

# Supplementary materials

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

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**Table 1, List of major material and data sources reviewed in this study**

	Title of the source	Specific themes	Author and time
Historical gazetteers and chronicles	New Compilation of General Gazetteer of Yunnan (新纂云南通志)	Records of over 2000 years' history of Yunnan; 266 specific volumes on meteorological conditions (precipitation, land cyclone, phenology), geology and geography, agriculture, disasters and famine relief, etc.	Yun Long (龙云), Zhongyue Zhou (周钟岳), 1912-1949, Republic of China
	General Gazetteer of Yunnan (云南通志),	Petition on Building Water Conservancies (兴修水利疏)	E'ertai (鄂尔泰) Yongzheng period (1723-1735) of Qing Dynasty
	Gazetteer of Dayao County (大姚县志)	local environment information at village and town levels	Daoguang period of (1821-1850) of Qing Dynasty
	General Gazetteer of Yunnan (云南通志),	natural disasters; farmland and taxes	Guangxu period (1875-1908) of Qing Dynasty
	County Gazetteers of Sichuan (四川郡县志)	History geography; natural environment	Xichun Gong (龚煦春), 1935
	Xichang Gazetteer (西昌县志)	Disasters and the impacts on people and properties	1912-1949, Republic of China
	Gazetteers of Sichuan (四川省志)	Earthquake and the impacts	1998, Peoples' Press of Sichuan
	Gazetteer of Sichuan Water Conservancy (四川省水利志)	Water Conservancy facilities	Sichuan Provincial Department of Water Resources and Hydropower, 1989
Compiled thematic data sets	Table of natural and man-made disasters in China (中国历代天灾人祸表)	Statistical data of natural and man-made disasters in China from 221BCE to 1911.	Gaoyong Chen (陈高傭), 1986
	Chinese History of Famine Relieves (中国救荒史)	Statistical data of natural disasters in China's history of 1766BCE to 1937, which covers floods, droughts, wind, earthquake, locust, etc.	Yunte Deng (邓云特), 1984
	Selected History Materials of Yunnan (云南史料选编)	History records related to disasters and impacts	Chunlong Li (李春龙), 1997
	Historical dataset on natural disasters in agriculture of China(中国农业自然灾害史料集)	Agriculture relevant meteorological disasters, biological disasters, environmental disasters, as well as famine and disaster relief.	Bo Zhang (张波), Feng Feng(冯风), et al. 1994.
	Chronicle of Great Natural Disasters and Abnormal Phenomena in Ancient China (中国古代重大自然灾害与异常年表总集)	Collection of abnormal phenomena and disaster events before 1911 in China history	Zhenghai Song (宋正海), 1992. Guangzhou Education Press

	Chronicle of the Natural Disasters and Agricultural Policies in Historical China(中国历代自然灾害及历代盛世农业政策资料)	Collection of natural disasters and the major managing policies from Han Dynasty to Qing Dynasty in China.	Institute of History, Chinese Academy of Social Sciences. Beijing: Agriculture Press, 1988
	Historical Records of Floods and Droughts in Yunnan Province (云南省历史洪旱灾害史料实录)	Records of floods and drought disasters, with focus on the Yunnan area before 1911.	Zhenxiang Jiang (江振祥), 2008. Yunnan Science Press.
	Dictionary of the Chinese Meteorological Disaster (Sichuan, Yunnan, Tibet) (中国气象灾害大典. 四川卷, 云南卷, 西藏卷)	Various weather-related disasters in China over the years, with more detailed information on especially the 20 <sup>th</sup> century.	Group Editorial, 2006. Beijing: Meteorological Press
	General History of Disasters in China (中国灾害通史: 元代, 明代, 清代)	Collection and analysis of natural disasters over the last 2000 years of China	Zhuliang Yuan, 2008-2009, Press of Zhengzhou University
	Compilation of historical data on 2000 years of flood disasters in Sichuan (四川两千年洪灾史料汇编)	Collection of flood events at basin and county levels in Sichuan with maps.	Group Editorial, 1993. Cultural Relics Publishing House
Recent research publications	Research publications in scientific books and journals from 1911 to the very recent are referred respectively in the citations and bibliography.		

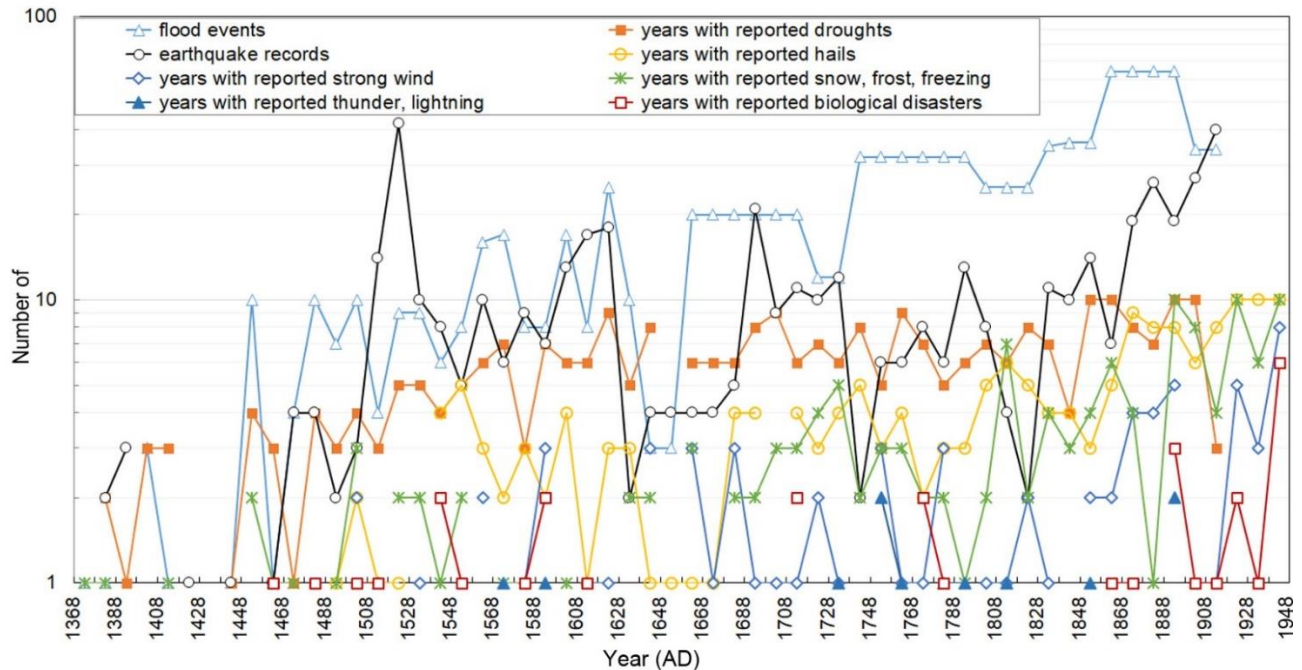
## 1. Natural disasters and impacts at various scales

### 1.1 Natural disasters over time

As observed from available historical records on natural disasters, the THR area suffered mainly from earthquake, floods, droughts, and diseases in its early time (Gu 2004). Since the Yuan (1271-1386) and Ming Dynasties (1386-1644), the development of mining and mountain agriculture exacerbated the frequency of various disasters. Meanwhile, disaster events were increasingly reported and documented, which provided information on less known disasters such as debris flows, landslides, cold waves, frost and snow, fires, wind disasters (Zhou 2014). Overall, the records of disasters in the study area are relatively little and simple in early times but much more detailed in the later time, especially in the Ming Dynasty and Qing Dynasty.

An overall analysis of the disaster materials in table 1 indicated that, the major disasters such as drought, flood, earthquake, hail, snow and freezing showed an increasing trend in the focused historical period. By the Republic of China (1912-1949), drought, flood and earthquake have basically occurred every year, and in some places they occurred even several times a year. There could be three reasons for such a significant trend: 1, The increasingly complex crop planting structure has promoted the sensitivity of the agricultural production to disaster events; 2, The increase in population and the expansion of agricultural sectors contributed to the hazard exposure and vulnerability of social systems; 3, The progress of disaster monitoring technology and the increase in documentation have objectively led to an increase in disaster records and data. After the establishment of the Republic of China in 1912, the recording of natural disasters has become more comprehensive, accurate, and scientific. Disaster statistics also covered more details down to county-level or even village level, as well as more comprehensive information of multiple aspects of disaster impacts.

In terms of disaster changes over time, the THR region doesn't manifest clear periodic or phased changes in general. However, there are a few periods that specific disasters concentrated relatively more than others. For instance, Yang (2005) argued a quasi-3-year circle and a 11-year cycle of the beginning time of the rainy season in Yunnan. In addition, the statistical analysis of natural disasters in Yunnan (Figure 1) tells that, floods and earthquakes were the most frequent disasters that were reported in documents for the past 600 years. Though with many fluctuations, a general trend of increasing can be observed in all the different types of disasters. This is in consistent with Liu and Zhang (2015) who reconstructed the flood series at Kunming using more explicit local data and identified increasing flood and drought frequencies from 1332 to 2013.



**Figure 1, An incomplete counting of natural disasters in Yunnan during the Ming Dynasty and Qing Dynasty with 10-year interval.** Most data of this graph sources from the Dictionary of the Chinese Meteorological Disaster (Yunnan) (Table 1), with complement information from Li (2014), Zhang and Li (2012), and Yunnan Seismological Bureau (1988).

## 1.2 Spatial patterns of natural disasters

The Tea-Horse Road region, as largely overlapped with the Tibetan Plateau, is geologically developed with fault structures, strong neo-tectonic activities with complex and diverse strata lithology, strong wind erosions and significant vapor-air exchange, which provide good disaster-pregnant conditions (Cui *et al* 2017). The types of disasters mainly include: earthquakes, debris flow, landslides, floods, snow disasters, droughts, frost freezing, glacial lake outbursts. Generally, the spatial pattern of disasters over the large THR area manifests four characteristics:

1. Geological disasters e.g. earthquake occurred densely along the seismic fault belts, where the south east margin of the Tibetan Plateau suffered most frequently.
2. Geomorphic disasters including landslides and rock collapses distributed often at the deep-cut alpine valleys. Such valleys concentrate right at the THR region due to the fact that many roads were originally developed along the valleys.
3. The uneven spatial-temporal distribution of water and precipitation leads to significant horizontal differences of floods and droughts. The lower THR regions in Sichuan and Yunnan had severe seasonal droughts and floods as documented in various literature. While the higher regions had more stable water situation due to available snow and ice resources.
4. Though physically disaster events shew certain spatial patterns, they concentrated very much in areas with intensive human activities from the social-economic perspectives. This is in consistent with the more recorded disaster information in Sichuan and Yunnan, in comparison with Tibet.

Through the analysis of historical records, it is further found that the spatial pattern of natural disaster occurrence highly relates to the types of disasters at the THR region. For instance, droughts occurred widest than other disasters in nearly all areas and caused the most severe losses, especially along the valleys where human settled and agriculture was developed. Floods together with landslides and debris flow are the most frequent disasters while mainly concentrated in the lower mountain areas in the east and south margin of the THR region. Other disasters like diseases didn't perform significant spatial patterns due to special inherent characteristics and limited data.

Specific studies have further shown that the areas between Kunming and Dali as well as those between Chengdu and Ya'An are the most severely flooded areas (Xiong *et al* 2019). High-density flood areas are mainly concentrated in central Yunnan and the Sichuan Basin and the transition areas from mountain to plain. Some small plains along the river valleys also suffered from frequent floods but often at local scale with limited impacts. This pattern lasts over hundreds of years and to the recent time. Meanwhile, it does not rule out that the intensification of human activities changed the disaster-prone environment to a certain extent. On the one hand, researchers increasingly believe that land use changes especially the deforestation and destruction of vegetation directly aggravated the intensity and scope of many flood events. On the other hand, major river diversions, water storage projects, and construction of water conservancy projects played an important role in adjusting and mitigating the occurrence of large flood disasters (Xu *et al* 2020). A well-known example is that, the Dujiangyan Water Conservancy system used natural features to regulate river water for irrigation, flood, and flow control in 256 BC, which is still functioning today and has broken a cycle of summer floods and winter droughts in the Chengdu Plain (Cao *et al* 2010).

The size of disaster losses is obviously related to the population and socio-economic development, as well as the property types, values and specific locations. Particularly, human deaths in disasters concentrated very much in the areas with better developed agriculture, settlements, trading nodes and towns (Yang and Liu 2012). The difference in the spatial pattern of disaster losses is the certain result of the uneven development of regional social systems. At a given disaster intensity, the magnitude of the disaster loss depends further on the disaster-bearing body's coping capacity and resilience. As a traditional agricultural society with mainly walking transportations, the THR region has relatively weak capacity to resist disasters. However, it is worth noting that local capacities to withstand natural disasters have become stronger as a result of the general social development, and that the casualties caused by natural disasters have gradually decreased though the economic losses were often increased.

**Table 2, Details and specific information of disaster impacts at locals of the Tea-Horse Road region.**

Disaster events	Disaster details	Type of impacts	Specific impacts	Sources
Earthquake at Xichang in 1536	<ul style="list-style-type: none"> <li>Occurred on March 19, 1536</li> <li>At Xichang, Sichuan</li> <li>Level M7.5</li> <li>It started at around 1am at night.</li> <li>Many aftershocks lasted in the coming month</li> <li>Large areas at the northeast of Xichang were affected, including Ya'An, Garze.</li> </ul>	House collapse	间有地裂; 山崩地裂 Cracks on ground 城垣崩塌数多, 房屋倾压; 城廓靡宇皆倾; 城市尽塌; 本都司并建前二卫大小衙门、官厅宅舍、监房仓库、内外军民房舍、城垣、门壁、城楼、操口、城门俱各倒塌堵塞 Many wall collapses, and houses fell down to each other.	(Tong 2013), (Jiang 2005) and the sources they cited.
		Casualty	死者数百人; 死伤不计其数 hundreds of deaths, countless casualties 官吏, 军夷死数近万 Over ten thousands of officials, soldiers and ordinary people died. 压死都指挥一人、指挥二人、千户一人、百户一人、镇抚一人、吏三人、士夫一人、太学一人、指挥二人、千户一人、百户一人、镇抚一人、吏三人、士夫一人、太学生一人、土官土妇各一人 (This is a report with specific numbers about the various people who died in the earthquake)	
		Agriculture loss	地震坍塌, 段氏所施之田, 尽皆化为沧海 Due to the land subsidence, croplands of Duan's family became a lake.	
		Living environment	水涌地裂, 陷下三、四尺 Water surged due to ground sinking. 五昼夜雷声不绝 Underground thunders lasted for 5 days. 烈风可畏 Strong gale wind 山泉河水皆黄浊 Springs and rivers turned to yellow and turbid.	
		Rumor spread	军民惊惶无措 People are in panic due to various rumors “古城陆沉”, “邓都地陷”, “於州沉海” A most spreading rumor was that Xichang will sink into a large barrier lake after the earthquake. 愚民倡为古、护州沉海之言, 转相煽惑, 几至为变 People in panic all day long, and many escaped from Xichang. The risk of social chaos and upheavals raised.	
Famine in Yunnan (1815-1817)	<ul style="list-style-type: none"> <li>Cool summers from 1815 to 1817</li> <li>Crops (rice) deflated</li> <li>Wheat didn't grow mature</li> <li>It appeared in most areas in Yunnan</li> </ul>	Poor harvest	麦不熟, 饥民哭 Wheat didn't grow mature. People cried due to hungry. Failed harvest results from cold in 1815, cold and drought in 1816, and drought in 1817. Agricultural harvest showed a great drop from 1815 to 1817, even down to 5.3 fen in 1816 (only 53% harvest of the former year).	(Oppenheimer 2003) (Yang <i>et al</i> 2005) (Brönnimann and Krämer 2016) (Hao <i>et al</i> 2020)
		Hungry	大饥, 斗米三两, 饥者食草根树皮土粉 Famine occurred and rice price was very high. Hungry people ate grass roots, tree barks, and soil powder (white clay). 民有食董土者, 多由之死 Some people ate white clay and many of them died. 南北山头土可粥, 争先锄取倾筐归 People took white clay and cook it for food.	

		Famine deaths	是岁大饥，路死枕籍 A big starvation caused many deaths on roads. 邑中大饥，城乡饿殍载道 Famine hit the city, and hungry people died on road. 穷民求食不得，有毙于路者 Hungry people can't get food, and some died on road. 李于阳在《卖儿叹》中写道：“三百钱买一升粟，一升粟饱三日腹。穷民赤手钱何来，携男提女街头卖。明知卖儿难救饥，忍被鬼伯同时录……” A poem indicated that hungry people had to sell their children to survive themselves.	
Snow, freezing and hails	At mountain areas with high elevation - Occurred seasonally, most seriously in autumn and winter	Living conditions	1827: 入冬普降前所未有之大雪，即老人亦闻所未闻... 确已沦落破产之境 Elderly have never seen such heavy snow. Many families were nearly bankrupt. 1828: 多数牛、山绵羊受害致死，百姓生活极端贫困 People became very poor due to the loss of husbandry animals. 1828: 使安多果阿学和赛杰坚140户牧民流落到阿里那仓 About 140 pastoral families at Anduo had to migrate to Ali. 1927: 所有牲畜，包括政府租畜，几乎死绝，百姓失去居留所依 Almost all animals died, people lost what they can survive with. 1927: 平时百姓仅依牲畜乳品为生，今年多数百姓无法进行冬季贸易。 People live on livestock products, but they are not able to trade in this winter (due to heavy snow).	(Zhou 1990)  (Sun 1999)  (Ni and Xie 2007)
		Animal husbandry	1827: 大批人、马、牛、绵羊、山羊死亡，现仅剩一二头牛和绵羊。 Many animals died. Only very few yak and sheep left live. 1828: 雪灾致使官马及少许私有牦牛，如羌地百姓之牲畜一样，死亡甚多 Snow caused many deaths of both government-owned horses and private yaks. 1926: 连降大雪，灾情甚重，马牛羊皆大量倒毙 Continuing snows caused serious disaster, which killed many horses, yaks, and sheep.	
		Crop failure	1797: 南木林地区穷地之政府、贵族、寺院众百姓，今年遭受雹灾，收成全无 Namling suffered from hails, almost no crop harvest. 1822: 遭受严重雹灾，... 秋收全无，估计只能勉强收回种子 Hails caused failure crop harvest. It is expected to only harvest some seeds. 1848: 贡嘎“六月一日、二十五日、七月三日，连遭前所未有之严重雹灾” Gongga suffered three unprecedented hail disasters during one month time. 1851: 林周今年五月卅日下午至日落前，卡尔、美多与伦雪三地又遭受前所未有之雹灾，以政府谿卡自营地为代表之农田基地，颗粒无收 Croplands in Linzhou suffered from unprecedented hail disaster, which caused failure crop harvest.	
Geomorphic disasters, e.g. landslides, debris flow	Intensive and frequent at the center areas of the THR region - Especially at high mountain and deep valleys - Often triggered by heavy rainfall - Occurred in short time - Occurred at individual sites	Block roads	Roads were blocked and occasionally travelers could be seriously injured if happened being at the disaster site.	(Cui <i>et al</i> 2003) (Shang <i>et al</i> 2003) (Gao 2010) (Wang <i>et al</i> 2019)
		Damage assets	Water with stones and debris destroy buildings, roads, rail ways, hydropower stations, mining sites, etc., along its flowing way. Disaster materials stop and sediment at plain areas where human settlements are often located, thus damage houses, crops and agriculture facilities.	
		Casualty	Casualties were mostly caused by sudden occurrence of such disasters, when effective disaster reduction preparations can hardly be made. In the mountainous THR region, livestock deaths are a significant consequence of the disasters in addition to human injury.	
		Block rivers	River was blocked, which forms reservoir with unstable dam (stones, debris, soil, woods, etc.). Failure of the dam could cause catastrophic flood along the valley.	

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