn locusts (summer locusts, autumn locusts, or summer-autumn continuous locusts) mainly occurred in Cangzhou, with the summer locust accounting for 60.6%, followed by the autumn locusts, accounting for 34.8%, and the summer-autumn continuous locusts and third generation locusts, accounting for 3.8 and 0.8% respectively (Figure 2B; Table 2). Overall, the locust plagues were mainly distributed in the humid and hot May and June in summer, with the generation dominated by the summer locust of one generation in Cangzhou.

3.1.2 Dynastic and centurial patterns of locust plagues

Dynastic patterns of the locust plagues. As shown in Figure 3A, there were 214 locust plague years, accounting for 16.1%, ignoring the effect of the locust plague grades, an average of 1 year of it every 6 years. Locust plagues occurred about once every 21.4 years during the Tang Dynasty (618–960); once every 8.9 years during the Northern and Southern Song Dynasties (960–1279); once every 3.3 years during the Yuan Dynasty (1279–1368); once every 4.8 years during the Ming Dynasty (1368–1644); once every 4.4 years during the Qing Dynasty (1,644–1911); once every 2.1 years during the Republic of China (1911–1949). As a whole, Cangzhou showed the frequency of the locust plagues rising in volatility from 618 to 1949, with significant frequent outbreaks during the Yuan Dynasty and the Republic of China, when the impact of the

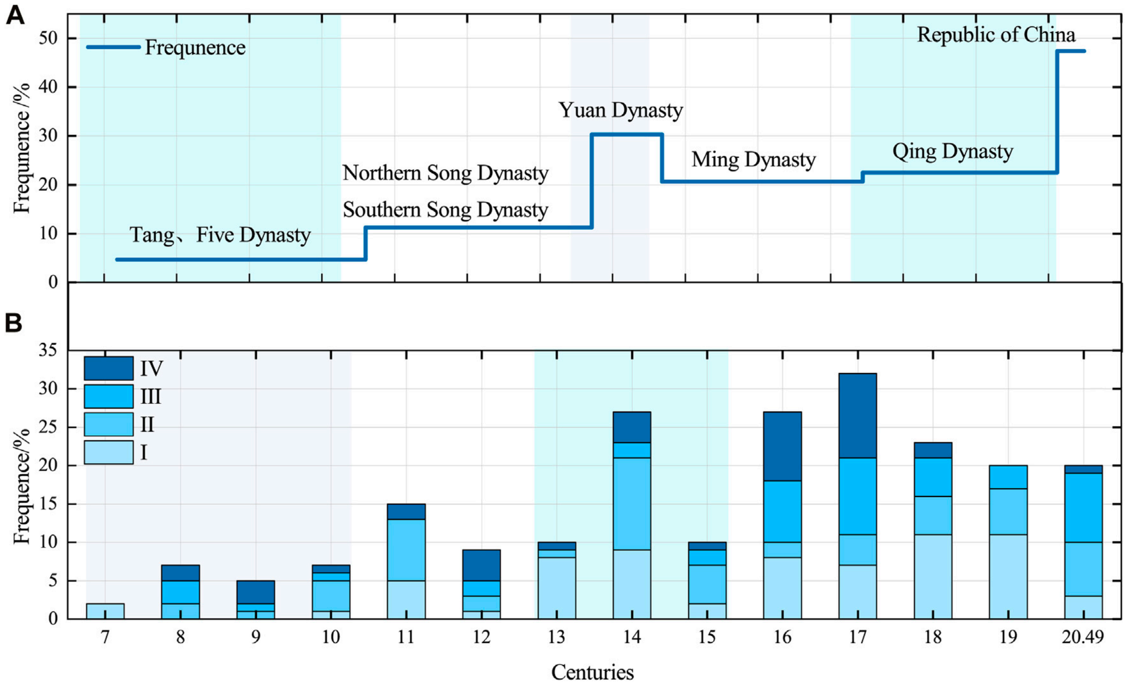

FIGURE 3
Patterns of frequency of the locust plagues in dynasties and centuries in Cangzhou from 618 to 1949. **(A)** Patterns of frequency of the locust plagues in dynasties. **(B)** Patterns of frequency of the locust plagues in centuries.

locust plagues deepened under the influence of national government, and diminished social coordination and control ability (Wang, 1999; Zhao, 2007; Zhang, 2008b).

Centurial patterns of the locust plague grades. According to Figure 3B, the grades of the locust plagues also rose in volatility and could be divided into four waves. It appeared that the first band of the locust plagues was from the 7th to 10th centuries, with slight numerical differences between centuries; the second band was from the 10th to 13th centuries, with a peak in the 11th century; with a peak in the 14th century, the third band was from the 13th to 15th centuries; and the fourth band was from the 15th to 20th centuries, with high grades of the locust plagues in the 16th, 17th, 18th centuries. In the 11th century, the climate changed from warm to cold, and the locust plague outbreak was concentrated. China entered into the “Little Ice Age” in the 16th century, forming the famous Ming Jiajing great locust plagues. Moreover, during the “Little Ice Age” and social unrest in the 17th century, the Ming Chongzhen, Qing Shunzhi, and Qing Kangxi were the most severe period of locust plagues. There were also Qing Qianlong great locust plagues in the 18th century, but feudal rule was at its peak, and national coordination and control were high (Zhan, 2007), so high-grade locust plagues were rare, and their impacts were less severe. Still, the introduction of advanced Western science and technology curbed the harmful effects of locust plagues (Zhao, 2015), and the grades of the locust plagues were low in the Republic of China.

As a whole, the frequency and grades of locust plagues rose in volatility, and their impact increased significantly from the Ming Dynasty to the Republic of China, and the 17th century was the peak.

3.1.3 Grade patterns of locust plagues

Dynastic patterns of locust plague grades. As shown in Table 3, 16 years of the locust plagues occurred during the Tang Dynasty, with grades II and IV of the locust plagues predominating and grades I and III occurring less often. Moreover, there were 36 locust plague years during the Southern and Northern Song Dynasties, with grades I and II predominating, grades IV lesser occurring, and grades III rarely occurring. The Yuan Dynasty experienced 27 years of locust plagues, with grades I and II dominating, followed by grades IV. Furthermore, there were 57 locust plague years during the Ming Dynasty, with grade IV being the highest, and grades I, III, and II also occurring more frequently, with minor numerical differences between grades. During the Qing Dynasty, 60 years of locust plagues occurred, half of which were grade I, and grades III and II frequently occurred, while grade IV was the least. A total of 18 years of the locust plagues were recorded in the Republic of China, predominating grades III and II and fewer of grades I and IV.

TABLE 3 Dynastic patterns of locust plague grades in Cangzhou from 618 to 1949.

Dynasty	Tang	Northern and South Song	Yuan	Ming	Qing	Republic	Total
Dynastic years/a	342	319	89	276	267	38	1,331
locusts years/a	16	36	27	57	60	18	214
Grade I/a	2	13	11	14	26	2	68
Grade II/a	5	13	9	12	13	7	59
Grade II/a	4	3	2	13	16	8	46
Class IV/a	5	7	5	18	5	1	41

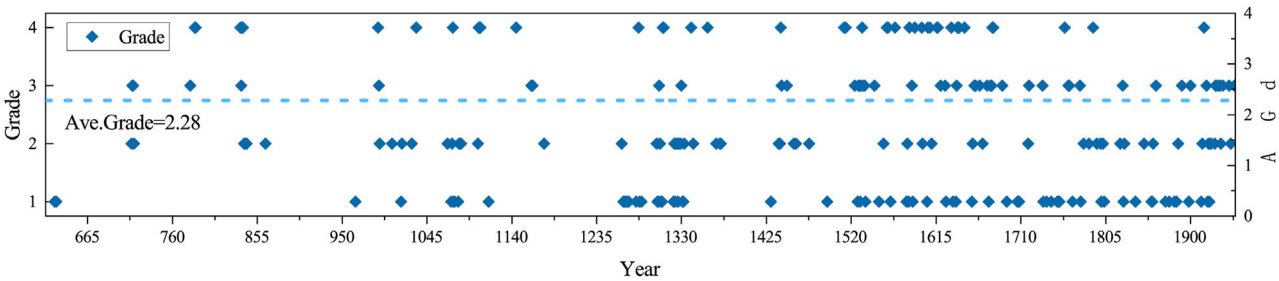

FIGURE 4
Distribution of locust plague grades in Cangzhou from 618 to 1949.

Temporal distribution of locust plague grades. The average grade of the locust plagues was 2.28, between slight and moderate, with fewer negative effects. Most slight and moderate locust plagues were found in all dynasties, while severe and catastrophic ones were concentrated from the Ming Dynasty to the Republic of China, accounting for 80.4% and 58.5%, respectively (Figure 4). Furthermore, severe and catastrophic locust plagues revealed the characteristics of continuous occurrence from the Ming Dynasty to the Republic of China, such as 1531–1532, 1616–1617, 1639–1640, 1658–1659, 1676–1677, 1678–1679, 1763–1764 and 1928–1929, which corresponded to the great locust plague periods such as the Ming Jiajing, Ming Wanli, Ming Chongzhen, Qing Shunzhi, Qing Kangxi and Qing Qianlong periods.

Generally, locust plagues fluctuated upward, and their impacts were widespread and severe. The impact of locust plagues gradually transformed from emergent and disturbance grades to hazard and disaster grades and increased significantly from the Ming Dynasty to the Republic of China.

3.1.4 10a frequency and 1a counties patterns of locust plagues

Decadal frequency and anomaly of the locust plagues. Based on the above macroscopic analysis, the 10a frequency and 1a number of counties were used to explore the microscopic temporal dynamics of locust plagues in Cangzhou from the perspectives of frequency and scale. Figure 5A showed that the frequency ranged from 0 to 8 years with an average of 2.89 years, with a fluctuating upward trend and gradual decreases in the numerical differences, and locust plagues occurred regularly. It was possible to divide the anomaly of the locust plagues into three phases. Phase 1 (618–1068): the mean anomaly of the locust plagues was -0.89, with only 8 years of positive frequency (15.7%), much lower than the proportion of positive frequency overall (37.6%), with a low frequency. Phase 2 (1077–1510): it was noted that the mean anomaly was -0.13, with 15 years of the positive frequency (30.6%), an increase from the positive frequency in phase 1, but still below the overall positive average. Phase 3 (1519–1949): the mean anomaly was 1.01, with 33 years of positive frequency (67.4%), and the anomaly was much greater than in phases 1 and 2, with the locust plagues occurring more frequently (Figure 5B).

The number of counties of the locust plagues. Figure 5C showed that 916 counties occurred the locust plagues, with an average of 0.69 counties/a. The scale and impact of the locust plagues fluctuated and expanded, but the magnitude of change was moderate. Locust plagues occurred at seven peak times in the Tang Kaiyuan (714–716), Song Shenzong (1080–1083), Yuan Dade (1303–1310), Ming Jiajing

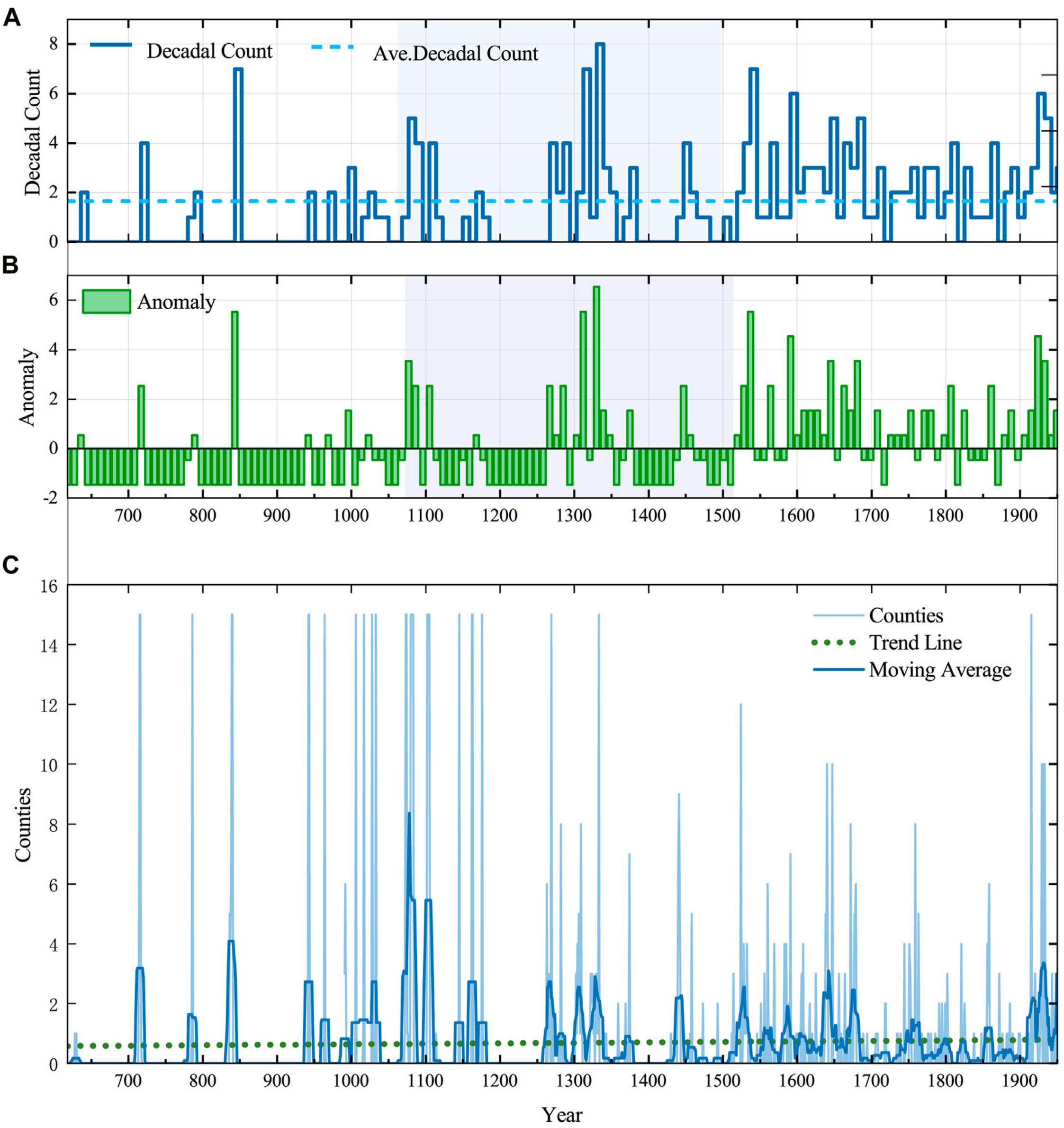

FIGURE 5
Decadal frequency, anomaly and number of counties of the locust plagues in Cangzhou from 618 to 1949. **(A)** The decadal frequency of the locust plagues. **(B)** The anomaly of the locust plagues. **(C)** Number of counties of the locust plagues.

(1524–1533), Qing Kangxi (1676–1679), Qing Xianfeng (1856–1858) and the Republic of China (1927–1934) of 34, 60, 25, 28, 18, 12 and 35 counties respectively, with an average of 5 counties/a, including 24a greater than 5 counties. On centennial scale, the locust plagues of the 10th, 11th, and 17th centuries were the heaviest, at 155, 121, and 94 counties, respectively, followed by the 14th and 16th centuries at 78 and 75 counties, respectively, and the lightest in the 7th century (2 counties), as they were influenced by the macro and micro descriptions of the spatial location, especially the relatively sketchy records of the Tang, Song and Yuan Dynasties, which made it difficult to pinpoint it to the county level, with the 10th and 11th century figures being high.

Briefly, the frequency of the locust plagues fluctuated and rose, and the scales and impacts of the locust plagues gradually expanded, with the gap in the frequency decreasing after the 16th century, and the high value occurring frequently, the 17th century being the period of the highest.

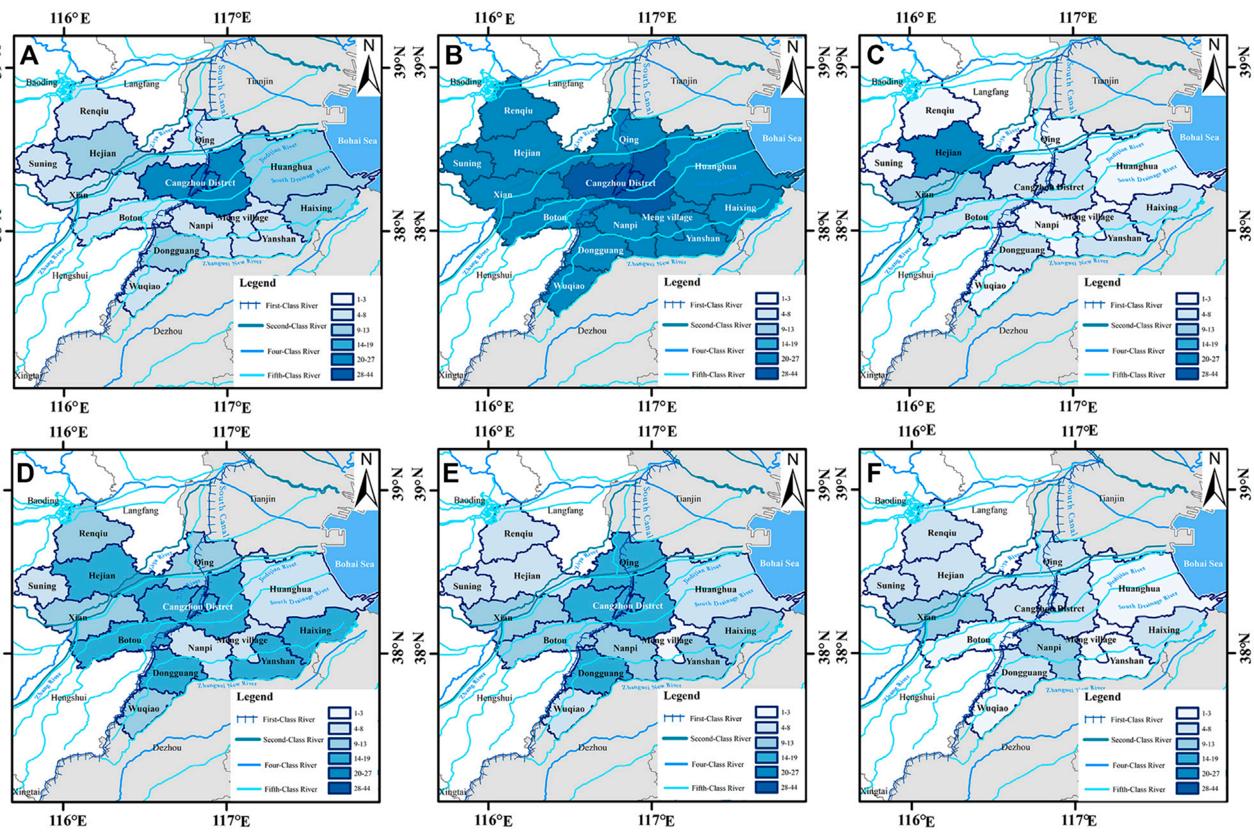

FIGURE 6
Distribution of the locust plagues in Cangzhou from the Tang Dynasty to the Republic of China. **(A)** Distribution of the locust plagues in the Tang Dynasty. **(B)** Distribution of the locust plagues in the Northern and Southern Song Dynasties. **(C)** Distribution of the locust plagues in the Yuan Dynasty. **(D)** Distribution of the locust plagues in the Ming Dynasty. **(E)** Distribution of the locust plagues in the Qing Dynasty. **(F)** Distribution of the locust plagues in the Republic of China.

3.2 Spatial patterns and evolution of locust plagues

Based on the temporal series of the locust plagues, this part first studied the spatial distribution and dynamic evolution of historical locust plagues, natural disasters and water environment vicissitude data were overlaid to explore the spatio-temporal patterns of the locust breeding areas.

3.2.1 Spatial evolution of locust plagues

Cangzhou was rich in water resources and was crossed by rivers of different levels, such as the South Canal, Ziya River and Zhang River ect., forming complex water environment patterns. From Figure 6A, 16 years of locust plagues occurred in Cangzhou during the Tang Dynasty, concentrated in the middle, east, and west, especially flowing through the South Canal, Ziya River, Zhang River, and Xuanhui River. Moreover, total of 36 years of locust plagues occurred in the Northern and Southern Song Dynasties, with severe locust plagues across the territory, with Cangzhou District still the most affected area (28–44 counties) and the rest of the frequency ranging from 20 to 27 (Figure 6B). During the Yuan Dynasty, there were 28 years of locust plagues, centered in the eastern plains such as Hejian (20–27 counties) and Xian (9–13 counties). Besides, Hejian, Botou, Dongguang, Haixing, and Yanshan which flow along the South Canal and Xuanhui River, where the number of counties was 4-8, while fewer locust plagues occurred in the northeast, northwest and south (Figure 6C). During the Ming Dynasty, 57 years of locust plagues occurred, mainly near the South Canal, the Zhang River, Xuanhui River, and Ziya River, with Cangzhou District, Hejian, and Haixing being the most affected areas (14–19 counties), Renqiu, Qing, Xian, and Wuqiao following (9–13 counties), and the rest of the counties being less affected (Figure 6D). Furthermore, there were 60 years of locust plagues in the Qing Dynasty, with Qing, Cangzhou District, and Dongguang, through which the South Canal flowed, being the areas where the locust plagues occurred

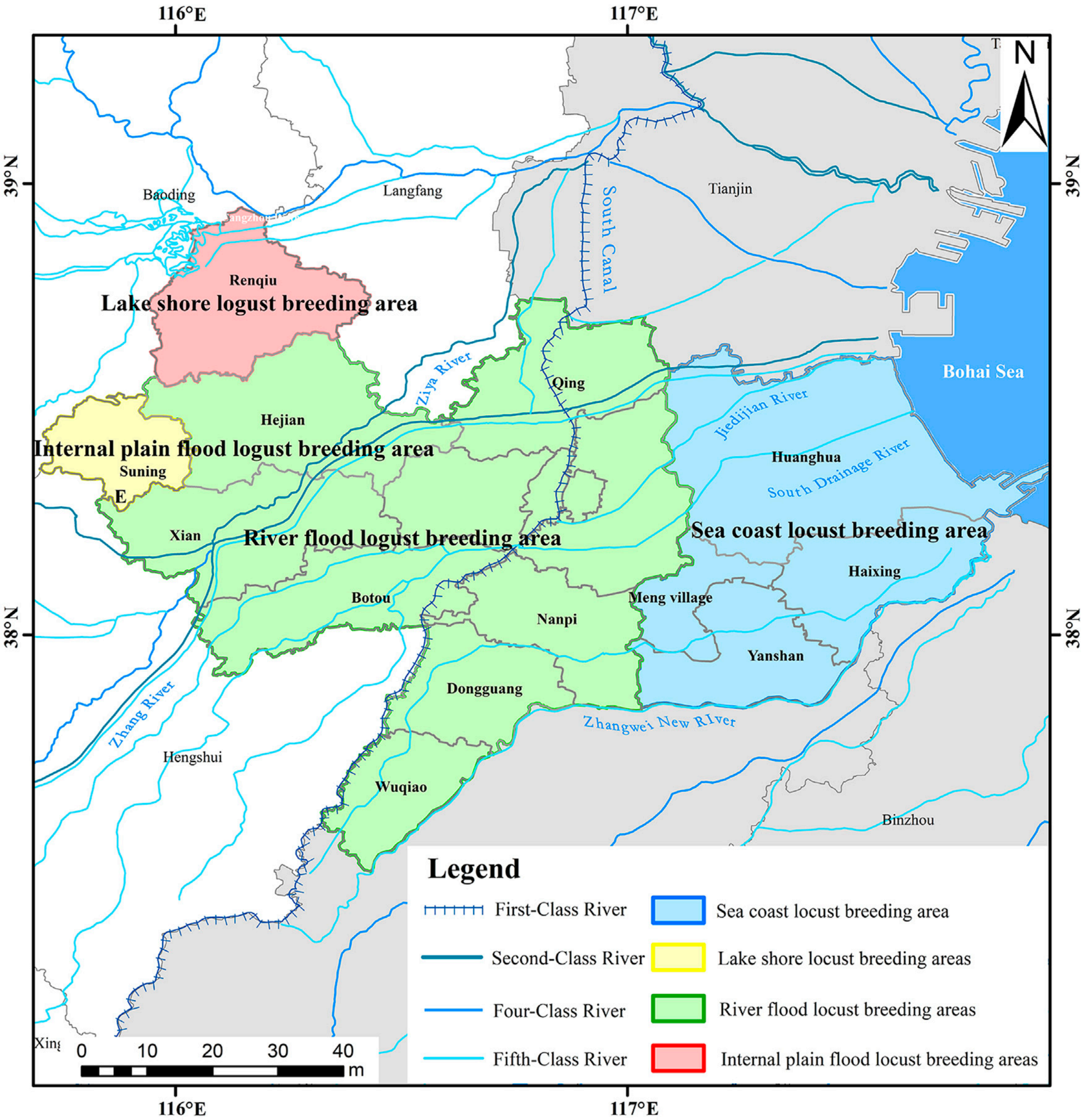

FIGURE 7
Classification of the locust breeding areas in Cangzhou from 618 to 1949.

severely (14–19 counties), followed by Xian, Boto, Nanpi, Yanshan and Haixing in center where occurred more frequently (9–13 counties), and less frequently in the parts of the northeast, northwest and south where the river network was less dense, such as Suining and Renqiu (Figure 6E). In 18 years of the locust plagues in the Republic of China, Xian and Nanpi were locust plagues-prone areas (9–13 counties), while some locust plagues occurred in the northeast, central, northern and western regions (4-8 counties), and to a lesser occurrence in the east, such as Huanghua, Meng Village and Yanshan (Figure 6F).

Therefore, the locust plagues were widely distributed throughout Cangzhou from the Tang Dynasty to the Republic of China, concentrated in the main watersheds of the South Canal, Ziya River, Xuanhui River, and Zhang River, with a high incidence in areas with dense river and lake systems, and influenced by the spatial pattern of the water environment, with significant hydrophilia.

3.2.2 Spatial evolution patterns of locust breeding areas

A division of the historical locust breeding areas. It was evident from the above analysis and historical records that the locust plagues were closely linked to water patterns. Historical locust breeding areas could be divided into four categories. Huanghua, Haixing, Yanshan, and Meng Village were located in the coastal alluvial of the Bohai Sea in the east and were strongly influenced by sea tides and sea overflows, forming "locust-sea" response mechanisms and designating them as "sea coast locust breeding areas", for example, sea tides flooded Yanshan in 1914, and it suffered a severe locust plague accordingly in 1915. In the plains formed by the alluvial flow of rivers in the center, containing Qing, Cangzhou District, Nanpi, Dongguang, Wuqiao, Botou, Xian, and Hejian, "locust-river" response patterns were observed, with river floods providing extensive habitats for the locust plagues, which were divided as "river flood locust breeding areas", for instance, river floods occurred in Hebei in 715, resulting in a high grade of the locust plagues within central Cangzhou in the same year. The large wetland Baiyangdian in Renqiu in the northwest had established a "locust-lake" response system, dividing the areas into typical "lake shore locust breeding areas", for example, there was a storm in Baiyangdian wetland in 1523, providing suitable humidity for locust eggs growth, which matured in the summer of 1524. In the southwest, there were no significant rivers or lakes in Suning, which was located in a low-lying inland, classifying it as "internal plain flood locust breeding areas", such as the 993, 1738, 1797, 1809, and 1879 all had records of inundation in Suning, corresponding to massive locust plagues in similar years, as shown in Figure 7.

Spatial evolution patterns of the locust breeding areas. Following the above research on locust breeding areas, this section explored the spatial evolution of historical river flood locust breeding areas to seek the spatial dynamics of other types of locust breeding areas. The frequent locust plagues were accompanied by severe river flooding and vice versa, and the spatial distribution of the two was similar over time. During the Tang Dynasty, both river floods and locust plagues were highly prevalent in Cangzhou District, with the number of counties of locust plagues ranging from 20 to 27 counties, corresponding to river floods ranging from 28 to 46 counties, with secondary occurrences in Dongguang, where the locust plagues ranged from 9 to 13 counties and river floods from 14 to 27 counties, with relatively few occurrences in the remaining areas (Figure 8A). During the Song Dynasties, Cangzhou District was also a major disaster area, with locust plagues occurring between 28 and 44 counties and river floods between 70 and 110 counties (Figure 8B). In the Yuan Dynasty, the locust plagues and river floods were concentrated in Hejian and Xian, with the number of counties of the locust plagues ranging from 20 to 27 and 9 to 13, respectively, corresponding to river floods ranging from 0 to 13 and 14 to 27, with fewer occurrences in the rest of the region (Figure 8C). During the Ming Dynasty, the locust plagues were mainly concentrated in Hejian, Cangzhou District, and Yanshan, with the number of counties of the locust plagues ranging from 14 to 19, corresponding to river floods 47 to 69 and 14 to 27 respectively, with Hejian being the most severe, indicating close correlation between the locust plagues and river floods (Figure 8D). Locust plagues and river floods occurred most severely in Qing and Cangzhou District, corresponding to 14–19 and 111–143 counties, respectively, and their impact on the Qing Dynasty reached the highest (Figure 8E). Moreover, the variability of the two decreased across counties in the Republic of China, and remained consistent in their changes (Figure 8F).

Thus, Cangzhou was divided into four main types: the eastern sea coast locust breeding areas, with Huanghua, Haixing, Yanshan, and Meng Village as the core; the central river flood locust breeding areas, with Qing, Cangzhou District, Nanpi, Dongguang, Wuqiao, Botou, Xian and Hejian as the base; the northwestern lake shore locust breeding areas, with Baiyangdian wetlands in Renqiu as the centre; and the internal plain flood locust breeding areas with low-lying terrain in Suning as the primary. The locust plagues were widespread throughout Cangzhou, with high outbreaks in the center and the most severe occurrence and impact of the locust plagues in the Qing Dynasty.

3.3 Climatic environment and social impact of locust plagues

Locust plagues were widely embedded in geospatial units such as locust breeding areas composed of complicated water environments. The locust plagues were biological disasters, with climate directly influencing their formation and spread. Therefore, the study attempted to investigate the influence of climate on the locust plagues in conjunction with the spatio-temporal evolution of the locust breeding areas by overlaying the series of the historical locust plagues counties with reconstruction series of the historical temperature and precipitation, and by comparing historical river flooding influenced by climate and locust plague events to clarify the relationship between the climate and the locust plagues and locust breeding areas.

3.3.1 Climatic environment of locust plagues

Locust plagues and temperature. The relationship between the locust plagues and temperature in China. Using a series of temperature changes in China 2000 years ago with a temporal resolution of 10a, Yang et al. (2002) reconstructed from historical climate records. Figure 9A showed that there were five distinct peak periods in the number of counties of the locust plagues, including a sub-peak from the 820s to 940s; during the 1950s–1280s, when temperatures were significantly warmer, the number of counties peaked; from the 1370s to 1480s, the number of counties reached a sub-peak again; and there was an increase in the number of counties, being sub-waves during the cold period of the 1540s–1780s; As temperatures rebounded, the

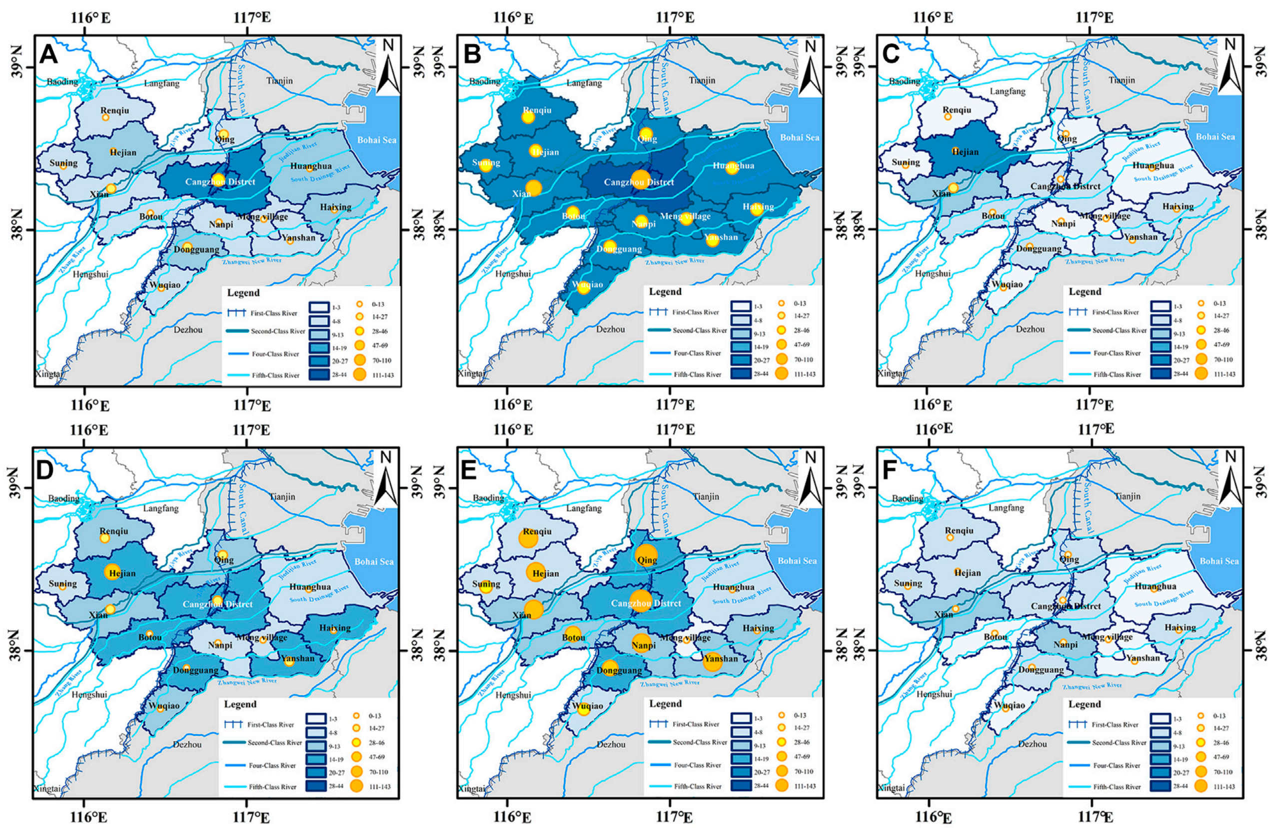

FIGURE 8
Distribution of the locust plagues and river floods in Cangzhou from the Tang Dynasty to the Republic of China. **(A)** Distribution of the locust plague and river floods in the Tang Dynasty. **(B)** Distribution of the locust plagues and river floods in the Northern and Southern Song Dynasties. **(C)** Distribution of the locust plagues and river floods in the Yuan Dynasty. **(D)** Distribution of the locust plagues and river floods in the Ming Dynasty. **(E)** Distribution of the locust plagues and river floods in the Qing Dynasty. **(F)** Distribution of the locust plagues and river floods in the Republic of China.

number of counties reached another small peak during the 1810s–2050s.

The relationship between the winter temperature and locust plagues. Ge et al., (2003) reconstructed a temperature series for the winter (October to March) in eastern China using the historical document, with 30a as the time scale. Figure 9B showed that this could be divided into five peaks periods: There was a small peak in the number of the counties of the locust plagues during the cold and warm transition period from the 830s to the 950s; and it was a warmer period between the 1040s and 1280s during the peak; during the 1370s–1490s, the number of counties of the locust plagues again reached a sub-peak and temperatures gradually turned colder; There was a cold period during the 1550s–1790s, accompanied by a concentration of locust plagues with reduced interannual variation; As temperatures dropped, the number of counties of the locust plagues increased between the 1850s and the 1930s.

Locust plagues and precipitation. There were 93 years when the locust plagues occurred at the same time as floods, accounting for 43.5% of the locust plague years and 20.7% of the number of flood years. The locust plagues occurred in the same year as the drought in 100 years, accounting for 46.7% of locust plague years and 35.7% of the drought years. The locust years and the flood years had an apparent mismatch, with locust plagues mostly occurring after floods or during non-flood periods (Figure 10A), while the locust plagues and droughts had robust synchronization (Figure 10B), because this was based on the biological features of the locusts, which were that excessive precipitation have a mechanical killing effect on locusts and that rainy and humid environments breed pathogens that increases locust egg mortality. Precipitation also promotes the formation of the habitat of the locust plagues such as floodplains. When drought provides sufficient light and heat, the survival rate of locusts increases significantly. Based on the water

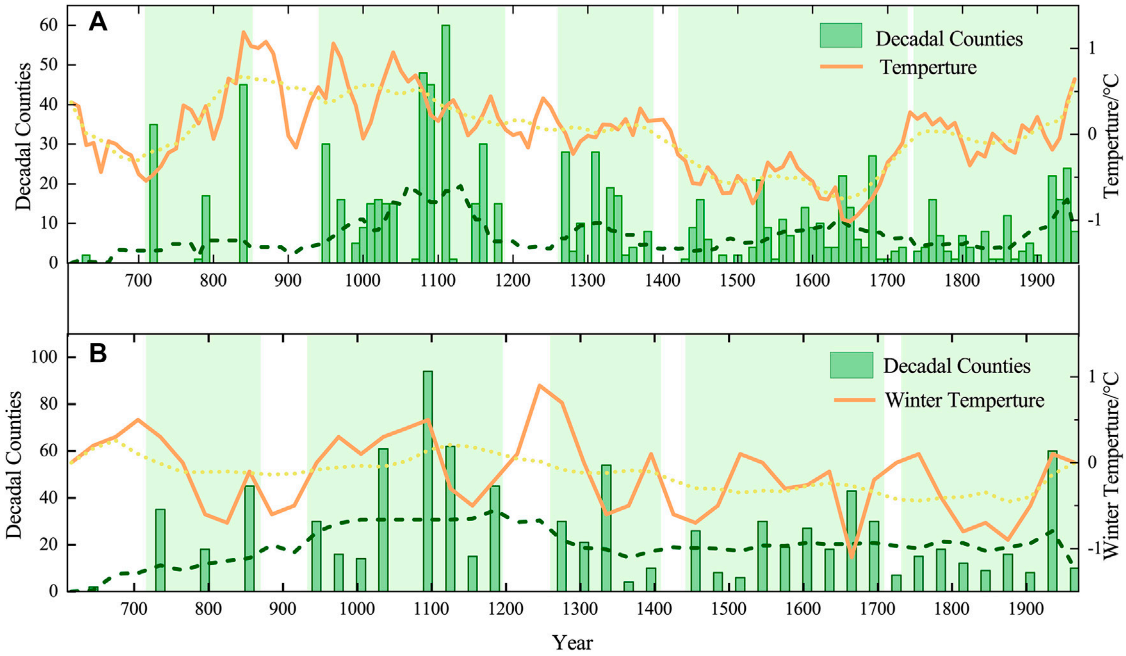

FIGURE 9
Comparison of the locust plagues and temperature in China from 618 to 1949. **(A)** Comparison of the locust plagues and temperature in China. **(B)** Comparison of the locust plagues and winter temperature in Eastern China from 618 to 1949.

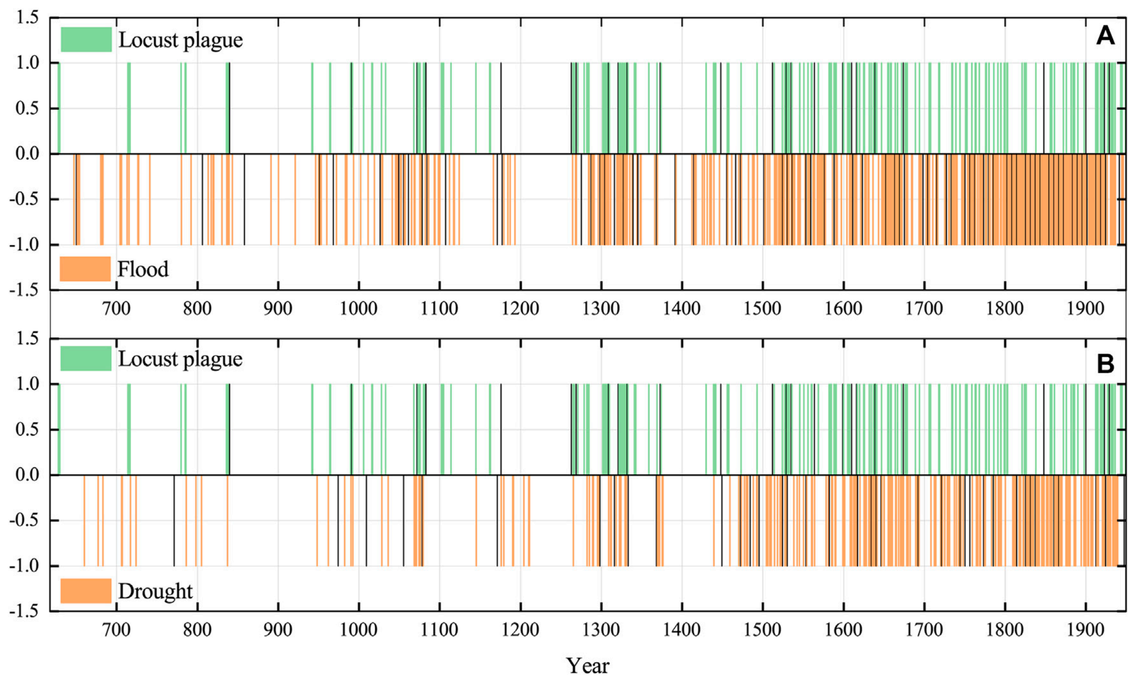

FIGURE 10
Comparison of the locust plague years with flood and drought years in Cangzhou from 618 to 1949 (+1: locust plague year; −1: river flood year and drought year). **(A)** Comparison of the locust plague years with flood years. **(B)** Comparison of the locust plague years with drought years.

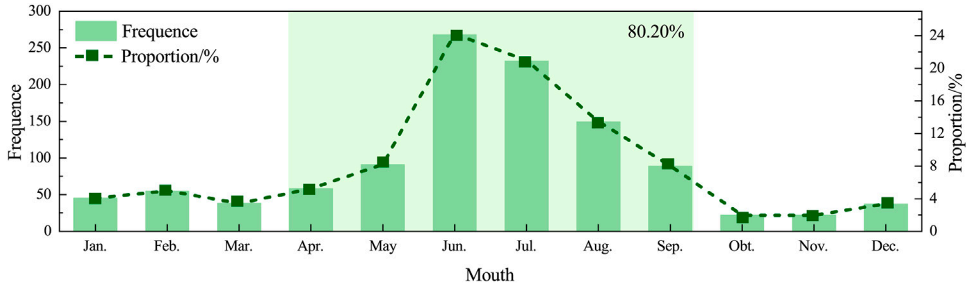

FIGURE 11
Month distribution of the river floods in Cangzhou from 618 to 1949.

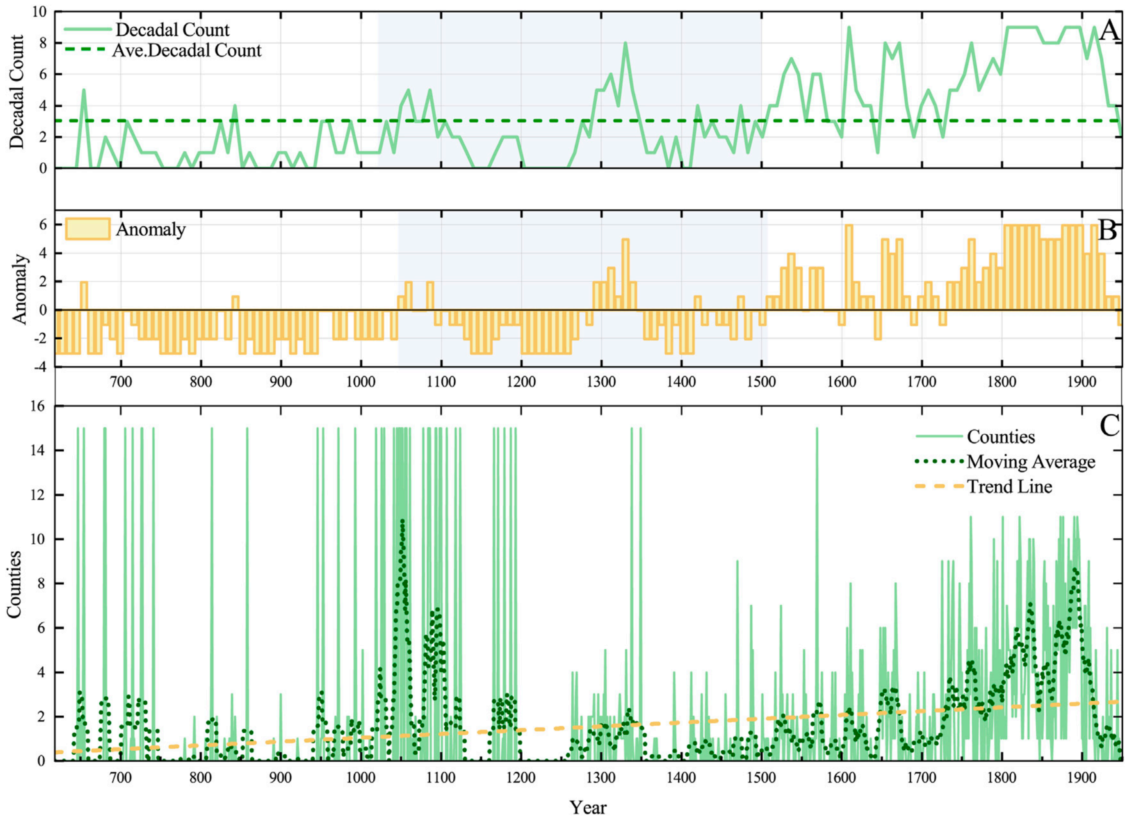

FIGURE 12
Decadal frequency, decadal anomaly and number of counties of the river floods in Cangzhou from 618 to 1949. **(A)** Decadal frequency of the river floods. **(B)** Decadal anomaly of the river floods. **(C)** Number of counties of the river floods.

environment, generated the biogeocoenosis of locust breeding areas, and forming a "climate—water—locust—people" chain.

Hence, there was no significant correlation between the spatio-temporal evolution of the locust plagues and temperature, and the precipitation affected their formation.

Locust plagues and river floods. The locusts in East Asia often select soils with a moisture content of 8–22%, locust eggs being suitable for development in a suitable moist environment (Li, 2014). The statistics for the month of the river floods in Cangzhou (Figure 11) showed that river floods occurred less frequently in May and before, providing suitable moisture environment for summer locust development and reducing the mechanical killing effect of excess moisture on locust growth, corresponding to a peak of locust plagues in June. River floods

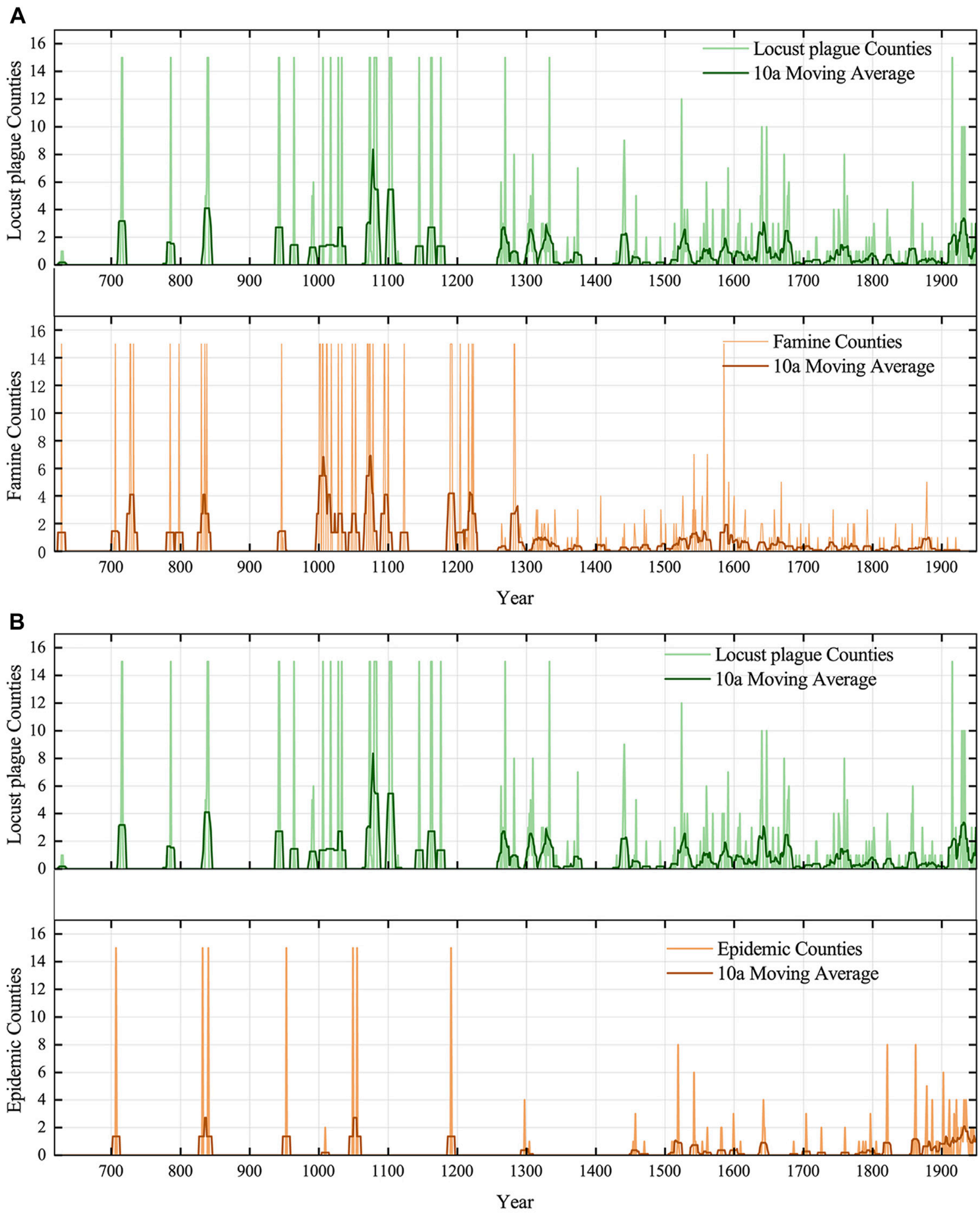

FIGURE 13
Comparison of counties of famine, epidemic and locust plagues in Cangzhou from 618 to 1949. **(A)** Comparison of Number of counties of famine and locust plagues. **(B)** Comparison of Number of counties of epidemic and locust plagues.

peaked in June and July, when the locust breeding areas contained significantly more moisture, inhibiting the occurrence and development of the autumn locusts.

Figure 12 showed that the frequency range was 0-10a/10a with an average value of 6.05a/10a. Combined with the 10a frequency of the locust plagues, both frequencies displayed a

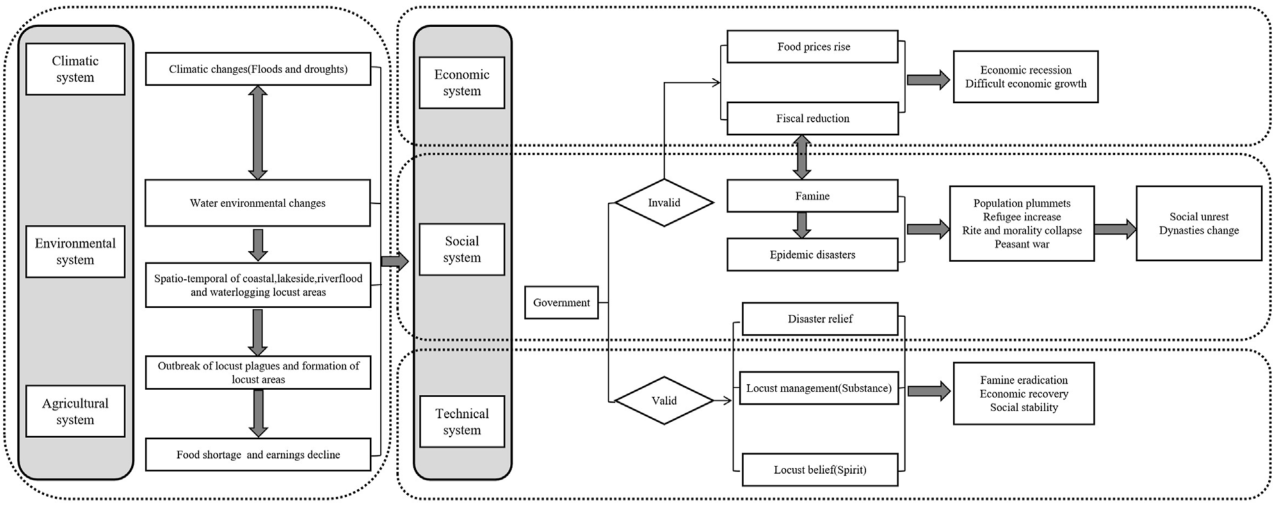

FIGURE 14
Environmental and social impact dynamics of the locust breeding area in Cangzhou from 618 to 1949.

fluctuating upward trend and a significant positive correlation (Sig:0.00<0.05: correlation coefficient: 0.552>0). The changes in anomaly between river floods and locust plagues could be divided into the same 3 stages (Figure 12A). Stage 1 (618–1068): the mean anomaly of river floods was −1.81, with only 4 years with positive anomalies (7.8%) much lower than the mean positive (37.6%), and the anomalies of the locust plagues and river floods were low. Stage 2 (1077–1510): the mean anomaly of the river flood was -0.99, with 10 positive anomalies (20.4%), with significant increase in the anomalies of the locust plagues and river floods, but both were still below the average of positive anomalies. Stage 3 (1,519–1949): the mean anomaly of the river floods was 2.87, with 41 positive years (83.7%), the anomalies between the locust plagues and river floods were much greater than Stage 1 and Stage 2, and both occurred more frequently (Figure 12B).

The number of counties of river floods in Cangzhou was 2038, with an average of 1.53 counties/a (Figure 12C). Combined with the number of counties of the locust plagues, there was a strong correlation between the locust plagues and the river floods. The scales of locust plagues and river floods were consistent, with a fluctuating upward trend, but the change in the locust plagues was moderate, while the upward trend in river floods was significant. Cangzhou experienced river floods during the peak of the locust plagues during the 714–716, 1080–1083, 1303–1310, 1524–1533, 1676–1679, 1856–1858, and 1927–1934, which occurred river floods in 15, 2, 14, 20, 3, 9 and 10 counties respectively, and a certain number of counties had river floods about 3 years before the peak of the locust plagues.

Accordingly, the locust plagues and river floods were significantly positively correlated, with a fluctuating upward trend, with locust plagues being most prevalent in summer, followed by autumn, and rarely in winter and spring, with the 17th century being an extensive distribution period for river floods locust breeding areas.

3.3.2 Social impact and response of/to locust plagues

Social impact of the locust plagues. Locust plagues and famine. Figure 13A showed that the locust plagues and famines occurred in 54 years, accounting for 32.3% of famine years and 26.6% of locust plague years, with nearly one-third of the years when locust plagues occurred experiencing food shortages and famine in Cangzhou. Locusts like to feed on plants and crops, proliferated, and have a solid migration ability (Li, 2008). 99.1% of the locust plagues occurred from March to September (spring, summer, and autumn), the main time the cereal was sown, grown, matured, and harvested, directly affecting agricultural harvests. The great locust plagues were found in Cangzhou in 714–716, 1080–1083, 1303–1310, 1524–1533, and 1676–1679, which seriously threatened the stability market of provisioning and made the people unable to afford the high prices of the grain, resulting in massive famines. However, some occurrences of the locust plagues and famines were not synchronized, which may due to the government or social organizations took timely and effective measures to reduce agricultural taxes and provide relief. The social system was resilient and effective in containing and mitigating the famine after the disasters.

Locust plagues and epidemics. Figure 13B showed that the locust plagues, and epidemics occurred simultaneously for 28 years, accounting for 32.2% of the epidemic years, with epidemics in 1599–1600, 1640–1641, 1918–1921, 1927–1929, and 1933–1934 corresponding with the locust plagues. A comparative analysis of epidemics and famines showed that they occurred around the same time for 18 years, with correspondence in 1191, 1513, 1518, 1542–1544, 1599–1600, 1640–1641, 1877–1878, and 1920. The locust plagues, famines and epidemics occurred at the same time for only 6 years, which were adjacent and misaligned in the periods of 838–840, 1560–1561, 1640–1642, and 1920–1921, with the locust plagues and directly influencing famine and mediately inducing epidemics. For example, the massive locust plague that struck Hebei in 840 (Tang Kaicheng) severely damaged agricultural production, resulting in severe famine, the failure to meet the people's basic needs, and the outbreak of an epidemic, and hardship for the people (Shen and Rong, 2011). Furthermore, there were high densities of locusts in Hejian and Wuqiao in 1641 (Ming Chongzhen), blotting out the sky with their flights, inducing the halt of agricultural production, causing severe famine, disrupting human social rituals, and leading to uncivilized social behavior in cannibalism (Ni, 1960; Wu, 1992). Thus, when the locust plagues broke out, the feudal peasant economy went bankrupt, resulting in massive famines, a lack of food supply for human, and a rapid decline in immunity, coupled with the death of a large number of people and the failure of medical and sanitary technology to dispose of dead bodies scientifically and harmlessly, accelerating the spread of epidemic viruses. Therefore, the epidemics were delayed to a certain extent by the locust plagues, and the natural disasters transmitted negative effects to the social system, forming a development chain of "locust plagues-famines-epidemics". If the government and social organizations contained the famine in time, the probability of the epidemic would be greatly reduced, so the year of the epidemics would be less than that of the famines and locust plagues.

Social response to the locust plagues. Ideological responses to the locust plagues. The Chinese people have used their wisdom to consider and explore methods of dealing with locust plagues in two main aspects: ideology and technology, providing the experience for modern natural disaster management. In ancient China, the core concept of "correspondence between nature and human, the divine right of kings" guided the political and economic development of the country and the lives of its people. In the face of the threat of the locust plagues, in feudal society, which was relatively hysteresis in science and technology, the ruling class and the people alike used rituals and virtues to regulate the administrations of government and change the behaviors of people in order to stabilize social order and maintain feudal governance. The most typical of these was the Temple of Bala and Temple of General Liumeng, where the gods were worshipped to eliminate the locust plagues, which originated in the Pre-Qin periods and Northern Song Dynasty, respectively. Since the Song Dynasty, the scientific cognition and implements of the locust plagues increased, and the belief in locust plagues transformed from respecting the gods only to scientifically preventing and controlling locust plagues. In Cangzhou, there have been 13 counties that had built Temples for General Liumeng, and one county had been built for the Temple of Bala. During the Ming Hongwu period, General Huicheng was credited with capturing locusts at the end of the Yuan Dynasty, and he was made General Liumeng by the emperor (Wan, 1999). During the frequent locust plagues in Cangzhou in 1718 (Qing Kangxi), Weijun Li prayed to General Liumeng and received divine inspiration, so he submitted a petition for the establishment of temples to General Liumeng in all cities and counties of Cangzhou to be worshipped regularly in spring and autumn each year (Wan, 1999). Thus, the Temple of General Liumeng served as an ideological response to the locust plagues in Cangzhou. For example, the locust plagues occurred in Hebei province, and the government ordered relevant departments to deal with the locust plagues through sacrifices. When the government sacrifices were completed, there was no grain in the fields in 1103. In 1719, severe locust plagues occurred in Cangzhou District and Qing, and the Prefecture Li prayed at the Temple of General Liumeng. Through regular sacrificial activities to pray for the disappearance of the locust plagues, promote the implementation of benevolent rules and regularize the people's behaviors, and reduce the damage to the natural-human system. However, to a certain extent, it hindered the country and the people from taking positive and practical actions to deal with the locust plagues and control the negative effects.

Technical responses to the locust plagues. As ancient China became more scientific in cognition of natural disasters and their prevention, the government and people of various periods created many effective control methods of the locust plagues. Locusts were prevented and treated in various ways in Cangzhou, including manual hunting of locusts, burying locusts in trenches, burning locusts, purchasing locusts, and treating locusts with medicine and natural enemies to reduce the agricultural damage caused by them. For instance, the document recorded the occurrence of the locust plagues in Hebei in 943 and 1752, which was controlled by manual hunting and burying locusts in trenches. When the locust plagues occurred in Hebei in 715, people used fire to burn the locusts at night. Renqiu experienced the locust plagues in 1802, and the government used warehoused grain or coins to exchange and buy locusts, mobilizing the people's enthusiasm and enhancing the effect of the locust plague controls. There were locust plagues in Botou and Hejian in 1715, by taking advantage of birds' insect-eating nature and obeying nature's laws to eradicate the locusts. While keeping and improving manual trapping, natural enemy control, and chemical locust control techniques, modern locust control techniques have gradually dispensed with time-consuming methods such as digging ditches and burying locusts. Moreover, the regions (Cangzhou and neighboring areas, such as Langfang and Tangshan) worked collaboratively to control the locust plagues, incorporating the characteristics of China's development and implementing coordinated approaches to control the locust plagues. Through the historical experience of locust plague control, the modern agricultural management system was developed and improved, which took into account the historical experience of the locust plague control. In addition, during the Tongzhi period of the Qing Dynasty, Chen pointed out that locusts mostly occurred in drought years, but that locusts were born in suitable water environment and that flood followed by drought would result in locust plagues (Chen, 1874), clarifying the hydrophilia of the locust plagues and the importance of transforming locust breeding areas, guiding modern society to control locust plagues at the root by transforming the water environments (controlling water levels in rivers and lakes, establishing irrigation and drainage systems, and planting trees, etc.) to reduce the suitable habitat for locust growth and development.

Nation and people's responses to the locust plagues. The responses to the locust plagues have been centered on the central government, the local government, and the grassroots, with diversified social responses from top to bottom. The central government was responsible for providing guidance, worshipping the gods, reducing taxes and exemptions, providing relief, institutional guarantee, and legal defense, while the local government implemented strategies based on central guidance, and most people passively accepted strategies, but a small number actively responded. The central government enacted laws and regulations to ensure that the locusts were dealt by the situation and the extent of their impact and to guide local authorities in the implementation of prevention and control of the locust plagues, ensuring the proper implementation of control measures and improve their effectiveness through supervision and evaluation. For example, in the Yuan Dynasty, the locust plagues in Renqiu were so severe that the government provided emergency relief in the form of coins and rice to meet the survival needs of the people directly; in the Qing dynasty, when the locust plagues occurred in Cangzhou District, Yanshan, and Haixing, the central government formulated hunting guidelines on thoughts and technologies of the locusts to implement local responsibilities for controlling locusts plagues; the Republic of China, following the needs for locust control in Hebei, issued 13 temporary regulations to monitor the implementation of managerial measures. At the end of the nation's reign, the political struggles, frequent wars, and profligate rulers led to the corruption of the disaster management system, making it difficult to implement control strategies of the locust plague effectively.

Based on the above analysis, it was clear that the historical disaster system and the human social system were two inseparable parts interlinked, influencing and responding to each other. Natural disasters were formed by the combined effects of the climate and human society, acting as a medium to transmit the harmful effects to the human social system, exacerbating social conflicts and promoting the vicissitude of dynasties (Figure 14). The subsistence peasant economy was the economic foundation of the social system in ancient. Climate change affected the spatio-temporal evolution of the locust breeding areas, increasing the availability of suitable habitats for locusts, and the large-scale occurrence of the locust plagues, directly affecting the agricultural system (food prices rise and fiscal reduction), thereby mediately influencing the economic system, social system, and technical system. Suppose the nation could intervene in the negative effects of the locust plagues by constructing disaster relief and managing systems and beliefs; In that case, the social impact could be gradually reduced, the economy could recover, and social stability could be maintained. If the state failed to control the locust plagues, the additional negative effects of famine and epidemics would have led to population plummets, an increase of refugees, collapse of the rite and morality, and frequent peasant wars, which would have brought about the dynasty extinction and the society renew.

4 Discussion and conclusion

4.1 Discussion

This study explored the spatio-temporal evolution of the locust breeding areas and the connection between locust breeding areas and climate from a microscopic perspective, taking into historical locust records and superimposing water environmental data on floods and droughts and analyzing the relationship between natural disaster systems and human social systems. It was found that the locust plagues were widespread in all types of suitable habitats (locust breeding areas), and that the spatial expansion of the locust breeding areas gradually transmitted negative effects to social systems. The historical locust plagues in the study area showed significant "hydrophilia", and most scholars had reached similar conclusions in their studies of basin disasters, especially the locust plagues at the basin scale. For example, Min (2004) pointed out that the north of the Yangtze River Basin during the Qing Dynasty was an essential source of the locust plagues in the Jiangnan; Chen (2005) believed that the occurrence of the locust plagues was closely related to the ecological environment caused by the large-scale water system vicissitudes and the overlapping floods and droughts caused by the long-term capture of Huai River by the Yellow River; Zhang (2008b) noted that the locust plagues in the Han and Tang Dynasties were concentrated in the Huai River Basin; Kong et al. (2016) concluded that tidal disasters influenced the occurrence of the locust plagues by affecting the patterns of water systems and hydrological vicissitudes, which corresponded well with the locust plague years.

Few researchers studied the historical spatio-temporal dynamics of the locust breeding areas, and most have studied them from the biological, agricultural, or insect perspectives. For instance, Shi et al. (2004) explored the relationship between locust breeding areas and the soil environment, pointing out that the high humidity and weak alkaline soil environments were suitable for the locusts breeding; Based on the survey data, Lv et al. (2008a, 2008b) analyzed the relationship between the occurrence of East Asian flying locusts and meteorology in the river flood locust breeding areas in Henan Province and developed a prediction model; Liu et al. (2006) used remote sensing to extract soil moisture in two periods and three major locust breeding areas in Huanghua, and found that soil moisture was significantly lower in years of major locust plagues than less occurrence; Wang et al. (2004) examined the current situation of locust breeding areas in Dongping County, and proposed management measures such as renovating flooded areas, establishing an emergency locust control system, protecting and using natural enemies, implementing pharmaceutical control and biological control; Based on historical data since 1949 and the results of seven locust breeding area surveys, Tian and Zhang (2005) studied the evolution of East Asian flying locust breeding areas in Wudi County and found that some of the sea coast locust breeding areas were gradually transformed into internal plain flood locust breeding areas, etc. Overall, scholars had less often studied the dynamics of locust breeding areas from the perspective of historical environmental change, and there was a lack of research on them before the 20th century. Thus, based on water environment patterns and historical records of disasters, this study identified four main types of locust breeding areas: sea coast, river flood, internal plain flood, and lake shore locust breeding areas, analyzing the temporal-spatial distribution of different locust breeding environments, and the formation of the locust plagues and the spatial grade structure of the locust breeding areas were both influenced by river and lake systems and their vicissitudes.

However, when it came to the spatio-temporal evolution of the locust breeding areas, this study only studied from the perspective of natural disasters but didn't analyze it based on the spatio-temporal dynamics of various water systems and didn't explore the internal relationships and response mechanisms of "locust-water" in depth. Meanwhile, historical records have the characteristic of "stress the present rather than the past", with historical records becoming more complete and detailed as time went on, while records of the locust plagues at the county level were missing from the Tang to Song Dynasties, while the most historical records from the Yuan Dynasty to the Republican of China were accurate to the county level. In the future, we will further establish complete databases of the locust plagues in Cangzhou, collect data on other related disasters, climate, hydrology, and social responses, and enhance the analysis of great locust plagues and hydrological events, refining the temporal series of historical locust disasters in Cangzhou. The study will gradually draw the spatial evolution atlas of the patterns of "locust-river", "locust-sea" and "locust-lake", and build environmental/hazard response models for the formation and evolution of the locust breeding areas by simulating their dynamics. Based on the global climatic variability and historical disaster research results, the study will fully be integrated with contemporary risk disaster issues, predicting and assessing the risk of modern natural hazards, providing realistic implications for contemporary society to coordinate natural ecological and human social systems and maintain international social security and stability.

5 Conclusion

Based on the historical records of the locust plagues and locust breeding areas, we analyzed their spatio-temporal evolution, taking the river flood locust breeding areas as typical, and explored the relationship between locust plagues and climate and social system. The basic conclusions were described below:

1) In the temporal dynamics of the locust plagues, the locust plagues were mainly distributed in the hot and humid May and June, with the summer locust generation being the main one. The frequency and grades of the locust plagues fluctuated and rose, and the 17th century was the period of the highest locust plagues. The impact of locust plagues gradually changed from emergent and disturbance grades to hazard and disaster grades and increased significantly from the Ming Dynasty to the Republic of China.
2) In the spatial patterns of the locust plagues, locust plagues were widely distributed throughout Cangzhou, mainly concentrated in the main watersheds of the South Canal, Ziya River, Xuanhui River, and Zhang River, with a high incidence of areas with dense rivers and lakes. They were influenced by the spatial patterns of the water environment, with significant "water linkage". Meanwhile, locust breeding area in Cangzhou was divided into four main types: the eastern sea coast locust breeding area, the central river flood locust breeding area, the north-western lake shore locust breeding area, and the south-western internal plain flood locust breeding area.

3) In the climatic environment of the locust plagues, there was no significant correlation between the spatio-temporal evolution of the locust plagues and temperature, and the precipitation affected the formation of locust plagues, and the locust plagues and river floods were significantly positively correlated, with a fluctuating upward trend.
4) At the social impacts and responses to the locust plagues, natural disasters were formed by the combined effect of the climatic environment and human society, acting as mediums to transmit the negative effects of climate and human activities to the human social system.

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

GL and WX designed the research; CF performed the research; CF, XW, and SW analyzed data; CF wrote the paper; GL, CF, and XG revised the manuscript. All authors reviewed the manuscript.

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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.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feart.2022.1015462/full#supplementary-material

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