Drought, hunger, and migration: A retrospect of North China from the mid-18th century to the early 20th century

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ABSTRACT Given the limited knowledge about the dynamics of the drought-migration nexus with social change, this study revisited the extreme droughts of 1743, 1877, and 1920 CE in North China based on multiple written sources and compared the characteristics of climate-related migration at different stages of sociocultural transformation between the mid-18th and early 20th centuries. It was found that the pathway of precipitation deficits → harvest failure → famine → migration was always strictly followed, revealing low precipitation and fleeing hunger as the initial trigger and root motivation for climate-related migration, while changes in management and transport changed the size and distance of the migration along the abovementioned pathway by influencing the possibility and necessity of moving. Additionally, a broader comparison including the outstanding droughts of 1911 and 1921 in Germany suggests that ensuring individual/household food consumption security was a core task for minimizing drought-induced migration.

KEY WORDS climate-related migration – drought – social change – comparative study – North China

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1. Introduction

Climate and weather-related hazards are considered a key driver of vast human displacements worldwide (Estok 2023) and are projected to create tens or even hundreds of millions of displaced persons throughout the 21st century (Rigaud et al. 2018). Thus, growing attention from both academics and policymakers has been paid to migration (Kaczan, Orgill-Meyer 2020), as a strategy to manage environmental uncertainties or a remedy when in situ adaptation to climate shocks fails (Jennings, Gray 2015; Hoggarth et al. 2017; McLeman 2018; Ivanova et al. 2024). Especially in recent years, studies from historical and modern perspectives have made important progress in this field, unfolding migratory behavior as a multi-causal phenomenon, recognizing changes in the role of climatic factors in population mobility, and underscoring the context-specific process of migration decision-making (Glaser, Himmelsbach, Bösmeier 2017; Falco, Donzelli, Olper 2018; Hermans, Garbe 2019; Damette, Goutte, Pei 2020; McLeman et al. 2022; Merchant, Grace 2024).

Among various climate shocks, drought is most likely to facilitate migration. Unlike rapid-onset events (e.g., floods) that tend to immediately deplete household resources and constrain the capacity to move, the slow-onset nature of drought usually gives individuals time to obtain enough resources for relocation (Kaczan, Orgill-Meyer 2020). The strong relationship between drought and migration has been illustrated in a number of cases under different socio-environmental conditions. Historically, drought was considered the driver of tribal migrations to or passed Roman borders between the 1st century BC and the 5th century CE (Drake 2017), Anasazi's (pre-Columbian Native American) abandonment of long-inhabited region in the late-13th century (Benson, Petersen, Stein 2007), and the large-scale population movements in northern China in the late-15th century (Han, Yang 2021). During the 1930s, the Dust Bowl caused a mass exodus from the drought-stricken rural areas in the Great Plains (Worster 2004; Gilbert, McLeman 2010; Gutmann et al. 2016). While in recent decades, drought has remained an existential threat, resulting in increased human mobility are still observed in northern Ethiopia (Hermans, Garbe 2019) and Central American Dry Corridor (Fuerte Celis, Bolaños Guerra, Olivera-Villarroel 2024).

Nevertheless, drought-migration nexus is nonlinear (i.e., the relationship between variables is not proportional) and dynamic (i.e., the relationship between variables is not static). In other words, the magnitude and manner in which migration occurs do not consistently match the severity of precipitation deficits (Kaczan, Orgill-Meyer 2020). The mediation of non-climatic factors, involving livelihoods, economic conditions, social networks, and political circumstances, is an evident source of such nonlinearity, which has been elaborated in a series of case studies (Ivanova et al. 2024). Overall, it contributes to diverse mechanisms for drought-induced migration and, in a few cases, to relatively counterintuitive outcomes, such as decreases in households deciding to relocate (Quiñones, Liebenehm, Sharma 2021) and temporary increases in male migrants heading to affected areas (McLeman et al. 2022). As for dynamics, alterations in the strength and/or direction of lower precipitation influencing migration over time have been pointed out by several studies based on long-term demographic data (Gutmann et al. 2005; Jennings, Gray 2015; Gray, Hopping, Mueller 2020), which are hardly detected in single cases. However, knowledge of which components and why the effects of drought on migration have changed remains inadequate, as these time series analyses generally do not carry details that often support reconstructing and explaining various processes of migration decision-making in empirical case studies.

In light of this, the current study designed longitudinal multi-case research to present detailed answers to the question of whether, how, and why the drought-migration nexus changes with social change. In brief, a literature-based retrospect was first organized within a limited scope, i.e., three representative drought events in North China from the mid-18th to early 20th centuries, focusing on the course of events and the characteristics of migration. During this period, the region not only underwent a transition from national prosperity to political chaos but also witnessed the transformation from agrarian to early industrial societies. Next, a cross-event comparison was conducted to explore and explain commonalities and differences in decision-making processes and migration patterns under different social circumstances in North China around 1743, 1877, and 1920 CE. Finally, the drought-migration nexus uncovered in North China was re-examined under the outstanding droughts of 1911 and 1921 in Germany, two events with similar climatic conditions but somewhat different outcomes to the North China droughts, in an effort to identify core tasks for minimizing drought-induced migration.

Constrained by the low availability of historical data at the individual/household level, migration here was broadly defined as the act of people leaving their usual places for others, regardless of whether incomers stayed temporarily or permanently in host destinations (Ma 2016). This definition is able to capture the mainstream of population flows, which reflects the common purposes, directions, and routes of people moving in a particular situation, and meet the needs of research from a historical perspective (Ge 1997).

2. Data and methods

2.1. Study area

North China has been a traditional agricultural region since ancient times (Fang et al. 2021) and the political center of China for nearly 800 years. In this study, it

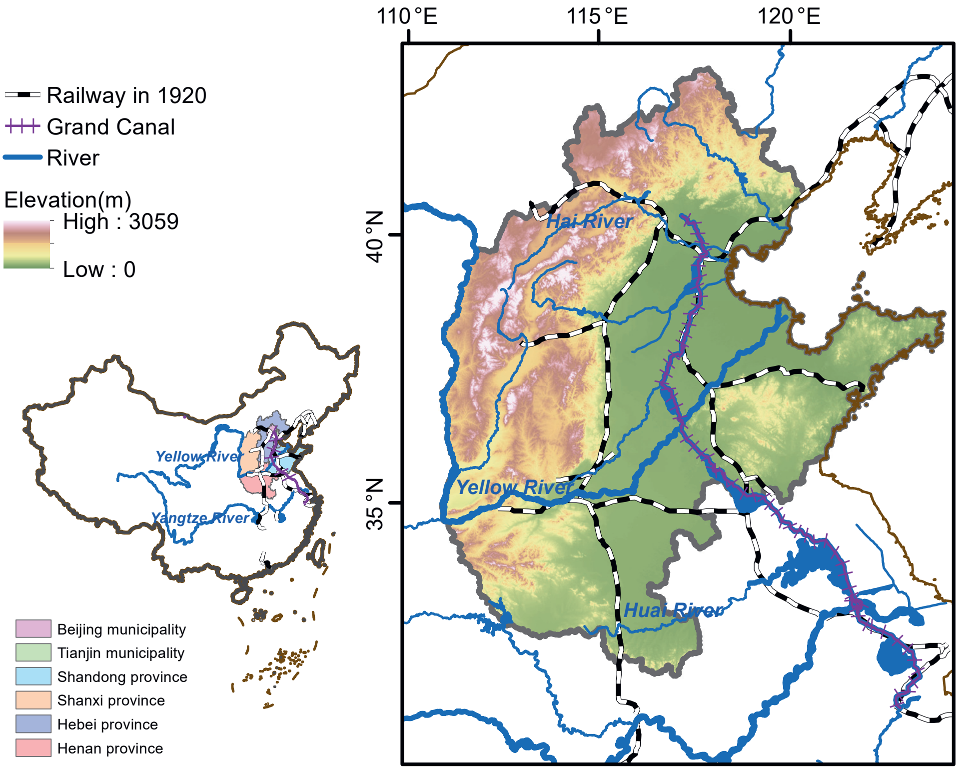

Fig. 1 – An overview of the study area. Only railways confirmed to pass through North China in 1920 (Far Eastern Geographical Establishment, Dingle 1917) are displayed in the maps.

refers to six present-day administrative divisions, including two municipalities (i.e., Beijing and Tianjin) and four provinces (i.e., Hebei, Henan, Shandong, and Shanxi; Fig. 1). This area is mostly located on the North China Plain, with a gradual increase in elevation from southeast to northwest in general, and is mainly covered by the Hai River, Yellow River, and Huai River basins from north to south. As dominated by the East Asian monsoon, precipitation here shows a concentration (approximately 60% of annual precipitation totals) in summer months and a high inter-annual variability, resulting in frequent spring droughts, high risks of multi-season droughts, and strong likelihoods of compound drought-heatwave events (Ding et al. 2013; Zheng et al. 2019; Kong et al. 2020).

As a densely populated zone in China, North China had been a major region of population outflow throughout the Chinese history of migration. From this region, millions of migrants headed to the Yangtze River Basin before the 14th century, and over ten million population migrated to borderlands in northeast and western China between the mid-19th and mid-20th centuries (Xing 2000). North China was also known for its intra-regional population movements, especially when disasters (e.g., droughts, floods, and wars) threatened local livelihoods. As factors that could exacerbate social destabilization and even directly cripple the central government in Beijing, climate extremes and subsequent displaced persons in North China tended to receive more attention, and, in many cases, became indispensable parts of official records and popular topics for later research. The abundant documentation enabled the re-examination of climate-migration linkages in this area from a long-term perspective.

2.2. Reconstructing the progression of the representative drought events

This study took the 1743, 1877, and 1920 droughts, three rare intense dry events in North China over the past 300 years (Zheng et al. 2018), as representative cases. The representativeness of these events depended on the severity of precipitation deficits and the socioeconomic situation of the country. More specifically, all three events experienced four seasons of precipitation deficits in their peak years (i.e., 1743, 1877, and 1920), together with a summer precipitation anomaly ranging from −53% to −32%, which was considered the worst of the 29 extreme dry years during 1736–2000 CE (Fig. 2a). Meanwhile, these events occurred in the prosperous era (1731–1790), during the collapse (1851–1911), and a decade after the fall of the Qing Dynasty (1644–1911), respectively, providing profiles of climate-migration linkages in the transition from a strong management and generous relief to a power vacuum and humanitarian neglect (Fuller 2013, Xiao 2020).

Reconstructing the progression of a given extreme event, namely its onset, development, and cessation, was the first step in examining the climate-migration linkages it implied. Here, two types of written documents contributed to the reconstruction of event progression. The first was subject-specific databases, compilations, and reports that provided the original content of drought narratives. The second was secondary research on drought impacts and social responses, including monographic studies and peer-reviewed articles (Table 1). Therefrom, five categories of textual information on climate phenomena and their effects, mostly containing temporal information at a seasonal scale, were extracted, which were: (1) abnormal weather conditions, such as precipitation deficits (i.e., a period of low precipitation or dry conditions, for example "spring drought, no rain until the sixth month of the Chinese calendar") and heatwaves (i.e., abnormally hot weather that lasted for days to months, for example "the fifth month of the Chinese calendar was extremely hot"); (2) climatic effects on ecosystems, represented by vegetation damage and locust outbreaks; (3) unsatisfactory crop performance (e.g., harvest failure), indicating that agricultural systems were affected; (4) inadequate water supply in hydrological systems, manifested by low water levels in rivers, lakes, and

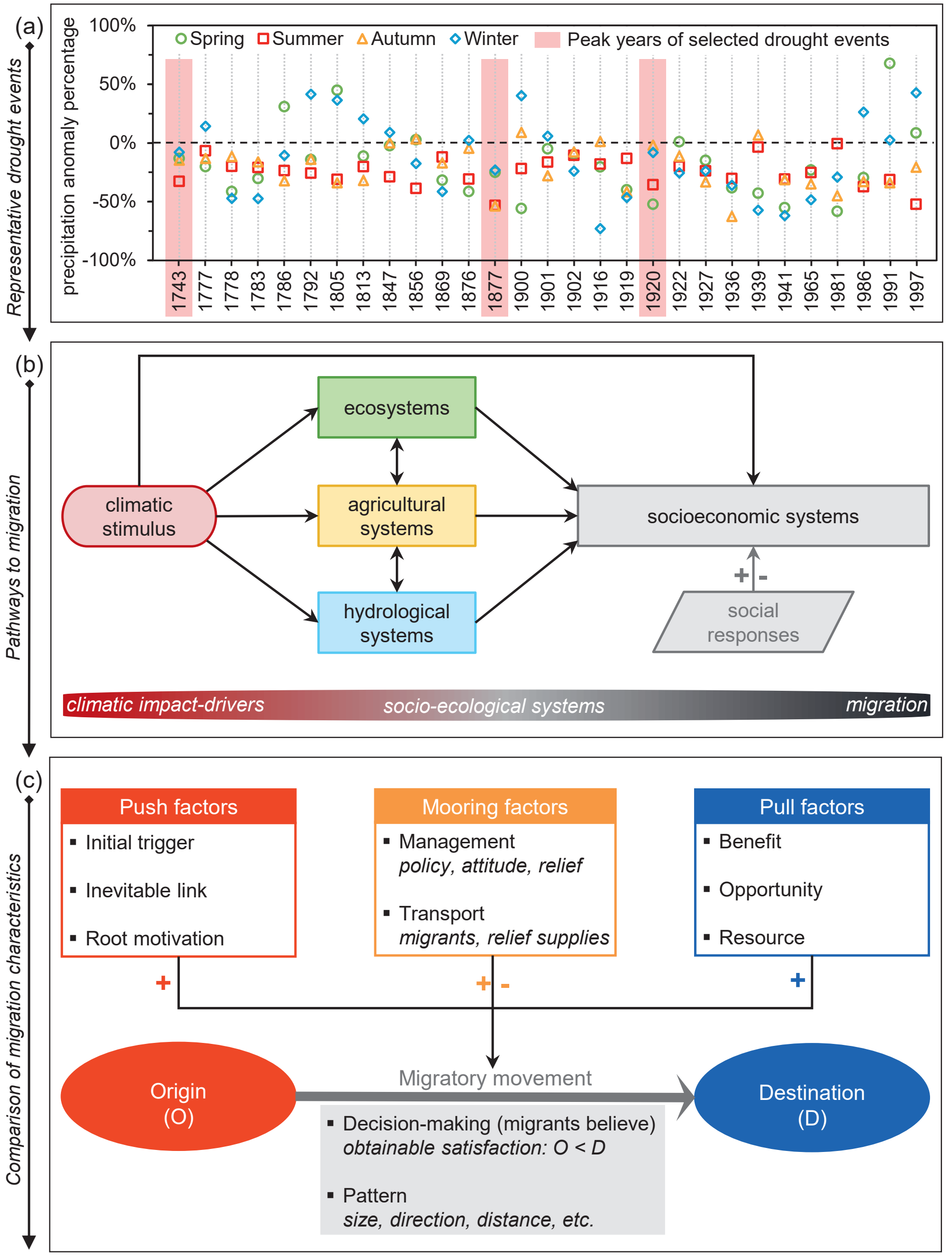

Fig. 2 – Analytic framework of this study, including (a) seasonal precipitation anomaly percentage for the 29 extremely dry years in the North China during 1736–2000, according to Zheng et al. (2018); (b) conceptual impact chains representing the propagation of a given climate stimulus through the socio-ecological systems; and (c) push-mooring-pull framework for analyzing migratory movements during each extreme drought event.

Table 1 – Data sources for drought progression, impact propagation, and migration characteristics during the three representative extreme drought events

Type		Title of data source	Citation	Events involved
Original content of drought narratives	Database	The Integrated Natural Disaster Information System of Qing Dynasty (1644–1912) [清代自然灾害信息集成数据库]	(Fang et al. 2020) (Xia 2015)	1743 event, 1877 event
	Compilation	The China meteorological disaster dictionary [中国气象灾害大典]	(Ding 2008), (Liu 2005), (Pang 2005), (Wang 2008), (Wang, Sun 2006), (Xie 2005), (Zang 2007)	1743 event, 1877 event, 1920 event
		A compendium of Chinese meteorological records of the last 3,000 years [中国三千年气象总集]	(Zhang 2013)	1743 event, 1877 event
		The continuation of disaster annals in recent China 1919–1949 [近代中国灾荒纪年续编 (1919–1949)]	(Li 1993)	1920 event
		The China disaster annals: Republic of China volume [中国灾害志・断代卷：民国卷]	(Cai 2018)	1920 event
		China historical population data and the relevant studies [中国历代人口统计资料研究]	(Yang 1996)	1920 event
	Report	China famine conditions: which I have just seen	(Lambuth 1921)	1920 event
Secondary research on impacts and social responses to drought	Monographic study	Climate, disasters, and social ecologies in the North China during the Qing Dynasty [气候, 灾害与清代华北平原社会生态]	(Xiao 2020)	1743 event, 1877 event
		The international relations of the Chinese Empire [中华帝国对外关系史]	(Morse 2006)	1877 event
		The tenth greatest disasters in early modern China [中国近代十大荒灾]	(Li et al. 1994)	1877 event, 1920 event
		The worker of Tianjin, 1900–1949	(Hershatter 1986)	1920 event
		Natural disasters and rural society in the Republic of China [民国时期自然灾害与乡村社会]	(Xia 2000)	1920 event
		Fighting famine in North China: state, market, and environmental decline, 1690s–1990s	(Li 2007)	1920 event
	Peer-reviewed article	How has ancient China responded differentially to the long and short timescale climate extremes? Case of the drought and heatwave in 1743	(Tao et al. 2024b)	1743 event
		Regional interactions in social responses to extreme climate events: a case study of the North China Famine of 1876–1879	(Zhai, Fang, Su 2020)	1877 event
		North China famine revisited: unsung native relief in the Warlord Era, 1920–1921	(Fuller 2013)	1920 event

wells; and (5) climate-induced problems in socioeconomic systems, ranging from food insecurity (e.g., famine) to health challenge (e.g., death) to social instability (e.g., migration). Accordingly, the timeline of each event could be pieced together based on the chronological order of these climate-related descriptions.

2.3. Establishing impact chains from climate to migration

An impact chain is a general representation of how a particular climatic stimulus propagates through a system via its direct and indirect impacts (ci:grasp 2.0: https://www.pik-potsdam.de/cigrasp-2/ic/ic.html). Impact chains can be applied to visualize the pathways through which a climatic impact-driver (CID), namely the physical climate system condition that affects an element of socio-ecological systems (IPCC 2021), may cascade (Estoque et al. 2022). Meanwhile, they can also be used as an analytical tool to help reveal the factors that trigger particular risks or effects in the system of concern (GIZ 2018). Although the impact chain method is considered inadequate in quantitative modeling and simulation (Menk et al. 2022) capturing, systemizing, and prioritizing factors contributing to climate risks are essential for developing cause-oriented climate risk and vulnerability assessments (CRVA, it is well-suited for literature-based studies where non-numerical data are common.

Thus, this study adopted the concept of impact chain to structure different forms of climate-related descriptions (Fig. 2b). Specifically, for a given event, every documented phenomenon of abnormal weather conditions was first considered as a potential CID of migration and the beginning of an impact chain. Then, effects of each potential CID on ecosystems, agricultural systems, hydrological systems, and socioeconomic systems were sorted in a causal order to act as intermediate links of impact chains. Lastly, impact chains starting with abnormal weather conditions and ending with migration were identified, which served as the basis for analyzing the causes of migratory movements in extreme events. In particular, social responses to climate-induced socioeconomic issues were also considered in the impact chains, as they might emerge new risks or impacts (IPCC 2022) that promoted or inhibited migration.

2.4. Comparing migratory movements in the push-pull-mooring framework

The push-pull-mooring (PPM) framework is a dominant paradigm in human migration studies, revealing the interactive factors that lead to the movement of persons from one place to another in a certain period of time (Bansal, Taylor, James 2005). It is developed from the push-pull theory (Bogue 1969), a simple causal model that has served as a theoretical basis for climate-migration research from the long-term perspective (Pei, Zhang 2014), and allows further consideration of intervening obstacles (Lee 1966) or rather mooring variables in migration decision-making (Moon 1995). In short, this framework interprets the motivations behind population movement by evaluating the negative (push) factors at the origin and the positive (pull) factors at the destination (Lewis 1982), while considering mooring factors that may facilitate or hinder migration decisions under different personal and social circumstances (Jackson 1986). Admittedly, the push-pull theory on which the PPM framework is grounded is an early contribution to the field of migration studies and, as a functionalist model, is difficult to interpret migration decisions not rooted in optimization strategies (e.g., migrating out of preferences and aspirations; de Haas 2021). However, the "push-pull" perspective is still considered valuable in the context of climate-related migration, especially for those driven by extreme events, as migrants in such circumstances are more likely to be forced to leave due to dangerous situations, rather than leaving out of individual preferences or aspirations.

In this study, the PPM framework was applied as a unifying framework for analyzing various migratory movements mentioned in different extreme drought events (Fig. 2c), to ensure comparability between cases regardless of changes in social contexts and carries of historical information. Here, the push factors at the origin were captured based on the previously established impact chains, with a particular focus on the initial triggers, inevitable links, and root motivations for drought-stricken persons to leave their places of usual residence. To be specific, CIDs that started an impact chain containing migration were regarded as initial triggers. Intermediate links that commonly existed in different impact chains of climate-related migrations were considered inevitable. Meanwhile, the last link before migration on each impact chain was a main basis for exploring root motivations. For the pull factors at the destination, special attention was given to benefits that displaced persons expected, opportunities that might help migrants out of their predicament, or other resources that were scarce in drought-stricken areas but obtainable in new places. As for the mooring factors, management and transport were taken as social elements that could have a major influence on the possibility and necessity of migrating. The former involved the government's long-term policies and short-term attitudes towards migratory movements, as well as its disaster relief efforts, while the latter referred to the means of transporting both migrants and relief supplies. Due to little documentation at the individual/household level, this study did not cover personal elements of mooring factors such as family structure and wealth.

On this basis, climate-related migrations during each extreme drought event could be characterized in a comprehensive and uniform manner by the explanatory factors in the PPM framework, along with the order of magnitude of migration flows (i.e., size) and general migration routes (i.e., direction and distance; Fig. 2c). Later, migration decision-making processes and migration patterns were compared among events to identify similarities and differences in climatic effects on migration under different circumstances, as well as to analyze possible causes of changes over time.

3. Results

3.1. From drought to migration during the 1743 event

The 1743 event, characterized by severe spring-summer droughts coupled with unbearable summer heat, occurred at a time when the national finances were doing well and public order was steady. In its peak in 1743, abnormal dry conditions affected two-thirds of the study area, and almost all plains in North China suffered from severe precipitation deficits (Fig. 3a). The lack of precipitation started in spring 1743 and intensified strongly in the following summer (Fig. 3b). Drought effects on ecosystems, agricultural systems, hydrological systems, and socioeconomic systems occurred immediately, manifesting themselves in vegetation damage and locust plagues, crop wilting and harvest failures, low water levels in rivers and wells, and famines. Simultaneously, the deadly heatwave in July 1743, during which Beijing witnessed its highest summer temperature (44.4 °C) in the past 700 years (Zhang, Demarée 2004), not only exacerbated drought effects on ecosystems and agricultural systems but also directly caused infrastructure damage (e.g., metal components of buildings melted) and widespread death (Tao et al. 2024a). Afterward, precipitation deficits persisted at a relatively moderate level over the next two seasons, worsened again in spring 1744, and ended in late July 1744 with abundant rainfall. During this period, locust plagues were reported several times as not a serious threat to crops, the drying up of wells was mentioned again but without seasonal information, and famines recurred as a result of successive poor harvests and led to deaths from toxic food substitutes (e.g., died from eating flour made from fruits of Tribulus and burnt straw).

Two waves of migration, mainly towards Beijing and eastern Inner Mongolia (Fig. 3a), occurred during the passage of summer to autumn in 1743 and at the beginning of 1744. The two waves shared the pathway of harvest failure → famine → migration, although their CIDs were not exactly identical (Fig. 3c). Specifically, the earlier wave of migration was induced by a combination of precipitation deficits and heatwaves, while precipitation deficits in 1743 were the only CID of the latter wave of migration. In the face of over tens thousands of displaced persons (Xiao 2020), the central government showed strong willingness and made considerable efforts to tackle food insecurity and subsequent displacement

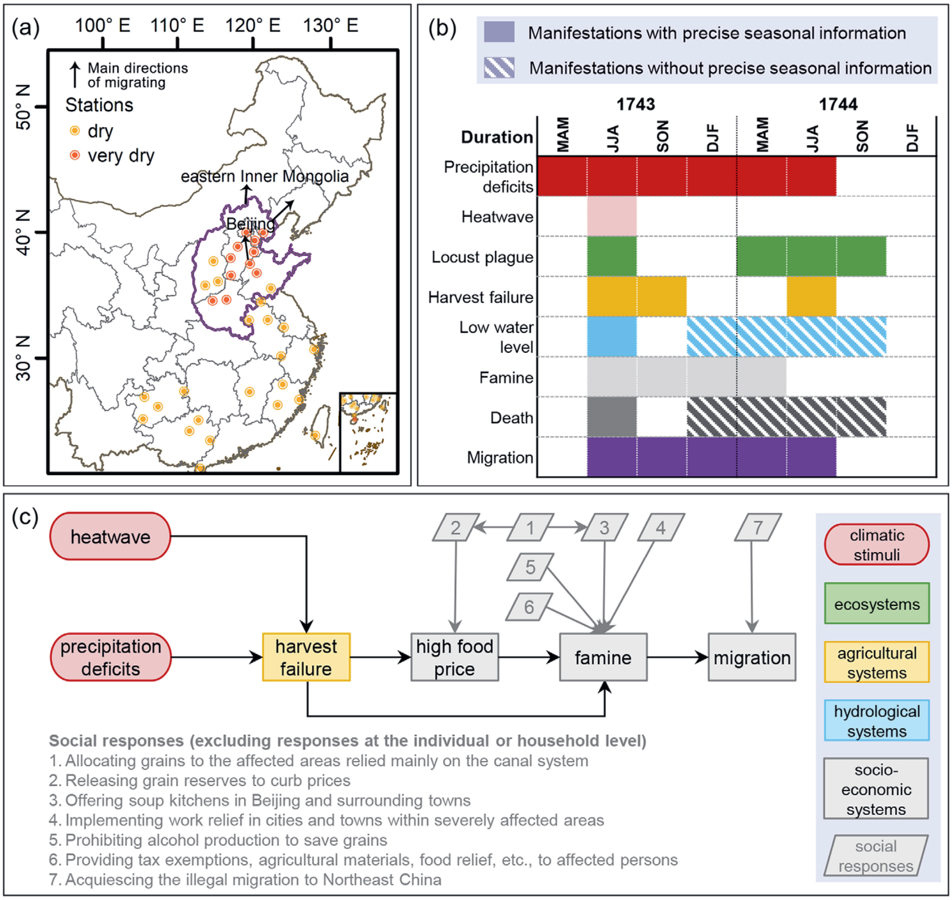

Fig. 3 – General information on the 1743 event, including (a) drought extent in 1743, according to the semi-quantitative reconstruction of dry-wet grades at 120 stations in China (Chinese Academy of Meteorological Sciences 1981), and main directions of migrating during the whole event; (b) development of abnormal weather conditions and their impacts at a seasonal scale; and (c) impact chains from climate to migration.

in drought-stricken areas. Grains surplus to requirements were allocated from less affected areas to drought-stricken areas mainly via the Grand Canal (Fig. 1), which was an arterial route for material exchange between the north and the south from the 7th century to the mid-19th century (Li 2007). Meanwhile food and work relief were organized in several cities (esp. Beijing) and towns in the hardest-hit areas. In addition, the government twice silently relaxed the prohibition on Han people relocating to Northeastern China on a limited basis, making it possible for migrants to reach the less affected and under-exploited lands in eastern Inner Mongolia. This prohibition was first issued in 1688 CE and strictly enforced from

1740, with the aim of ensuring the possession of rich land resources in Northeast China by the Manchus (i.e., the ethnic group of Qing emperors; Xiao 2020). These timely and sufficient responses succeeded in preventing catastrophic starvation and maintaining social order while unintentionally increasing the attractiveness of specific destinations to displaced persons. Nevertheless, throughout the 1743 event, neither the coincidence with deadly heatwave nor the implementation of famine mitigation made a noticeable difference to the propagation from climatic impacts to migration – heatwave did not result in intermediate links independent of existing drought effects, while multiple reactive responses to famine remained insufficient to completely disrupt the chain from hunger to migration (Fig. 1c).

3.2. From drought to migration during the 1877 event

The 1877 event, also known as the Ding-Wu Great Famine (丁戊奇荒), took place in the late Qing Dynasty when the central government was losing the capacity for addressing disasters. Overall, it was one of the most serious droughts in North China over the last 300 years due to its prolonged duration, extensive affected areas, and huge population losses (around 17% of the population in North China; Cao 1997, Hao et al. 2010). Unusual dry conditions dominated most seasons from spring 1875 to summer 1878 and affected the study area and neighboring provinces widely at its peak in 1877 (Fig. 4a, 4b). Precipitation deficits set on in the spring 1875, followed by a life-threatening heatwave in the summer (Tao, Su, Kang 2021). Drought effects on ecosystems (e.g., locust plague) and agricultural systems (e.g., harvest failure) were immediate, while its serious effects on socioeconomic systems became evident in 1876, manifesting as high food prices and food shortages due to poor harvests. The consequences of insufficient rainfall aggravated to the worst in 1877 and heatwaves reoccurred. In the face of extremely food scarcity after consecutive harvest failures, the price of food substitutes (e.g. tree roots) was even higher than grain prices in normal times. Deaths caused by famine and plague were seen almost everywhere between the summers of 1877 and 1878, and the occurrence of human cannibalism in the later phase of the food crisis revealed the collapse of social morality. Finally, the drought in most areas moderated after the summer of 1878, and the autumn crop harvest recovered to close to normal levels (Hao et al. 2010).

Massive migratory movements had already occurred in 1876 and continued between spring 1877 and summer 1878, during which over 20 million people were believed to leave their hometowns for survival (Morse 2006). As with the 1743 event, the pathway of harvest failure → famine → migration triggered essentially by precipitation deficits and exacerbated by heatwaves was considered indispensable in the impact chains from climate to migration during the 1877 event (Fig. 4c).

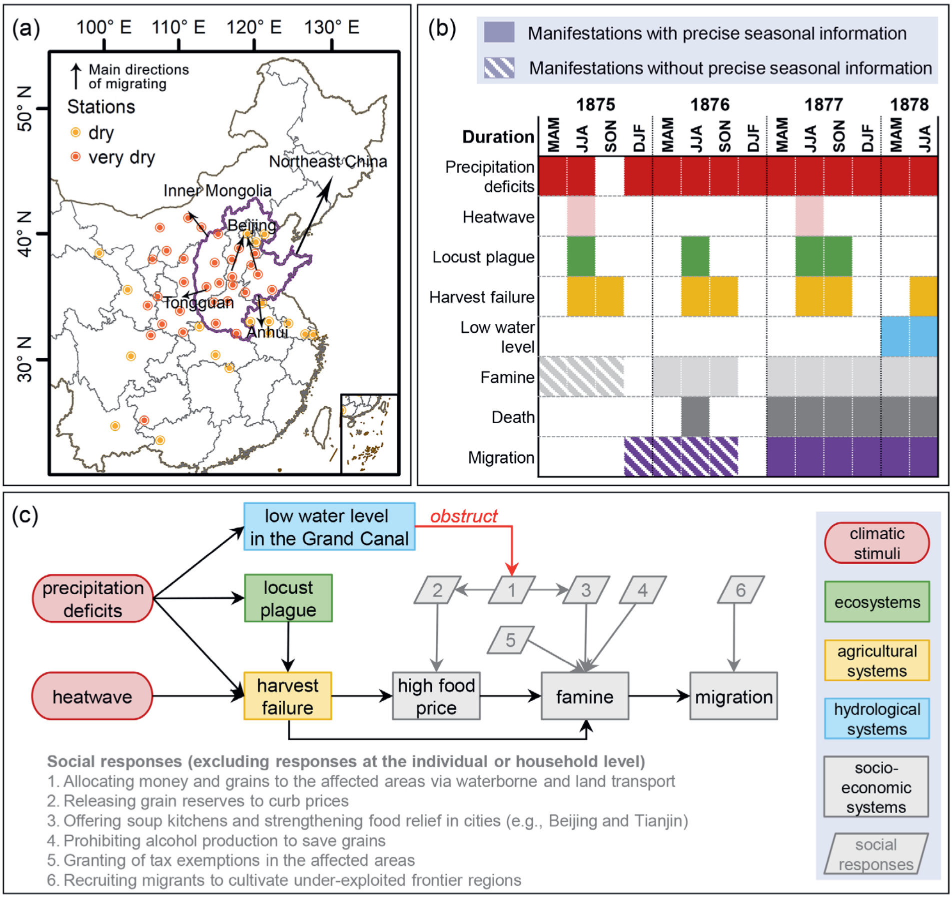

Fig. 4 – General information on the 1877 event, including (a) drought extent in 1877, according to the semi-quantitative reconstruction of dry-wet grades at 120 stations in China (Chinese Academy of Meteorological Sciences 1981), and main directions of migrating during the whole event; (b) development of abnormal weather conditions and their impacts at a seasonal scale; and (c) impact chains from climate to migration.

Differently, in this case, frequent locust plagues put additional pressure on crop performance, while low water levels in the canal system obstructed the transport of relief grain and thus hindered famine mitigation in migrants' origins. Furthermore, the route to Shanxi province, one of the hardest-hit areas that were inaccessible by canals, was described as "a nightmare to travel" (Li 2007) due to its frightful disorder. This made it difficult to transport relief grain by carts and wagons as well. Consequently, social responses to food insecurity, such as grain allocation and food relief that worked well in the previous event, were no longer effective in this event, due to a significant weakened government's capacity for disaster assessment, cross-regional coordination, and financial support (Li 2007; Xiao, Huang, Wei 2012). But nonetheless, soup kitchens in cities (e.g., Beijing) and towns (e.g., Tongguan) still contributed to the rural-to-urban migration within drought-stricken areas. Untimely and inadequate relief, together with the prolonged and widespread nature of the disaster, resulted in a spillover of displaced persons to less affected regions (e.g., Anhui) at a distance from the hardest-hit areas regardless of poor transport conditions (Xiao, Huang, Wei 2012). Meantime, the liberalization of migration policy since the 1860s (Cao 1997) and temporary recruitment efforts (Fig. 4c) encouraged migrants to relocate to under-exploited lands in the heartland of Northeast China and Inner Mongolia (Fig. 4a).

3.3. From drought to migration during the 1920 event

The 1920 event was marked by a yearlong drought amid an era of fragmentation, military conflict, and foreign interference. In terms of affected areas and populations in North China, this event could almost be viewed as a repeat of the 1877 event (Li et al. 1994). Precipitation deficits started in the autumn 1919, lasted for the following five seasons, and got alleviation after spring 1921 (Fig. 5b). When the event reached its peak in 1920, the lack of precipitation was reported in the entire study area and neighboring provinces (Fig. 5a). Drought effects on ecosystems, agricultural systems, hydrological systems and socioeconomic systems were reported intensively in autumn 1919 and summer 1920. At that time, the food system in North China had become too fragile to endure the combined shocks of dryness, locust plague, etc., due to the expansion of cash crops and opium after decades of wars (Li et al. 1994). As a result, the vast majority of Beijing, Hebei and Henan provinces suffered from crop harvests that were at least 50% below average in two consecutive harvest seasons, leading to severe food shortages and massive population deaths from starvation, toxic food (e.g., potato tops) and diseases (Lambuth 1921, Li et al. 1994). The huge amount of starving people had no choice but to sell their clothes, livestock, farming tools, land, and even family members (into concubines, servant, prostitutes, etc.) at very low prices in exchange for limited food or travelling expenses to escape from hunger. However, a large number of them were still killed by hunger, epidemic, and coldness in the winter of 1920/1921, even though that winter was described as "not being particularly harsh" (Lambuth 1921, Xia 2000).

A large outflow of population from the drought-stricken areas began in summer 1920 and lasted until winter 1920/1921, involving approximately one million of affected individuals (Yang 1996). Precipitation deficits were the only CID in the impact chain of climate-related migration in this event, but the pathway of harvest failure → famine → migration was found to be as inescapable as in earlier

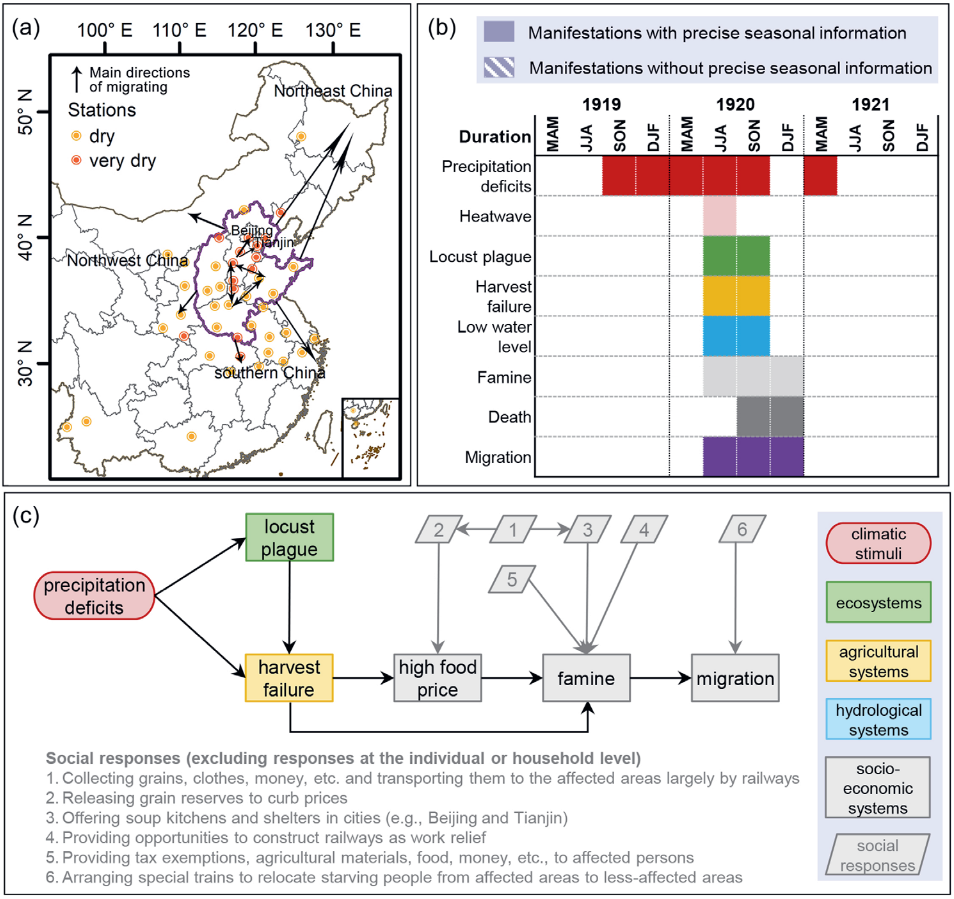

Fig. 5 – General information on the 1920 event, including (a) drought extent in 1920, according to the semi-quantitative reconstruction of dry-wet grades at 120 stations in China (Chinese Academy of Meteorological Sciences 1981), and main directions of migrating during the whole event; (b) development of abnormal weather conditions and their impacts at a seasonal scale; and (c) impact chains from climate to migration.

events, with locust plagues likewise engaged in the manner of aggravating unsatisfactory crop performance (Fig. 5c). In addition, local authorities, regional military leaders (i.e., warlords), and non-government relief organizations (e.g., China International Famine Relief Commission) replaced the central government's dominance in disaster response at the time, but their efforts to alleviate famines remained traditional and insufficient (Lambuth 1921, Fuller 2013). Consequently, major cities in the hardest-hit areas (e.g., Beijing and Tianjin) continued to be popular destinations for starving people owing to the availability of soup kitchens and shelters, and provinces adjacent to North China were again hit by the influx of migrants (Fig. 5a). The involvement of railways, a more time-efficient and drought-resilient transport mode than canals, in disaster relief was a unique feature of the 1920 event, as reflected in the transport of both relief supplies and displaced persons. Railway construction in China since 1881 had not only strengthened intra-regional connections in North China but also enhanced its accessibility to Northeast China, Northwest China, and the Yangtze River Basin during the 1920 event (Li 1993, American National Red Cross 1921; Fig. 1). Accordingly, moving along the railways became an emerging pattern of migration. Some migrants wandered within the affected areas and gathered at train stations in the hope of obtaining relief grain, while others traveled by trains, either spontaneously or organized, to make a living in unaffected regions (e.g., Zhejiang) or to resettle in the sparsely settled lands in the hinterlands of Northeast and Northwest China (Fig. 5a).

4. Discussion

4.1. Cross-event comparison of migration pattern and decision-making process in North China

Section 3 have provided pictures of drought propagations and migratory movements in North China in the 1743, 1877, and 1920 events, respectively. Here, drought severity, PPM factors of migration decisions, and consequent migration characteristics were abstracted from each event and presented together in Table 2, in order to systematically compare decision-making processes under different circumstances and analyze possible causes of similarities and differences in migration patterns.

Indicators of drought severity implied dissimilarities between the extreme events of 1743, 1877 and 1920 in terms of duration, extent, and intensity (Table 2). Amidst those events, the 1743 event was characterized by a relatively short duration (six months), limited coverage (76.2% of stations), and low intensity of abnormal dry conditions (Pa for summer 1743: −32.7%), but it was accompanied by the worst heatwave. The 1877 event was highlighted by the most prolonged (14 seasons) and intense precipitation deficits (Pa for summer 1877: −53.2%), along with extensive affected areas (95.2% of stations) and severe summer heat. As for the 1920 event, it experienced a continuous lack of rainfall (8 seasons) that had similar coverage to the 1877 event (100% of stations) and similar intensity to the 1743 event (Pa for summer 1920: −35.6%).

Despite distinct severity of droughts, commonalities were found in both decision-making processes and patterns of migration (Table 2). Comparisons in the PPM framework revealed the common push and pull factors across all three events that prompted drought-stricken populations to migrate. For push factors, insufficient precipitation was identified as the CID that initially triggered migratory movements. Crop failures and subsequent food crises were considered inevitable links in the pathway from climate to migration. Escaping from the life-threatening hunger was the root motivation for individuals fleeing from their origins. Neither compound or secondary hazards of drought nor social responses to drought were able to significantly influence the impact chain of precipitation deficits → harvest failure → famine → migration in North China during the mid-18th to the early 20th centuries. Hence, although drought severity and socioeconomic situations differed from case to case, places where starving people could be fed directly, get jobs to earn food, or obtain resources for food production were always attractive, making food relief, work opportunity, and uncultivated land the identical pull factors for migration destinations. As a result, three similar directions of migratory movements were observed across drought events: (1) flocking to cities, towns, etc., within the affected areas, where food and/or work relief were available; (2) wandering through the affected areas and gradually spreading to nearby less affected areas; and (3) relocating to under-exploited lands outside the affected areas, where the human-land contradictions were less tension.

However, changes in management and transport, two mooring factors that could increase or decrease the possibility and necessity of moving, contributed to differences in the size and distance of migration among the events. During the sociocultural transformation between the mid-18th and the early 20th centuries, North China witnessed the weakening of state capacity, the shift in the official attitude to population movement, the functional decline in the canal system, and the emergence of the railway system as an important means of transport. Consequently, a negative relationship was found between the size of migration flow and the efforts of disaster relief, while the distance of movement often increased with the relaxation of migration policy and the improvement of transport conditions (Table 2). As Lewis (1982) argued, "the basis of any decision to migrate is the households' belief that the level of satisfaction obtainable elsewhere is greater than its present level of satisfaction". Timely and sufficient in situ famine mitigation, typified by the positive government actions in the 1743 event, could effectively alleviate the pressure of life-threatening hunger on drought-stricken populations, making migration less necessary for many starving people. Regarding migration policies (incl. long-term regulations and short-term attitudes) and transport conditions, they acted more as thresholds for migratory movements. As demonstrated in the 1920 event, migrating across multiple administrative and even geographical boundaries became possible when lax mobility rules and relatively convenient transport conditions reduced the cost of individuals to move, especially over long distances. In summary, the bidirectional effect of mooring factors on the possibility and necessity of affected individuals to could explain

Table 2 – Indicators of drought severity, push-pull-mooring (PPM) factors of migration decisions, and characteristics of migration patterns in North China during the extreme events of 1743, 1877, and 1920

Elements			1743 event	1877 event	1920 event
Drought severity	Duration	Onset	Spring 1743	Spring 1875	Autumn 1919
		Cessation	Summer 1744	Summer 1878	Spring 1921
	Extent [1)]	Dry	76.19% in 1743	95.24% in 1877	100% in 1920
		Very dry	57.14% in 1743	80.95% in 1877	52.38% in 1920
	Intensity [2)]	Peak	Summer 1743	Summer 1877	Summer 1920
		Variance (Pa)	–32.72%	–53.22%	–35.56%
	Concurrent hazards	Compound	Deadly heatwave	Severe heatwave	Heatwave
		Secondary	Locust plague	Destructive insect plague	Destructive insect plague
PPM factors	Push	Initial trigger	Precipitation deficits	Precipitation deficits	Precipitation deficits
		Inevitable links	Harvest failure, famine	Harvest failure, famine	Harvest failure, famine
		Root motivation	Escape from hunger	Escape from hunger	Escape from hunger
	Pull	Benefit	Food relief	Food relief	Food relief
		Opportunity	Work relief	Work relief	Work relief
		Resource	Uncultivated land	Uncultivated land	Uncultivated land
	Mooring (management)	Long-term	Strictly restrict mobility	Loosely restrict mobility	Barely restrict mobility
		Short-term	Connive migration	Encourage migration	Encourage migration
		Relief	Very strong	Very weak	Weak
	Mooring (transport)	Migrants	On foot	On foot, by boat	On foot, by train
		Relief supplies	Canals (mainly)	Canals, carts, wagons	Railways (largely)

Elements		1743 event	1877 event	1920 event
Migration patterns	Size [3] (total population)	10^4 migrants ($0.82 \times ^{108}$ in 1776)	10^7 migrants ($1.05 \times ^{108}$ in 1880)	10^6 migrants ($1.23 \times ^{108}$ in 1910)
	Direction	Flock to cities and towns	Flock to cities and towns	Flock to cities and towns
		Spread to nearby less affected areas	Spread to nearby less affected areas	Spread to nearby less affected areas
		Relocate to under-exploited lands	Relocate to under-exploited lands	Relocate to under-exploited lands
	Distance	Short	Medium	Long

Note:

1. The extent of each drought was shown as the percentage of stations reporting dry (very dry) among the 21 stations in North China in the year when the event peaked, based on Chinese Academy of Meteorological Sciences (1981). Figures 3a, 4a and 5a have presented the spatial distribution of these stations.
2. The intensity of each drought event was represented by the precipitation anomaly percentage (Pa) for the season in which the event reached its peak, according to Zheng et al. (2018).
3. For a straightforward cross-event comparison, the size of migrants during each event was presented here only in an order of magnitude. The total population of North China in the nearest years to 1743, 1877, and 1920 derived from Zhang et al. (2022)this study first identified the environmental factors that significantly affect the population distribution through Geodetector analysis and then constructed a population spatial distribution model based on the random forest regression algorithm. Finally, with this model and historical population data that were examined and corrected by historians, gridded population distributions with a spatial resolution of 10 km by 10 km in the traditional cultivated region of China (TCRC, hereafter, in order to provide a rough proportion of the total population migrated.

why the pattern of drought-induced migration in North China was not always determined by the extremity of climate hazards, although such effect was not enough to eliminate the influence of push and pull factors on the overall desire to migrate.

4.2. Drought, hunger, and migration: a definitive outcome unique to North China?

When placing the drought-migration nexus uncovered above into a broader context, it is not difficult to see that the pathway from drought to migration via hunger is not unique to North China, at least on the eve of modernity. Barely a year after the onset of the 1920 North China drought, an exceptional drought with similar characteristics challenged societies on the other side of the Eurasian continent, i.e., the European drought of 1921. With regard to climatic conditions, this European drought also stood out for its yearlong uninterrupted precipitation deficits (i.e., from autumn 1920 to autumn 1921), its coincidence with remarkable summer heatwave, and its wide spatial extent (i.e., across Europe; van der Schrier et al. 2021). Particularly in Germany, it has been detected as one of the most outstanding droughts since 1500 CE, considering both the extremity of dryness and the magnitude of impacts (Glaser, Kahle 2020).

The climatic information and migration outflows shown in Figure 6, together with drought-related reports from weather chronicles and newspapers, offered a glimpse of climate-society interactions in Germany at that time. From late autumn 1920, drought effects arose gradually in ecosystems (e.g., withered meadow, insect plague, and wildfire), agricultural systems (e.g., fodder shortage and harvest failure) and hydrological systems (e.g., low river level and insufficient reservoir storage) and culminated in socioeconomic systems during the extraordinary hot summer of 1921 (Nees, Kehrer 2002; Bundesanstalt für Gewässerkunde 2025). In addition to drastic increases in heat-related infant deaths, exorbitant prices of basic foodstuffs also plagued the vulnerable post-war society (Berliner Tageblatt 1921). Despite a series of consultations and negotiations surrounding harvest failures and subsequent escalation of food prices (Freiburger Zeitung 1921a), food crisis still turned unmanageable as the effectiveness of disaster relief was generally diminished under the pressure of war reparations, restrictions imposed by the Treaty of Versailles, and overall tough sociopolitical circumstances. Moreover, pervasive profiteering and panic buying worsened the predicament (Freiburger Zeitung 1921c), and some governmental actions, such as abolishing official bread prices and raising wages, even further pushed up bread prices by 40% (Freiburger Zeitung 1921a, 1921b). In this situation, hunger became an everyday experience for many, and moving elsewhere, especially where lands and/or jobs were more available, was a popular escape from poverty and starvation. Accordingly, German emigrants exceeded 23,000 in 1921 alone, almost reached 37,000 in 1922, and surged to over 115,000 in 1923 (Statistisches Reichsamt 1933), a number last seen in the early 1890s (Fig. 6b). North America was the destination for over three-quarters of these emigrants (Lumpe, Lumpe 2017).

Nevertheless, the comparison between North China and Germany is not intended to strengthen the impression that migration is doomed to occur in the face of extreme droughts, regardless of human agency and ability to cope with disaster. On the contrary, the propagation from climatic stimuli to migration is possible to stop partially or even completely when in situ mitigation efforts, especially those protecting drought-stricken populations from hunger, take timely and adequate effect, as in the 1743 North China drought where positive government actions prompted many starving people to stay and wait for relief.

In this regard, another outstanding drought in Germany, which occurred a decade prior to the 1921 European drought and also coincided with deadly summer heatwave, provides additional empirical evidence. Throughout 1911, although drought and heat damage to ecosystems, hydrological systems, agricultural

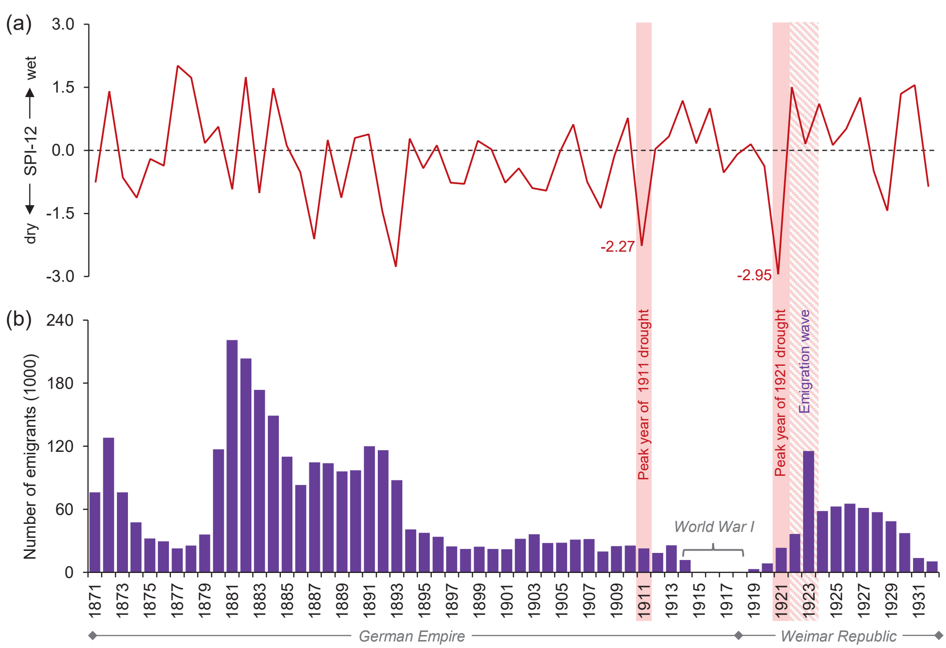

Fig. 6 – Dry-wet conditions and migratory movements in Germany during 1871–1932, including (a) the reconstructed 12-month standardized precipitation index (SPI-12) for Germany (Glaser, Kahle 2020), and (b) the official statistics on German emigrants registered at German ports (mainly Hamburg and Bremen) and other European ports (e.g., ports in the Netherlands, Belgium, and France; Statistisches Reichsamt 1890; 1900; 1910; 1933)

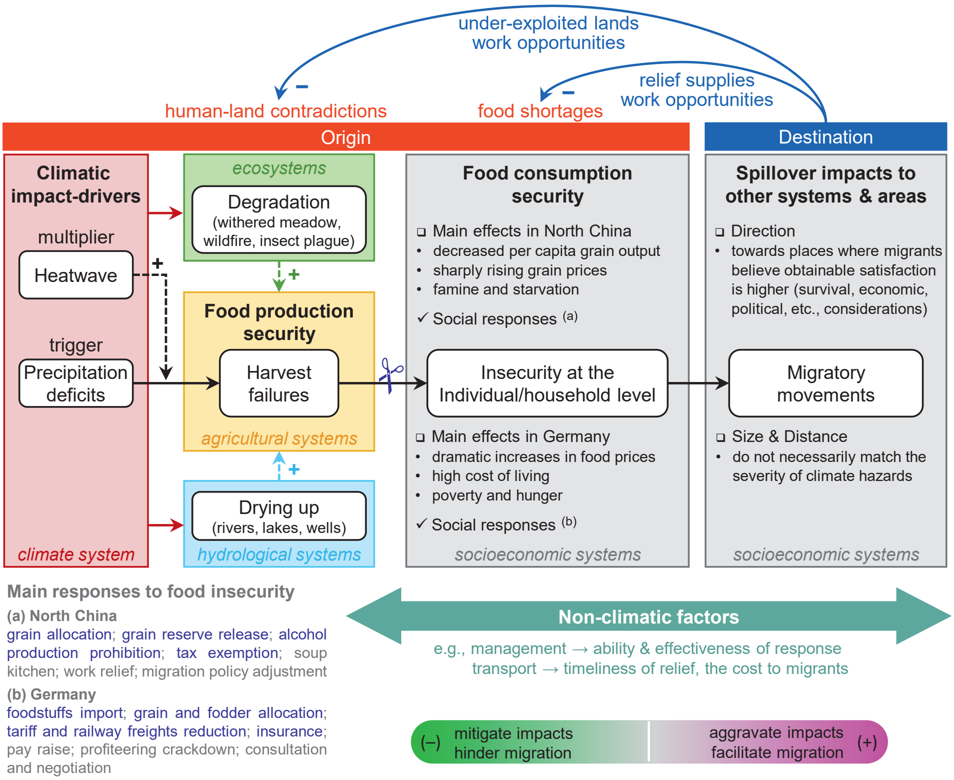

Fig. 7 – Conceptual model of drought-migration nexus in North China and Germany with food security at its core. The breakdown of food security into production security and consumption security was based on Fang et al. (2015).Bremen) and other European ports (e.g., ports in the Netherlands, Belgium, and France; Statistisches Reichsamt 1890; 1900; 1910; 1933)

systems, and health were widely reported as it was in 1921 (Berliner Tageblatt 1911a, 1911b; Neue Hamburger Zeitung, 1911; Nees, Kehrer 2002; Bundesanstalt für Gewässerkunde 2025), prices of basic foodstuffs except for perishable dairy products remained relatively stable, and the number of German emigrants maintained its downward trend since 1890s (Fig. 6b). An explanation was that, in addition to slightly milder precipitation deficits (Fig. 6a), the 1911 drought took place in the context of better governance and a more resilient society. Unlike the fraught years after World War I, trade and import of foodstuffs were convenient and extensive in the early 1910s (Hungerland, Wolf 2022)with new data on all products, all trade partners, quantities, and values, at annual frequency, 1880–1913. Historical product categories are reclassified according to the Standard International Trade Classification (SITC, and coordination between surplus and shortage areas were efficient within a more structured political framework.

Additionally, a state-sponsored insurance system also offered individuals some protection against damages. All of these contributed to timely compensation of harvest losses, effective food price containment, and sufficient assistance to those suffering. Consequently, government's responses to drought-induced increases in living expenses (e.g., reducing tariff and railway freights on basic foodstuffs) were considered productive (Daily Herald 1911). Poverty and starvation were less of a concern, and moving seemed less necessary and worthwhile.

Despite different types of migration in North China (internal) and Germany (external), a conceptual model of drought-migration nexus shared by the five cases described above could be distilled, at the core of which was food security (Fig. 7). Here, the state of food was considered insecure at two levels – low availability and low access – and two processes were identified in the propagation of climate impacts to local societies. The first process was the progression from climate shocks to food production insecurity (i.e., low availability), which took place outside the socioeconomic systems. Within this process, insufficient precipitation served as the initial trigger for harvest failures, the sign of food production insecurity; while heatwaves acted as a multiplier and, together with the environmental consequences of drought, expedited the process. The second process was the development from food production insecurity to food consumption insecurity (i.e., low access), which largely depended on the available resources and organizational capacity of societies. In other words, non-climatic factors, as represented by management and transport, began to play an active role.

Migration was not the first option for many when sufficient allocable resources, efficient cross-regional coordination, and speedy transport of relief supplies could minimize the impact of harvest failures on food consumption security to a manageable level, as seen in the 1743 North China drought and the 1911 German drought. However, if in situ mitigation failed to address imbalances in local food supply and demand, food access for affected individuals/households would gradually decline to a survival-threatening level. At this point, despite great attention and considerable effort, relief was always insufficient compared with actual needs, and leaving became the last choice for those still able to act. Whether crossing national borders or not, such movements showed common directions: (1) heading to places where food was obtainable directly or through work, with the intention of temporarily escaping from hunger; and (2) relocating to places where resources or opportunities were readily accessible, in the hope of re-establishing stable livelihoods.

5. Conclusion

To better understanding the drought-migration nexus in the context of social change, this study revisited climate-society interactions during the exceptional droughts of 1743, 1877, and 1920 in North China and compared characteristics of climate-related migration at different episodes of the significant sociocultural transformation since the mid-18th century. Based on multiple sources of written documents, the retrospect found that:

(1) Insufficient precipitation was the initial trigger of migration, as evidenced by the impact chain of precipitation deficits → harvest failure → famine → migration being the only pathway leading to migration, independent of the severity of concurrent hazards (e.g., heatwave and insect plague).
(2) Fleeing life-threatening hunger was the root motivation that pushed drought-stricken populations to leave for places with higher access (e.g., disaster relief) or availability (e.g., land resources) for food, such as nearby cities and under-exploited remote areas.
(3) Management and transport showed mooring effects on the size and distance of migration, contributing to the mismatch between drought extremity and migration characteristics. Competent management and efficient transportation would ensure timely and adequate disaster relief and thus reduce the necessity for leaving; while relaxed migration policies and improved transport conditions could lower the threshold and cost of moving, thereby increasing the maximum distance of migration.

Moreover, the outstanding droughts of 1911 and 1921 in Germany were incorporated into a broader comparison, as they had similar climatic characteristics to North China droughts but showed partially different outcomes due to divergent responses. The comparison demonstrated that the abovementioned pathway of drought-induced migration was observable in many sociocultural contexts, with precipitation deficits, heatwaves, and disaster responses acting as the trigger, multiplier, and regulator of migratory movements, respectively. Although common, the propagation from drought to migration was preventable when in situ mitigation accomplished the core task of ensuring individual/household food consumption security, which required sufficient allocable resources, efficient cross-regional coordination, and speedy transport of supply. However, once hunger spread, relief efforts would lose the persuasiveness of getting starving people to stay and wait.

References

AMERICAN NATIONAL RED CROSS (1921): Report of the China famine relief, American Red Cross, October, 1920 – September, 1921. America National Red Cross, Shanghai.

BANSAL, H.S., TAYLOR, S.F., JAMES, Y.S. (2005): “Migrating” to new service providers: toward a unifying framework of consumers’ switching behaviors. Journal of the Academy of Marketing Science, 1, 33, 96–115. https://doi.org/10.1177/0092070304267928

BENSON, L., PETERSEN, K., STEIN, J. (2007): Anasazi (pre-columbian native-american) migrations during the middle-12th and late-13th centuries – were they drought induced? Climatic Change, 1–2, 83, 187–213. https://doi.org/10.1007/s10584-006-9065-y

BERLINER TAGEBLATT (1911a): Berliner Tageblatt und Handels-Zeitung, edition from 23.07.1911, https://zefys.staatsbibliothek-berlin.de/list/title/zdb/27646518/-/1911/#jul (10.2.2025).

BERLINER TAGEBLATT (1911b): Berliner Tageblatt und Handels-Zeitung, edition from 01.08.1911, https://zefys.staatsbibliothek-berlin.de/list/title/zdb/27646518/-/1911/#aug (10.2.2025).

BERLINER TAGEBLATT (1921): Berliner Tageblatt und Handels-Zeitung, edition from 30.07.1921, https://zefys.staatsbibliothek-berlin.de/list/title/zdb/27646518/-/1921/#jul (1.3.2023).

BOGUE, D.J. (1969): Principles of demography. Wiley, New York.

BUNDESANSTALT FÜR GEWÄSSERKUNDE (2025): Undine: Information platform on hydrological extreme events (floods, low flow), https://undine.bafg.de/index_en.html (16.7.2025).

CAI, Q. (2018): The China disaster annals: Republic of China volume. China Social Sciences Publishing House, Beijing.

CAO, S. (1997): History of migrations in China (volume 6). Fujian People’s Publishing House, Fuzhou.

CHINESE ACADEMY OF METEOROLOGICAL SCIENCES (1981): Yearly charts of dryness/wetness in China for the last 500-year period. SinoMaps Press, Beijing.

DAILY HERALD (1911): Cheaper Food, edition from 20.09.1911, https://trove.nla.gov.au/newspaper/article/105336442/10495690 (18.7.2025).

DAMETTE, O., GOUTTE, S., PEI, Q. (2020): Climate and nomadic migration in a nonlinear world: evidence of the historical China. Climatic Change, 4, 163, 2055–2071. https://doi.org/10.1007/s10584-020-02901-4

DE HAAS, H. (2021): A theory of migration: the aspirations-capabilities framework. Comparative Migration Studies, 1, 9, 8. https://doi.org/10.1186/s40878-020-00210-4

DING, Y. (2008): The China meteorological disaster dictionary: Comprehensive volume. China Meteorological Press, Beijing.

DING, Y., WANG, S., ZHENG, J., WANG, H., YANG, X. (2013): China natural geography monograph series: Chinese climate. Science Press, Beijing.

DRAKE, B.L. (2017): Changes in north atlantic oscillation drove population migrations and the collapse of the Western Roman Empire. Scientific Reports, 1, 7, 1227. https://doi.org/10.1038/s41598-017-01289-z

ESTOK, S.C. (2023): Climate change and migration. Neohelicon, 1, 50, 239–251. https://doi.org/10.1007/s11059-023-00686-w

ESTOQUE, R.C., OOBA, M., TOGAWA, T., YOSHIOKA, A., GOMI, K., NAKAMURA, S., TSUJI, T., HIJIOKA, Y., WATANABE, M., KITAHASHI, M. (2022): Climate impact chains for envisaging climate risks, vulnerabilities, and adaptation issues. Regional Environmental Change, 4, 22, 133. https://doi.org/10.1007/s10113-022-01982-4

FALCO, C., DONZELLI, F., OLPER, A. (2018): Climate change, agriculture and migration: a survey. Sustainability, 5, 10, 1405. https://doi.org/10.3390/su10051405

FANG X., HE F., WU Z., ZHENG J. (2021): General characteristics of the agricultural area and fractional cropland cover changes in China for the past 2000 years. Acta Geographica Sinica, 7, 76, 1732–1746.

FANG, X., SU, Y., YIN, J., TENG, J. (2015): Transmission of climate change impacts from temperature change to grain harvests, famines and peasant uprisings in the historical China. Science China Earth Sciences, 8, 58, 1427–1439. https://doi.org/10.1007/s11430-015-5075-9

FANG, X., ZHAO, W., SONG, R., CHEN, S., YE, Y. (2020): The integrated natural disaster information system of the Qing Dynasty. The Social History Research Journal, 1, 29–46.

FAR EASTERN GEOGRAPHICAL ESTABLISHMENT, DINGLE, J.E. (1917): Railway Map of China. (inset) Sketch Map of Manchuria. North-China Daily News & Herald, Ltd., Shanghai.

FREIBURGER ZEITUNG (1921a): Freiburg 1784–1943, edition from 10.8.1921, https://fz.ub.uni-freiburg.de/show/fz.cgi?cmd=showmonth&year=1921&month=08&project=3 (1.3.2023).

FREIBURGER ZEITUNG (1921b): Freiburg 1784–1943, edition from 11.8.1921, https://fz.ub.uni-freiburg.de/show/fz.cgi?cmd=showmonth&year=1921&month=08&project=3 (1.3.2023).

FREIBURGER ZEITUNG (1921c): Freiburg 1784–1943, edition from 13.8.1921, https://fz.ub.uni-freiburg.de/show/fz.cgi?cmd=showmonth&year=1921&month=08&project=3 (1.3.2023).

FUERTE CELIS, M.D.P., BOLAÑOS GUERRA, B., OLIVERA-VILLARROEL, S.M. (2024): Drought: the silent evil of Central American migration in the period 1990 to 2019. Estudios Fronterizos, 25. https://doi.org/10.21670/ref.2403139

FULLER, P. (2013): North China famine revisited: unsung native relief in the Warlord Era, 1920–1921. Modern Asian Studies, 3, 47, 820–850. https://doi.org/10.1017/S0026749X12000534

GE, J. (1997): History of migrations in China (volume 1). Fujian People's Publishing House, Fuzhou.

GILBERT, G., MCLEMAN, R. (2010): Household access to capital and its effects on drought adaptation and migration: a case study of rural Alberta in the 1930s. Population and Environment, 1, 32, 3–26. https://doi.org/10.1007/s11111-010-0112-2

GIZ (2018): Climate risk assessment for ecosystem-based adaptation – a guidebook for planners and practitioners. GIZ, Bonn.

GLASER, R., HIMMELSBACH, I., BÖSMEIER, A. (2017): Climate of migration? How climate triggered migration from southwest Germany to North America during the 19th century. Climate of the Past, 11, 13, 1573–1592. https://doi.org/10.5194/cp-13-1573-2017

GLASER, R., KAHLE, M. (2020): Reconstructions of droughts in Germany since 1500 – combining hermeneutic information and instrumental records in historical and modern perspectives. Climate of the Past, 4, 16, 1207–1222. https://doi.org/10.5194/cp-16-1207-2020

GRAY, C., HOPPING, D., MUELLER, V. (2020): The changing climate-migration relationship in China, 1989–2011. Climatic Change, 1, 160, 103–122. https://doi.org/10.1007/s10584-020-02657-x

GUTMANN, M. P., BROWN, D., CUNNINGHAM, A.R., DYKES, J., LEONARD, S.H., LITTLE, J., MIKECZ, J., RHODE, P.W., SPIELMAN, S., SYLVESTER, K.M. (2016): Migration in the 1930s: beyond the Dust Bowl. Social Science History, 4, 40, 707–740. https://doi.org/10.1017/ssh.2016.28

GUTMANN, M.P., DEANE, G.D., LAUSTER, N., PERI, A. (2005): Two population-environment regimes in the Great Plains of the United States, 1930–1990. Population and Environment, 2, 27, 191–225. https://doi.org/10.1007/s11111-006-0016-3

HAN, J., YANG, Y. (2021): The socioeconomic effects of extreme drought events in northern China on the Ming dynasty in the late fifteenth century. Climatic Change, 3–4, 164, 26. https://doi.org/10.1007/s10584-021-02972-x

HAO, Z., ZHENG, J., WU, G., ZHANG, X., GE, Q. (2010): 1876–1878 severe drought in North China: facts, impacts and climatic background. Chinese Science Bulletin, 26, 55, 3001–3007. https://doi.org/10.1007/s11434-010-3243-z

HERMANS, K., GARBE, L. (2019): Droughts, livelihoods, and human migration in northern Ethiopia. Regional Environmental Change, 4, 19, 1101–1111. https://doi.org/10.1007/s10113-019-01473-z

HERSHATTER, G. (1986): The workers of Tianjin 1900-1949. Stanford University Press, Stanford.

HOGGARTH, J.A., RESTALL, M., WOOD, J.W., KENNETT, D.J. (2017): Drought and its demographic effects in the Maya Lowlands. Current Anthropology, 1, 58, 82–113. https://doi.org/10.1086/690046

HUNGERLAND, W.-F., WOLF, N. (2022): The panopticon of Germany's foreign trade, 1880–1913: New facts on the first globalization. European Review of Economic History, 4, 26, 479–507. https://doi.org/10.1093/ereh/heac001

IPCC (2021): Climate change 2021 – the physical science basis: Working Group I contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

IPCC (2022): Climate change 2022 – impacts, adaptation and vulnerability: Working Group II contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

IVANOVA, A., SINGH, D., RAI, P., RICHARDS, C., VASCONCELOS, H., GOLDSBY, M. (2024): Climate hazards and human migration: literature review. Environmental Research: Climate, 4, 3, 042002. https://doi.org/10.1088/2752-5295/ad6fc4

JACKSON, J.A. (1986): Migration (aspects of modern sociology: social processes). Longman, London and New York.

JENNINGS, J.A., GRAY, C.L. (2015): Climate variability and human migration in the Netherlands, 1865–1937. Population and Environment, 3, 36, 255–278. https://doi.org/10.1007/s11111-014-0218-z

KACZAN, D.J., ORGILL-MEYER, J. (2020): The impact of climate change on migration: a synthesis of recent empirical insights. Climatic Change, 3–4, 158, 281–300. https://doi.org/10.1007/s10584-019-02560-0

KONG, Q., GUERREIRO, S.B., BLENKINSOP, S., LI, X.-F., FOWLER, H.J. (2020): Increases in summertime concurrent drought and heatwave in Eastern China. Weather and Climate Extremes, 28, 100242. https://doi.org/10.1016/j.wace.2019.100242

LAMBUTH, W.R. (1921): China famine conditions: which I have just seen. American Committee for China Famine Fund, New York.

LEE, E.S. (1966): A theory of migration. Demography, 3, 47–57. https://doi.org/10.2307/2060063

LEWIS, G.J. (1982): Human migration: A geographical perspective. Routledge, London.

LI, L. M. (2007): Fighting famine in North China: state, market, and environmental decline, 1690s–1990s. Standford University Press, Stanford. https://doi.org/10.1515/9781503625686

LI, W. (1993): The continuation of disaster annals in recent China 1919–1949. Hunan Education Publishing House, Changsha.

LI, W., CHENG, X., LIU, Y., XIA, M. (1994): The tenth greatest disasters in early modern Chin. Shanghai People's Press, Shanghai.

LIU, Q. (2005): The China meteorological disaster dictionary: Shanxi volume. China Meteorological Press, Beijing.

LUMPE, C., LUMPE, C. (2017): German emigration via Bremen in the Weimar Republic (1920–1932). Working Paper 53–2017. MAGKS Joint Discussion Paper Series in Economics.

MA, Y. (2016): The opening of contemporary railways and rural migration in North China. Journal of Zhengzhou University, 2, 49, 112–116.

MCLEMAN, R. (2018): Thresholds in climate migration. Population and Environment, 4, 39, 319–338. https://doi.org/10.1007/s11111-017-0290-2

MCLEMAN, R., FONTANELLA, F., GREIG, C., HEATH, G., ROBERTSON, C. (2022): Population responses to the 1976 South Dakota drought: insights for wider drought migration research. Population, Space and Place, 2, 28, e2465. https://doi.org/10.1002/psp.2465

MENK, L., TERZI, S., ZEBISCH, M., ROME, E., LÜCKERATH, D., MILDE, K., KIENBERGER, S. (2022): Climate Change Impact Chains: A Review of Applications, Challenges, and Opportunities for Climate Risk and Vulnerability Assessments. https://doi.org/10.1175/WCAS-D-21-0014.1

MERCHANT, E.K., GRACE, K. (2024): Attending to history in climate change–demography research. Vienna Yearbook of Population Research, VYPR 2024, 2024. https://doi.org/10.1553/p-hzdz-jega

MOON, B. (1995): Paradigms in migration research: exploring "moorings" as a schema. Progress in Human Geography, 4, 19, 504–524. https://doi.org/10.1177/030913259501900404

MORSE, H.B. (2006): The international relations of the Chinese Empire. Shanghai Bookstore Publishing House, Shanghai.

NEES, G., KEHRER, H. (2002): Alzenauer Wetterchronik. Die interessantesten Wetterereignisse in Alzenau, im Kahlgrund und am Untermain von 265 bis 1999. Keim, Weil der Stadt.

NEUE HAMBURGER ZEITUNG (1911): Neue Hamburger Zeitung, edition from 1.8.1911, https://www.europeana.eu/de/item/9200338/BibliographicResource_3000094605007 (17.7.2025)

PANG, T. (2005): The China meteorological disaster dictionary: Henan volume. China Meteorological Press, Beijing.

PEI, Q., ZHANG, D.D. (2014): Long-term relationship between climate change and nomadic migration in historical China. Ecology and Society, 2, 19, art68. https://doi.org/10.5751/ES-06528-190268

QUIÑONES, E.J., LIEBENEHM, S., SHARMA, R. (2021): Left home high and dry-reduced migration in response to repeated droughts in Thailand and Vietnam. Population and Environment, 4, 42, 579–621. https://doi.org/10.1007/s11111-021-00374-w

RIGAUD, K., KANTA, DE SHERBININ, A., JONES, B., BERGMANN, J., CLEMENT, V., OBER, K., SCHEWE, J., ADAMO, S., MCCUSKER, B., HEUSER, S., MIDGLEY, A. (2018): Groundswell: preparing for internal climate migration. The World Bank, Washington, DC. https://doi.org/10.1596/29461

STATISTISCHES REICHSAMT (1890): Statistisches Jahrbuch für das Deutsche Reich (1890). Schmidt, Berlin.

STATISTISCHES REICHSAMT (1900): Statistisches Jahrbuch für das Deutsche Reich (1900). Schmidt, Berlin.

STATISTISCHES REICHSAMT (1910): Statistisches Jahrbuch für das Deutsche Reich (1910). Schmidt, Berlin.

STATISTISCHES REICHSAMT (1933): Statistisches Jahrbuch für das Deutsche Reich (1933). Schmidt, Berlin.

TAO, L., SU, Y., CHEN, X., TIAN, F. (2024a): Processes, spatial patterns, and impacts of the 1743 extreme-heat event in northern China: from the perspective of historical documents. Climate of the Past, 11, 20, 2455–2471. https://doi.org/10.5194/cp-20-2455-2024

TAO, L., SU, Y., CHEN, X., TIAN, F., GONG, Z. (2024b): How has ancient china responded differentially to the long and short timescale climate extremes? Case of the drought and heatwave in 1743. Natural Hazards, 15, 120, 14625–14647. https://doi.org/10.1007/s11069-024-06799-4

TAO, L., SU, Y., KANG, Y. (2021): Reconstruction and analysis of chronology of high temperature events in eastern China during Ming and Qing dynasties. Journal of Palaeogeography, 02, 23, 449–460.

VAN DER SCHRIER, G., ALLAN, R. P., OSSÓ, A., SOUSA, P. M., VAN DE VYVER, H., VAN SCHAEYBROECK, B., COSCARELLI, R., PASQUA, A.A., PETRUCCI, O., CURLEY, M., MIETUS, M., FILIPIAK, J., ŠTĚPÁNEK, P., ZAHRADNÍČEK, P., BRÁZDIL, R., ŘEZNÍČKOVÁ, L., VAN DEN BESSELAAR, E.J.M., TRIGO, R., AGUILAR, E. (2021): The 1921 European drought: impacts, reconstruction and drivers. Climate of the Past, 5, 17, 2201–2221. https://doi.org/10.5194/cp-17-2201-2021

WANG, J., SUN, D. (2006): The China meteorological disaster dictionary: Shandong volume. China Meteorological Press, Beijing.

WANG, Z. (2008): The China meteorological disaster dictionary: Tianjin volume. China Meteorological Press, Beijing.

WORSTER, D. (2004): Dust Bowl: The Southern Plains in the 1930s. Oxford University Press, New York.

XIA, M. (2000): Natural disasters and rural society in the Republic of China. Zhonghua Book Company, Beijing.

XIA, M. (2015): Big data and ecological history: the compilation and database construction of the historical sources of Chinese disaster history in an information age. The Qing History Journal, 2, 67–82.

XIAO, L. (2020): Disasters and the social ecology of the North China Plain in Qing Dynasty. Science Press, Beijing.

XIAO, L., HUANG, H., WEI, Z. (2012): Comparison of governmental relief food scheduling and social consequences during drought of 1743–1744 AD and 1876–1878 AD in North China. Journal of Catastrophology, 1, 27, 101–106.

XIE, P. (2005): The China meteorological disaster dictionary: Beijing volume. China Meteorological Press, Beijing.

XING, L. (2000): Population Changes and Migration in Rural North China in the Modern Era – A Reconsideration of Zongzhi Huang's Theory of "Involution". Historical Research, 4, 17–25.

YANG, Z. (1996): China historical population data and the relevant studies. China reform publishing houses, Beijing.

ZANG, J. (2007): The China meteorological disaster dictionary: Hebei volume. China Meteorological Press, Beijing.

ZHAI, X., FANG, X., SU, Y. (2020): Regional interactions in social responses to extreme climate events: a case study of the North China Famine of 1876–1879. Atmosphere, 4, 11, 393. https://doi.org/10.3390/atmos11040393

ZHANG, D. (2013): A compendium of Chinese meteorological records of the last 3,000 years. Jiangsu Education Publishing House, Nanjing.

ZHANG, D., DEMARÉE, G. (2004): Extreme summer heat in North China in 1743: a study of historical hot summer events in a relatively warm climate. Chinese Science Bulletin, 21, 49, 2204–2210. https://doi.org/10.1360/04wd0260

ZHANG, X., WANG, F., LU, W., LI, S., ZHENG, J. (2022): Gridded reconstruction of the population in the traditional cultivated region of China from 1776 to 1953. Science China Earth Sciences, 2, 65, 365–378. https://doi.org/10.1007/s11430-020-9866-2

ZHENG, G., JIAO, M., DING, Y., SONG, L. (2019): China climate. China Meteorological Press, Beijing.

ZHENG, J., YU, Y., ZHANG, X., HAO, Z. (2018): Variation of extreme drought and flood in North China revealed by document-based seasonal precipitation reconstruction for the past 300 years. Climate of the Past, 8, 14, 1135–1145. https://doi.org/10.5194/cp-14-1135-2018

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