Social resilience and its scale effects along the historical Tea-Horse Road

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Abstract
This study adopted an empirical analysis to explore social resilience to major natural disasters along the Tea-Horse Road (THR) in southwest China and to understand why and how the THR and its connected communities maintained and developed over a long period. A set of archive data, literature re-analysis, statistical data, monitoring data, and surveyed materials were collected and qualitatively and quantitatively analysed to support a holistic investigation of disaster impacts and social resilience. The results indicate that (a) natural disasters occurred frequently but were distributed over place and time and had various impacts, which left possibilities for maintaining social development with diverse and specific coping strategies; (b) strong central and local governance continually improved infrastructure and engineering technologies, and collaboration in social networks with local experience and disaster cultures were the major contributing factors that enhanced social resilience at various levels; (c) the THR area demonstrated various features of social resilience to natural disasters in terms of spatial-temporal scales, where the combination of multiple resilience measures enabled the resilience of the entire social system at various places over long time periods. Generally, larger social systems with diverse response capabilities were more resilient than small and individual entities over a long time scale. The study highlights that the THR region withstood frequent natural disasters but maintained a general development of social economy, transportation, and advanced technologies, and performed a positive transformation to a more resilient status. Overall, this paper describes the scale effects of multiple resilience measures along the THR and calls for specific studies on social resilience and transformation of diverse social entities over multiple spatial-temporal scales.

1. Introduction
In the earth's environment, human beings are not only observers but also participants. Unlike other animals, they have subjective initiative; that is, human beings can change their behaviour on the basis of their understanding of nature to adapt to it or change it (Han 2000). The so-called adaptation of human society to the environment refers to the behaviour of human beings who adjust their own production and lifestyles in the face of an ever-changing environment (Smit and Wandel 2006). It has been more than 10 000 years since the advancement in human production methods from collecting, fishing, and hunting to primitive agriculture. However, the period when human activities adapted very significantly to
the environment is concentrated over mainly the past 2000 years (Yang et al. 2017) and mostly after the Industrial Revolution in the middle of the 18th century (Han 2000).

Although adaptation tends to be actor-centred, the resilience approach is a system-oriented dynamic view that regards adaptive capacity as a core feature of resilient socio-ecological systems (Nelson et al. 2007). Resilience originates from the Latin resiliō, which in the present context refers to the capacity of a socio-ecological system to absorb stresses and maintain function in the face of external stresses such as climate change and disaster events (Folke 2006). Therefore, studying resilience is important to offer a more systemic and cross-cutting approach to understanding environmental impacts and social feedback. Also, more importantly, that study offers arguments from a positive perspective by its examination of transformation, learning, replication, or upscaling (Miller et al. 2010), in comparison with the traditional concepts of risk, vulnerability, damage, and loss (Smit and Wandel 2006). Indeed, increasingly, detection and attribution studies are suggesting that societies have largely continued to settle and develop in hazard-prone areas and periods (Yang et al. 2019a). Consequently, through various experiences, knowledge, tools, and measures, diverse communities have had to live with, cope with, and reduce risks from various natural disasters from early farming times (Flohr et al. 2016, Nicoll and Zerboni 2020) across long history (Wei and Finné 2018, Yang et al. 2019a, Zhang et al. 2020) to very recent times (Kim and Marcouiller 2016, Wei et al. 2020).

Over the past 40 years, the concept of resilience has gradually become an important topic in the scientific study of socio-ecosystems (Adger 2000, Folke 2006). Interest in resilience is surging in research on ecosystems, agriculture systems, human settlements and communities, mountain regions, urban studies, and coastal areas. (Côté and Darling 2010, Meerow et al. 2016, Sharifi 2016, Douxchamps et al. 2017). At the same time, dozens of quantitative and qualitative approaches have been developed to analyze, measure, assess, and model resilience from various perspectives. This has led to and recently emphasized the significance of understanding the dynamic process of deeply rooted resilience manifested at various scales (Yang et al. 2019b). Unfortunately, there is still a lack of integrated analysis of the spatial and temporal dynamics of resilience in a specific socio-environmental context.

Because of this research gap, it is necessary to adopt comprehensive approaches to elucidate the spatio-temporal dynamics of resilience. Consequently, the present study empirically re-analysed documented materials and literature to explore social resilience in the face of major natural disasters along southwest China’s Tea-Horse Road (THR). The THR was built across many high mountains at the southeast margin of the Tibetan Plateau, thus is notorious for its difficult terrain, extreme weather, and frequent natural disasters (Tian et al. 2019). However, the THR and its adjacent communities have persisted and developed over two millennia, and many of the communities have rapidly increasing populations and properties (Zhao et al. 2018). Therefore, to understand why and how the THR and its connected communities maintained and developed over this long period, it is of research interest to analyse why and how their special livelihood ways survived and evolved at regional and local levels.

2. Research area and materials

2.1. The THR and its environment

The historical THR was a network of trade roads across the Hengduan Mountains in southwest China, which extended from inland China to Tibet and farther to ancient India (Forbes and Henley 2011) (figure 1). It was constructed over 1000 years ago. Although it is globally far less known than the Silk Road, the THR is a similar road network with special historical and geographical implications. It partly originated in the early Qin dynasty (221–207 BCE) and thrived in the Tang (618–907 BCE) and Song (960–1279 BCE) dynasties through to the Republic of China (the mainland period, 1911–1949). In the road network, two major roads connected Tibet with Sichuan in the north and Yunnan in the south (Zhou et al. 2010, Forbes and Henley 2011). The north road starts from the region of Chengdu and Ya’an and continues up the mountains to Ganze, Markom, and Chamdo. The south road links the traditional tea-producing area of Pû’er, Dali, and Kunming to the north through Lijiang and Diqing (Zhou et al. 2010, Xu et al. 2019). Both roads join at the region of Markom and Chamdo and then run westward to Nyingchi, Lhasa, and beyond. It must be pointed out that the above routes are only the main trunk lines of THR that are conventionally recognized (figure 1), and the road locations and directions may vary in certain areas. In addition to the main lines, THR also includes many branch lines that are not well-known or not recognized yet.

The central area of the THR network is the southwest margin of the Tibetan Plateau, where many ethnic minorities live in remote and steep mountainous areas (Gu 2004). As shown in figure 1, the large THR region typically covers low plain lands in the Sichuan Basin, the middle mountains in Yunnan, and the high mountains in Tibet. Accordingly, the major land area is characterized by alpine grasslands, meadows, and shrubs due to high elevation and low air temperature, while farming areas are concentrated mainly on low areas and valleys with a mild climate and fertile soils. The climate in the region varies, largely depending on local topography, but is generally dominated by the transition and combination of both the Indian summer monsoon and the western North Pacific
summer monsoon (Wang and Lin 2002, Hao et al 2020), with an average annual temperature of 15 °C to 20 °C and overlapping rainy and hot seasons. The average annual rainfall ranges from 1100 to 1400 mm but is concentrated from May to September (Li 1987, Zhang 1989). With their dense river networks and sharp changes of terrain and elevation (from over 7000 m to approximately 600 m at Chengdu), areas along the THR particularly face more frequent and intense natural disasters; e.g. drought, flood, debris flow, landslides, cold waves, and earthquakes, while the human activities of deforestation, slope cultivation, road construction, and mining increase the risks (Zhou 2014). However, overall, as with a typical mountain society, the THR region people kept living with such disasters and developed continuously through their long history.

2.2. Research materials and methods
This study collected data from various historical gazetteers, chronicles, compiled datasets, and recent research results, which provided information on meteorological and hydrological records, flood events, disaster impacts, and disaster relief, as well as elevation data from digital elevation models (DEMs), and modern social–geographical research findings. Note that because local materials and records of the THR region before the central China power managed the region in the Ming dynasty (1368) are relatively rare, mainly the available literature from the Ming (1368–1644) and Qing dynasties (1636–1912) was examined. Meanwhile, there are much less historical data on the Tibet areas than on Yunnan and Sichuan provinces. Therefore, some published materials in recent times were referred to and reanalysed based on alternative sources.

Specifically, various local gazetteers in the THR region were reviewed to get specific information on hazard events and impacts. Another source of adopted materials was the chronicles of the Ming and Qing dynasties, from which disaster information was collected for this study. It is not possible to list all the gazetteers and chronicles here because sometimes only one sentence or a few words of a chronicle are referred to, and several materials had no clear source. Several thematic datasets compiled in the 20th century further supported essential information at a larger scale with comparable information on other areas of China. Also, the adopted materials came from sources of research publications in recent times, most of which are referred to in the bibliography. The DEM data in figure 1 were accessed from the ASTER GDEM V2 (www.gscloud.cn) by CIAT (Jarvis et al 2008). Details of the major material sources are listed in the supplementary table 1 (available online at stacks.iop.org/ERL/16/045001/mmedia).

3. Natural disasters and impacts at various scales
3.1. Spatial–temporal patterns of natural disasters
According to historical records on natural disasters, in its early time the THR area suffered mainly from earthquakes, floods, droughts, and diseases. Since the Yuan (1271–1386) and Ming dynasties (1386–1644), the development of mining and mountain farming
increased the frequency of various disasters. Disaster events were increasingly reported and documented, which provided information on debris flows, landslides, cold waves, frost and snow, fires, and wind disasters. Overall, early records of disasters in the study area were relatively scarce and simple but much more detailed than in later times, especially after the Ming and Qing dynasties.

In terms of changes in types of disasters over time, the THR region does not manifest clear periodic or phased changes in general. However, there were a few periods when specific types of disasters were more concentrated than in others. For instance, Yang argued that there were a quasi-3 year cycle and an 11 year cycle of the beginning times of the rainy seasons in Yunnan. Also, a statistical analysis of natural disasters in Yunnan (details in the supplementary section) found that floods and earthquakes were the most frequently reported disasters documented in the past 600 years. There are many fluctuations, but a general increasing trend can be observed in all the various types of disasters.

The THR region, because it largely overlaps the eastern part of the Tibetan Plateau, is geologically developed with fault structures, strong neotectonic activities with complex and diverse strata lithology, much wind erosion, and significant vapour–air exchange. Those conditions increase the region’s susceptibility to disasters (details in the supplementary section). Generally, the spatial pattern of disasters over the large THR area has four characteristics:

(a) Geological disasters such as earthquakes were densely distributed along the seismic fault belts, and the southeast margin of the Tibetan Plateau suffered them most frequently.

(b) Geomorphic disasters including landslides and rock collapses were mostly distributed in the deep-cut alpine valleys. Such valleys were concentrated in the THR region because many roads were originally constructed along them.

(c) The uneven spatial–temporal distribution of water and precipitation led to significant horizontal differences of floods and droughts. The lowland THR regions in Sichuan and Yunnan had severe seasonal droughts and floods, as documented in various records. However, the higher-elevation regions had more stable water situations due to available snow and ice resources.

(d) From the social–economic perspective, although physical disaster events showed certain spatial patterns, they were concentrated mainly in areas with intensive human activities. Therefore, the extent of disaster losses was closely related to the areas’ populations, their levels of socio-economic development, and the property types, values, and specific locations.

3.2. Disasters impacts at the local scale
Disaster events could cause various damages and losses in all aspects, particularly in agricultural production, housing, schools, and infrastructure including roads, dams, and bridges. However, the macro statistics of disaster impacts are often merely a collection of numbers and cannot show the real situations of specific victims. To provide more ground-based information on the natural disasters, in this section a few specific disaster events and their impacts on local communities and households are analysed.

A level M7.5 earthquake occurred at Xichang on 19 March 1556 (明嘉靖十五年二月二十八日), which affected a large area between the Chengdu Plain and central Yunnan (Jiang 2005). The main effects of the earthquake were house collapses and casualties. Because the earthquake occurred at midnight, the number of deaths was large and not precisely counted. A few archives particularly documented that many local government officials and soldiers died in the disaster. Beyond the significant damage to croplands and the living environment, long-lived rumours and whispers had cast an inextricable shadow on the psychology of the local residents. Most people could not distinguish the authenticity of much of the information, which led to long-term social turmoil and panic (details in supplementary table 2).

A 3 year famine in Yunnan from 1815 to 1817 (嘉庆云南大饥荒) was the largest and most severe famine recorded in pre-modern Yunnan. That disaster resulted from the significantly poor harvest of main crops such as rice and buckwheat caused by low summer and autumn temperatures after the eruption of the Tambora volcano in 1815 (Yang et al 2005, Hao et al 2020). The lowest temperatures were in 1816 when the average temperature in August was likely 2.5 °C–3 °C lower than the annual average; this was called the ‘year without a summer’ (Oppenheimer 2003). Also, cool winds and drought aggravated the weather conditions so much that rice failed to flower and the millet died in the field without maturing (Hao et al 2020). This case indicates that failed harvests result from bad climate conditions; e.g. cold in 1815, cold and drought in 1816, and drought in 1817. Due to the failed harvests in Yunnan, famine affected 29 of the total 88 counties. Many people died or were forced to migrate. In extreme cases, people ate a type of white clay soil (观音土) but it could have led to death because it was indigestible.

Heavy snow, freezing, and hail are frequent disasters that occurred mainly in alpine areas, especially on the Tibet plateau. Due to its harsh climate conditions, the north and west parts of Tibet had more snowstorm and freezing disasters, whereas the east and south areas suffered more from hail (Zhou 1990). Such disasters may not have directly caused loss of human life, but they affected livestock and
crop production, which in turn endangered the living conditions of local farmers and herders (details in supplementary table 2). Some snowstorm events lasted 3–5 months, which caused serious food shortages and livestock deaths from freezing. The loss of livestock production resulted in pastoral families descending into extreme poverty. Many residents had to migrate, and livestock markets closed (Zhou 1990, Sun 1999). Hail disasters had relatively less impact, but they occurred suddenly and were difficult to prepare for. Because hail disasters occurred mostly in summer and autumn in valley areas (e.g. Shannan and Nyingchi) with relatively advanced agricultural production, the major loss from hail disasters was a failure of the crop harvest (Ni and Xie 2007).

Another typical type of disaster in the THR region was geomorphic disasters due to the unique landforms of high mountains and deep valleys with intensive human activities, such as those along roads with much traffic. Most of those disasters were site-specific and based on the local geomorphic environment, and occurred over short durations; i.e. often from a few minutes to hours. The spatial effect of a single disaster was relatively small, and there was rarely an individual geomorphic disaster that caused large-scale damage (and thus resulted in fewer relevant historical records). However, the power of disasters can make them enormously destructive, and they occurred broadly across many sites of the THR region from the past to the present (Shang et al. 2003, Wang et al. 2019). Geomorphic disasters could result in deaths of humans and animals, damage to roads, buildings, and hydropower stations, and subsequent floods and river siltation.

4. Resilience measures for coping with disasters

While enduring frequent natural disasters over many centuries, people in the THR area have made great achievements in exploring and practicing various measures to prevent disasters, reduce losses, and enhance their recovery capacity. Overall, the response measures in the THR region manifested mainly in four aspects: the governing system, technology applications, social networks, and knowledge–culture aspects.

4.1. Governing measures for disaster relief

4.1.1. Central governing system

Disaster management and relief in traditional societies along the THR were dominated by multilevel governments with complementary efforts from other sectors and entities. The significance of their role forced the governments to strengthen the construction of a ‘disaster relief system’ (荒政 in Chinese) which involved laws, institutions, regulations, and relief measures. The system had been well developed by the time of the Ming dynasty and was maturely operated and improved through the Qing dynasty (Li 1994, 2011, Ye 1996, 1998, Jiang 2005, Zhou 2007, Cui 2014). Here, several major measures are briefly listed:

- Grain storage for disaster relief preparedness. The central government had major grain warehouses (公仓), and local authorities also maintained many grain warehouses (常平仓, 社仓, 义仓) to store grain for emergency famine relief.
- Assessment of natural disaster impacts. Central governments actively investigated disaster events and assessed damages and losses (报灾, 勘灾, 审户), which enabled them to provide an effective basis for disaster relief thereafter.
- Distribution of relief materials, mostly grains (赈粮), food (粥赈), and money. This included emergency distribution of relief materials immediately during and after a disaster event and more long-term relief for a certain period after the disaster.
- Tax exemption and deferment (蠲免, 缓征). Based on an assessment of the disaster impact, some taxes could be exempted or postponed.
- Stabilization of prices of grain (平粜), clothing, medicines, etc. Sometimes, disaster victims could even buy grain at reduced prices and receive grain subsidies.
- Resettlement of disaster victims on living and farm lands, and encouraging agricultural production (劝课农桑).
- Assistance in rebuilding of houses, roads, dams, channels, irrigation facilities, etc.

4.1.2. Local governing system

The local government could take the same measures as the central government while considering specific conditions at the disaster sites. Beyond that, local governments could initiate necessary requests to other entities and systematically organize all relief activities. For instance, the Disaster Relief Records of Zhaotong, Yunnan (云南昭通工赈记) document that the local governor, Mr Wen Long (龙文), was ordered to do disaster relief after a flood in 1892 (Li 2019). He requested relief funds from higher-level governments, stabilized market prices, and regulated the river channels by using disaster survivors, which all together significantly relieved the disaster situation.

Historically, the Native Chieftain system (土司制度) actually ruled many ethnic minorities and undertook most of the relief work (Zhang 2005). The chieftains could localize external relief measures and take their own measures in their traditional and cultural ways, which made the relief easier to distribute and be accepted by local people. The Tibetan communities at the western parts of the THR region were relatively less developed over the
long period, and they had the unique Gaxag system (噶厦) to operate disaster management affairs with local religions and cultural traditions (Zhou 2004). Both the Tusi and Gaxag systems ensured that local governments obtained accurate information and formulated effective coping measures in emergencies.

The Weisuos were military groups established to maintain local social stability, but they were required to feed themselves by developing agricultural production. Therefore, the Weisuos had the combined roles of guarding and farming and were a significant power in coping with natural disasters. In particular, at the beginning of the Ming dynasty, many military households moved into northwestern Yunnan, which led to the rapid development of agriculture and the construction of many water conservancy facilities (Lu 2005). This also gradually transformed many herdsmen into farmers and promoted land reclamation on many suitable small plains in the hilly areas. Overall, the parallel operations of Tusi and Weisuos in the THR areas constituted a strong joint political and military force and certainly improved population integration, agricultural development, and social resilience to external stresses.

4.2. Technologies for disaster prevention and reduction

4.2.1. Agricultural technologies

In concert with the large number of immigrants and extensive economic development in the Ming and Qing dynasties, agriculture developed very quickly and extended to most of the plain areas and some of the hilly slopes of the THR region. However, agriculture was dominated by small-scale peasant economies that were sensitive to the impacts of natural disasters. Thus, disaster reduction was essential for agricultural production, and people in the THR regions created and learned many farming techniques (Shao 2009, Yan et al 2016). Specifically, the technology systems for reducing agricultural disaster effects were:

- Soil tillage techniques that enabled moisture preservation in drought periods (土壤翻耕). This involved exacting techniques and skills to determine the depth of soil ploughing, the time of tillage, and the times of tillage per year.
- Field management measures for preventing and controlling diseases, pests, and weeds (田间管理). Field management covered the entire period of crop growth and comprised thinning plants, using weeding tools, adjusting the amounts of various fertilizers, and preventing early frosts or freezes.
- Techniques of crop cultivation regarding cropland use plans at different times and locations (耕作制度). The techniques focused on the sequence, time, structure, and distribution of various crops in limited croplands, which enabled the optimal use of the lands and the maximum output from them.
- Selection and breeding of high-yield and resistant crop varieties (选种育种). The introduction and promotion of high-yield and easy-to-plant crop varieties were among the major agricultural technologies for preparing for and preventing natural disasters. For instance, the extensive planting of potato, corn, and barley and the introduction of rice, tea, vegetables, and many cash crops significantly enhanced the food security and livelihoods of local residents.

4.2.2. Infrastructure and engineering technologies

Infrastructure and engineering measures were often considered to be the most effective ways to reduce the effects of disasters. The official road construction across the mountains started in the Qin dynasty (221 BCE to 207 BCE). The goal was to conquer the minority areas in Sichuan and Yunnan. Some major and popular roads; e.g. the Wuchi Road (五尺道), the Lingguan Road (灵关道), and the Bonan Road (博南道) formed the original network of the THRs. Those stone-paved roads, together with many zip lines, cliff plank roads, and transfer hubs enabled human communication and goods exchanges over a larger geographical area. Although official maintenance of these traffic facilities was often insufficient or not timely, spontaneous road repairs by travelers and businessmen occurred over time. As an output of collective efforts, the roads were repaired after disaster impacts and contributed to disaster relief at its connected areas. Along with the general social-economic and technical developments, road construction was greatly advanced and better maintained from the Ming dynasty to the Qing dynasty. The improved traffic conditions played a bigger role in the deployment of personnel and materials in disaster contexts.

Water conservancy projects appeared early in the Warring States period (475 BCE to 221 BCE) in China. The mastery and improvement of water management technologies greatly alleviated the negative effect of local drought and flood disasters. In the THR area, the well-known Dujiangyan irrigation system at the west of Chengdu is still working today with effective flood control and irrigation functions. In particular, flood prevention and irrigation facilities such as channel gates, dams, reservoirs, and canals could further promote the expansion of agricultural land reclamation. A recent study also identified that the integrative construction and use of canals, dams,
sluices, and reservoirs in the Erhai Lake basin maintained and enhanced the resilience of local social-hydrological systems (Xu et al 2020). They also argued that for the development of Kunming city, credit must be given to two historical water control projects: the Songhua Dam (松花坝) to control the flooding of the Panlong River, and the Haikou River (海口河) dredging project to control the drainage of Dianchi Lake (滇池) (Zheng 2013).

Local people in the THR area have gained much experience in the construction of various buildings and formed their unique security concept and disaster prevention system with local characteristics. They include location selection and construction technology and some social and behaviour preferences. The geomantic omen (风水) has been the most important basis for the survey and selection of suitable settlement places based on terrain and favourable topology. The geomantic omen could identify good places for traffic convenience, water access and drainage, sunshine, air flows, landscape, etc, which enabled a preliminary risk reduction in droughts, floods, landslides, and somehow also frost, freezing, and diseases.

4.2.3. Early warning and forecasting technologies
The people of ancient China had a wealth of meteorological knowledge, especially of agricultural hazards. They were good at grasping the signs of future disasters based on accumulated experience and scientific reasoning. Specifically, with simple phonological observations, weather observations, and solar term understandings, certain weather and harvest forecasts could be made to arrange farming activities accordingly and prevent harmful consequences. Some qualitative analysis on agricultural meteorology conditions using meteorological instruments such as anemometers, rain gauges, hygrometers, and ground temperature meters were also developed to make more accurate forecasts. Those forecasts ensured that predisaster preventive measures could be taken before the disasters occurred, which helped to optimize the use of available coping measures and reduce potential losses. Although most of the technologies were simple and developed slowly, the continuing progress improved the population’s ability to withstand disasters. In addition, such technologies were rooted in daily life and easy to learn and pass on through groups and generations.

4.3. Social networks in disaster relief
4.3.1. Social charity and voluntary assistance
Spontaneous social charity and voluntary assistance have been a tradition in many grassroots societies in China. On one hand, the THR area was far away from the central dynastic government. That government’s top-down policies and measures were often insufficient or were implemented less effectively and not in time. On the other hand, local gentries including Tusi, squires, noble families, wealthy landlords and businessmen, religious leaders, etc. had extensive influence and an extraordinary right to speak in the grassroots society. Those influential people and their families often actively participated in disaster relief, donated funds, and mobilized and integrated different social resources and relief forces to strengthen the cohesion of the local society and make up for the lack of official relief. That also extensively increased their own prestige and reputation. In the case of Zhaotong governor Mr Wen Long’s (龙文) disaster relief, local gentry represented by Li Youting (李耀廷) not only actively donated money and food but also personally participated in disaster relief activities and made great contributions to overall disaster relief. These nongovernmental forces could to a large extent fill the gaps and deficiencies of government disaster relief through various measures such as donating money and food, providing medical aid, and contributing manpower. Some very influential gentries could organize fast temporary fundraising and arrange manpower for emergency relief and infrastructure construction.

Social charity also came from other areas that were not affected by disasters (灾免). Charity relief was an activity of nongovernmental organizations or persons who organized and raised funds by themselves and distributed relief materials directly to the disaster victims. The rise of charity relief was due to combined social factors; e.g. insufficient official relief, general social–economic development, simulation of Western missionaries’ relief activities, spontaneous human kindness, and the intervention of modern media such as newspapers and telegrams (Zhang 2010). Charity relief has made remarkable advances and was gradually integrated with official relief in the late Qing dynasty and the period of the Republic of China.

4.3.2. Social and family network relief
Social networks basically include connections within a neighbourhood or community and the blood relationships within a large family. A social network is an important resource for disaster victims, especially in emergency cases that governmental or external relief cannot attend to in time. For a specific person or family threatened by a disaster, neighbourhood relief is often the first effective aid and can be significant in both emergency cases and postdisaster recovery.

Fortunately, communities and villages in the THR area were traditionally developed over many generations and lived in a close social network. People were very familiar with each other and had enduring neighbourhoods due to stable settlements and farming. They also had a strong sense of common geographic identity. In some ethnic minority areas, there were popular traditions of collective labour and mutual
labour assistance among village member households. The grassroots organizations in the Ming and Qing dynasties, such as Lijia (里甲) and Baojia (保甲) even assumed the function of helping the weak in both official and moral matters. Most of the elderly, weak, sick, and disabled relied heavily on assistance from those people and organizations. Also, in the rural landlord and peasant relationship, landlords and wealthy households assisted the tenant farmers by waiving or reducing rents in disaster cases.

In the traditional Chinese rural society, blood-related assistance in a clan family was another important model of mutual relief (Yang 2019). Many of them even had rules with a clear definition of mutual assistance and interactive support. In the agricultural societies, these assistance functions were achieved mainly through the establishment of Yizhuang (义庄) and Yitian (义田), which were common farmlands with resources to aid vulnerable family members and strengthen family cohesion. The clan families were also very concerned about their population growth and encouraged fertility because a large family had advantages in cultivating more croplands, developing diverse livelihood strategies, defending other famil- 

ies from bullying, surviving natural disasters, and so forth.

4.4. Experience, culture, and belief

Due to the lack of scientific and technological knowledge, cultural and religious thought played an important role in the construction of local disaster concepts. The ideological and cultural forms, as well as the belief systems of the specific historical area, also influenced and reflected disaster response models. In the continuous adaptation to natural disasters, many subareas along the THR formed unique disaster cultures, which are reflected in many aspects such as folk beliefs, religious ceremonies, living etiquette, agriculture production, and daily life. For example, in the Yi minority region (彝族地区) at Xichang, the oral culture represented by Erbi (尔比) is rich in local knowledge about disaster reduction with regional characteristics, which reflects the Yi people’s perception of climate change and the prediction of and preparation for disasters. Their disaster reduction measures in daily life carry their rich experiences in adapting to the habitat environment; they have been maintained through the family clan system. These unique cultural matters have been passed down from generation to generation and form the local knowledge system related to disaster reduction.

5. Spatial–temporal scale effects of social resilience

5.1. Diverse resilience measures

As analysed in section 4, officials, gentry, and ordinary people have all made various efforts to cope with disaster impacts, involving different levels of prevention and relief measures before and after the occurrence of a disaster. Each measure could have a different influence on the resilience of various entities at a certain spatial scale and over a certain period (figure 2), which is expressed synthetically as scale effects. The systematic implementation of these measures ensured the overall resilience of the THR social system.

The resilience measures were further classified into nine types, which covered multiple dimensions regarding governance, technology, and social and cultural aspects (figure 2). For each type of measure, its functioning suitability at different spatial and temporal scales was identified; i.e. at what scale the measure is effective. In figure 2, the scale effects are illustrated on the x axis (temporal scale) and y axis (spatial scale). In addition, the effects of each measure were qualitatively assessed in terms of their utility and effectiveness in enhancing the resilience to flood disasters. The qualitative assessments were made relative to each other based on statements in the literature cited in this study as well as on some general knowledge. For instance, measures of the central government could recover from post-disaster recovery in a few weeks or months or to systematic and large-scale water conservancy projects in years or decades. Many regions have their own experience, culture, and beliefs regarding disaster management, which could benefit resilience enhancement at all times. However, these measures generally have little actual effect in the practice of disaster relief, thus many black bubbles occupied various scales but with small sizes (figure 2).

5.2. Spatial scales of social resilience

In analyzing the various resilience measures, it was found that the suitability and effects of each measure varied when the targeted spatial scope changed. A certain measure was effective only in some suitable areas. For example, local governing measures can be implemented only in their responsible territories, and social networks can be helpful often only at a physically reachable region where people can help each other in person. Local governing measures may contribute very little if the aim is to improve the resilience of the nation as a whole or a few individual households or individuals. It is therefore argued that the specific spatial scope must be clarified when judging the effectiveness of a resilience measure. Note that the scale effects of these measures in figure 2 were evaluated separately. The bubble size indicates the effect of each individual measure being implemented separately. However, the different measures were generally implemented in parallel and with superimposition and integration, which enabled a comprehensive resilience to disasters at various scales, from individuals to national and global scales. In the case study of the THR area, there had not been any measures
to improve resilience at the global scale (figure 2), because the global scale was not involved in this case study, no flood event had affected the globe, and no countermeasures could work at a global scale.

Due to the different spatial scale effects of the resilience measures, the resilience of an entire social system also manifested largely in different spaces. A city is often more resilient to disasters than a village because a disaster event may greatly destroy a village but is unlikely to destroy an entire city (assuming that the city has a larger area, a higher population, more diverse economic sectors, and so forth). Therefore, the major functions of a larger urban system could still operate when parts of it are destroyed. This means that a larger urban system is more resilient than a smaller village system, which could completely lose all functions. Many components in a large, complex system could be substitutable, so the system as a whole can survive and continue after a catastrophic impact on several components. In other words, in the case of several households damaged in a flood event, there could be low or no resilience of those households to the event, but an entire community or city could have high resilience to the event. In this regard, it is generally true that a larger social system with diverse components is more resilient than a simple smaller social system. Thus, it makes significant sense to clarify the spatial scale and the entity when considering the resilience of a social system.

This further indicates that diversity can support a resilient system with a self-regulation mechanism and a bottom-up decision-making process. The resilience of the THR area is due to the combined result of many interactive measures, including empirically wise and scientific coping measures, the motivation to pursue economic and trade benefits, hard work and patience in life, and the strong religious beliefs of the local people. Beyond that, the area also received significant governance, regulations, and assistance from powerful central dynasty authorities.

5.3. Temporal scales of social resilience

Similar to the spatial scale effects, the effectiveness of resilience measures performs a dynamic role over different time periods. For instance, a blood-based family network may lose its cohesion after it develops over generations, so the existing relief function among family members will become less effective or even disappear. Meanwhile, the next generation will create its own new family network, which could update or replace the fading network of the old generations. Technologies of disaster prediction and prevention could develop and advance to be more precise and broadcast timely. Others, like agricultural techniques, could be generally adopted and eventually internalized as a normal state of the social system, which may not be considered as a disaster-resistant measure but indeed could enhance social resilience in general. As shown in figure 2, although very few single measures could keep direct effects over periods at century level, many can indeed be repeatedly and continuously implemented and transformed to more advanced measures. Therefore, the effects of resilience measures can actually be accumulated and continued at a century scale and longer.

Accordingly, the overall social resilience is also dynamically strengthened and improved as time evolves. Especially, people learned new knowledge and skills from past disaster relief activities, which enriched the social knowledge system and were transferred to future generations. Here, Friedrich Nietzsche’s motto ’What does not kill me makes me stronger’ is appropriate, and it could be argued that as long as a social system is not completely destroyed, it could and should develop to be more resilient to a repeated
disaster event. This may not apply to very small scales like individual people or households because they are often the direct victims and can be dead or completely destroyed in flood events. Rather, the resilience of larger entities (e.g. villages, towns, cities, nations) can be and was indeed continually developed and strengthened over time.

It is true that the ancient THR has declined in recent times, together with its tradition and culture of transporting goods by human carriers and horseback through the rugged mountain paths. It is also true that many people migrated out, villages were abandoned or merged, very little trace of horseback transport remains, tea and horse trades were significantly reduced, etc. However, note that the decline was caused mainly by the general development of social economy and technologies, not the impacts of natural disasters and environmental stresses. The decline may be better called a transformation; i.e. the upgrading of the THR area to a more advanced and more resilient social system. The livelihood and living conditions of residents as well as local infrastructure and social connections have all largely improved. With these, the human society in the THR area has become much more resilient in the face of disasters that it used to suffer.

6. Conclusions

The THR was developed across the Hengduan Mountains at the southeast margin of the Tibetan Plateau and is notorious for its difficult terrain, extreme weather, and frequent natural disasters. The harsh environmental conditions largely impacted human life, production activities, and social culture over a long period. However, the THR and the communities alongside maintained and developed over two millennia, and many were and are maintaining development with quickly increasing populations and properties. This reflects the significant and diverse social resilience regarding governance, technology, social networks, and cultural aspects.

- Governments at various levels held the authority and resources and could undertake large-scale disaster relief by reasonably allocating different resources for various relief demands. Both central and local governments in the THR area performed great disaster relief considering their capabilities at the time, which dominated the overall effect of relief efforts over a long historical period.
- Technology applications and infrastructure development were the hard basics of disaster prevention, relief, and recovery. The THR area has been developing and adopting many techniques and skills regarding farming, construction, project designing, forecasting, and planning, which together have built up a solid foundation for coping with disasters as well as developing social economics in general.
- Social network relief is the fastest and perhaps most efficient way of assisting those in disasters. People in a social network often know each other well and are also spatially close to each other, especially in ancient societies, so they understand the real situation of people in danger and can provide immediate and targeted assistance. Social charity activities among non-acquaintances further strengthened the social power of disaster relief in the THR area.
- Experience, culture, and belief generally strengthened the ethnic identities of patience and hard work among the ethnic groups in the THR area. People hold strong and long-lasting desires for survival and daily clever wisdom for living better. Many subareas along the THR have formed unique disaster cultures and beliefs, which reflect the role of spiritual power and local knowledge in disaster relief.

Overall, resilience measures show different effectiveness at different spatial–temporal scales. A single measure in coping with natural disasters is effective only in a certain space and period. However, all measures together demonstrate the full scope of their spatial–temporal effects, which cover nearly all the scale levels. Such an empirical analysis from the THR area further indicates that a larger social system with diverse response capabilities is more resilient than a simple, smaller social system. These various resilience measures jointly manifest a multidimensional picture of social resilience to natural disasters as well as their effects at different spatial and temporal scales.

Also, the overall social resilience dynamically strengthened and improved as time passed. Especially, people shaped new experiences and skills from past disaster relief activities, which enriched the social knowledge system and were transferred to future generations. As long as a social system was not completely destroyed, it could develop to be more resilient to a repeated disaster event. It is therefore argued that the spatial and temporal scales must be clarified when studying the effectiveness of a resilience measure and the resilience level of a certain social system.

Data availability statement

All data that support the findings of this study are included within the article (and any supplementary files).

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