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Social impacts of extreme drought event in Guanzhong area, Shaanxi Province, during 1928–1931

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Abstract
Case studies on the impacts of extreme weather events at different spatial and temporal resolutions can help further the understanding of the impacts of climate change and serve as references for coping with future climate change challenges as well. We reconstructed the monthly time series data on social impacts of an extreme drought event in the Guanzhong area, Shaanxi Province, China, using newspaper records from 1928 to 1931. Changes in food substitutions, food prices, social unrest, and social resilience are analyzed to show how the drought affected the area. The results show that (1) the evolution of social impacts of the drought can be divided into five stages, and the variation in the impact magnitude is strongly influenced by the summer and autumn harvests; (2) the cumulative effects of the persistent drought are observed, and the level of social resilience declined rapidly and nonlinearly; and (3) there are two kinds of spreading patterns of drought's impacts across natural, supporting, and humanity systems: hierarchical propagation and cascading effects. They act over different spatial and/or temporal scales and could provide the inspiration for the strategies designed to mitigate the impacts of climate change and extreme weather events today.

Keywords Extreme drought event · 1928–1931 drought · Guanzhong area · Social impacts

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1 Introduction

Mechanisms and processes of past human-climate-ecology interactions at multiple spatial and temporal scales are of great significance for the research in the Past Global Changes project (PAGES 2009). Long-term climate reconstructions could indicate the trend changes in the mean state of the climate and help to assess impacts and adaptation, while short-term case studies focus more on the impacts of historical extreme weather events and response patterns. The past is the key to the future. These two approaches are with the same aim to enhance our understanding of the impacts of contemporary climate variability and human adaptation. In the context of global climate change, the frequency and intensity of extreme weather events have increased substantially, causing severe losses and requiring more timely and effective responses (IPCC 2014). Research on the impacts of and responses to past extreme weather events is thus significant, as it reveals interaction mechanisms and contributes to better decision-making (IHOPE 2010).

Compared with the quantitative research on long-term climate change trends and the impact propagation, there is insufficient research related to the impacts of and responses to historical extreme weather events. For the former, quantitative approaches, such as the reconstruction of continuous long-term series of socio-economic proxy indicators, have promoted the exploration of the climate change impacts and impact propagation chains, as well as the response processes and mechanisms. The topics of related works include the relationships between temperature and precipitation and grain harvests (Su et al. 2014; Yin et al. 2016), climate-driven migration (Zhang et al. 2011), human health (McMichael 2012), economic development (Wei et al. 2014, 2015), social conflict (Su et al. 2016; Tol and Wagner 2010), social rise and decline (Lee et al. 2017; Wang et al. 2020; Yin et al. 2016), and political or societal collapse (Büntgen et al. 2011; DeMenocal 2001). However, for the research on extreme weather events, limited by the features of historical records, which are usually discontinuous, scattered, and qualitative, it is more difficult to carry out quantitative studies through the series reconstruction of high-resolution socio-economic proxy indicators over short time scales.

Being different from other extreme weather events, droughts occur more gradually and can last for months, or even years. This has enabled the integration of the same quantitative approach and data series reconstruction in the drought-related research. Besides, extreme drought events often affect vast areas with widespread and long-lasting impacts, which can be fatal for the traditional agrarian societies. For these reasons, the influence of droughts has attracted much scholarly attention, with past works exploring the effects of severe and persistent droughts on the decline or the fall of civilizations, such as Maya (Kennett et al. 2012; Lucero 2002), Angkor Wat in Cambodia (Buckley et al. 2010), and the Ming Dynasty in China (Zheng et al. 2014).

Most part of China has a monsoon climate, which is characterized by instability, high variability of rainfall, and frequent flood/drought disasters. This is particularly obvious in northern China, with the temperate monsoon climate in the east and continental climate in the west. The annual average precipitation is 608.9 mm in north-eastern China (Zhang 1999) and 231.9 mm in north-western China (Zhai 2008). The former has a rainfall variability of 30–40%, while for the latter, it is 20–60% (Feng and Zheng 1986). In monsoon area of East China (east of 102.5° E), drought events are dominated by the inter-annual variation of the East Asian summer monsoon (Zhang and Zhou 2015). The late onset of summer monsoon or the weak monsoon circulation will cause precipitation deficiency, which might lead to extreme summer drought over north-eastern China. Moreover, North China, in which the political center of China lies since ancient times, has a long history of intensive agriculture development, with vast alluvial plains and high population densities. Therefore, many efforts have been put into the research on extreme drought events in northern China. Most researchers carry out qualitative descriptive analyses, aiming to examine natural and social causes of famines and the impacts of droughts on production, population, economy, and social activities (Wang 2006; Wei 2014). Some have discussed the disaster response activities in various social sectors and their effects (Yang 2010; Zhu 2008). Also, there are some quantitative studies on the impacts of droughts on human societies. For example, through multiple/partial wavelet coherence analysis, Lee et al. indicated that in Northwest China, the drought was generally the common cause of famine, epidemics, nomadic invasion, and rebellion in 1500–1911 A.D., but this connection is not unchanging and might be affected by social factors, especially the government policies (Lee and Yue 2020; Lee et al. 2016).

China serves as a good setting for studying past extreme weather events given its long history of agriculture-based economy, along with the abundant and continuous documentary records (Fang et al. 2014). These provide the feasibility of data resolution improvement, and it is thus possible to conduct the quantitative research on extreme drought events. In this paper, we examined the extreme drought in Guanzhong area, Shaanxi Province of China, during 1928–1931. Based on newspaper reports, we reconstructed monthly time-series data on three socio-economic proxy indicators: food substitutions, food prices, and social unrest. We then discussed how social resilience had been affected by the drought and the propagation processes of disaster impacts, as well as the associated cascading effects. This work can be used as a reference for understanding the influences of extreme weather events on human society.

2 Data sources and methods

2.1 Case introduction

It is necessary to introduce the background of the drought before analyzing its impacts. What needs to be clarified is that the occurrence of drought does not necessarily coincide with the emergence of its social impact. The drought may have occurred, but it is reasonable that its social impact has not yet been recognized. Therefore, although some studies have pointed out that the time range of the drought might be 1927–1932 (An 2010), in this paper, we discussed the social impacts of the extreme drought event from 1928 to 1931, which is determined by the dates of the earliest and the latest existing records.

The extreme droughts that occurred in northern China in the 1920s had a wide range of effects and caused severe losses, which have attracted the attention of many scholars. Liang et al. (2006) confirmed that there was a large-scale drought in North China in the 1920s through tree-ring data analysis. A literature review conducted by Zeng et al. (2009) indicated that this drought was one of the three most severe droughts in northern China over the past 300 years. The drought struck almost the entire Northwest China and part of North China. Reports on drought were found in Shaanxi, Gansu, Shandong, Anhui, Suiyuan (now the central and southern parts of Inner Mongolia), and Chahar (has been incorporated into current Beijing, Inner Mongolia, Hebei, and Shanxi Provinces). The drought is referred to as *the famine in the 18th year of the Republic of China* (An 2010) and lasted for a long time, leaving a quite sufficient amount of data for the research on disaster impacts and response operations.

Records have demonstrated the damages caused by the drought. In the core drought-stricken area, Shaanxi Province, approximately 2 million people starved to death, roughly 2 million were displaced, and more than 8 million survived eating bark, grass roots, Kaolin clay, and even corpses (Wang 1980). Its population decreased by a quarter from 11.82 million in 1928 to merely 8.97 million in 1931 (An 2010). A book titled *Yearly Charts of Dryness/Wetness in China for the Last 500-Year Period* (Chinese Academy of Meteorological Sciences 1981) further shows that the Guanzhong area of Shaanxi was severely affected, especially in 1928–1929.

The Guanzhong area, also called the Wei River Plain, is formed by alluvial deposits from the Wei River, the largest tributary of the Yellow River. Guanzhong has a history of agricultural development over 2000 years. Irrigation canals were built here since 246 B.C. It has developed a winter wheat/corn double cropping system. Winter wheat is planted in the autumn for the summer harvest (from May to June), while corn is planted in summer for the autumn harvest (in September) (Hao et al. 2003). Before the Tang Dynasty (618 A.D.), 13 dynasties had founded their capitals in the Guanzhong area. Being the economic, political, and cultural center of ancient China for such a long period, it was densely populated. In the 1930s, the population density of Guanzhong area was 302 people/km^2, and the rural population accounted for 97.5% of the total (Jiang 1938). The impacts of the extreme drought are thus devastating to this densely populated agricultural area.

During 1928–1931, administratively, Guanzhong was the area within the borders of the "Guanzhong," which included 45 county-level administrative units (Fig. 1) (e.g., Tongchuan County, Xianyang County, and Xingping County) and generally consistent with the combined jurisdiction areas of 5 current prefecture-level cities: Baoji, Xianyang, Xi'an, Tongchuan, and Weinan.

2.2 Data sources

Studies on the impacts of past climate change in China have widely used the records from local chronicles and Chinese canonical texts. The data from these sources is not with high temporal resolutions, and hence, it is unsuitable for the quantitative research on extreme weather events.

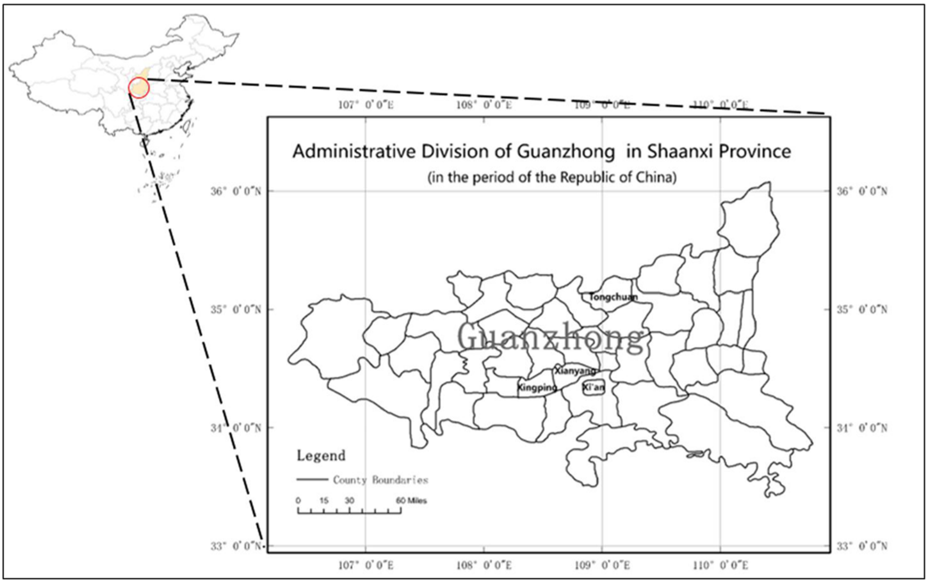

Fig. 1 Administrative division of Guanzhong area in Shaanxi Province

However, newspapers and magazines are published daily or monthly; in other words, they are the documentary records with high temporal resolutions. Modern newspapers began to appear in China in the nineteenth century. During the period of the drought, many newspapers and magazines kept a close eye on social and livelihood issues and left a large amount of reliable text data for the present case study. For these reasons, newspaper records can be used to reconstruct the high-resolution series of social impacts caused by the extreme drought.

The *Newspaper Clippings on Drought and Flood Disasters During the Republic of China*, published by *the* China Institute of Water Resources and Hydropower Research (2018), collected 54,000 clippings of the reports on drought/flood disasters from various sources, including the most popular newspapers at that time, such as *Ta Kung Pao*, the *Republican Daily News*, the *Sin Wen Pao*, and *Shun Pao*. So the newspaper records needed in this study mainly come from this newspaper clipping. From this set of clippings, we searched for the related reports from 1927 to 1932 and finally extracted 97 records. The first report appeared in December 1928 (but the earliest record describing drought can be dated back to June 1928), and the last report was published in June 1931, covering a period of 37 months.

2.3 Quantification method

A human-environment system (Turner et al. 2003) can be divided into three levels: natural system (containing environment and resource subsystem), supporting system (containing production and infrastructure subsystem), and humanity system (containing population, economic, and social subsystem) (Bossel 1999; Fang et al. 2019) (Fig. 2). Given the features of data and the research aims, the population, economic, and social subsystems were considered the core of this study. First, based on this conceptual framework, three proxy indicators were established respectively for the three subsystems within the humanity system. Then, the 97 selected records were classified into these three subsystems.

Next, we built a matrix of 5-point grading scale (Table 1) to measure the severity level of each descriptive record in the population and social subsystems. Based on historical records, the 5-point grading scale was previously adopted by some researchers to carry out quantitative

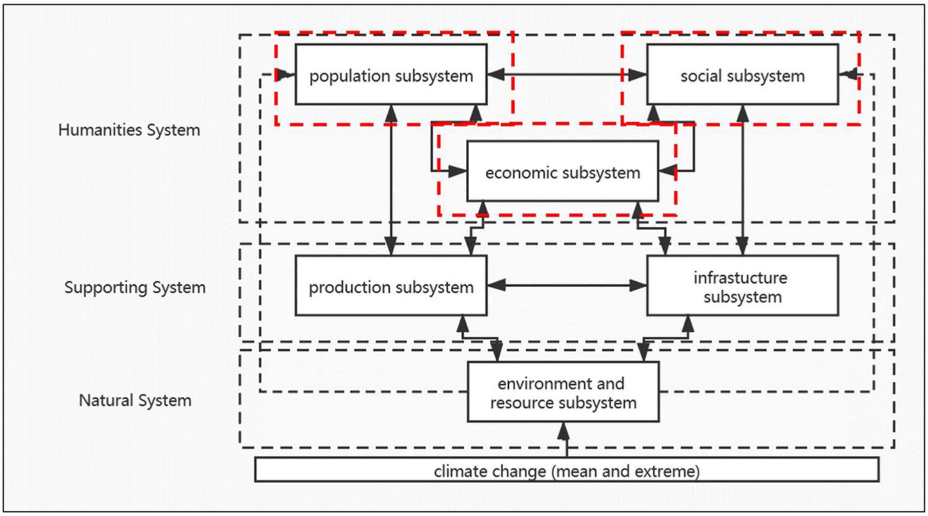

Fig. 2 Conceptual framework of a human-environment system (based on Fang et al. (2019))

Table 1 Grading matrix: definitions for the impacts of the drought on population and social subsystems

Severity levels	1	2	3	4	5
Population subsystem					
Food substitution	Normal food	Leaves and grass	Livestock and plant roots	Clay	Cannibalism
Examples of descriptions	None	Persimmon and apricot leaves; all kinds of leaves	Cattle, mules, and horses; bark and roots	Lithoid white dry powder (Kaolin clay, also known as “Guanyintu” in Chinese)	Corpses; human buttocks and feet
Social subsystem					
Social unrest events	Normal conditions	Dismissal and unemployment	Begging and displaced	Robbery	Banditry
Examples of descriptions	None	Landlords and businessman dismissed workers	Inhabitants begged in groups during the day and slept on the streets at night	People eating melons were surrounded and robbed by starving people	Rape, arson, murder, and other serious crimes

analyses of the variation in the harvest and economic development level. Results of those works have proved that it is applicable and effective for the quantification of the qualitative documentary materials (Wei et al. 2014, 2015; Yin et al. 2016). Last, the impacts of and responses to the extreme drought were analyzed through the reconstructed monthly proxy indicator series.

(1) "Food substitution" is the proxy indicator for the population subsystem. Because of the lack of statistical evidence, the drought-induced monthly deaths and migrations are unknown. However, there are a lot of records that people took abnormal forms of "food" (e.g., bark, clay, corpses) as the drought had resulted in food shortages. The severity level of food substitution not only reflects the intensity of the drought-caused famine but also suggests the health condition and even death of the victims. Therefore, we used the quantified data on food substitution as an indicator here. Twenty-eight relevant records over a period of 25 months were extracted from the collected newspaper clippings. Then, the severity level (from 1 to 5) was scored, indicating the magnitude of the drought's impacts on the population subsystem (see Table 1 for the criteria and examples).
(2) "Food price" is the proxy indicator for the economic subsystem. Guanzhong's commodity economy was heavily affected by the drought as manifested in rising food prices, the devaluation of farming land and instruments of production, and the trafficking of women and children. Among these reports, changes in food prices were well-documented and appeared to be quite drought-sensitive, representing the fluctuations in the economic subsystem as a result of the drought. Seventeen records on food prices were extracted from the collected clippings, covering a period of 14 months. Here, as the quantitative data, food prices were directly used after the unification of the measurement units.
(3) For the social subsystem, the severity levels of social unrest and extreme social events were chosen as the proxy indicators. The drought seriously affected social stability in Guanzhong area. From the records selected, we identified two types of social issues. One is social unrest, including begging, robberies, rebellions, and other behaviors resulting from food shortages, unemployment, etc. The other is the extreme social event, referring to victims' extreme behaviors, such as suicide and human trafficking. These two kinds of issues were used for the generation of the proxy indicator, demonstrating the extent of the damage to the social subsystem made by the drought. Twenty-five records of "social unrest events" were identified and scores (severity levels 1–5) were given (criteria and examples are shown in Table 1). Besides, 26 records of "extreme social events" were extracted, consisting of 12 records of mass suicide and 14 records of human trafficking, both found in 9 months. We did not grade this kind of events, but just noted down the time of occurrences and added them into the monthly data series.

Along with the grading criteria, the reconstruction of monthly proxy indicator series also follows the operating principles below:

(1) For months with newspaper records, the impact severity level for each subsystem was determined by the contents. When there are two or more records for the same subsystem in the same month and with the same level, the severity level of the subsystem will not be multiplied, remaining the same level as that of each record. When several records for one subsystem are not at the same level, the highest will be chosen and assigned.

(2) For months without records, the principle varies. In the beginning phase of the drought (from the winter of 1927 to August 1928), given newspapers' general tendency of reporting abnormalities instead of normalities, for any subsystem, if there is a month without records, it will be assumed not being affected at the time. If months with no data appeared after the record of a certain drought event and the number of the months without data was smaller than 4 within the period of half-year, it was assumed that the impact level should be generally unchanged. Thus, months without data were interpolated with records immediately preceding and following them. However, in this situation, if the 6 months contains harvest season, the value of the nearest month following that harvest season was used for interpolation. Otherwise, no interpolation was performed and those months were left blank.

The quantification results are shown in Table 2. In the food substitution time series, the severity levels of 25 months (67.6%) were graded based on records, and the levels of 12 months (32.4%) were graded through interpolation. In the food price time series, food prices for 14 months (37.8%) were obtained directly from records, and food prices for 6 months (16.3%) were obtained through interpolation. In the social unrest time series, the severity levels of 17 months (45.9%) were graded based on records, and the levels of 16 months (43.2%) were graded through interpolation. It is notable that due to the limitations of the existing records, more than half of the food prices and social unrest series are interpolated or missing, which might affect the accuracy of results.

3 Analysis of social impacts of the drought

The reconstructed time series (Fig. 3) shows that the extreme drought event had affected all the three subsystems of the human system. According to the variations of the indicator values, the whole drought period in Guanzhong area was divided into five stages, and social impacts were analyzed separately.

The first stage (from the beginning of the drought to April 1929) is the primary phase of drought evolution. In the *Yearly Charts of Dryness/Wetness in China for the Last 500-Year Period*, the records provided by the Xi'an observation station showed that the dry grade was 3 in 1927 (i.e., a normal condition), while in 1928, the grade was 5 (i.e., extremely dry) (Chinese Academy of Meteorological Sciences 1981). The number of reports on drought began to increase in August, and most of the contents are about environmental conditions. In this stage, the average value of food substitution grade was 2.0, and there were no fifth-level months. The low-level months (levels 1 and 2) accounted for 72.7% of the total. It was manifested that

Table 2 Quantification results of the records

Grading method	Food substitution series		Food price series		Social unrest series	
	Number of months	Proportion	Number of months	Proportion (%)	Number of months	Proportion (%)
From records	25	67.6%	14	37.8	17	45.9
By interpolation	12	32.4%	6	16.3	16	43.2
Missing	0	0	17	45.9	4	10.9

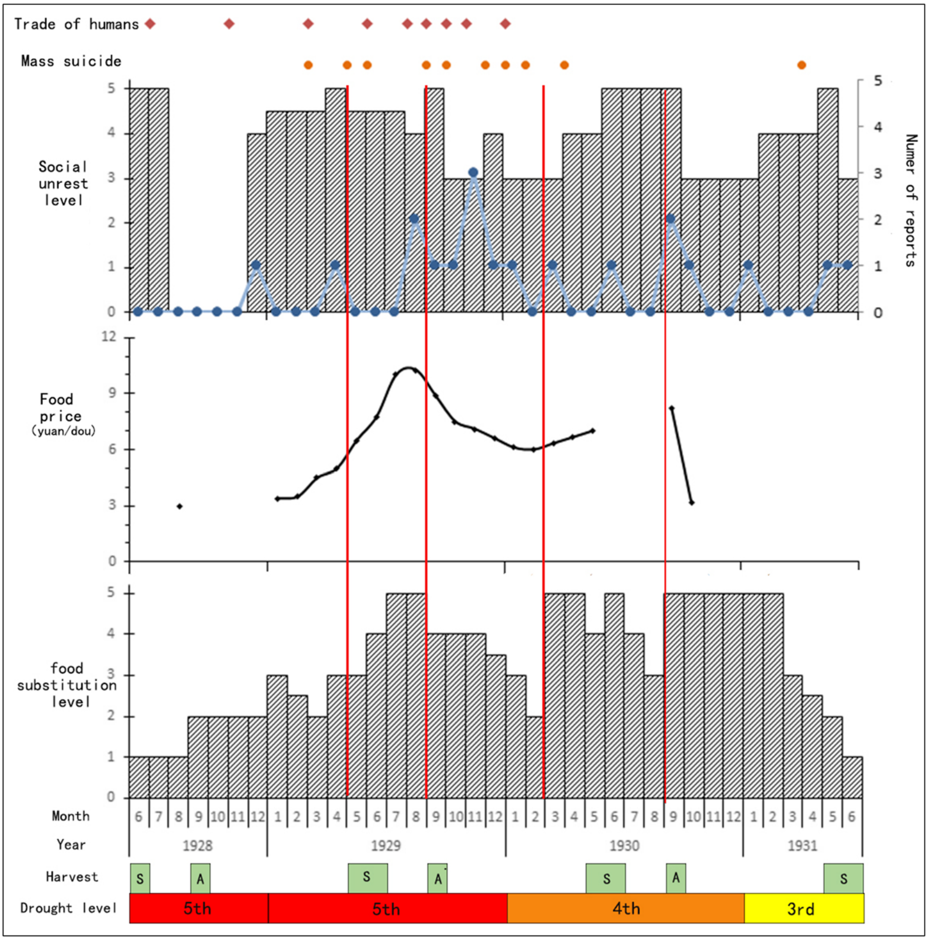

Fig. 3 Monthly time series of the social impacts of the extreme drought events in Guanzhong area. "A" autumn harvest, "S" summer harvest

people in Guanzhong began to eat oil dregs and wild potherbs, but the situation was not too bad. There were few records of food prices (5 pieces), but the recorded food prices remained stable at about 3 *Yuan per dou* (roughly equal to 72.2 g of silver/10.354688 l of wheat) and showed an upward trend in the later stage. The level of social unrest was relatively high (4.6), and there were fifth-level months (accounting for 27.3%). From the perspective of the level, the social situation was severe; but in view of the amount of reports, only 2 reports were related to social unrest events in this stage (it should be pointed out that the high-level reports in June and July did not appear at that time, but were mentioned in the report *Shaanxi disaster situation report (the Sin Wen Pao)* on April 8 of the following year). So in this stage, there were some reports of food robbery ("those selling street food in cities and towns were robbed as soon as the stall was set"), but these events were still rare. Although there was a drought, the overall situation remained controllable, as the individual food reserves could make up for the food shortages caused by a poor harvest.

The second stage (May 1929 to August 1929) was a period of severe drought conditions. Using tree-ring data, Liang et al. (2006) explained the precipitation deficiency from April to

June and the drought index from May to June in Guanzhong area. Their study proved that the drought in 1929 was the most severe in the past 400 years. April and May in 1929 have witnessed the rapid escalation of food and social crisis. In the economic subsystem, the food prices rose threefold and reached the highest price of 10.26 *Yuan per dou* in August. The problem of food substitution was very serious, with an average grade of 4.3, and the proportion of fifth-level month accounted for 50%. Facing serious food shortages, extreme behaviors such as cannibalism and corpse-eating started to happen. The average level of social unrest was 4.4. There were clear signs of social breakdown through the more and more frequent reports of extreme events; e.g., people committed suicide by self-poisoning (*entire families committed drug-induced suicide*) or jumping off cliffs ("Some people who self-injure intended to commit suicide by jumping off the cliff"), and women prostituted themselves ("middle-aged women carrying their children on their backs and prostituting themselves"). The serious summer harvest failure led to the failure of social adaptive mechanisms. The impacts of the extreme drought event were observed in all subsystems of the human system.

The third stage (September 1929 to February 1930) experienced the alleviation of drought impacts. Autumn harvest was carried out in September. Despite the decline in harvests, both the food prices and the severity level of food substitution showed downward trends. The level of food substitution gradually declined, with an average level of 3.5. Among them, the fifth-level month had disappeared, and the lowest level had reached level 2. This showed that although some people ate tree roots and Kaolin clay, the situation was generally improved. The price of wheat gradually went down and was close to the level during the early stage of the drought, at approximately 6 *Yuan per dou*. In the social subsystem, the level of social unrest was significantly reduced (average level 3.3). Records on begging and food robbery were also quite common, but there were fewer reports of much more serious social unrest events such as murders and riots. However, the suicide and human trafficking were still reported with high frequency. The cumulative effects of the drought were primarily and still experienced by a small proportion of the lower class.

The fourth stage (March 1930 to August 1930) marked the second peak of the drought. In February 1930, food reserves had run out, and there would be at least 3 months for the winter wheat to reach full maturity. The severity levels of food substitution experienced a sharp increase, even sharper than that during the second stage. In merely 1 month, the severity level of food substitution rose from 2 to 5. The average food substitution level was 4.3, and the proportion of 5-level months was 50%. "It has become common to eat children and share corpses." There were no records on food prices in this stage. The extreme food shortages completely destroyed the adaptive mechanisms of markets, leading to the market collapse and shutdown. Thus, it was impossible to obtain any food from the market. Severe social unrest events also occurred. The level of social unrest increased significantly, with an average level of 4.3, and the proportion of 5-level months accounted for 50%. In Xi'an, the political center of Guanzhong, there were "arson, killings, robberies, and looting by bandits." In other places, "bandits harmed residents, and people's safety could not be secured."

In the fifth stage (from September 1930 to the end of the drought period), conditions began to improve. The completion of the autumn harvest in September 1930 contributed to a rapid reduction in food prices (from 8.2 *Yuan per dou* to 3.2 *Yuan per dou*), but the records of food substitution were still common. It was until February 1931 that the number of related records started to decrease gradually. During this period, social unrest events were occasionally reported (no more than 2 times/month), suggesting that social impacts of the drought were fading away. What needs to be explained here is that, unlike the quick fall of the food prices, food substitution remained at its peak for a relatively long time. The reasons might be, firstly, according to the operating principles mentioned above, the severity level of each month was determined by the highest score of all the related records within this period. But these reports might just reflect the living conditions of a relatively small number of people at the bottom of the society, appearing to be less general and sensitive compared with the food price indicator. Secondly, in the later stages of the drought, the number of related reports reduced. This might also cause disturbance to the interpolation process of some months.

Mostly, the breakpoints of the five stages are also the starting points of the summer or autumn harvest. The drought affected harvests, causing the breakdown of the human-environment system in Guanzhong area. The magnitude of impacts depends on the severity of the drought and also on harvests. The summer harvest failures in 1928 and 1929 had gradually worsened the impacts of drought on society. Autumn harvests, on the contrary, had brought the mitigation to a certain extent.

4 Discussion: the loss of social resilience and the spread of impacts

4.1 A society that lost resilience

The concept of social resilience was integrated into the field of sociology of disaster. The relevant research focuses on how human society responds to disturbances and imbalances through self-organization and active adjustments and upgrades the function of social systems at the same time (Manyena 2006). The representative theory explains resilience's four basic characteristics: robustness, that a system will not suffer degradation or loss of function after a disturbance; redundancy, that a system can substitute certain functions after being impacted by a disaster and free from functional loss; resourcefulness, that a system can identify problems in time and establish a way to mobilize required resources; and rapidity, that a system can rapidly recover and rebuild (Bruneau et al. 2003). In the face of extreme weather events, the human-environment system can be resilient and mitigate losses through various means. However, when a disaster exceeds a system's capacities, the system cannot adopt response measures, resulting in the loss of resilience.

An article titled "Miserable Shaanxi Disaster" published in *Ta Kung Pao* on June 25, 1929, states:

> "In the spring of the 17th year (1928), a few harvests were barely enough to maintain the living. At the end of the summer and start of autumn, except exiles, the starving victims lived on grass roots, bark, and oil dregs. From the middle of winter till now, even grass roots and bark were not available. Every day more and more people starved to death, leaving corpses all along the road. Taking the exiles into consideration, it is more difficult to count all the victims."

This example demonstrates that the severity level of food substitution is associated with social resilience. In the early stages of the drought, people in Guanzhong area managed the impacts through many ways (e.g., eating the stored or distributed food, restricting food consumption), and the drought did not bring significant damages to society. However, as the drought continued, neither individuals nor governments were able to implement reasonable and effective disaster response measures, and the food shortages became more and more serious. At that time, the severity level of food substitution gradually increased. The features of food substitution indicator echo with the four characteristics of social resilience, and its appearance revealed the degradation and loss of the functions of food production and allocation in human system. The situation kept worsening, and the choices of alternative sources of nourishment became less and less. People even started resorting to cannibalism for survival.

The food substitution series were further processed to analyze the change of social resilience. Firstly, according to the common way of defining the four seasons in China, we grouped the 12 months into four 3-month periods: spring (March, April, and May); summer (June, July, and August); autumn (September, October, and November); and winter (December, January, and February). As shown in the bar chart in Fig. 4, the relative frequency of each severity level of food substitution in each season was calculated. Then, we assigned 5 values in an arithmetic sequence respectively to the 5 levels of food substitution (level 1, 1.0; level 2, 0.75; level 3, 0.5; level 4, 0.25; and level 5, 0). Taking the relative frequency as the weight, a weighted average of each season was calculated in order to indicate the changes in the strength of social resilience (line chart in Fig. 4). The line shows a general downward trend with an exceptional rise after the autumn harvest in 1929. The fitting curve shows that the weakening

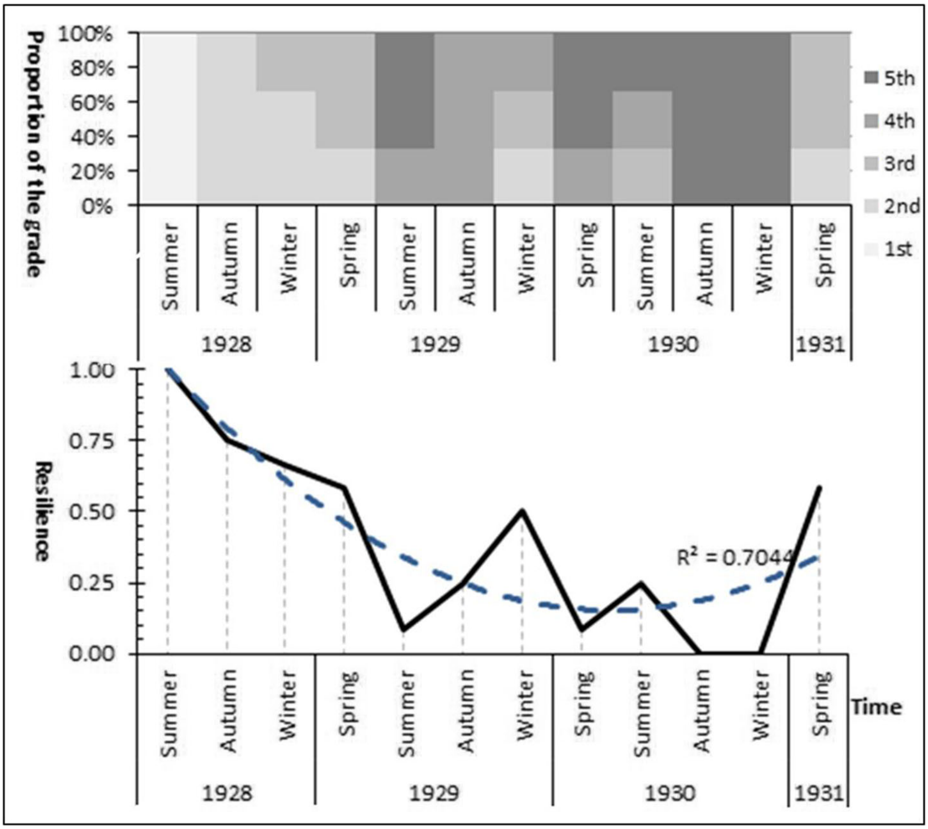

Fig. 4 Changes in the strength of social resilience during the drought (1928–1931). The blue dashed line is the fitting curve ($y = 0.0153 \times ^2 - 0.2598x + 1.2557$, $R^2 = 0.7044$) and it passed the significance test (sig. = 0.004). The p value for the test on each coefficient (including constant) from left to right is 0.006, 0.020, and 0, which means that the coefficients in the fitting curve are also statistically significant

of social resilience was a rapid and nonlinear process. As the drought came close to its end, social resilience had slowly recovered.

In the face of the drought, society, as a system with resilience, had sought adaptive strategies to reduce the impact and ensure the normal operation. In the early stages of the drought, the resilience of society was relatively strong, and people had adopted a variety of measures as disaster response. As the effects gradually accumulated, the resilience of society rapidly weakened. The original “ideal” countermeasures failed, and people had to seek other “less ideal” measures. When the most extreme measure also proved ineffective, the society lost its resilience.

This is an attempt to use the severity level of food substitution to indicate the strength of social resilience. It is not comprehensive (for example, the amount of data involved in the analysis is small), but feasible and reasonable. Compared with modern multi-source quantitative data, the historical data is limited, causing difficulties to develop the same evaluation indicators that are commonly used in the current case studies on social resilience. Though the disaster relief of governments is a conventional indicator, for this drought, there is a lack of related relief actions and records. An article, “The Victims in Shaanxi Will All Die of Starvation”, published in the *Republican Daily* on April 7, 1930, mentioned that “disaster relief organizations in many counties of Shaanxi Province had ceased operations one after the other because of the short on food storage.” Another example, “Report on the Disaster Situation in Guanzhong,” published in *Ta Kung Pao* on August 6, 1929, wrote that “the military and political authorities were busy with military affairs and had no time to deal with the drought.” In addition, there are many phrases such as “successive years of war” (the *Sin Wen Pao*, December 3, 1928) and “frequent wars” (*Shun Pao*, December 10, 1928). Therefore, the disaster relief cannot be used to quantify social resilience in this case study. In the absence of this data, we used food substitution instead, with aims to demonstrate social context and indicate social resilience.

4.2 Spread of the impact: hierarchical propagation and cascading effects

On the basis of the research on climate change in historical China, some scholars put forward their findings that the impact of long-term climate change propagated through the human-environment system level by level, in the order of “natural system→supporting system→ humanity system.” Each system has its corresponding threshold of climate change impact. Only when the threshold is violated will the impact be further amplified and spread to the next level (Fang et al. 2014). However, in the case of this paper, with different temporal-spatial scales and socio-economic conditions, will the spread of impact show the same pattern, or how will it be? To address this question, we carried out the analyses of the number and content of disaster reports.

The first part is an analysis of the monthly report count (Fig. 5). Generally speaking, there were reports of the drought in almost every month, suggesting its long-lasting impact on the Guanzhong human-environment system. The earliest drought report was published in December 1928, yet the content is mainly about the drought conditions in August. It indicated that at first, the drought did not cause widespread concern, and the society was not significantly affected.

For the lower-level systems (natural system and supporting system), disaster reports were relatively less published, most of which appeared intermittently before March 1930. For the higher-level system (humanity system), however, the reports appeared quite continuously, and there is a peak period from August 1929 to October 1930. Also, in the three subsystems, the

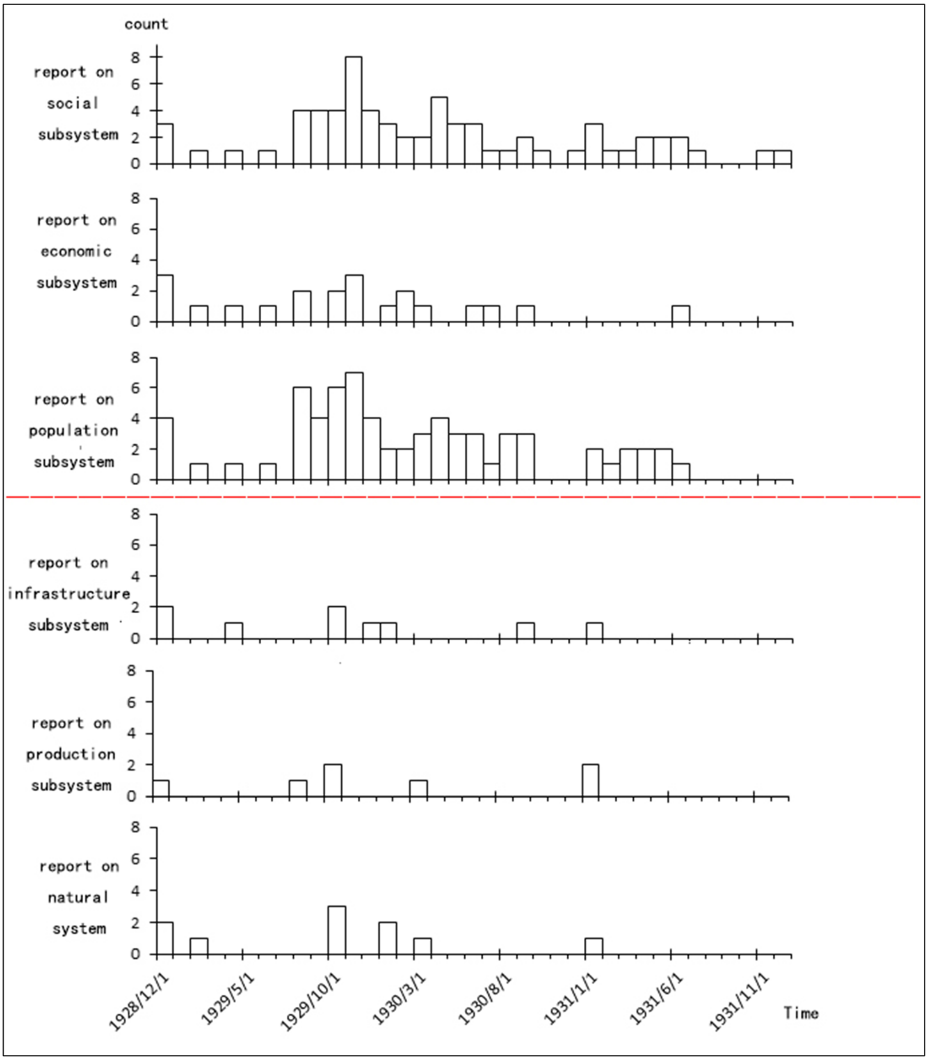

Fig. 5 Monthly count of reports on extreme drought event (1928–1931) in Guanzhong area sorted by subsystem

appearance of the impact records was basically at the same time, and they shared the same peak period. This means that the impacts of the drought on these three subsystems were manifested concurrently. The soaring food prices, food substitution, begging and robberies, suicide, and human trafficking were complexly interrelated. The cascading effects had presented: the initial impact triggered other phenomena and they integrated, leading to serious consequences.

The figure did not demonstrate an obvious sequence of “hierarchical propagation” process of the drought impacts, possibly because of the restrictions of time resolution and systematic errors in the process of record sorting. With a daily time resolution, the process of hierarchical propagation might be able to capture. However, in fact, sometimes the information on the damages of different subsystems came from one report. For these records, the date of publication is the same, but the date of the occurrence of the specific event could be different.

The second part of the analysis is based on the contents of reports. We sorted the relevant descriptions in chronological order and then visualized the spreading process of the drought impacts (Fig. 6). The crop failure happened in the supporting system firstly affected the humanity system by generating food shortages. This in turn overloaded the three upper subsystems, causing them to fail as well. The victims began to sell their property, such as land and agricultural tools at low prices in order to earn enough money for food. This then caused damages to the infrastructure subsystem. As a consequence of the cheap sale of farming land and equipment, population decline, and social unrest, the normal agricultural cycle was disturbed, and it had further worsened the food shortages. These factors had formed a vicious circle and made the disaster conditions in Guanzhong more serious and complex. The increasing reports of more severe food substitution and social unrest indicated the panic among victims and the loss of social resilience.

From the analysis of the contents, there are two main findings. One is that the spread of the impact of extreme weather event shows some characteristics of the hierarchical propagation process. The natural and supporting systems were damaged in the first place, and then, the impact spread to the humanity system. The environmental effects, drought and water shortage, preceded the crop failure that happened in the production subsystem, followed by a series of social effects, such as food shortages, food substitutions, and soaring food prices. The other is that the spreading paths of the drought impacts on humanities system appeared to be multi-level and complex, in accordance with the findings in the first part and reflecting the nature of cascades.

It is notable that the complex cascading effects observed in the spreading process of the drought impacts can be closely related to the social background of Guanzhong area. In the 1920s and 1930s, the vulnerability of Guanzhong society was obvious and it had lost the ability to mitigate the impacts of extreme weather events.

On the one hand, social vulnerability can partly attribute to the insufficiency of arable land per capita, which created a high level of poverty. At that time, in northern China, roughly

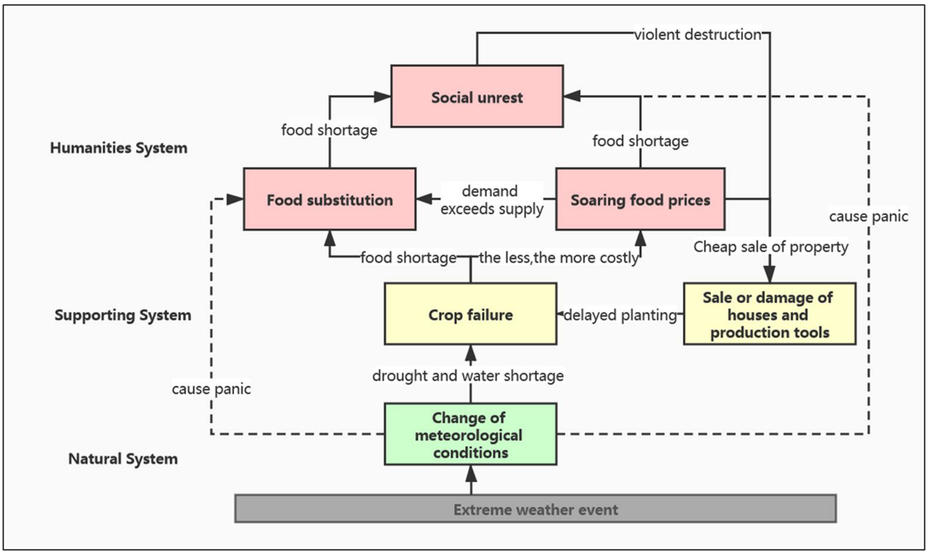

Fig. 6 The spreading process of the drought impacts in Guanzhong human-environment system

0.33 ha of arable land was needed by one person, and on average, a household in Guanzhong included 5.1–5.8 people (Jiang 1938); so for every household, approximately 2 ha of arable land was necessary to meet the food demand. However, 70% of households there owned less than 2 ha of arable land (ibid.). Even in the normal harvest years, there is still very significant insufficient food supply per capita. Thus, once this situation is superimposed with the drought, it is very likely that there will be serious food security problems. In Guanzhong, under the difficult living conditions, 60.8% of household income was spent on nourishment, whereas only 11.3% was spent on life quality improvements and medical care (Xiong 1942). According to Engel's law, most people were living in poverty. On the whole, the rural economy in Guanzhong was depressed during that period.

On the other hand, years of war and government inaction had left the area in poverty and disorder. In addition to many reports of wars mentioned above, during 1929–1930, in 80% of the counties in Shaanxi, a large number of working-age populations were subject to compulsory military service and joined the army (Xiong 1942). This had severely affected agricultural production. Besides, the allocation of military expenses increased local financial stress. Guanzhong was a war-stricken area in that period, and the degree of damage in agriculture and economy might be greater compared with other places in Shaanxi. Worse still, the government failed to put the focus on drought relief and the rescue of victims, but was busy dealing with the frequent wars (*Ta Kung Pao*, August 6, 1929: *the military and political authorities were busy with military affairs and had no time to take care of the drought*). It had made the disaster conditions in Guanzhong even more serious.

Overall, combining previous research and this case study, for the impacts of extreme weather events, both hierarchical propagation and cascading effects were observed in the spreading process. From a perspective of large temporal-spatial scale, the spread of the climate change impacts in the human-environment system generally follows a hierarchical pattern, while for some cases, at a smaller temporal-spatial scale, such as extreme conditions (extreme weather events, disasters, mass poverty, wars), the spreading process of impacts turned out to be more complex. Apart from the linear path of hierarchical propagation, it also shows the same multi-level paths of cascading effects. Sometimes, the impacts will simultaneously appear in both upper and lower systems. In general, hierarchical propagation (long-term, national/regional-level) and cascading effects (short-term, local-level) should be applicable on different spatial and/or temporal scales.

5 Conclusion

Based on newspaper reports, this study reconstructed the social impacts series data of the extreme drought event in Guanzhong area of Shaanxi Province from 1928 to 1931. The severity of the drought impacts was quantitatively expressed by three indicators: food substitution, food prices, and social unrest (together with extreme social events). Based on the theories of social resilience and human-environment systems, we then analyzed changes in social resilience and the spreading patterns of the drought impacts. Conclusions can be summarized as follows:

1. The evolution of the extreme drought conditions in Guanzhong area from 1928 to 1931 can be divided into five stages. Mostly, the breakpoints corresponded with the starting time of summer or autumn harvest. The two severe summer harvest failures in 1928 and

1929 aggravated the social impacts of the drought, while autumn harvests alleviated the situation to some extent.

2. Under the influence of drought, social resilience declined rapidly and nonlinearly. In the early stages, social resilience was relatively strong. A variety of disaster response measures were available, and resilience improved with the arrival of the harvest season. However, as the drought continued, the level of social resilience rapidly declined, and the response measures gradually became extreme. When the most extreme measures still failed, the social system lost its resilience.
3. The spreading patterns of the drought impacts in the human-environment system include not only the hierarchical propagation from a low level to a high level but also the complex and multi-level paths of cascading effects among subsystems. The former is obvious on the large temporal-spatial scales, while the latter is more significant on the smaller temporal-spatial scales.

Affected by global warming, the possibility of extreme drought events in Shaanxi in the future is increasing (Li 2008), so the case studies on the past extreme droughts are particularly important. After understanding the evolution mechanism of the impacts of drought on society, we would be able to propose more effective strategies to mitigate the losses, which is the significance of this case study. On the one hand, in order to adapt to the long-term warming trend, we need to sustain sufficient areas of arable land and promote technological progress and ensure the safety of food production. With these measures, the initial step of hierarchical propagation can be interrupted. On the other hand, facing extreme drought events, it is necessary to adopt measures such as food allocation to avoid dramatic fluctuations in food prices, which can strengthen the key nodes in the network and prevent the cascading effects.

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Data availability The data that support the findings of this study are available on request from the author.

Declarations

Conflict of interest The authors declare no conflict of interest

Code availability Not applicable..

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