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Monographic issue

Natural disaster risk profile of the People's Republic of China

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Letter from the Editor

The Emergency and Disaster Reports is a journal edited by the Unit for Research in Emergency and Disaster of the Department of Medicine of the University of Oviedo aimed to introduce research papers, monographic reviews, and technical reports related to the fields of Medicine and Public Health in the contexts of emergency and disaster. Both situations are events that can deeply affect the health, the economy, the environment, and the development of the affected populations.

The topics covered by the journal include a wide range of issues related to the different dimensions of the phenomena of emergency and disaster, ranging from the study of the risk factors, patterns of frequency and distribution, characteristics, impacts, prevention, preparedness, mitigation, response, humanitarian aid, standards of intervention, operative research, recovery, rehabilitation, resilience and policies, strategies, and actions to address these phenomena from a risk reduction approach. In the last thirty years has been substantial progress in the above-mentioned areas in part thanks to a better scientificknowledge of the subject. The journal aims to contribute to this progress by facilitating the dissemination of the results of research in this field.

This monographic issue is about the disaster risk profile of the People’s Republic of China. China is a geographically vast country with the world’s largest population. Because of the vast land area that stretches from the high plateau to temperate coasts, China is prone to a variety of natural disasters. Globally, China is regularly among the top three countries most affected by disasters every year, in terms of disaster frequency, lives lost, and economic damages.

In addition to natural hazards, China faces a variety of social vulnerabilities, including significant inequalities in income and health outcomes. Vulnerable populations include rural communities, poorer provinces, and people of lower socioeconomic status. While there are some efforts to target the inequalities in society, the current disparity remains large and these populations will be much more vulnerable to disasters.

This monographic issue analyzes the disaster risk of China by implementing the hazard-exposure-vulnerability models. The data on disaster incidents used in the report came from a variety of sources, including peer-reviewed articles and intergovernmental organization reports. Vulnerabilities are analyzed through a socioeconomic lens, addressing the complexity of the cultural and historical background. In the end, coping mechanisms, including technological initiatives and disaster risk management mechanisms are presented. As China's demographic changes and global warming exacerbate, preparing for future disasters will become increasingly important.

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List of Abbreviations

ADB	Asian Development Bank
CMA	Chinese Meteorological Administration
CMIP5	Coupled Model Inter-comparison Project Phase 5
CNY	Chinese Yuan
DLSS	Disaster Loss Statistics System
DRR	Disaster Risk Reduction
EWS	Early Warning System
FAO	Food and Agriculture Organization
GDP	Gross Domestic Product
GNSS	Global Navigation Satellite System
IDNDR	International Decade for Natural Disaster Reduction
RCP	Representative Concentration Pathways
SMS	Short Messaging Service
SPEI	standardized precipitation evaporation index
UN	United Nations
UNDRR	United Nations Office for Disaster Risk Reduction
USD	United States Dollars
WMO	World Meteorological Organization

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1. Country Overview

A country located in East Asia with over 1.4 billion people, the People's Republic of China has the largest population in the world and the world's second-largest economy (1). The population is primarily concentrated in the eastern portion of the country, which is more developed and urbanized, while the western portion of the country is relatively sparsely populated. As of 2018, six Chinese cities contain a population of over 10 million each (2). However, because of recent societal-level demographic change and legislations like the strict one-child policy, there has been a rapid and significant decline in fertility in the past decades (3), causing population growth to slow down for decades. The elderly population is growing exponentially, and the trend will last for decades in the future (4). The country is rapidly undergoing urbanization, with the urban population surpassing the rural population in 2012 (5). With urbanization comes an enormous number of rural migrants who live and work in urban cities without formal urban registration status (6). China is at a demographic turning point as it shifts from an agricultural society to an urban society. However, such demographic change comes with multiple challenges. To name a few, the increasing burden on the social welfare system of an aging society, and the growing inequality among households and regions.

The country is the 5th largest country in the world in terms of physical area, occupying 9,596,960 km^2(7). China borders more countries than any other country except Russia. On land, it borders 14 countries: Russia, North Korea, Vietnam, Myanmar (Burma), India, Pakistan, Afghanistan, and four states of Central Asia (8). China's geographic landscape is diverse. The west of the country contains the highest plateau on earth, the Tibetan Plateau. The elevation decreases from west to east (9). The eastern plains and southern coasts are characterized by fertile lowlands where most of the country's agricultural output and population are located (10).

The Chinese population is highly diverse. While the country does not have a racial discourse popularized in Europe and notably the Anglo-Saxon societies, Chinese society mainly uses the notion of *minzu* (people-lineage, often translated as *ethnicity*) for the categorization of the Chinese people (11). It is said that China consists of a Han majority and fifty-five minorities, together forming a Chinese nation (*zhonghua minzu*). The concept of nation is of utmost importance, as it underscores the importance of loyalty to the Chinese state, no matter the *minzu* identity (12). Interethnic conflict often happens, but the employment of such a mechanism obscures conflict and renders the discussion of discrimination irrelevant (as opposed to the fierce discussion of racism in the United States).

China's economy, remarkably, has grown since the economic reform of the 1970s. Between 1979 and 1990, the average annual growth rate of GDP is 9%. The number increased to 10.4% from 1990 to 2010. Many acknowledge that such an improvement is impressive and "extraordinary (13)." The poverty rate, likewise, has been decreasing rapidly. The percentage of people living on $2.15 a day is 0.1% in 2019, compared to 62.7% in 1990 and 36.5% in 2002 (1). However, income inequalities have increasingly become a significant problem in the country. The Gini index is a common measure of income inequalities, with 1 being the most unequal and 0 being perfectly equal. In 1990, China's Gini index was 0.32. The number has been continually growing until 2010, reaching the highest point at 0.437. While the number has been overall decreasing since, the country faces increasing inequalities among regions, between rural and urban areas, and across socioeconomic status (section 4.1). Health outcome follows a similar pattern. While measures like life expectancy and under-5 mortality improved significantly, the disparity between the poorer and richer populations remains large (section 4.4).

Because of China's enormous land area that contains drastically different altitudes, latitudes, and distances from the coast, it features an extremely diverse climate. According to climate features, we can divide the country into five areas: Southern China is tropical, with high temperature and heavy rainfall during the summer months (May to September); southeastern China features more moderate temperature; Inner Mongolia and Tibet has a harsh climate, with cold weather and strong winds in high-altitude areas; Central and eastern China, in comparison has fewer climate extremes but has very humid summer; North China has a highly varied climate with little predictability (14).

Because of climate change and other factors, the climate in China has been undergoing multiple changes. From 1901 to 2010, the average surface air temperature increased by 0.98°C. The change is especially significant since 1980. Since 2010, the warming increases to 0.25°C per decade. The temperature rise is the strongest in the north and the weakest in the South. Extreme cold events are less frequent in the country, while heat wave frequency is on the rise. On the other hand, there have been no significant changes in annual average rainfall between 1960 and 2010. While the spring and autumn precipitation has been declining, it has been increasing in summer. However, Ma et al. (15) have observed an increase in the frequency of dry days and drought, and the intensity of rainfall between 1960 and 2013.

To assess the potential change in climate in the future, World Bank employs the Coupled Model Inter-comparison Project Phase 5 (CMIP5) model. The model discusses four Representative Concentration Pathways (RCP) and estimates the future temperature and precipitation by 2100. An RCP is a greenhouse gas concentration trajectory used by the IPCC. Different RCP describes different scenarios of the volume of greenhouse gases. Pathways considered in the CMIP5 model include RCP2.6, RCP4.5, RCP6.0, and RCP8.5 (14). The number labels refer to the estimated radiative forcing values in 2100. For example, RCP8.5 refers to the scenario where the change of energy flux due to climate change is 8.5 watts/m^2 and corresponds to the air concentration of 1250ppm (16). RCP 2.6 and RCP8.5 refer to extremely low and extremely high pathways. While RCP2.6 means a coordinated global effort to mitigate climate change, RCP8.5 represents the worst-case scenario where nothing is done to address greenhouse gas output.

In the years up to 2100, China will continue to experience temperature increases, most significantly in the central and northern regions. In RCP 8.5, the annual temperature will increase by more than 5°C, much higher than the global average (figure 1). Although there is considerable uncertainty over the prediction of precipitation, the model shows an increase in precipitation in the Central, Southern, and Eastern regions of China in all emission pathways, with a reduction in the Western region.

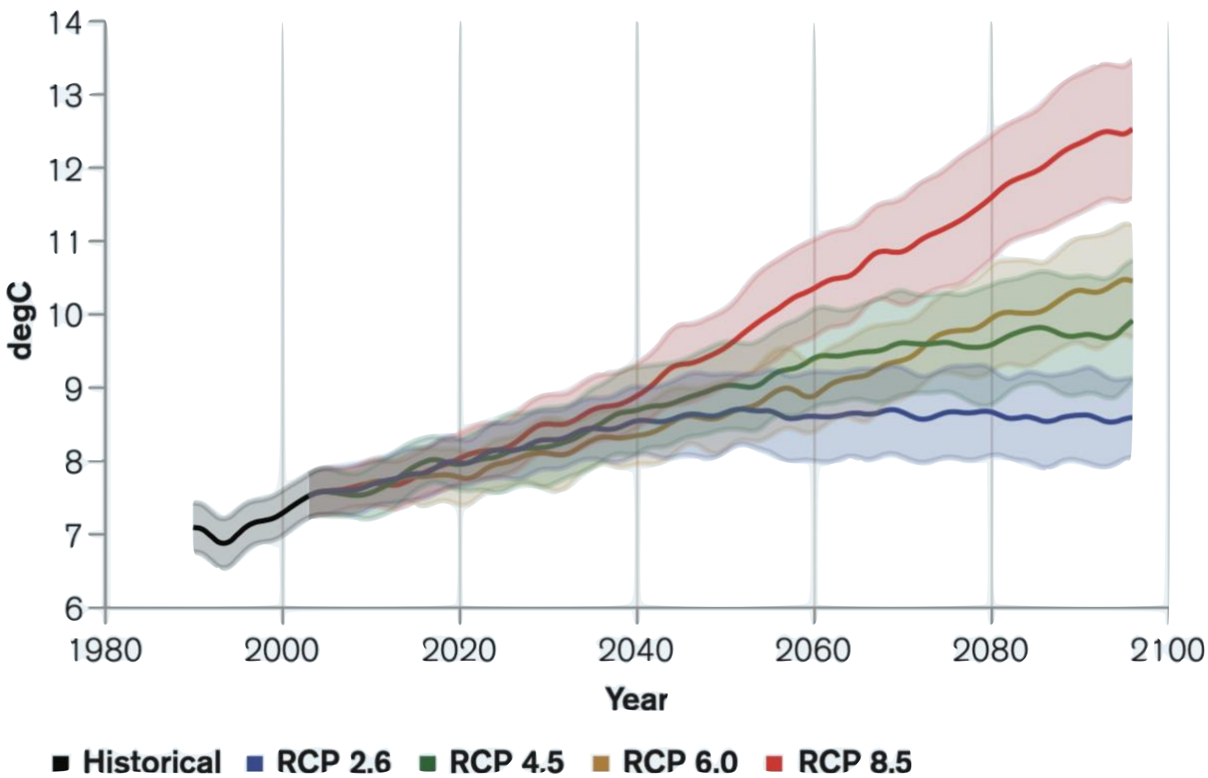

Figure 1. Historic and projected average annual temperature in China under RCP2.6 (blue) and RCP8.5 (red) estimated by the model ensemble

Shading represents the standard deviation of the model ensemble. (14)

2. Methodology

2.1 Concepts

In the field of disaster studies, social scientists have long been struggling to operationalize the concept of disaster and vulnerabilities. After all, disaster is not a fact - it is socially constructed. For example, we can say that an earthquake has occurred. But it doesn't necessarily lead to a disaster if, for example, no one lives in the affected area. The United Nations Office for Disaster Risk Reduction, therefore, determines that one of the most significant concepts of disaster is that it seriously disrupts the "functioning of a community or a society at any scale (17)."

However, social scientists have long been in discussion on the view of vulnerabilities. Several models have been created. The "hazard-centric" or environmental model emphasizes the hazard itself. People living near volcanos, flood plains, and fault lines are at risk because of their geographic proximity to the hazards. Lack-of-resources model, on the other hand, emphasizes whether an individual or a given community has adequate resources (food, housing, infrastructure) to cope with disasters. For example, while the first model explains famine as being geographically located in an area prone to famine, the second model argues that vulnerabilities are mainly due to socioeconomic and political barriers (18). However, both models are comprehensive and focus on the immediate context of the disaster: the geographical proximity and the immediate socioeconomic environment.

Marino (19) attempt to explain the reproduction of vulnerabilities from the historical perspective through the political ecology model: Why does a group lack capacity and resources, and how did they occupy a such precarious position in the first place? While this marks distinct progress from the previous two models in that it takes the context into account, it completely leaves out the environmental aspect. Wisner et al. (20) developed a model of disaster vulnerabilities that considers the socioeconomic and political root causes, dynamic pressures, and unsafe conditions, combined with a hazard, can produce a disaster. In this model, known as the pressure and release model, the disaster risk is considered as follows:

$$risk = \frac{hazard \times exposure \times vulnerability}{coping\ capacity}$$

In this model, **hazard** refers to a "process, phenomenon or human activity that may cause loss of life, injury or other health impacts, property damage, social and economic disruption or environmental degradation." Such hazards may be natural or human made. They are usually categorized into three main categories: environmental, technological, and biological. More specifically, they can be due to meteorological, hydrological, extra-terrestrial, geological, environmental, chemical, biological, technological, and societal factors. More than 300 different categories of hazards that might cause catastrophes were recently listed by UNDRR and the International Science Council in their Hazard Definition and Classification Review. They cover both frequent occurrences like storms and floods as well as less frequent ones like pandemics and chemical accidents. **Vulnerability** refers to "the conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards." **Exposure** refers to the "situation of people, infrastructure, housing, production capacities and other tangible human assets located in hazard-prone areas. (21)" **Coping capacity**, on the other hand, is the ability to respond and to recover from a disaster. It is closely related to vulnerabilities, as the more one is vulnerable, the less one can cope (22).

This model underscores the idea that disasters are not only because of hazards, and shows the different factors involved in the attribution of risks (23). The UNDRR adopted this definition, defining the disaster as "serious disruption of the functioning of a community or a society at any scale due to hazardous events interacting with conditions of exposure, vulnerability, and capacity, leading to one or more of the following: human, material, economic and environmental losses and impacts (21). The fact that disasters are in a great part caused by vulnerability and exposure emphasizes the role of human decisions. Disasters don't happen naturally but are rather a result of how people interact with their environments. A specific mode of development and growth, together with long-term social, economic, cultural, and political processes are the primary source of disaster risks.

Disasters are categorized by their speed of development and the extent of their impact. In terms of speed, they are divided into rapid-onset events (such as typhoons, earthquakes, or flash floods) and slow-onset events (droughts, saltwater intrusion, or desertification). In terms of extent: extensive disasters refer to “high-frequency localized events that manifest over a dispersed area, causing recurrent small- and medium-scale impacts,” such as floods and droughts. Intensive disasters refer to large-scale events that affect large cities or densely populated areas, including major earthquakes or once-in-a-generation floods (21).

2.2 Sources, Objectives, Structure, Limitations

The main objective of this paper is to provide the reader with an overview of the natural disaster risk in China. Adopting the pressure and release model, the paper considers the multifaceted nature of a disaster: hazard/exposure, vulnerabilities, and coping mechanism. Section 3 (hazard/exposure), limited to the environmental aspect, describes the occurrence, characteristics, and trends of different natural hazards. Section 4 (vulnerabilities) is devoted to the pre-disaster societal context or social determinants of health. It addresses the main topics including poverty/inequalities, health, food security, and water. Section 5 (disaster risk reduction strategies) discusses the country’s progress in disaster risk reduction, including its political and technological advances.

Readers may argue that such categorization utilizes a narrow definition and limited view of each aspect and obscures the interactive relations between them. As discussed above, disaster risk is a combination of hazards, vulnerabilities, exposure, and coping mechanism. Such structure implies that *exposure* is only due to environmental threats, whereas in reality it is closely related to *vulnerability* (24). For example, marginalized people are more likely to live in an area prone to disasters. In addition, vulnerabilities and coping mechanisms are, as discussed, “the two facets of the same coin. (22)” An area with limited water resources (*vulnerability*) is likely to have an extreme limitation in providing water to its people during disasters (*coping mechanism*). A vertical approach to disaster risk reduction (for example, technological intervention and DRR policies), although necessary, is only likely to have a limited impact. A horizontal approach to address vulnerabilities will boost the area's DRR ability sustainability to a greater extent. Much research from international organizations (such as World Bank) adopts a "hazard-centric" model, completely obscuring the human role in disasters (24). While other organizations such as UN agencies are increasingly adopting the multifaceted "pressure-and-release" model, the rigid dichotomy of concepts such as exposure/vulnerability and vulnerability/coping mechanism obscures the intricate connection between different factors, and shapes the DRR effort to be vertically, in-comprehensive, and technologically focused. This paper, while limited in its structure that separates vulnerabilities from DRR strategies, keeps in mind the effect of social determinants and horizontal efforts while discussing the specific DRR strategies.

This paper is a narrative review. The literature search was conducted on Google Scholar search platforms for peer-reviewed articles, and Google search engine for reports from international organizations. The report also incorporates data from EM-DAT database. In describing trends and frequencies of natural disasters, both the latest available data and historical data are used. Therefore, the publish dates of the sources range from 1978 to 2023.

While this paper provides a quantitative description of hazards/exposure, vulnerabilities, and coping mechanism, I acknowledge that quantitative indicators are easier to compare across countries and provide at-a-glance information. Therefore, at the beginning of each section below, key points will be presented alongside the relevant INFORM Risk score, as well as China's rankings globally. For more information on how INFORM Risk score is calculated, consult the European Commission Disaster Risk Management Knowledge Centre website. This mixed-method approach, while allowing the reader to quickly gather necessary information, also provides the necessary context to interpret the numbers comprehensively (25).

3. Natural Hazards

INFORM-Risk Scores and Key Points: Natural Hazards

A higher overall score means higher risk. A lower country rank means higher risk. For example, a score of 8.4 means high risk; a country rank of 12 means only 11 countries experience more of the same type of hazards.
The score is from INFORM-Risk 2023 (26). The qualitative description is a summary of the section.

Earthquake	Overall Score **7.2**/10 Country Rank **51**/191	China is disproportionally affected by the earthquake, resulting in enormous casualties and economic loss. The extent of earthquakes is due to (1) the high population density, and (2) the vast land area located in high seismic intensity zones. The recent 2008 Wenchuan Earthquake and its secondary disasters caused 88,000 casualties and CNY 1 trillion in economic loss.
Heatwave	No score available	China is susceptible to extreme heat events. The intensity of heat waves has been increasing and will continue to increase. Heatwaves primarily affect Southeastern and North-Northwestern regions. By 2090, the worst-case scenario sees the probability of heatwaves grow 22%, while in the best case, the frequency of hot days will also increase.
Flood	Overall Score **8.4**/10 Country Rank **12**/191	Flood affects 77 million individuals annually, with an estimated cost of $9.25 billion. Flood risks vary across China in terms of the vulnerable population, death risks, economic risks, and agricultural vulnerabilities. Because of climate change and migration toward flood-prone urban cities, future floods will have a higher impact on casualties and economic loss.
Drought	Overall Score **4.6**/10 Country Rank **54**/191	While drought has become more frequent, the number of people and areas affected has been decreasing because of infrastructure improvements and DRR measures. Climate change will cause drought to be more extensive and severe, which will pose a further challenge in ensuring water security.
Landslide	No score available	Landslide, as a secondary hazard to heavy precipitation, earthquake, and flooding, primarily occurs in central China. Its intensity, related casualties, and economic loss are slowly increasing.

Land subsidence	No score available	Resulting from the over-extraction of water, and in some cities, minerals. Mainly occurs in the Eastern and Central regions. There has been significant economic loss due to property and infrastructure damage. Many coastal cities now fall below sea level, with more cities in danger.
Tropical cyclones	Overall Score **8.1/10** Country Rank **6/191**	Mainly affects Southern and Southwestern provinces. Although Guangdong suffers much more frequent tropical cyclones than other provinces, Zhejiang contributed to the most casualties and economic loss among all provinces. Eastern China experiences an increase in the frequency and intensity of tropical cyclones. Nationwide, there has been an annual increase in economic loss related to tropical cyclones.

Because of the vast land area that stretches from the highest plateau on Earth to the temperate coastal area, China is prone to a variety of natural disasters, including meteorological disasters, earthquakes and geological disasters, ocean disasters, biological disasters, and forest and grassland fires. Globally, China is regularly among the top three countries most affected by disasters every year, in terms of disaster frequency, lives lost, and economic damages. In recent decades, almost all types of major hazards have hit China, such as earthquakes, typhoons, floods, droughts, sandstorms, storm surges, landslides and debris flows, hailstorms, cold waves, heat waves, pests and rodent disease, forest and grassland fires, and red tides (27). According to the World Bank Group (28), China is especially prone to water-related disasters, including riverine, flash, and coastal. It also has very high exposure to tropical cyclones and their associated hazards, ranked 6th most frequent in the world. Drought exposure is proportionately lower but still significant, ranked jointly 55th globally.

All provinces in China have faced the negative impacts of natural disasters. Flooding affects 2/3 of the country’s territory, while tropical cyclones primarily impact the Eastern and Southern coastal regions as well as some inland provinces. Droughts are most common in Northeast, northwest, and north China. Each province in China has also experienced destructive earthquakes with a magnitude of greater than 5.0 on the Richter scale. Additionally, 69% of China's territory is made up of mountains and plateaus, making the country susceptible to landslides, debris flows, and rock collapses. Furthermore, 70% of China's cities are in areas prone to meteorological, earthquake, geological, and oceanic disasters (27).

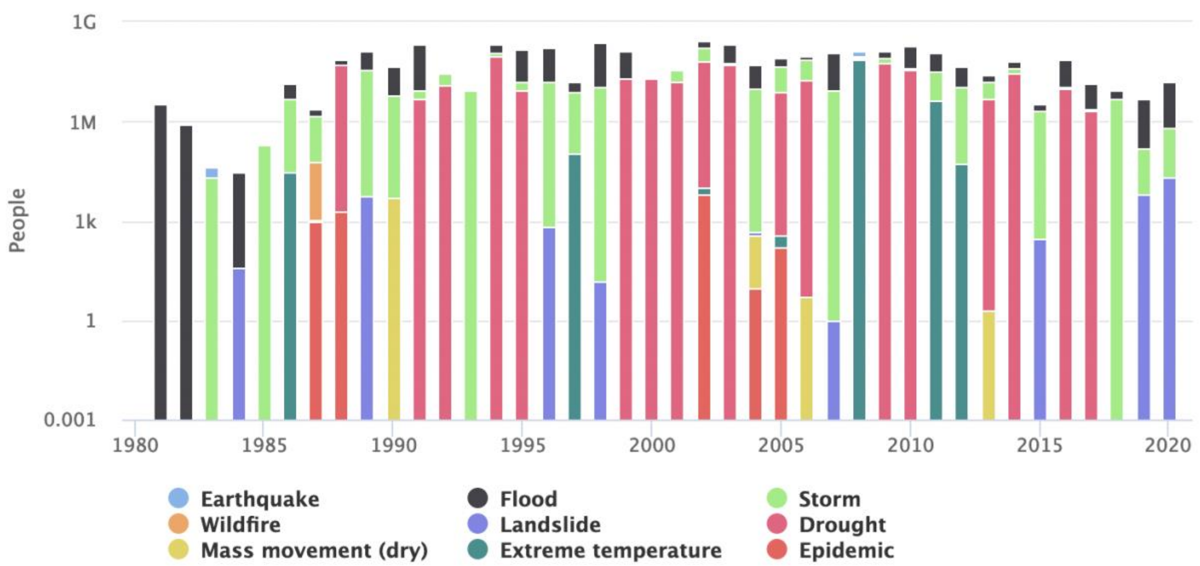

Figure 2. Key Natural Hazard Statistics for 1980–2020, Number of People Affected (28)

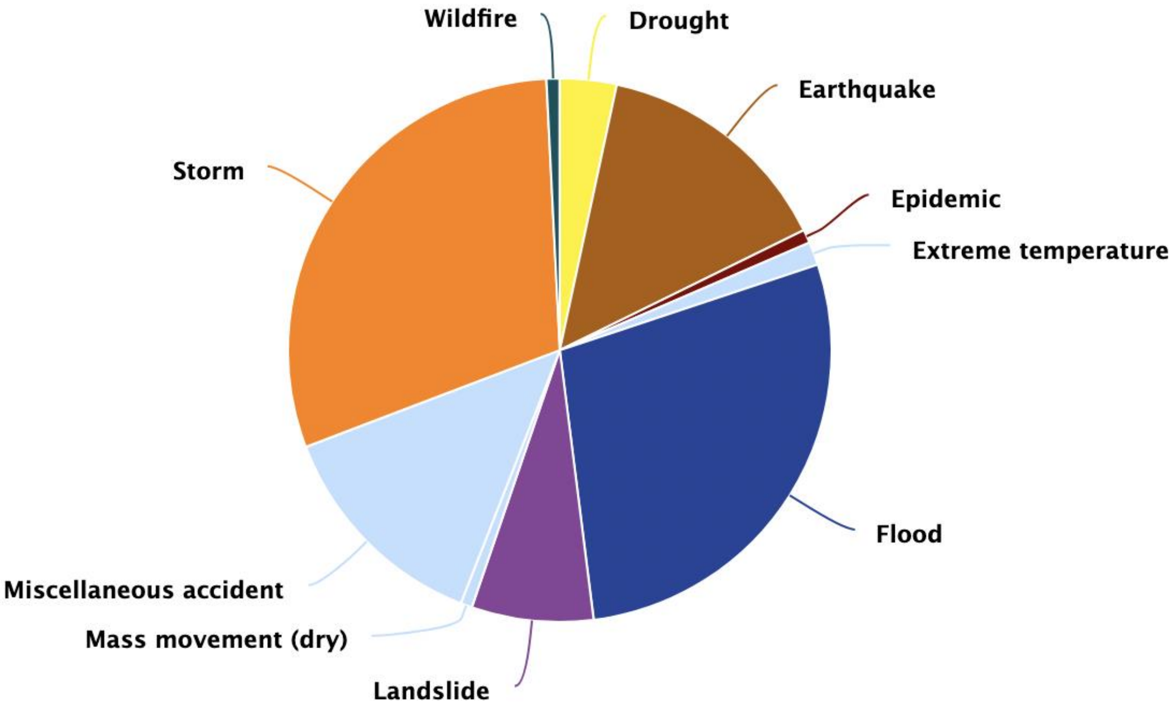

Figure 3. Average Annual Natural Hazard Occurrence for 1980–2020 (28)

Natural disasters in China are characterized by their high frequencies, significant losses, large scales, and increasing risks. The country experiences regional and partial droughts almost every year, with around 7 tropical cyclones hitting the eastern coastal areas annually. China is in a region where the Eurasian, Pacific, and Indian Ocean plates meet, making it prone to frequent earthquakes due to ongoing tectonic movements. The country also has many mountains and hills, which makes it vulnerable to frequent collapses, landslides, and debris flows. Fires are also common in China's forests and grasslands. The loss caused by natural hazards in China is significant, with 195,820 deaths and direct physical losses of US$1,698 billion (in 2018 values) between 1989 and 2018. The scale of these disasters is large. The 1998 flood affected 223 million people, killed 4150 people, and damaged 21.2 million hectares of crops and 6.85 million houses. The 2008 magnitude 8.0 Wenchuan earthquake killed 69,227 people and caused US$ 159 billion (2018 value) in direct economic losses. The risks of these natural disasters are increasing due to climate change, which exacerbates the frequency and intensity of events such as super typhoons and intense rainfall, leading to flash floods and riverine floods. Droughts and heat waves are also becoming more frequent and severe. Additionally, demographic changes such as population growth, economic development, rapid urbanization, and interregional trade integration also exacerbate the risks of natural disasters in China (27).

Figure 4. Losses from Natural Disasters in China: Direct Damages (27)

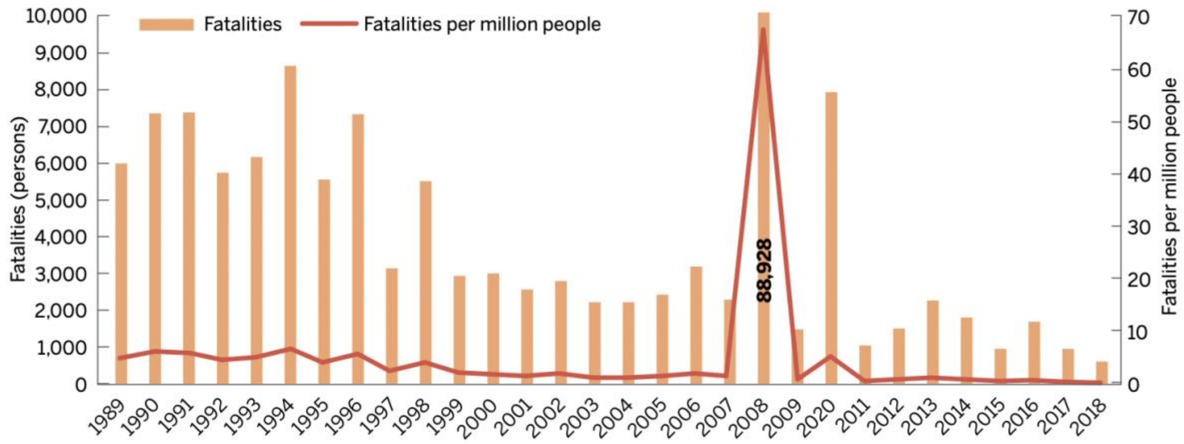

Figure 5. Losses from Natural Disasters in China: Fatalities (27)

3.1 Earthquake

Among all the natural disasters, earthquakes are the least predictable and most lethal of all. In the 20th century, Asia (461 events) had at least twice as many earthquake events as other continents, compared to 234 in the Americas and 68 in Africa (29). China bears the disproportionate earthquake burden globally, and is particularly vulnerable to the negative impacts, due to earthquakes' high frequency, high magnitude, shallow hypocenter, and large distribution. 35% of the world's continental earthquakes of magnitude 7 or higher occurs in China. Of the worldwide earthquake deaths of 1.2 million in the 20th century, China accounts for 590,000. Between 1900 and 2007, There have been 70 earthquakes of magnitude 7.0 to 7.9, and 6 earthquakes of magnitude 8.0 or higher, affecting hundreds of millions of people residing in 28 provinces, killing 590,000 people, and injuring 760,000 people. Merely during the 54 years since the establishment of the People's Republic of China in 1969 until 2023, there have been 193 earthquakes with a Richter scale of more than 5.0 (30). The disproportionate earthquake consequences on China is mainly due to two reasons: First, more than one-third of China is located in the high seismic intensity zones of VII degree or higher, compared to, for example, only 12% of the land area in the United States located in these zones. Second, the population density of China is much higher than most countries in the world, meaning higher direct casualties but also difficulties in evacuation and resource allocation in post-disaster efforts (31).

A seismic belt is a specific area on the Earth's surface where most earthquakes occur, usually in a narrow geographic zone (32). Within China's territory, there are mainly 7 seismic belts (33): (1) the southeast coast and Taiwan belt; (2) the belt starting from Shenyang and ending at Hubei Huangmei; (3) Yanshan Nanlu and central Shanxi basins; (4) Central Helan Mountain and Liupan mountain, passing through Gansu and Sichuan, until Zhendong area; (5) Himalayan area, as a part of Mediterranean-Southern Asian seismic belt; (6) West Kunlun and Hexi Zoulang; and (7) Pamir and Tianshan.

Overall, there is limited research on earthquakes in China, especially compared to countries such as the United States and Japan (29). However, from studying past earthquakes, it is found that earthquakes are more frequent in Western China. The East experience less frequent earthquakes, but seismic activity lasts for a long time following the initial impact. According to the frequency and intensity of earthquake events, China is divided into three areas. Areas of high intensity include Tibet, Gansu, Qinghai, Ning, western Sichuan, and Yunnan, accounting for 80% of all earthquake events in China in the 20th Century. Medium-intensity areas account for 15% of earthquakes. Although the magnitude can reach 7 to 8 on the Richter scale, they are typically less frequent and do not cause devastating impacts. Weak intensity areas include Jiangsu, Zhejiang, Chuandong, Heilongjiang, Jilin, and the majority part of Neimenggu. The earthquake magnitude only reaches as high as 6, and the time interval between earthquakes typically surpasses 100 years. They only account for 5% of earthquakes in China (33).

The occurrence and activities of earthquakes in China are closely related to active faults. By the end of the 20th century, all earthquakes with magnitude 8 recorded in China have all occurred within major faults with lengths of hundreds of kilometers and their bounding rift basins. The majority of 7–7.9 magnitude earthquakes occurred in active faults over 1000 kilometers in length and the rift basin, and 90% of 6–6.8 magnitude earthquakes in faults over tens of kilometers and rift basins. The distribution of strong earthquakes in China has also been related to specific structural positions of active faults: about 50% of strong earthquakes occur at the intersection of active faults in different directions, 15% occur at fault bend, and 15% at main active fault segments (33).

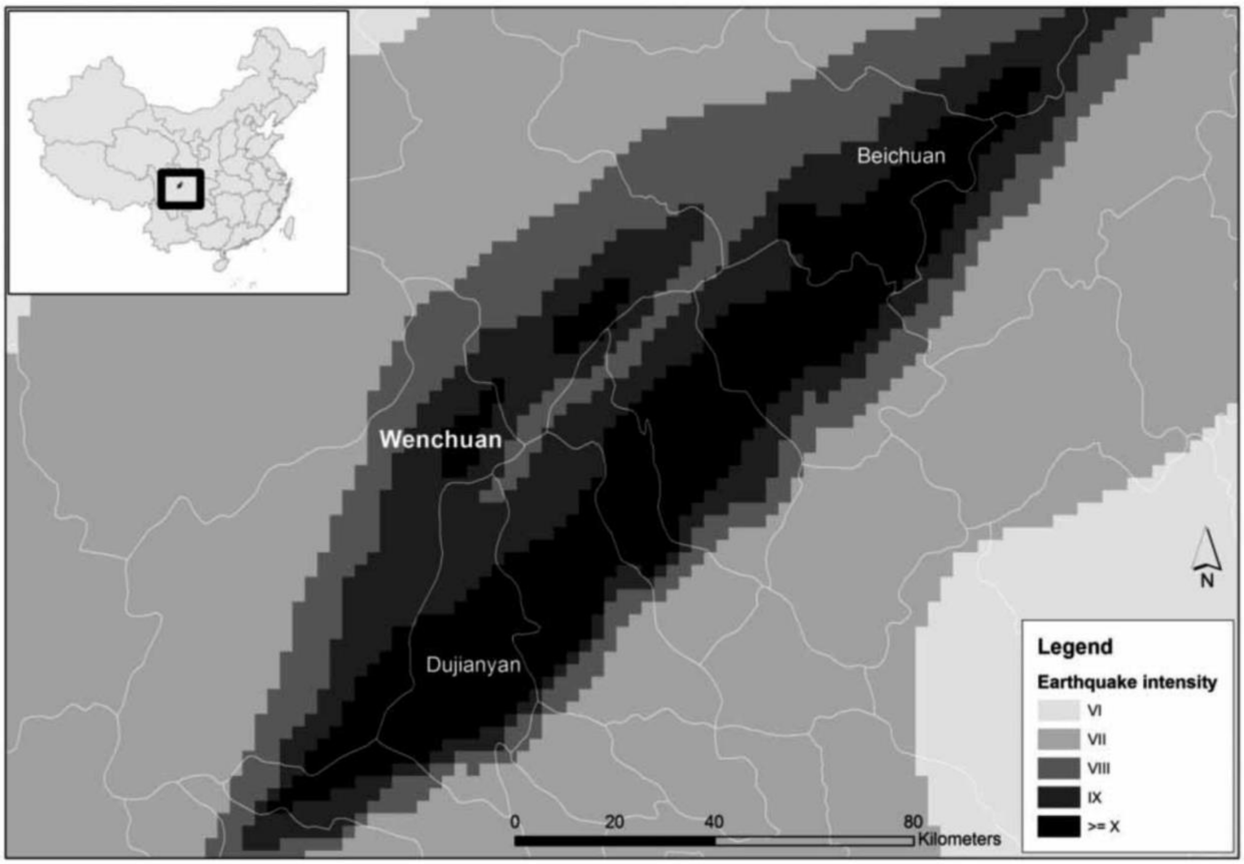

Figure 6. Earthquake intensity of Wenchuan and surrounding areas during the 2008 Wenchuan Earthquake (34)

One of the most devastating earthquakes ever in the history of China, an earthquake of 8.9 magnitudes occurred in Wenchuan County, Sichuan province on 12 May 2008 (35). The focal mechanism of the earthquake was a massive rock fracturing at Yingxiu at around 15 km deep. The earthquake affected over 100,000 km^2 of densely populated areas. Following the earthquake, by 30

June 2008, more than 13,000 aftershocks have occurred. The strongest aftershock has a magnitude of 6.4. The areas affected by the aftershock are as long as 300km long. In addition, the earthquake triggered 4,970 potentially risky sites, 1,701 landslides, 1,844 rock avalanches, 515 debris flows, and 1,093 unstable slopes (36). Transportation networks, communication infrastructures, and other lifeline systems were destroyed, posing extreme difficulties for rescue efforts. Due to the blockage of rivers by the earthquake landslides, numerous weirs were also formed, posing a great threat to the people downstream. President of the China Earthquake Administration, in his report to the Central Government, called the event "the most devastating seismic event to occur in China since 1949 (31)."

The impact of the Wenchuan Earthquake was devastating. There were 88,000 deceased or missing persons. The economic loss surpassed 1 trillion CNY. The direct economic loss accounted for 831.5 billion, and the indirect loss in the industry accounted for 176.8 billion in the first year alone and can cost up to 351.8 billion assuming the complete recovery takes 3 years (35). Following the Wenchuan earthquake, the Chinese government has made a significant investment in technological solutions. There has been a significant focus on prediction, including the investment in a seismological-electromagnetic satellite (37), and numerous early detection projects (section 5.2.2). However, earthquake-preventative policy measures are understudied and often overlooked by both academia and the government (34).

3.2 Heatwaves

The detrimental effects of extreme heat on various facets of human and natural systems have been well documented in the literature. It has significant impacts both on the individual level and the societal level. Heatwaves have been linked to increased mortality rates due to cardiovascular, cerebrovascular, and respiratory illnesses. Individuals with pre-existing cardio-respiratory diseases are particularly vulnerable to the adverse effects of heat stress, which may include increases in blood viscosity, cholesterol levels, red blood cell counts, and platelet counts. Additionally, patients with diabetes may experience fluctuations in glucose tolerance and changes in insulin absorption. The elderly population is particularly susceptible to the effects of heatwaves, owing to their decreased ability to regulate body temperature and a higher prevalence of chronic health conditions and medication use (38)." Heatwaves disproportionately affect outdoor workers, particularly those in the working class, who are engaged in occupations such as agriculture, construction, and manual labor. High temperatures and humidity can make these conditions dangerous and increase the risk of heat stroke, heat exhaustion, and other heat-related illnesses. On a societal level, heat waves can cause significant damage to infrastructure, including weakened roads and bridges, power outages, and wildfires. Moreover, the ability of plants to grow and produce is significantly impaired, leading to a decrease in crop yields.

Driven by climate change, global mean temperatures have been steadily increasing since the 1970s. Between 1951 and 2001, China's annual surface temperature rose by 1.1°C (39). The temperature increases brought about more frequent and more severe heatwaves in China and across the world. Unlike rapid-onset events such as earthquakes which have a clear definition and start/end dates, there lacks an agreement on the definition of heatwaves. Researchers commonly define it as the occurrence of several consecutive days with daily temperatures exceeding a specific threshold, where the threshold could be relative (a percentile of daily mean temperature) or an absolute value. However, the number of days and the threshold is often contested. World Bank, for example, uses "3 or more days" where the temperature "is above the long-term 95th percentile" as the threshold, regardless of country context (14). On the other hand, studies are attempting to define the most suitable definition by researching which threshold is correlated with the most impact. Yang et al.'s study ((38)) conducted research in mainland China, concluding that the percentile of 92.5% with a duration of 3 days or more is most strongly associated with mortality, after considering 15 different combinations of thresholds.

To investigate the geographical distribution of heatwaves, Ding and Qian (39) studied the trend of daily temperature and relative humidity from 1960 to 2008 to investigate geographical patterns and temporal variations of heatwave events. To include sufficient events for higher accuracy, they used a more generous definition of heat wave: the temperature above the 80th percentile of long-term average temperature lasting for 3 or more days. Because their data sources came from different weather stations across the country, they require the temperature above the above criteria must be measured by five adjacent weather stations to account for outliers. They found that there were 163 wet heat waves during this period, with a mean duration of 11 days. Future 7 shows the geographical distribution of dry and wet heat waves. The country is geographically divided into four areas: A (north-northwest), B (northeast), C (southeast), and D (southwest). Southeastern China (C) suffers disproportionally higher frequent dry and wet heatwaves, while the north-northwest region (A) mainly experiences dry heat-wave events.

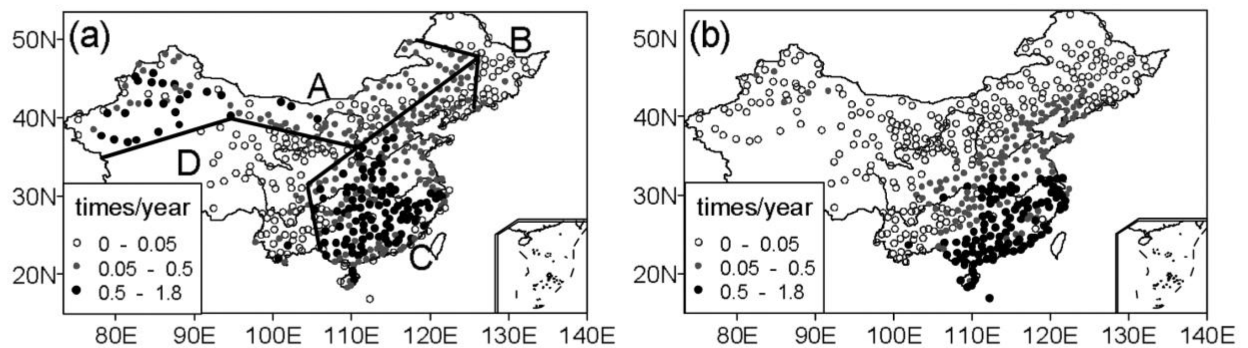

Figure 7. Geographical distribution of dry (a) and wet (b) heat waves, categorized by annual mean frequency (times per year) (39)

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According to a study by Yang et al. (38), although the southeastern region of a country experiences comparatively more extensive heatwaves than the northern region, the population in the north is at a greater risk of health hazards during heatwaves. This may be attributed to the fact that individuals in these regions are less acclimatized to high temperatures due to their local environmental conditions and individual behaviors. In contrast, residents of southern regions may be more accustomed to high temperatures and better equipped to handle heat waves.

Furthermore, the study found that cities with higher concentrations of PM2.5 are more susceptible to heatwaves, suggesting that the combination of high temperatures and particulate matter may have synergistic effects on health outcomes.

Recent research by the World Bank Group and Asian Development Bank (14) has shown that while the current probability of heatwave events in China is around 2%, there has been a marked increase in both the frequency and intensity of heatwaves in recent decades. A study by Ding and Qian (39) conducted a statistical analysis of past summer heatwaves (May to September) between 1960 to 2008, focusing on changes in frequency, severity (measured by the annual Ci number, with 1 being the most severe and 163 being the least severe), duration, geographical extent, and intensity. The study found that the frequency of heatwaves significantly increased by 0.29 times per decade, however, there were no significant changes in duration, extent, and intensity.

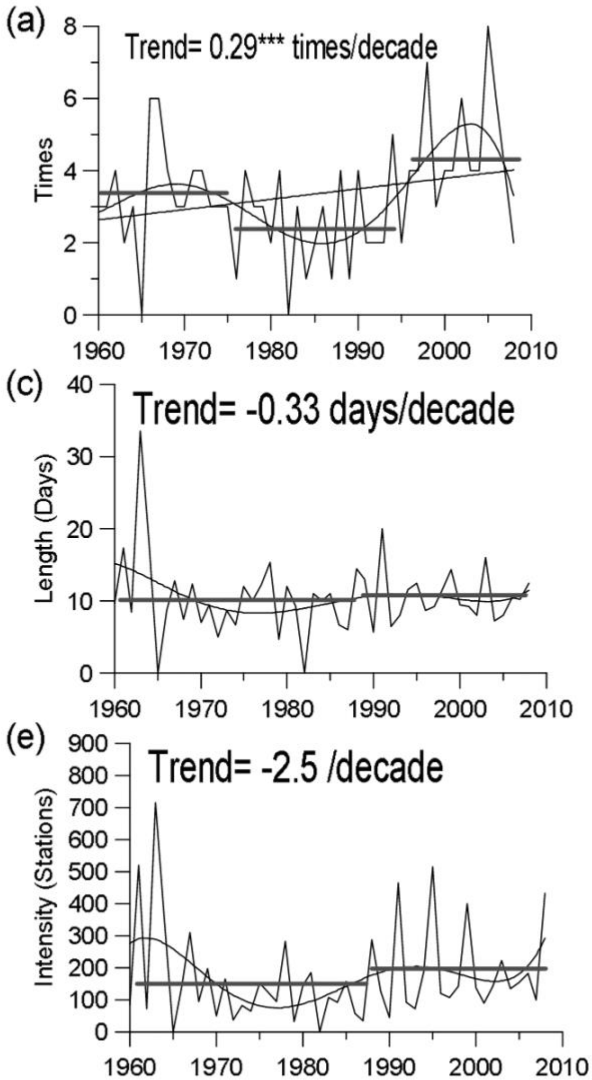

Figure 8. Linear trends and temporal variables of regional wet heat wave events

Graphs referring to (a)average frequency, (b)annual Ci number, (c)duration, (d)extent, and (e)intensity. Asterisks (***) denote significance at the 0.01level (39)

Recent research by the World Bank and Asian Development Bank (14) has examined the impact of climate change on extreme heat events. The findings indicate that by 2090, the annual probability of heatwaves will range from 5% to 22%, depending on the emissions pathways. Major cities such as Guangzhou, Shanghai, and Beijing are particularly susceptible to chronic heat stress. Even under the greatest reduction in emission of greenhouse gas (RCP 2.6), the average annual frequency of dangerous heat days is projected to increase by 2090s.

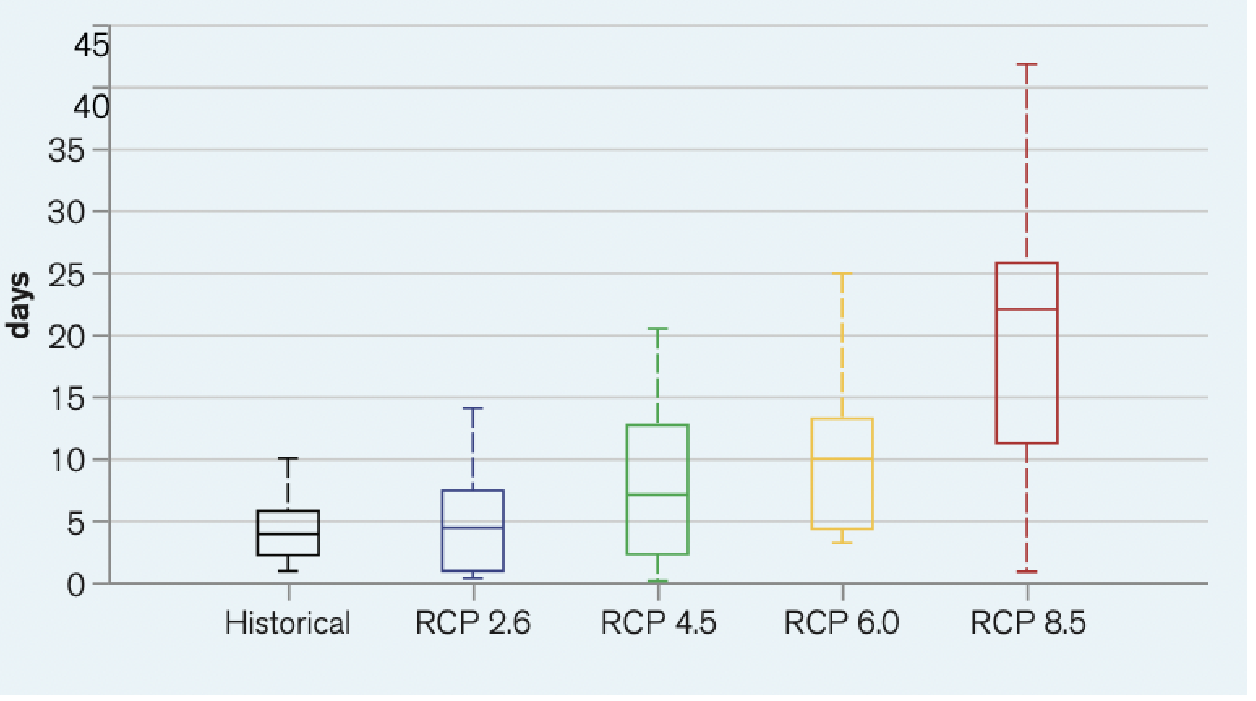

Figure 9. Historical (1986–2005) and projected (2080–2099) average annual frequency of dates with Heat index >35°C (14)

3.3 Water-Related Natural Disasters

According to the latest scientific research, global climate change is anticipated to result in an increased frequency, severity, and duration of extreme water-related weather events, including but not limited to excessive precipitation, storm surges, floods, and droughts. An analysis of historical data reveals a trend towards a greater frequency of heavy rainfall in many mid-latitude regions since 1950, as well as an expansion in the geographic regions affected by drought (40). Such changes in precipitation patterns will cause more people to be exposed and vulnerable to water-related natural disasters.

Water-related natural disasters can be broadly categorized as primary and secondary events. Primary water-related disasters encompass occurrences such as drought, flood, and storms, while secondary events include landslides triggered by excessive moisture. An examination of data from EM-DAT reveals that China has been disproportionately affected by river floods (152 events) and tropical cyclones between 1985 and 2013, resulting in annual economic losses of USD 8303 million and USD 2006 million respectively, as detailed in Table 1. However, it should be noted that due to the existence of varying criteria for disaster inclusion and underreporting, data from different sources may significantly differ. Nevertheless, the data presents a clear picture of the extent and pattern of impacts caused by water-related disasters in China.

Table 1. The average annual impact of Water-related natural disasters in the People's republic of china, 1985–2013 (41)

Type of Disaster	Disaster Subtype	Number of Events	Annual Frequency of Occurrence	Annual Number of Deaths	Annual Number Affected	Annual Cost of Damages ($ million)
Drought	Drought	29	1.00	121.86	21,636,417	3,050.25
Flood	Flash flood	19	0.66	56.97	3,855,206	267.61
	General river flood	152	5.24	832.41	66,391,088	8,303.41
	Storm surge or coastal flood	5	0.17	13.48	86,208	No data
	Unspecified	26	0.90	222.96	6,684,669	679.76
Mass movement – wet	Avalanche	2	0.07	2.34	38	No data
	Landslide	54	1.86	158.93	160,506	689.11
	Subsidence					Not recorded
Storm	Tropical cyclone	116	4.00	291.38	11,262,758	2,006.90
	Extra-tropical cyclone (winter storm)					Not recorded
	Local or convective storm	62	2.14	48.48	7,500,300	279.26
	Unspecified	36	1.24	65.62	1,094,360	92.62

EM-DAT = data from the international disaster database maintained by the Centre for Research on the Epidemiology of Disasters (CRED) of Belgium called "Emergency Events Database."

[a] EM-DAT: The Office of Foreign Disaster Assistance (OFDA) of the United States Agency for International Development (USAID)/CRED International Disaster Database. http://www.emdat.be – Université Catholique de Louvain – Brussels – Belgium. Data from 1985–2013.

3.3.1 Flood

Floods are the most frequently occurring and impactful water-related natural disasters, affecting the greatest number of people annually among all water-related natural disasters. According to the research conducted by the Asian Development Bank (ADB) in 2015 (41), floods affect 77 mullion individuals in China. Furthermore, the economic damage caused by floods is substantial, with an estimated annual cost of $9.25 billion.

A study conducted by Huang et al. in 2012 (cited in 41) found that the geographic distribution of flood risk varies across China. The south-central provinces of Hunan and Guangxi were found to have a higher risk in terms of the vulnerable population. Additionally, the northwestern provinces were found to have the highest risk of deaths. The east and southeast provinces of Zhejiang and Fujian were found to have the highest economic risk, while the east and central provinces of Henan and Hubei were found to have the highest agricultural vulnerability. This highlights the need for region-specific flood risk management strategies that consider the unique vulnerabilities of different geographic areas.

The impact and pattern of flooding in China changed dramatically over the past decades due to several factors: the population increasingly moving from the east toward the coast; the ever-increasing migration from rural villages to urban cities and the subsequent urban growth; the rapid economic, industrial, and commercial development; better flood management and strengthened disaster response on the local and central government levels; and changes in hydrology. These factors together caused the inland floods to impact more people but fewer houses, while coastal floods now affect fewer people in fewer houses. While livestock is increasingly being affected, the overall economic impact is decreasing in inland areas but increasing in coastal areas. Overall, there has been a decrease in flood mortality and the number of people affected on the national level, while the total costs associated with the damages remain the same (41).

While there has been improvement in disaster and flood management, the increasing risk of climate change will bring more severe floods. Research from Willner et al. (42) shows that there will be a significant increase in people exposed to flooding, with an additional 27–35 million people affected by fluvial flooding by 2030. These estimates represent that more than double the current exposed population will be affected, as the 1971–2004 median estimate stood at 24 million.

Changes in China's demographic, both in the rapid increase in population and the migration patterns, will likely exacerbate the risk as the urban concentration increases, especially in urban cities in the floodplain and the river delta regions. Assuming the protection for up to a 1 in 25-year event, by 2030, there will be 7.5 million people affected by flooding, and the damages will be USD 85 billion, compared to 6.2 million people and USD 42 billion damage in 2010, under the RCP8.5 emissions pathway (14).

Table 2. Estimated number of people in China affected by an extreme river flood* in the historic period 1971–2004 and the future period 2035–2044 (14)

Estimate	Population Exposed to Extreme Flood (1971–2004)	Population Exposed to Extreme Flood (2035–2044)	Increase in Affected Population
16.7 percentile	18,223,214	45,632,993	27,409,779
Median	23,857,707	55,244,696	31,386,989
83.3 percentile	34,316,364	69,442,970	35,126,606

* Extreme river flood is defined as being in the 90th percentile in terms of numbers of people affected.

3.3.2 Drought

Drought, an environmental disaster, occurs in all climate zones, both in high and low rainfall zones. It is "characterized by a deficiency in a region's water supply as a result of constantly below-average precipitation" over some time (41). Different than aridity, which is a permanent feature of the climate of an area, a drought is a temporary phenomenon. There is often confusion between a heat wave and a drought. A heat wave typically lasts for a week or more, while a drought typically lasts for months or years (43).

There are two primary types of droughts. Meteorological drought is associated with the precipitation of deficit. Severe meteorological drought is defined by a standardized precipitation evaporation index (SPEI) of less than -2. Hydrological drought is characterized by a deficit in surface and subsurface water flow (41).

Drought has a significant impact on the societal and individual levels both directly and indirectly. During drought periods, individuals may have limited access to drinking water or water used for cleaning. On the societal level, it leads to deteriorated water quality, crop production reduction, reduced agricultural output, and a decrease in power generation (43).

In China, drought is the second-highest cause of economic loss among all-natural disasters. In the past, droughts directly caused the death of millions because of inadequate infrastructures and a lack of policy measures. Now, together with the improvement in transportation, communications, and response time, drought rarely causes casualties, but only causes economic loss. Nevertheless, drought has a significant indirect impact on people's lives, affecting 21.6 million people per year in China. The most significant recent drought happened in 2016. The crop yield in the north of the country was reduced by 12%, affecting 18 million people in southern China alone due to its significant economic losses and severe drinking water shortages (41). Nationwide, the probability of a severe meteorological drought event (as defined above) is 4%. However, droughts do not affect the whole country equally. Research shows that the most significant extreme drought typically happens in the northern and western regions of China.

National sources indicate that the number of droughts, impacts on livestock, and damages from droughts are all increased in the past years. However, the number of people and hectares affected is decreasing. Analysis from World Bank (14) concludes that this is due to effective management actions to address droughts, the increasing total volume of water storage, and projects to increase the supply of drinking water from various sources (section 4.3). However, Zhang et al. (cited in 14) found that agriculture losses to drought have been increasing recently, especially in the northern and northeastern provinces, with the rate of loss reaching 14–18% in some provinces. Figure 10 shows the World Bank's projection of the changes in the SPEI index in the years 2080–2099. The probability of drought will increase by around 20 to 36% depending on emission pathways. While China has been achieving much to reduce the number of people and areas affected by drought, with the intensity and extent of drought increasing due to climate change, the national and local governments should be increasingly prepared to address emergencies brought about by drought.

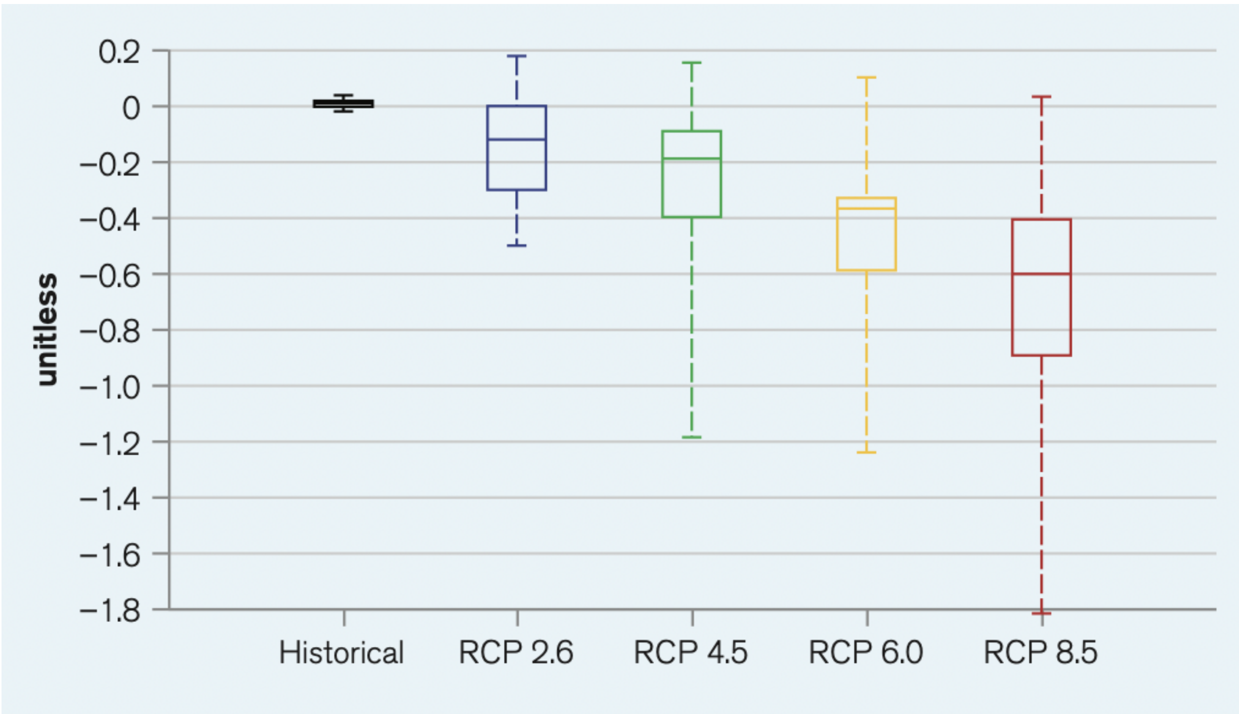

Figure 10. Projected changes in SPEI index of drought in 2080–2099 (14)

3.3.3 Mass Land Movements

Mass land movements are one of the major natural hazards worldwide. Mass land movements include landslide and land subsidence, both accounting for a great number of casualties and both direct and indirect economic loss. Landslide, specifically, is defined as the movement of a mass of rock, debris, or earth down a slope (44). Its severity depends on the landslide mobility, meaning the landslide speed and the travel distance (45). The landscaping represents landscape instability and can be triggered by a variety of events, such as rainfall, earthquake, or flood (41). In addition to the direct triggers, human activities such as deforestation or the altercation of slopes for roads or buildings are contributing factors to such hazards over time.

Landslide mainly occurs in Southern and Southwestern China and are often induced by primary hazards such as rainfall, earthquake, and floods. Rainfall landslide mainly occurs in Sichuan, Yunnan, and the Eastern Tiber region. Its frequency annually is highly variable, ranging from no event to almost 160 events. However, by studying landslide events in the past decades, research shows that the frequency is increasing at a rate of 2% annually. Overall, the number, mortality rate, the number of people affected, and cost of damage are all increasing year by year (41)

Land subsidence, on the other hand, causes ground elevation to drop slowly. It can become a disaster when, for example, the land level drops below sea level and therefore inducing flood in the coastal region. Two main reasons contribute to the hazard: human activities (excessive groundwater withdrawal) and geological actions (46).

In China, frequent drought leads to the over-extraction of water, melting of permafrost, clay soil shrinkage, and many other phenomena, leading to frequent land subsidence or collapse. It is mainly caused by the extraction of groundwater, or in some cities, mineral extraction. The government’s poor resource management and demand from the rapid economic growth led to the over-extraction of water and minerals. It has led to many lives lost, frequent injuries, damages to buildings and infrastructure, flooding, groundwater pollution, and loss of agricultural lands (41).

Land subsidence mainly occurs in 17 provinces in the Eastern and Central region, including Shanghai, Tianjin, and Hubei provinces. The susceptible areas are mainly located in the Delta region of the Yangtze River, and the North China Plain (Figure 11). The effect of land subsidence, according to the 2003 estimate, is dire. Overall, 93,855 km^2 are affected. Since 1950, there has been a direct loss of USD 78 billion to 87 billion. The annual infrastructure damages are estimated to be USD 139 million to 173 million. In the coastal region of Tianjin and Hebei Plain, many areas now fall below sea level. The land of Wenning Plain of Zhejiang Province is only 2.5 to 3.3 meters above sea level (41). The government must pay special attention to the prevention and control of land subsidence and introduce unified planning and comprehensive measures to protect the people and prevent further damage.

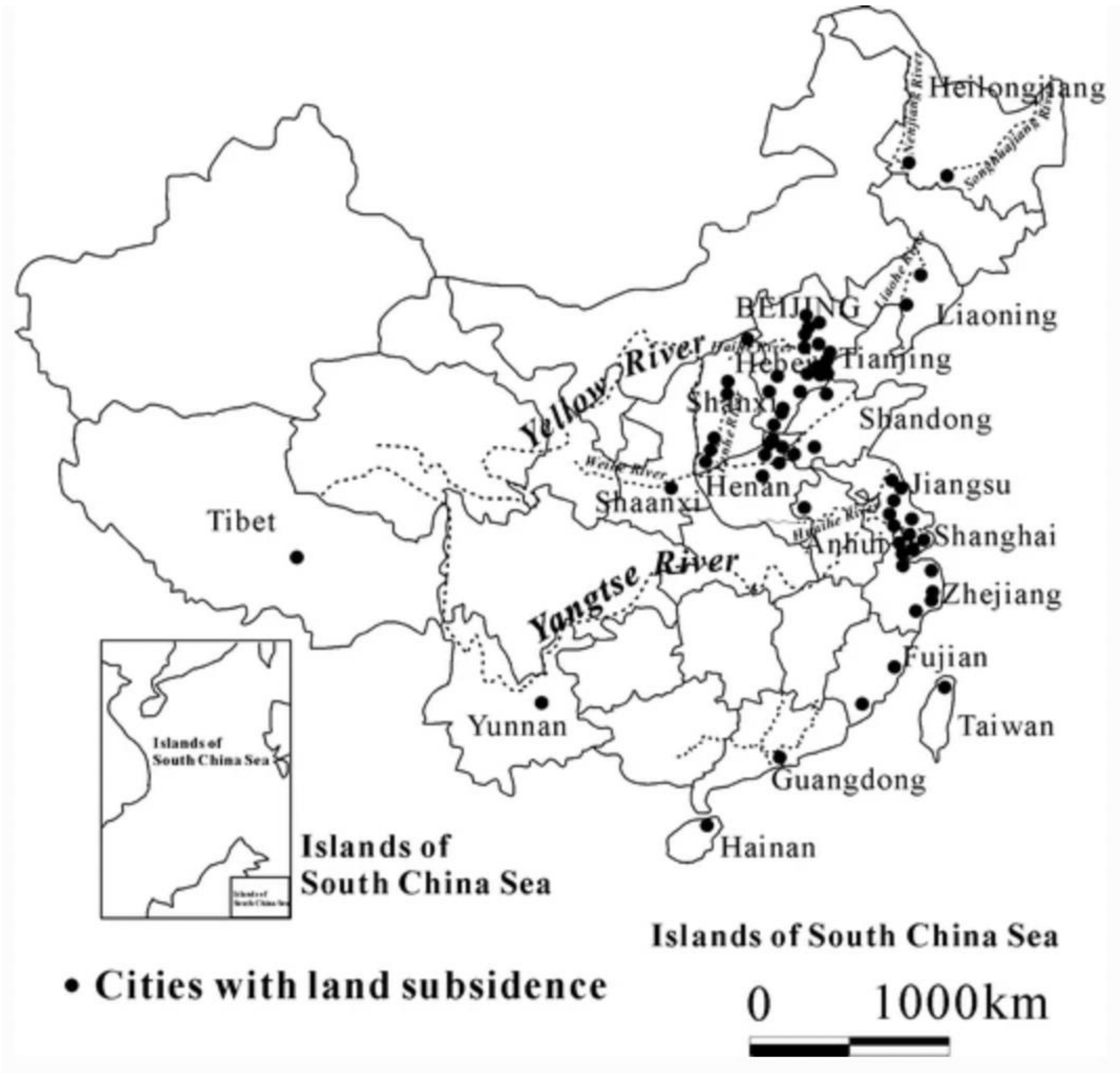

Figure 11. Major cities with land subsidence in China (46)

This figure does not reflect the administrative border of any country by the author or the affiliated institutions, and should not be constructed as such.

3.3.4 Tropical Cyclone

Tropical cyclones, also known as hurricanes or typhoons, are meteorological phenomena characterized by their large-scale circulation and formation over warm ocean waters in the tropical regions of the Earth (47). These storms are known for their high wind speeds and heavy precipitation. In disaster science, tropical cyclonic systems have a threshold of maximum wind speed exceeding 17.2 m meters per second (48). The hurricane, a type of tropical cyclone characterized by its intense winds, heavy precipitation, and storm surge, is widely recognized as one of the most destructive and life-threatening natural phenomena on Earth. They can cause widespread damage to coastal communities, disrupt shipping lanes and other infrastructure, and result in significant loss of life.

The formation of tropical cyclones is linked to the presence of warm ocean waters, as well as specific atmospheric conditions. A pre-existing weather disturbance, such as a tropical wave, can provide the initial focus for development. As the storm system gathers strength and develops an organized circulation, it is classified as a tropical depression. Further intensification leads to the formation of a tropical storm, and eventually, a hurricane (49).

All coastal provinces of China are affected by tropical cyclones, specifically the southern and southwestern provinces. Southern provinces, including Guangdong, Guangxi, and Hainan, are mainly affected by west-moving storms. Southeastern provinces, including Fujian and Zhejiang, are mainly affected by northwest-moving storms (41,48). From 2006 to 1983, Guangdong disproportionally suffers from tropical cyclones, averaging 2.9 events each year. Other provinces/regions in the Southeastern region experience less but significant numbers of events: Hainan, 1.3 events; Fujian, 1.2 events (Figure 12).

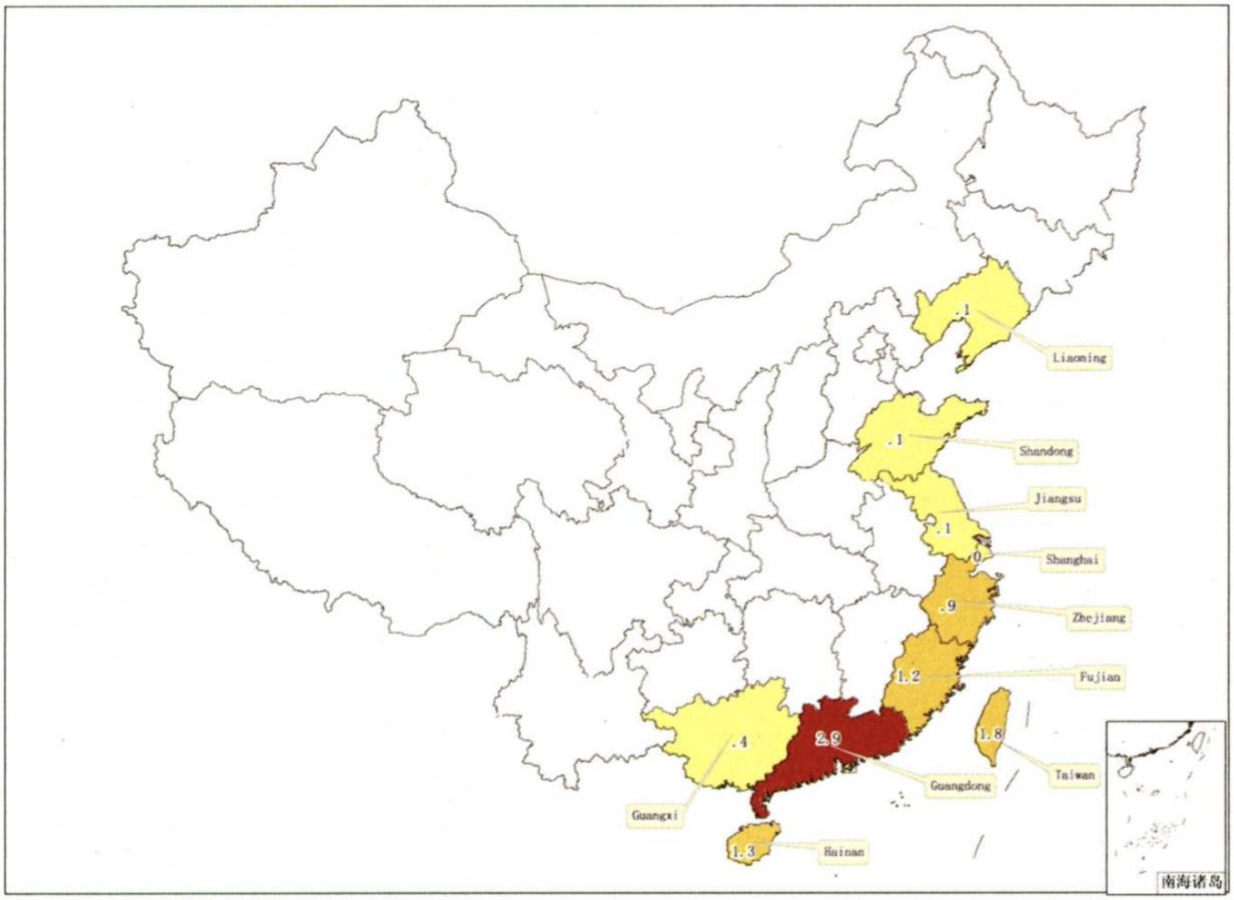

Figure 12. Annual mean frequency of tropical cyclones that make landfall in each province in China (1983–2006) (48)

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Tropical cyclones are known to cause significant casualties and economic losses. A study of data from the period 1983 to 2006 revealed an average of 472 deaths per year. Additionally, China alone experiences an average of CNY 28.7 billion in direct economic losses annually in the same period (48). Despite suffering fewer tropical cyclones than other coastal regions such as Guangdong, Hainan, Fujian, and the province of Zhejiang bears a disproportionate burden of casualties and economic loss. For instance, when compared to Guangdong, which experiences three times as many tropical cyclones as Zhejiang, the latter has a significantly higher number of annual mean casualties (140 compared to 85.2, as per Figure 13) and direct economic losses (CNY 6960 million compared to CNY 6000 million, as per Figure 14). Similarly, when compared to Fujian, another coastal province with a similar frequency of tropical cyclones, Zhejiang still l similarly higher casualties and direct economic losses.

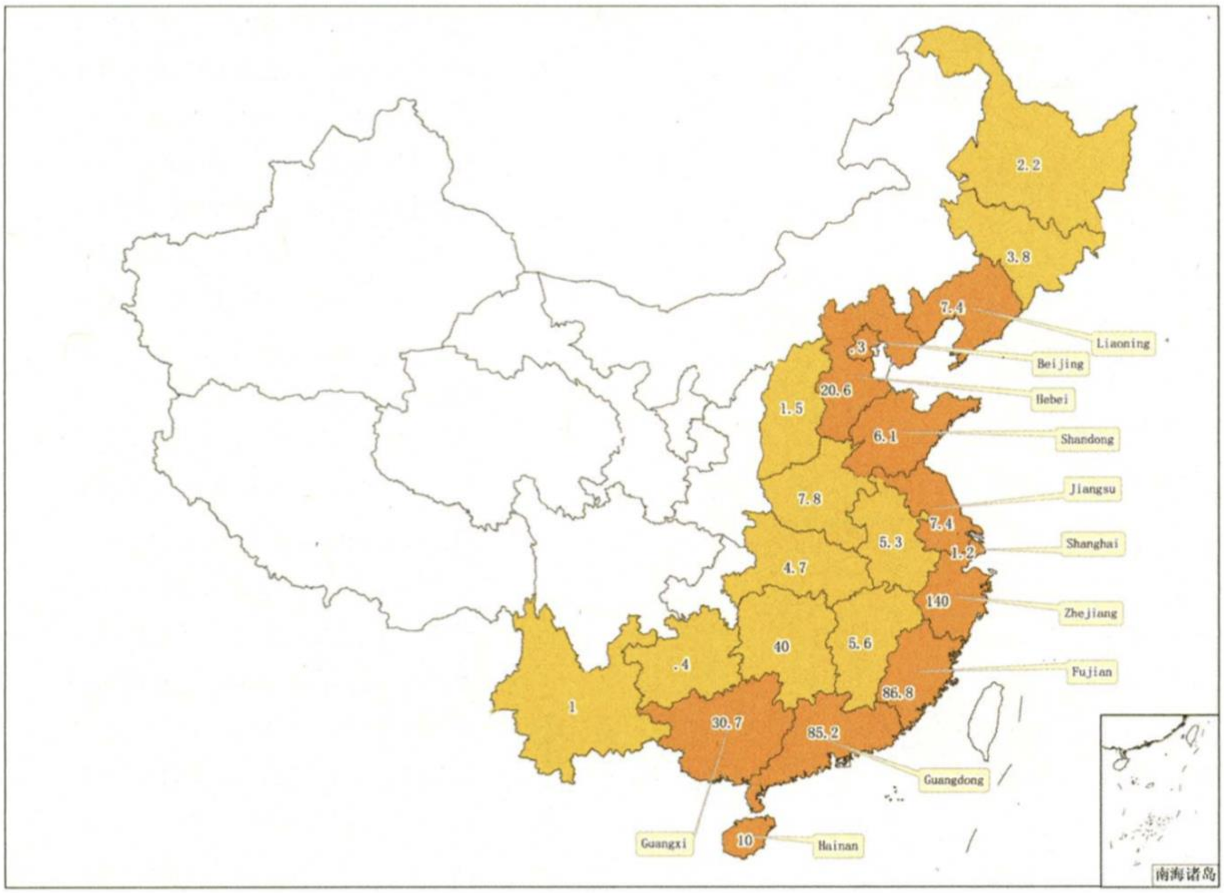


Figure 13. Annual mean tropical casualties for each province in China

This figure does not reflect the administrative border of any country by the author or the affiliated institutions and should not be constructed as such. **(**48)

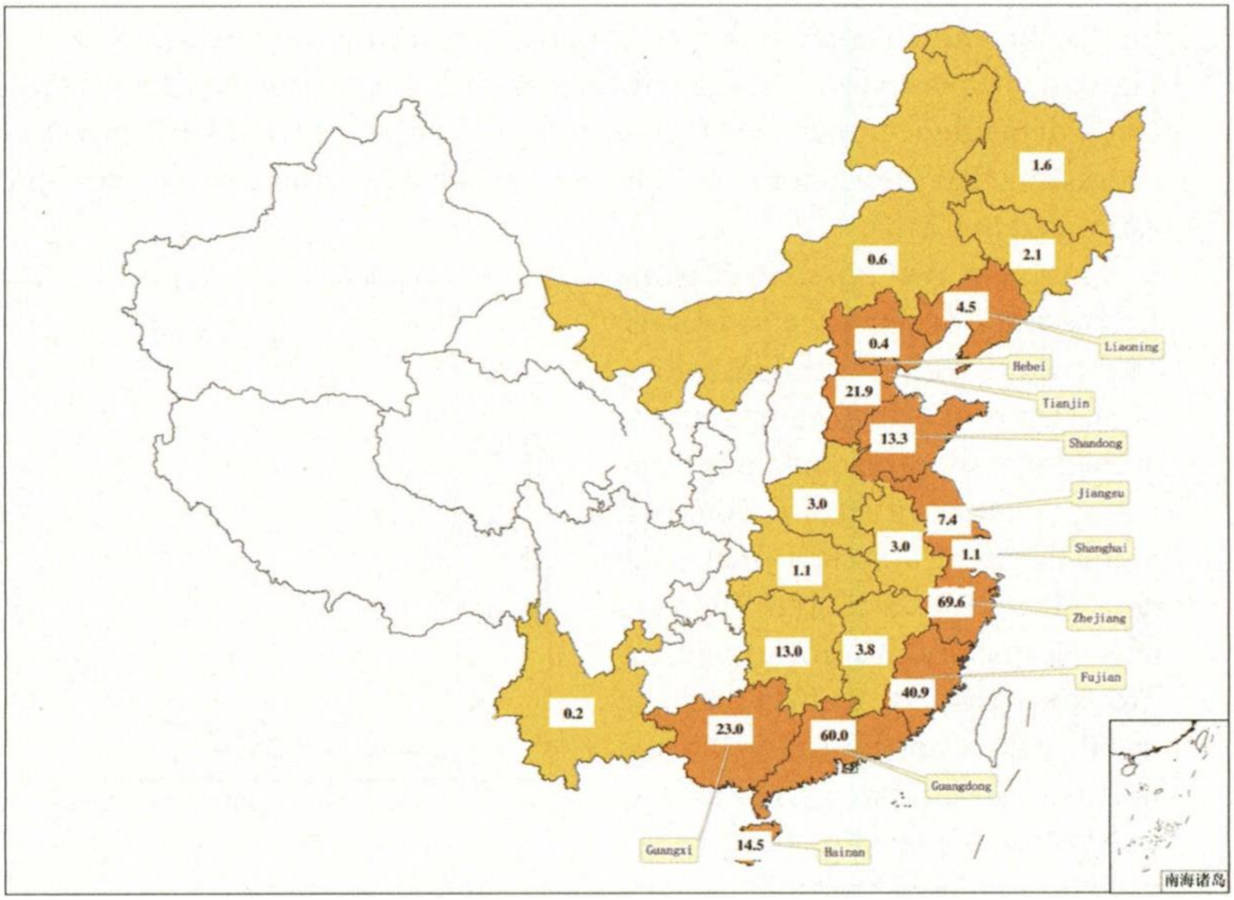


Figure 14. Annual mean direct economic losses for each province in China

Unit in 100-million-yuan, value of CNY in 2006.

tThis figure does not reflect the administrative border of any country by the author or the affiliated institutions and should not be constructed as such. (48)

Recent research has suggested that there has been an upward trend in the frequency, intensity, and resulting loss caused by tropical cyclones. This trend has been observed primarily in Eastern China, as opposed to the Southern coastline, which has historically been at high risk for these meteorological events (41). A study by Zhang et al. (48) analyzed data from the period 1983 to 2006 and found that there has been a statistically significant increase in economic loss due to tropical cyclones in Eastern China, with an average annual increase of CNY 1.19 billion. These findings suggest that there is a need for increased preparedness and mitigation efforts in Eastern China to address the growing threat of tropical cyclones.

4. Vulnerabilities

INFORM-Risk Scores and Key Points: Vulnerabilities

A higher overall score means higher vulnerability. Lower country rank means fewer countries have worst outcomes. For example, a score of 1.0 means low vulnerability; a country rank of 34 means only 33 countries experience worse outcomes in this category. Simply put, the lower the score, the lower the country rank, the better.

The score is from INFORM-Risk 2023 (26). The qualitative description is a summary of the section.

Poverty and Inequality	Inequality Score **2.8/10** Country Rank **62/191**	China has undergone impressive economic growth since the reform in the 1970s. However, income inequalities have not seen much progress. Inequalities are primarily marked by regional differences, urban-rural divides, and individual socioeconomic differences. Vulnerable people are susceptible to more health risks, higher exposure, and lower resilience to disasters.
Threat to Food security	Overall Score **1.0/10** Country Rank **34/191**	China is facing an increasing threat of a shortage of arable land because of industrial development and population growth. The disaster also causes a significant amount of agricultural loss. The government needs to urgently address the potential food shortage in the future, which may be a serious vulnerability in disaster settings.
Water	No score available	China is threatened by water shortage, which is exacerbated by the extremely unequal availability of water from the north and south of the country. Chinese government undertook several ambitious projects and nationwide policies, which are seeking to mitigate the issue. Although there is no short-term threat to water security, in the long term the country may face increasing pressure in water security, exacerbating its disaster vulnerabilities.

Health	**PREVALENCE OF HEALTH CONDITION** Overall score **0.4/10** Country Rank **54/191** **INACCESSIBILITY TO HEALTHCARE** Overall score **3.3/10** Country Rank **76/191**	Although there has been significant improvement in life expectancy and under-5 mortalities nationwide, such improvement is unequal. The disparity between poorer and richer urban and rural areas remains large. The primary healthcare system in China seeks to target this disparity. However, it faces several challenges such as an under-qualified labor force and inadequate funding. In a disaster setting, people suffering from poor pre-disaster health outcomes will be disproportionally affected. More research and evidence-based policies are urgently needed to address the disparity.

Vulnerability, in basic terms, can be understood as the potential for loss or susceptibility to harm (24). Wisner et al (20) defined vulnerabilities as "the characteristics of a person or group and their situation that influence their capacity to anticipate, cope with, resist and recover from the impact of a natural hazard." Vulnerabilities can refer to the pre-disaster socioeconomic status of groups and individuals. In this section, I discuss the pre-disaster reality in several key areas: poverty and inequality, food security, water, and health. I found that China is currently suffering great inequality in income and health outcomes. Vulnerable populations include rural communities, poorer provinces, and people of lower socioeconomic status. While there are some efforts to target the inequalities in society, the current disparity remains large, and these populations will be much more vulnerable to disasters.

4.1 Poverty and Inequality

In late 1978, China pushed for a series of economic reforms. Since then, few would argue against the fact that China's economic growth has been impressive. From 1979 to 1993, GDP grew 9.3 percent annually. The per capita income of farmers increased by 239 percent, while the per capita income of urban households increased by 152 percent. Absolute poverty declined significantly in rural areas, from 33 percent under the poverty line in 1978 to only 12 percent in 1990. Nationwide, the proportion of households under the absolute poverty line decreased from 53 percent in 1980, 18 percent in 1988, to 8 percent in 2001 (50).

At the beginning of the economic reform, as the Chinese leader, Deng Xiaoping famously said during the 3rd Plenary Session of the 11th Central Committee of the Chinese Communist Party, the party was preoccupied with "letting some people get rich first (51)." He believed that, with part of the population rich, the rest of the population would later catch up. While the economic reform brought about significant growth, such policy also expectedly entailed a sharp rise in wealth and income inequality. From 1978 to 2015, while the national income belonging to the top 10% rose from 27% to 41%, the bottom 50% of earners fell from 27% to 15% (1). China became the country with the highest inequality in Asia. The Chinese leadership recently recognized that inequality is a serious concern for instability and that it had a negative influence on the country's economic growth, and inequalities have increasingly become a concern for the country's development (52).

Income inequality in China is primarily attributed to three factors: household disparity, rural-urban divide, and regional inequality. The country's seeing the increasing disparity between people with different socioeconomic backgrounds. For example, the wage advantage of a person with a college degree over a person with a primary school degree was 9 percent in 1988, 39 percent in 1995, and 88 percent in 2002. Former urban workers who were retrenched from state-owned enterprises due to economic transition (i.e., privatization and state enterprise reform) would have a great wage disadvantage compared to their non-retrenched urban workers. Rural-urban migrants who are seeking work in urban areas would be treated as second-class citizens in the cities due to their rural *hukou* (residence registration) (52).

Second, China, more than most countries in the world, is marked by rural-urban differences, which entails severe income disparity between them. The ratio of urban to rural household income per capita reached 4.1 in 2007 (2.91 adjusted for spatial price differences), compared to 3.35 (2.28 adjusted) in 2002. Such disparity is exacerbated by a political economy that favors urban dwellers, as the central leadership sees urban cities as the main contributor to the country's economic growth. As Knight (52) analyzes, the rural-urban disparity is the single highest contribution to China's overall inequality, at 54 percent (41 percent adjusted for spatial price differences), meaning that most of China's income inequality would vanish if mean income per capita in rural and urban China were equal. Such a number is staggering even when compared to other developing countries.

Third, regional inequalities between provinces are also significant. Such rise in regional disparity was contributed by the fiscal decentralization and trade liberation policies of the central government during the economic reform. Fiscal decentralization allowed the wealthier coastal provinces to increase their income and stimulate economic growth, while trade liberalization allowed the coastal provinces to experience more rapid growth due to their favorable location and special treatment from the central government. As a result, inequality due to income differences between the coastal and inland regions reached 10 percent of the total province-level inequality in 2007, compared to 3 percent in 1980 (52).

An implication of the growing income inequalities is the significant differences in health between population groups. There is a clear correlation between the GDP per capita and life expectancy among 30 Chinese provinces. In the richest province (Shanghai, 78 years), life expectance is 13 years more than in the poorest province (Guizhou, 65 years). Compared to other countries, for example, the United States, the gap between the state with the highest and lowest life expectancy is only 6.5 years (53).

Malnutrition and undernourishment remain a problem in China. Although there was significant progress before 2014 to reduce the malnutrition rate, the progress slowed between 2014 and 2017 (WBG 2022b). Today, 124.5 million (9–10% of China's population) are undernourished. The majority of those people are found in rural areas, contributed by the staggering urban-rural disparity as mentioned above. There is a three-fold difference in levels of malnutrition in children less than 5 years old between urban and rural areas. In 2002, the prevalence of child stunting was 17.3% in rural areas, while only 4.9% in urban areas. While 9.3% of children were underweight in rural areas, only 3.1% were underweight in urban areas. Health disparities between geographical areas and households are a significant vulnerability during disasters, as its effects will be multiplied, resulting in more casualties, higher long-term impact, and more difficult reconstruction and re-achievement of pre-disaster level health outcomes.

Specifically, in terms of disaster, it is well documented that there will be significant differences between urban and rural regions, due to their different levels of exposure to hazards, vulnerabilities of communities, socioeconomic and cultural characteristics, levels of accessibility to infrastructure, and levels of capacity to respond (54). A quantitative study conducted by Chai et al (55) on the difference in preparation for the Wenchuan earthquake revealed that urban residents more readily have equipment for disasters, and are more likely to participate in emergency training and drills. On the other hand, rural workers are more exposed to hazards than their urban counterparts. Agriculture, for example, accounts for 27.7% of all labor forces in China (14), and the workers are exclusively located in rural settings. The workers and their livelihoods are disproportionally affected by increased flooding, unsafe temperature, and drylands expansion and desertification.

In addition to the rural-urban divide, the socioeconomic disparity between households also affects and determines the level of exposure to disasters. Heavy manual labor is the lowest-paid job in China, yet more susceptible to heat stress than most other occupations (14). Few other studies discuss regional and household inequalities and their effect on exposure, vulnerability, and resilience to disasters. However, the above discussion highlights that people from rural areas, from lower socioeconomic status, and from poorer provinces are much more disproportionally affected than their counterparts from urban, higher socioeconomic backgrounds, and major cities.

4.2 Agriculture and food security

In China, agriculture has had rapid development over the past years. China's economic reform in the late 1970s started with the restructuring of the agricultural sector. Since then, the productivity of the farms has increased significantly. In the last 70 years, China's grain output expanded five-fold, reaching 658 million metric tons in 2018. Today, China is the world's leading cereal grain producer (Ghose 2014). However, China remains a net importer of grains due to rapid urbanization and other complex reasons.

Currently, the country is facing growing challenges to maintain its planned grain self-sufficiency of 95%. The most significant threat is the loss of arable lands. China's per capita arable land is around half the world's average. Only 12.8% of the country's land is available for agriculture. Due to rapid industrialization and urbanization following the economic reform, the disappearance and degradation of land have occurred rapidly. In 12 years, between 1996 and 2008, cultivated land decreased by 6.4%, while grassland decreased by 0.59%. Since 1990, over 8 million hectares of arable land have disappeared. Per capita cropland decreased from 0.18 hectares in the 1950s to 0.1 hectares today. Furthermore, the quality of land is also under threat. Urbanization and industrialization caused improper disposal of domestic and industrial waste, while air pollution causes acid deposition in the soil. The quality of land leads to the production of grain with an excess level of heavy metal. A test in Guangzhou in 2013 found that most rice in local restaurants contained excessive levels of cadmium. The availability of suitable arable land is currently decreasing. Millions of hectares of land may be unsuitable for agriculture in the near future, leading to threats to food security in the country (56).

In addition to the disappearance of arable land, seven additional factors also pose great threats to agriculture in China, including loss of cultivated land, limited water resources, climate change, ecosystem changes, population growth, improved standard of living, and outdated agricultural infrastructures (56). Significantly, natural disaster accounts for a great portion of the loss. From 2008 to 2018, China suffered a cumulative agriculture loss of 153 billion US dollars, "a staggering record as far as any single country is concerned (57).” Indeed, China accounts for 55% of overall loss at the global level. The high number of losses is the consequence of China’s vast scale of agricultural operation and its extremely high exposure to hazards: on average, 27 large- and medium-scale disaster events take place every year, which is 6 times the average annual occurrence of upper-middle and high-income countries.

Four types of disasters are most destructive in terms of agricultural loss. Drought causes the loss of 28 billion USD in crop and livestock production. Earthquakes and storms cause a 27 billion USD loss in agriculture, respectively. Animal and plant pests and diseases cause an 18 billion USD loss mainly in livestock production. As shown in figure 15, from 2008 to 2018, the commodity most affected by disasters is pig meat, amounting to a 33 billion USD loss in 10 years. Vegetables, sweet potatoes rice, and cow milk also sustain a significant loss, ranging from 12 to 7 billion. In the period between 2008 and 2016, agricultural production loss ranges from 18.7 billion to 46.7 billion US dollars.

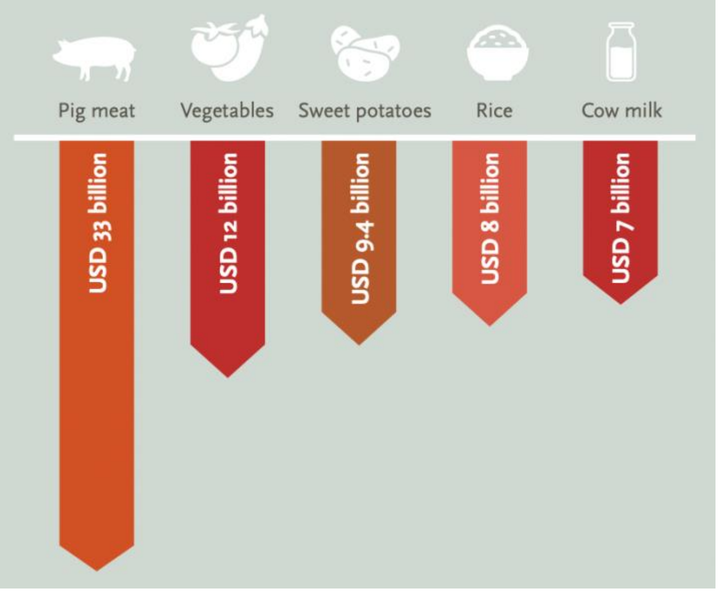


Figure 15. Most affected commodities by disasters, loss in USD billion, 2008–2018 (57)

Table 3. Highlights from China's agricultural loss profile (57)

Year	Disaster occurrences	Loss in agricultural production (USD)
2008	30	22.5 billion
2009	26	18.7 billion
2010	26	46.7 billion
2011	20	22.1 billion
2016	33	46.2 billion

Although the absolute value of agricultural loss due to disaster is significant, such loss only amounts to 1.8% of China's total potential production each year, compared to the average loss level of 4% globally (57). Chinese governments 'substantial investment and effort in reducing vulnerabilities and developing coping strategies helped buffer the negative impact of frequent disasters in the agricultural sector. Overall, FAO (57) believes that China can absorb and cushion any impact on food availability, food security, and nutrition. Nevertheless, to achieve food self-efficiency, China still faces several significant threats.

4.3 Water Resources

Water is essential for the health of human beings. Not only our basic needs are dependent on the availability of freshwater (drinking, showering, cleaning), but water is also needed in other areas to sustain our lives (for example, feeding animals and plants). In a disaster setting, water resources are even more important, which is why the Sendai Framework for Disaster Risk Reduction (17) emphasizes water management as an essential part to reduce the occurrence and severity of a disaster. However, there has been increasing pressure on the availability of fresh water, primarily due to human population growth and climate change (58). Ensuring the availability of water resources thus has been a top priority for countries worldwide. United Nations defines water security through three areas: first, “adequate protection from water-related disasters and diseases”; second, “access to sufficient quantity and quality of water, at affordable cost, to meet the basic food, energy, and other needs essential for leading a healthy and productive life”; third, “[no compromise of] the sustainability of vital ecosystems (59).”

China, one of the largest countries in the world, is facing increasing challenges in managing water resources. The total amount of water resources is around 2841 billion m^3, of which surface water accounts for 2739 billion m^3, while groundwater only accounts for 822 billion m^3. On average, the available water resources can provide up to 2200 m^3 annually if the water is completely captured and only used for human consumption. In reality, only around 795 billion m^3 is available for human use despite the variety of water sources available. For example, water available differs widely from Hai River (64% of water available) to rivers in the southwest (only 17% available). Such variability is determined by surface water flows, as well as the ability to regulate through dams, weirs, reservoirs, and access to groundwater (41).

In 2015, the country uses 590 billion m^3 of its water resources, of which 81% came from surface water, 18.4% from groundwater, and 0.5% from other sources (for example, rain collection). Domestic and industrial water use is at 123 billion m^3 annually, which has been growing at 4% per year over the past 30 years. Irrigation water has been continuing to raise too, albeit at a lower rate. Wastewater discharge is 80 million m^3, which has similarly been growing at 4% per year (41).

China’s water resources are distributed highly unevenly. 81% of water is located in the southern part of the country, despite it only accounting for 36% of the total land surface area (41). It is estimated that available water resources in Northern China will further decrease from 359 m^3 per capita to 292 m^3 (58). The northern rivers are under such strong stress that no further supply development options exist for these basins.

Chinese government adopted several projects and policy packages to mitigate water inequality in China and promote water security on a nationwide level. The most significant project is the South-

North Water Diversion Project, which is set to be the world's largest water diversion construction. The canal is set to be the largest concrete structure on earth. The $62 billion project is expected to divert around 45 billion m^3 of water per year from the Yangtse basin to the Yellow River basin in the north, with an end date of 2050 (56). This ambitious project, while being able to alleviate water stress in the north, requires a huge financial commitment and the resettlement of around 300,000 people (60). Another project, The Special Plan for Seawater Desalination and utilization has been constructing plants to convert seawater to potable water in coastal areas. At the end of 2010, the plan has been treating 0.43 million m^3 per day (41). Currently, China in total has 123 seawater desalination projects with a capacity exceeding 1.6 million m^3 per day. By 2023, the number is expected to exceed 2.9 million tons (61).

Embedded in national policy, the Chinese government is currently focusing on four priority areas: improving the efficiency of water use nationwide, controlling water demand and pollution loadings in industries, restoring the water environment, and ensuring water security (41). The Chinese government has developed several national water plan activities to ensure sustainable water usage while addressing the predicted effects of climate change. The National Water Policy, which aims to "implement a strict-as-possible water resources management" through "three red line controls" over the ensuing 2030 years, is one of the priorities. In a nutshell, this entails setting up a total volume control system on water consumption for the development and use of water resources, setting up a system to control water use efficiency and establishing a "red line for water efficiency control," and setting up systems to restrict the receipt of pollution in water function areas. The plan's successful execution will ensure and support the growth of environmental and economic rehabilitation, and contribute to China's social and economic stability (58).

Water and disasters are closely related. On one hand, disasters may result from both enough water (floods) and insufficient water (droughts). On the other hand, even in water-related disasters, getting to portable water sources is often quite difficult. In all phases of a catastrophe, from prevention and mitigation to disaster response to recovery and reconstruction, water security is crucial (62). Therefore, China's water policies, in sustainably securing the water needs of its population while preventing the occurrence of water-related illness, increase the resilience of the people and render them less vulnerable, even in disaster settings.

4.4 Health

To measure the level of population health, life expectancy is commonly used because of its ability to summarize mortality with a single number (63). The measure represents that in a given population, the number of average years a person is expected to live. China has made extraordinary progress in life expectance, rising from only 32 years in 1949, 44 in 1969, 61 in 1970 to 77 in 2020 (64). On the other hand, it is impressive that China has experienced an epidemiological transition from infectious diseases to chronic diseases in a much shorter time than most other countries (65). However, these patterns mean that China's health challenges now require population behavioral changes, including diets and physical activities (66).

Despite the economic achievements of China which are widely acclaimed as a miracle, China has been facing increasing challenges in the health equity of the population. The primary healthcare system in China provides basic clinical care and public health services to a population of 14 billion. It was first established in the early 1950s, which contributed to the significant reduction of communicable, maternal, and neonatal diseases, up until the 1970s (67). However, the market-based reforms in the late 1970s led to a decrease in government funding and less support for public healthcare providers. Consequently, costs surged, care became increasingly inaccessible, especially to the marginalized and vulnerable population, and the healthcare workforce became increasingly undertrained and short-staffed (68,69).

As the Declaration of Alma-Ata declares, a primary healthcare system provides universally accessible essential healthcare to the community, which should be the cornerstone of health equity in any country (70). The importance of the primary healthcare system has been shown in the success of significant reductions in diseases in China in the 1950s. Recognizing the increasing inequalities, the Chinese government introduced a series of healthcare reforms in 2009, including increased funding, universal insurance coverage, a basic health service program, and an essential drug system (71). Since then, access to and affordability of primary healthcare has significantly increased (72). The latest plan, Healthy China 2030 seeks to target two burdens at the same time: chronic non-communicable diseases, and increasing health expenditures (73). However, the primary healthcare system in China is currently suffering from the following problems: (1) primary healthcare doctors have low levels of training, inadequate certification, high rates of burnout, and low compensation; (2) IT systems for clinical care are either unavailable or inadequate; (3) even in new healthcare reforms, government subsidies are not enough to offset the decline in revenue from drug prescriptions, which may lead to the decreased incentive for doctors to provide appropriate treatment (74).

While on a national level, the primary healthcare system needs significant improvements. Within the country, there are significant disparities between regions, rural-urban areas, and households. Such differences are partly discussed in the above section on poverty, it is, therefore, unsurprising to see the same pattern emerge in healthcare. As previously mentioned, there is a clear correlation between GDP and life expectancy, as seen in figure 16. There is also a significant difference in the level of child stunting and underweight between rural and urban populations, shown in figure 17.

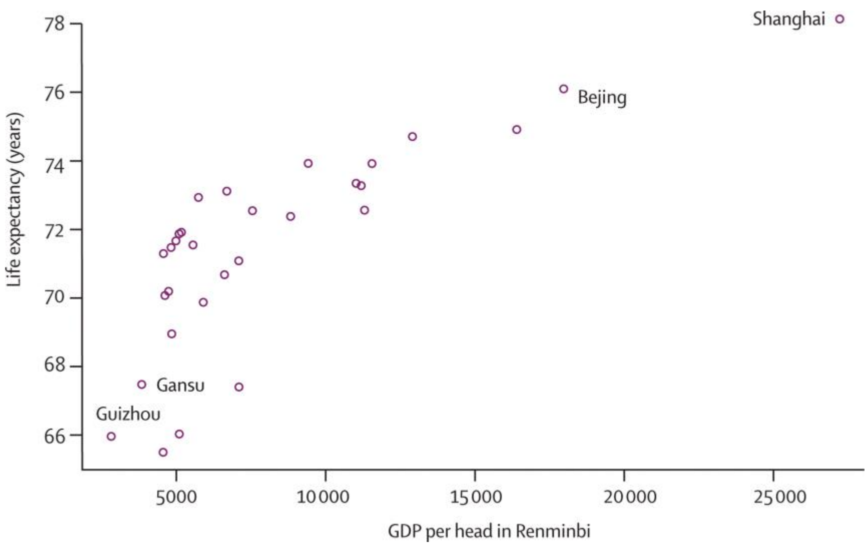


Figure 16. Life expectancy at birth by GDP per capita of 30 Chinese provinces in 2000 (53)

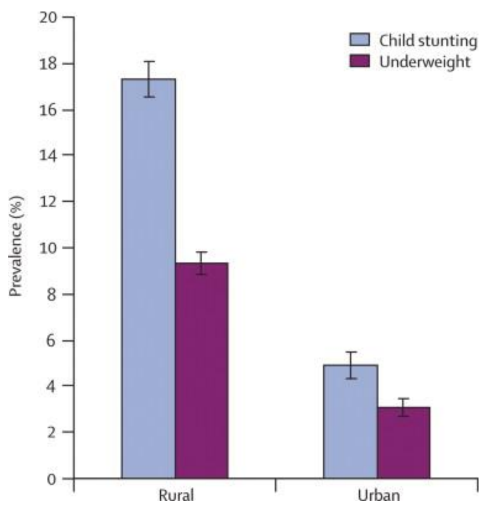


Figure 17. Disparities in child malnutrition between the urban and rural areas of China 2002 (95% CI shown) (53)

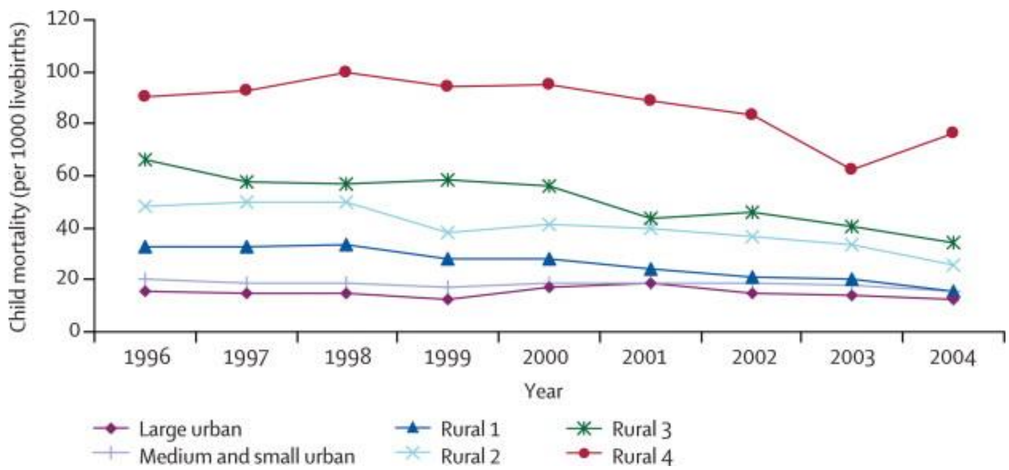


Figure 18. Trends in mortality in children aged less than 5 years by socioeconomic conditions of areas of residence, 1996–2004 (53)

Despite the overall improvement in health on the national level, the improvement has been largely uneven. First, improvement in life expectance has been much slower in poorer provinces than in richer ones. For example, megacities like Beijing and Shanghai experienced gains in life expectance of 4–5 years from 1981 to 2000, while the poorest province (Gansu) only gained 1.4 years in the same period. Second, the gap between under 5 mortalities in urban and rural areas remain high, and the gap between wealthy and poor rural areas has been increasing. While the rate has dropped by nearly 23% in urban areas and 47% in rural areas between 1996 and 2004, the disaggregated data of rural areas based on wealth level shows increasing disparity: the under 5 mortality decline in wealthy rural areas is about 50%, while only 16% in poor rural areas (53). The trend could be seen in figure 18, which disaggregated urban areas into large, medium, and small areas, and rural areas into four different categories, based on income level (1 meaning most affluent and 4 meaning the poorest).

Worldwide, there is a variety of studies that discusses health disparities in a disaster setting, despite the majority focusing on the United States (75–77). Unsurprisingly, they conclude that in low-income and rural areas where pre-disaster health outcome is already much worse than in the richer areas, the community suffers disproportionally much serious and longer-term consequences. There is inadequate research in China specifically, but we can suspect that poor rural areas, rural migrants, poorer provinces, and working-class individuals in urban cities will be disproportionally affected. More research specifically on building disaster resilience and minimizing disparity in the disaster setting is urgently needed, to ensure that in a disaster setting, no one is left behind.

5. Disaster Prevention and Risk Reduction

Key Points: Disaster Prevention and Risk Reduction

INFORM-Risk score not included, see reasons in the section introduction below. The qualitative description is the summary of this section.

Disaster Plans and Management Systems	DRR Plan specified the roles of central and local government in emergency response. DRR Plan increasingly changes from reactive to proactive and incorporates more numeric indicators, as per the Sendai Framework.
Disaster-Specific Early Detection and Early Warning Systems	There has been considerable effort to shift from a simple weather warning system to a risk-based early warning system nationwide, which will incorporate the probability of hazards, vulnerabilities, and level of exposure. Earthquake early detection is especially difficult, but there are multiple projects underway using new satellite and seismograph technologies.
Disaster Loss Statistics System (DLSS)	By 2022, DLSS in China is fully functional, and all information reach the central government within 24 hours. Various problem persists lack of validation, exclusion of environmental and economic loss indicators, and lack of data transparency.

Disasters have a significant impact on the lives of individuals and communities, and the ability to cope with these events is crucial for reducing the negative consequences. Coping mechanisms refer to the strategies and actions that individuals, communities, and societies use to manage the psychological, social, and economic impacts of disasters. The capacity of a country to cope with disasters is a crucial determinant of the overall impact of such events on its population and economy. This capacity is determined by the ability of individuals, organizations, and systems to effectively manage adverse conditions, risks, and disasters using the available skills and resources. Capacity encompasses a wide range of factors, including infrastructure, institutions, human knowledge and skills, and collective attributes such as social relationships, leadership, and management. The efficient functioning and coordination of these various elements are essential for effective disaster management (78).

In disaster terminologies, coping mechanism is closely related to exposure and vulnerabilities, which are also in turn two intertwining concepts (see section 2.1 for more discussion). For example, the less inequality a given community has, the more able such community is to be resilient against any given disaster, and the more likely that it recovers to the pre-disaster level of quality of life. As exposure is already discussed in section 3 and vulnerability in section 4, this section will be exclusively limited to different political/technical mechanisms of disaster risk reduction (DRR), including the DRR policies, early warning, and detection system, as well as post-disaster statistical systems.

Because of the overlapping nature of vulnerability and coping mechanisms, the INFORM-Risk indicator's categorization of any indicator in the two categories seems arbitrary. For example, while food security is included in the overall vulnerability score, water is included in coping capacity (in this article, both are included in the vulnerabilities). As it is difficult to summarize the DRR system and structure it into a numeric value, the only related measure in the INFORM-Risk indicator is the self-assessed "Hyogo Framework for Action Scores." As the INFORM group itself has admitted that such a measure's "reliability is unknown (26)." This section will therefore not incorporate any quantitative measurements.

5.1 Disaster Reduction Management Systems and Plans

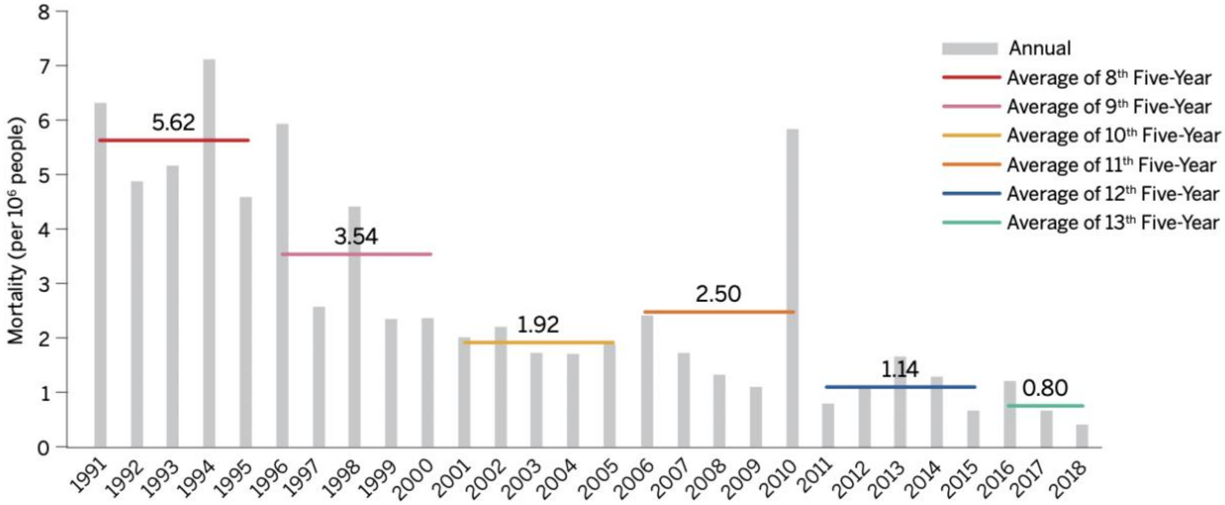
The disaster reduction management system in China requires coordination between national and local governments. The country's central government, through the State Council, provides overall leadership and guidance in managing disaster risk. Local governments, on the other hand, are responsible for leading response actions in the event of a disaster. Emergency plans, such as the National Comprehensive Disaster Reduction 11th Five-Year Plan (explained below), are in place to assign responsibilities among different government agencies during a disaster. Administrative heads in local governments are responsible for directing and coordinating actions during and after emergencies, with the help of operating departments such as the military, water resources, transport, and communication agencies.

During severe disasters, the National Coordination Office for Disaster Mitigation and Relief, which coordinates the National Committee for Disaster Reduction, the State Flood Control and Drought Relief Headquarters, the PRC Earthquake Administration, the Forest Fire Control Office, and the State Forestry Administration, takes charge at the central government level. This multi-level emergency response system ensures that the necessary personnel and equipment are quickly deployed, and financial assistance is provided to affected communities (41).

Responding to the United Nations International Decade for Natural Disaster Reduction (IDNDR) initiative declared in 1987, the IDNDR committee (now called National Disaster Reduction Committee) was established in 1989. The committee is an inter-ministerial coordination mechanism under the State Council, housed in the Ministry of Emergency Management. The council is responsible for drafting key disaster reduction policies and plans, such as the Comprehensive Disaster Reduction Five-Year Plans (27). The past plans include the Disaster Reduction Plan of the People's Republic of China for the period of 1998–2010, the National Comprehensive Disaster Reduction 11th Five-Year Plan (2007–2010), and the National Comprehensive Disaster Reduction 12th Five-Year Plan (2011–2015). The most recent one is the National Comprehensive Disaster Reduction 14th Five-Year Plan (2019-Now).

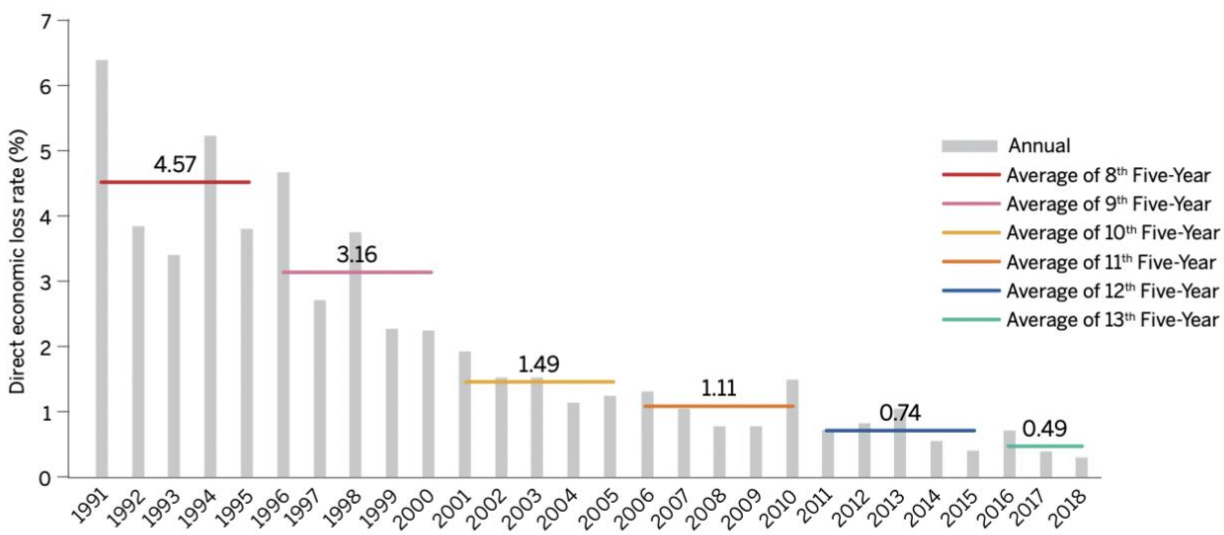
The latest plan made two significant changes compared to past DRR plans. First, disaster reduction shifted from reactive to productive. As the State Council announced during the commencement of the plan, the latest plan "Strives to realize a shift from focusing on post-disaster relief to prior-disaster prevention, from responding to individual disasters to responding to multiple disasters, from reducing disaster losses to reducing disaster risks (79)." There has been significant improvement in Disaster prevention and mitigation mechanism, disaster monitoring and information processing capabilities, disaster emergency response, and comprehensive risk prevention capabilities, according to the assessment from the Global Facility for Disaster Reduction and Recovery and World Bank (27). Second, the reduction of disaster mortality and economic loss is becoming increasingly important. During the 11th to 13th Five-Year Plan, the reduction of disaster mortality and economic loss becomes the main goal. Planning targets are increasingly becoming quantitative measurable indicators, which are consistent with the recommendation from the Sendai Framework for Disaster Risk Reduction 2015– 2030. For example, the 13th Five-Year Plan committed to reducing the mortality rate to ”less than 1.3 per million people" and the annual economic loss ranging from “less than 1.5% of GDP” to “less than 1.3% of GDP.”

China's disaster management system is characterized by a high degree of centralization and coordination, which allows for an effective and efficient response during emergencies. The disaster reduction plans from the central government are increasingly incorporating the Sendai Framework. China has succeeded in reducing mortality and direct economic loss because of natural disasters, showing a downward trend since 1991 (figure 19 and figure 20 respectively (27)). Thanks to the continuing efforts, the trend is expected to continue despite the significant challenges that lie ahead.



Data source: The annual disaster death toll from 1991 to 2017 is from the *China Civil Affairs Statistical Yearbook 2018*; the death toll of 2018 is from the Ministry of Emergency Management of China; and the population is from the *China Statistical Yearbook 2018*.
Note: The graph excludes the mortality from the Wenchuan Earthquake in 2008.

Figure 19. Annual Disaster Mortality Rate per 106 People in China, 1991–2018 (27)



Data source: The annual direct disaster economic loss for 1991 to 2017 is from the *China Civil Affairs Statistical Yearbook 2018*; the direct disaster economic loss of 2018 is from the Ministry of Emergency Management of China; and the annual national GDP is from the *China Statistical Yearbook 2019*.
Note: The graph excludes the losses from the Wenchuan Earthquake in 2008.

Figure 20. Annual Direct Disaster Economic Loss Rate to National GDP in China, 1991–2018 (27)

5.2 Disaster-Specific Early Detection and Early Warning Systems

In addition to its overall disaster management system, China has also implemented various disaster-specific early detection and early warning systems. These systems are designed to provide timely and accurate information about potential disasters, allowing for prompt and effective responses.

5.2.1 Risk-based Early Warning System for Meteorological Disasters

There has been an increasing push for a better early warning system for meteorological and hydrological disasters. The World Meteorological Organization (WMO) has been advocating for national meteorological and hydrological services to move away from simply providing weather information (general weather forecast), to providing weather and disaster information through a certain threshold (weather warnings), to eventually tell users how the weather will impact lives, infrastructures and economies (impact-/risk-based warning system, figure 21). The risk-based warning take account into the impact of an event, which is determined through the probability of hazard, vulnerabilities, and susceptibility of the population/economy, and the level of exposure.

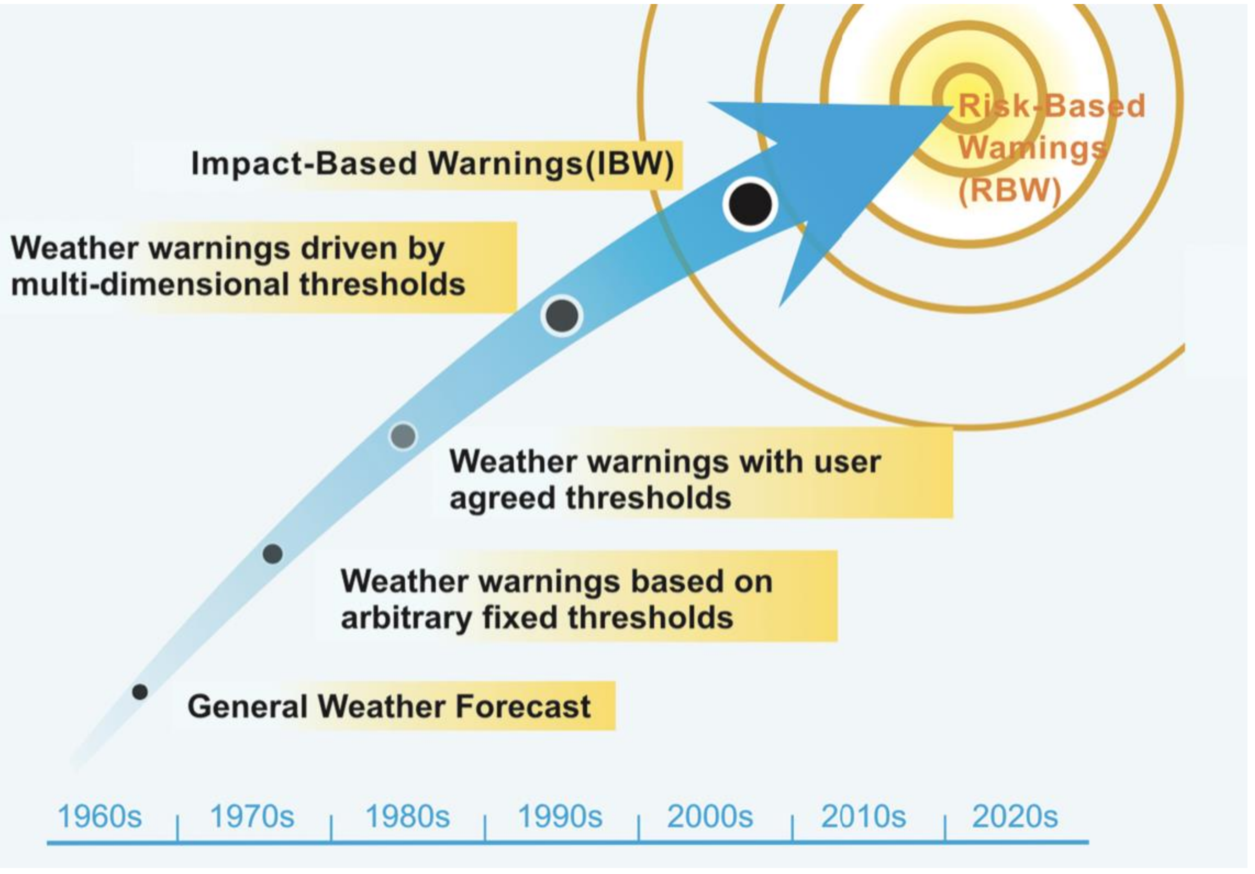


Figure 21. Global Evolution of Early Warning Systems (80)

The development of a risk-based warning system in China has been a multi-year endeavor. By 2007, major cities in the country had implemented multiple-hazard early warning services based on fixed thresholds. For example, if precipitation exceeded 50mm in a given region, it would be classified as a rainstorm and the corresponding early warning system would be activated. However, in 2009, following advocacy from the World Meteorological Organization (WMO), the Chinese Meteorological Administration (CMA) sought to evolve these systems towards being impact- and risk-based. This transition required the integration of interdisciplinary information, such as assessing hazards, vulnerabilities, and coping capacities. To accomplish this, CMA initiated a range of activities across various counties in the country, including:

1. Conducting flood disaster surveys in small and middle-sized river basins, and in locations experiencing flash floods, landslides, and mudflows, as well as incorporating historical risk information data.
2. Consult different sectors to determine the threshold to trigger a disaster response.
3. Incorporating satellite and radar data into the early warning system. Weather, climate, and hydrological information are gathered from the meteorological department of each locality, with a near real-time update frequency.
4. Water engineering projects and geological information mapping are conducted once a year, in partnership with the water resource and land management department.
5. Socio-economic information surveys from the annual census conducted by the statistical bureau.
6. Post-disaster information if applicable, is collected from the department of civil affairs. Through evaluating this information and mapping the spatial distribution of hazards, CMA conducted risk assessments for counties across the country (80).

Information dissemination is as important as gathering information. Following the EWS information becomes available, it is then disseminated through local and national TV stations, the China Weather website, the SMS system, mobile application, CMA service phone number, and the official WeChat account. In rural areas where many of the methods are not available, the information is disseminated through public radio speakers and public display boards. In addition, a direct line of contact is maintained between CMA and local government ministries, and central government (ministries of land and resources, transportation, health).

Anhui province became the first one to pilot such a new risk-based warning system. The EWS, which uses quantitative precipitation estimations and forecasts products in combination with disaster parameter precipitation thresholds and hydrological and land surface conditions, was able to predict flood-affected areas and set the warning system in motion. The service disseminated risk-related early warning information twice a day during the forecasted heavy rainfall event, which occurred from July 5–7, 2013, and provided professional services to government agencies every 3 hours. This led to the evacuation of 2,500 people living in flood-prone areas, ultimately resulting in no casualties and economic losses of CNY 727 million (80).

The risk-based system is aimed to launch in all of China soon. Such update will enable CMA offices in all provinces and counties to provide effective and timely early warning services to local people and to coordinate with national and local emergency services. The application of impact and risk based EWS has enormous potential benefits, including increased public response and better protection of life and property.

5.2.2 Earthquakes Early Detection Efforts

The prediction of earthquakes remains a challenging task, as highlighted by Zhang (31). Direct observation of the depths at which earthquakes occur is difficult, given their occurrence at depths of 10–20km. Additionally, large earthquakes are infrequent, occurring on a time scale of thousands of years, which exceeds the lifespan of both humans and machines. Furthermore, the underlying physical processes of earthquakes are complex and not well understood, adding to the difficulty of prediction. The prediction of earthquakes, particularly in the short term, has been a topic of ongoing debate among seismologists in the United States. While the consensus among scientists is that accurate forecasting of the time, location, and intensity of earthquakes within a few days to a few months remains elusive, some notable exceptions exist. The 1975 Haicheng earthquake in Liaoning Province, China, with a magnitude of 7.3, was successfully predicted due to the presence of foreshock activity. Additionally, earthquakes in regions such as Yunnan, Xinjiang, Qinghai, and Liaoning have also been successfully forecasted to some degree, enabling disaster mitigation efforts. However, the 2008 Wenchuan earthquake was not successfully predicted in the short term, despite it being accurately forecasted in a long-term forecast 15 years prior. Despite these challenges, seismologists continue to make progress in earthquake forecasting and prediction (31).

Enhancing capabilities for monitoring earthquakes remains a crucial area of research, as outlined by Huang et al. (81). One current project in this field includes the use of the Global Navigation Satellite System (GNSS), which was introduced into the geosciences and earthquake hazard mitigation observation system in China following the 2008 Wenchuan earthquake. The GNSS system incorporates data from GPS (United States), GLONASS (Russia), Compass (China), and Galileo (European Union). The China Earthquake Administration (CEA) has proposed the GNSS project as a means of meeting the new technical requirements of earthquake early warning. The GNSS observation network currently comprises 260 basic stable stations with data sampling frequencies of the 30s, 1 Hz, and 50 Hz, as well as 2000 portable stations that are observed once every 2–3 years.

Another project is the China Digital Earthquake Observation Networks Project, which includes a geophysical-/geochemical-anomaly monitoring network and a digital seismograph network. However, it should be noted that some regions, such as the Tibetan plateau, have very low monitoring capabilities and are incapable of capturing a high-resolution picture of the spatiotemporal variation of some geophysical fields, even in seismically active areas.

The geophysical background field project includes monitoring networks, a scientific exploring system, a data process, and an application platform system. It has 593 stable observation stations in the monitoring networks. The Earthquake prediction experiment sites are another initiative in this field. It is an attempt to conclude the statistical characteristics of empirical precursory anomalies and to evaluate the efficiency of stations and observation methods. The earthquake prediction experiment sites were built in Xinjiang, Yunnan, and Beijing to capture the precursory anomalies.

5.3 Disaster Loss Statistics System

China's diverse geo-climatic and socio-economic conditions make it particularly susceptible to a range of different disasters. To effectively manage and mitigate the impact of these events, it is necessary to develop a holistic disaster loss statistic system that aggregates data on hazards, vulnerabilities, and risks at all levels and across different scales. The creation of a nationwide disaster loss statistic system (DLSS) has been a top priority of the central government since the late 2000s.

In 2009, the Technical Committee on Disaster Reduction and Relief of Standardization Administration of China issued several national and industry standards on the disaster loss statistical system, as the first step in the creation of the DLSS. During the period from 2009 to 2012, the committee focused on refining the system by determining which indicators to include, establishing classifications and coding for natural disasters, developing sampling methods, and establishing methods for verifying disaster loss data. By 2014, the statistical systems for especially severe natural disaster losses were in operation and activated during the National Natural Disaster Relief Level I emergency response. The system was fully set up and officers were trained by 2018 when more than 734,000 disaster information officers from local villages were able to use computers and mobile phones to report information. By 2022, almost all information was reaching the central government within 24 hours, including population death statistics, the number of buildings that collapsed, and the number of people evacuated (27).

The nationwide disaster loss statistic system (DLSS) in China has made significant progress in recent years, however, several challenges persist. One crucial challenge is the validation of the reported data, as there is a potential for local officers to exaggerate the magnitude of destruction to acquire more resources and support. Another challenge is the inclusiveness and specificity of the indicators used in the DLSS. The system currently comprises 738 loss statistical indicators but lacks indicators on crucial aspects such as natural ecosystems. Furthermore, the DLSS currently lacks measurements for indirect economic loss and diminution of quality of life. Additionally, data transparency is a significant challenge, as the data collected through the DLSS is not available for public or researcher access, which might impede further research and understanding of the impacts of natural disasters in China (27).

6. Conclusion

The main objective of the paper is to provide readers with a comprehensive view of the natural disaster risk in China. As discussed in the methodology section, this paper adapts the "pressure and release" model, which considers disaster risk in three parts: hazards (exposure), vulnerabilities, and coping mechanisms, which are discussed in sections 3 to 5 respectively. It is worth noting that coping mechanism includes both vulnerabilities and risk reduction. Since section 4 already provides a comprehensive view of vulnerabilities, section 5 is limited to disaster prevention and risk reduction.

Because of the vast land area and diverse climates, China experiences practically every existing disaster. Globally, China is regularly among the top three countries most affected by disasters every year, in terms of disaster frequency, lives lost, and economic damages. The loss caused by natural hazards in China is significant, with 195,820 deaths and direct physical losses of US$1,698 billion (in 2018 values) between 1989 and 2018. The risks of these natural disasters are increasing due to climate change, which exacerbates the frequency and intensity of events such as super typhoons and intense rainfall, leading to flash floods and riverine floods. Droughts and heat waves are also becoming more frequent and severe. Additionally, demographic changes such as population growth, economic development, rapid urbanization, and interregional trade integration also exacerbate the risks of natural disasters in China.

However, the extremely high exposure in China is somewhat offset by its decrease in vulnerabilities. China has undergone impressive economic growth since the reform in the 1970s, lifting billions out of poverty and constant threats to food security. However, inequalities remain a significant issue, primarily resulting in significant health inequalities. Nationwide, there has been unequal distribution of water, which the government is seeking to address through policies and several ambitious projects.

The past years have seen significant progress in China's legislature in addressing disaster prevention and risk reduction. Risk reduction plans are increasingly becoming proactive, comprehensive, and measurable, following the recommendation in Sendai Framework. Research is undergoing in different disciplines to develop more accurate and informative disaster-specific early detection and early warning systems. The disaster loss statistics system was also significantly improved since 2009. By 2022, all information will reach the central government within 24 hours during a disaster.

In conclusion, while China experiences significant natural disaster challenges, the country has made significant progress in addressing its vulnerabilities and developing coping mechanisms to reduce the impact of disasters. However, challenges remain in addressing issues such as increasing inequalities and unequal distribution of resources. It is clear that as demographic changes and global warming exacerbate, addressing these challenges will become increasingly important.

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