7 Managing water-related vulnerability and resilience of urban communities in the Pearl River Delta

Liang Emlyn Yang

S. 121–141

aus:

Climate Change, Security Risks, and Violent Conflicts

Essays from Integrated Climate Research in Hamburg

Edited by Michael Brzoska and Jürgen Scheffran

Hamburg University Press
Verlag der Staats- und Universitätsbibliothek Hamburg
Carl von Ossietzky

Impressum

BIBLIOGRAFISCHE INFORMATION DER DEUTSCHEN NATIONALBIBLIOTHEK

Die Deutsche Nationalbibliothek verzeichnet diese Publikation in der Deutschen Nationalbibliografie; detaillierte bibliografische Daten sind im Internet über https://portal.dnb.de abrufbar.

ONLINE-AUSGABE

Die Online-Ausgabe dieses Werkes ist eine Open-Access-Publikation und ist auf den Verlagswebseiten frei verfügbar. Die Deutsche Nationalbibliothek hat die Online-Ausgabe archiviert. Diese ist dauerhaft auf dem Archivserver der Deutschen Nationalbibliothek (https://portal.dnb.de) verfügbar.
DOI https://doi.org/10.15460/HUP.208

ISBN 978-3-943423-81-5

COVERABBILDUNG

Coverabbildung: Alexas_Fotos (https://pixabay.com/de/photos/sonnenuntergang-abend-romantisch-2180346/) auf Pixabay (https://pixabay.com/de/)

SCHRIFT

Alegreya. Copyright 2011: The Alegreya Project Authors (https://github.com/huertatipografica/Alegreya). This Font Software is licensed under the SIL Open Font License, Version 1.1. This license is also available with a FAQ at: http://scripts.sil.org/OFL

DRUCK UND BINDUNG

Books on Demand – BoD, Norderstedt

VERLAG

Hamburg University Press, Verlag der Staats- und Universitätsbibliothek Hamburg Carl von Ossietzky, Hamburg (Deutschland), 2020
http://hup.sub.uni-hamburg.de

Table of Contents

7 Managing water-related vulnerability and resilience of urban communities in the Pearl River Delta

Liang Emlyn Yang

Abstract

Globally, growing concern about disaster risks necessitates the implementation of actions that combine vulnerability reduction and resilience building. This paper applies the concept of vulnerability and resilience to urban communities in the Pearl River Delta along the Southern Chinese coast that are facing climate-related water hazards. The study integrates a reanalysis dataset and model projections with literature results on long-term climate changes, which support a comprehensive risk analysis of both floods and water shortages in the Pearl River Delta within the regional climate change context. A flood vulnerability assessment indicates that pre-existing vulnerabilities are exacerbated after flood impacts. The main factors influencing the vulnerability of coastal communities are related to economics, institutional capacity, and the accessibility of knowledge for local community-based organizations. Many communities have been able to reinforce their resilience through local initiatives, including investing in infrastructures, sharing responsibilities, diversifying engagements, network recoveries, and water security nets for the most vulnerable ones. To ensure that the delta's communities are well adapted to climate and water threats, it is clear that investing in building community resilience and safety nets is important. This paper further highlights that community efforts, government supports, and external assists should be better organized to reinforce the abilities of the people at the local level.

KEYWORDS: *Climate change, flood risks, vulnerability, community resilience, water security, Pearl River Delta.*

Introduction

Currently, concerns are increasing that climate change would increase disaster risks like droughts, floods, and storms, which pose security problems to human societies (IPCC 2012), especially in coastal urban areas. Among many disasters, the concerns about climate-related flooding have led to increasing interest in understanding the interactions between climate, flood, and human responses (Yang et al. 2015). Several decades of research have produced a considerable understanding of the complex interacting factors contributing to social vulnerability to natural hazards. Despite these insights and the efforts of the disaster risk reduction and humanitarian organizations to reduce hazard vulnerability, natural hazards remain a considerable challenge to poverty reduction and development in many countries around the world and particularly in fast developing Asia (Nitivattananon et al. 2012).

Cities are dynamic social systems: their future developments are shaped by many interacting forces, including changes in the environment. With a projected sea level rise of up to 0.6–1.6 m by the end of this century (Jevrejeva, Moore, and Grinsted 2010), many of the world's large coastal cities are at increasing risk. Besides sea level changes, climate change is likely to increase rainfall variability, drought intensity and duration, and damages on water-related infrastructure by extreme weather events, which all increasingly threaten the local water availability (Schewe et al. 2014). Water supply is becoming more complicated due to population growth, economic development, and difficulties in response/management (Yang, Chan, and Scheffran 2018).

In particular, cities in the highly populated Asian coastal areas will increasingly face complex inter-related problems associated with greater intensity and frequency of climate extremes (Dewan 2013; Yang et al. 2015). Impacts affect both urban and rural communities along the coast including housing, infrastructure, and economic facilities. Some of the key challenges in Asia related to climate change are: impacts of extreme weather events (i. e. floods, storm surges, sea level rise); identification of social vulnerabilities to multiple stressors during climate and environmental change; and adaption strategies concerning agro-technology, water resources management, and integrated coastal zone management (Nitivattananon et al. 2012). Disasters and climate change impacts as well as increased water demand pose serious risks to the provision of sustainable urban water services, e. g., drinking water, sanitation, and safe drainage, especially in cities (Zhang et al. 2009; Li 2009). These challenges call for a transition toward improved water management, including vulnerability reduction and resilience building.

While there are different meanings of the term vulnerability depending on the scientific discipline, the IPCC has clarified its meaning for the climate and disaster communities: Vulnerability is comprised of exposure, sensitivity, and adaptive capacity

(IPCC 2012). However, vulnerability assessment alone is not able to support information on probability, extent of, or recovery from a disaster event. Thus, there is a need to integrate local vulnerability into disaster risk analysis and resilience enhancement by means of regarding climate change impacts. As Whittle et al. (2010) argues, resilience can somehow be considered as the flip-side of vulnerability. However, this relationship is not always straightforward. The truth is that different definitions of resilience have emerged across a wide range of disciplines (Meerow, Newell, and Stults 2016; Liao 2012). In spite of this, evidence was found of nine core elements of community resilience that were common among all definitions, including local knowledge, community networks and relationships, communication, health, governance and leadership, resources, economic investment, preparedness, and mental outlook (Patel et al. 2017).

There can also be very large differences in the capacity of city authorities, households, and organizations to take measures to mitigate risk and ensure rapid, effective responses to disasters (Nitivattananon et al. 2012), and thus differences in resilience. There is a lack of consensus in the literature about what constitutes vulnerability and resilience and how to measure these phenomena. While some important work has focused on the long-term effects of coastal hazards on economic growth, little has been done to understand, in quantitative terms, the extent to which coastal communities may be vulnerable to such hazards and, if so, whether they can be resilient (Patel et al. 2017). A focus on these local communities may be more productive than attempting to define and study community resilience as a distinct concept.

The objective of this paper is to undertake a comprehensive, systematic analysis of the climate-related hydrological risks as well as the vulnerability and resilience of local communities in the highly urbanized Pearl River Delta (PRD) in South China. While specific strategies for vulnerability reduction and resilience building are still one of the challenges faced by local, state, and national agencies, this paper provides a framework to improve comparative identifications of disaster resilience at the community level. Some priority measures will be discussed to enhance the capability of urban communities in coping with climate- and water-related threats.

Climate change and water risks in the Pearl River Delta

The Pearl River Delta

The Pearl River Delta (PRD) is formed as a 42 657 km^2 sedimentary plain of the Pearl River with its three branches, namely the West River, the North River, and the East River (Figure 1). The PRD is dominated by a sub-tropical monsoon climate with

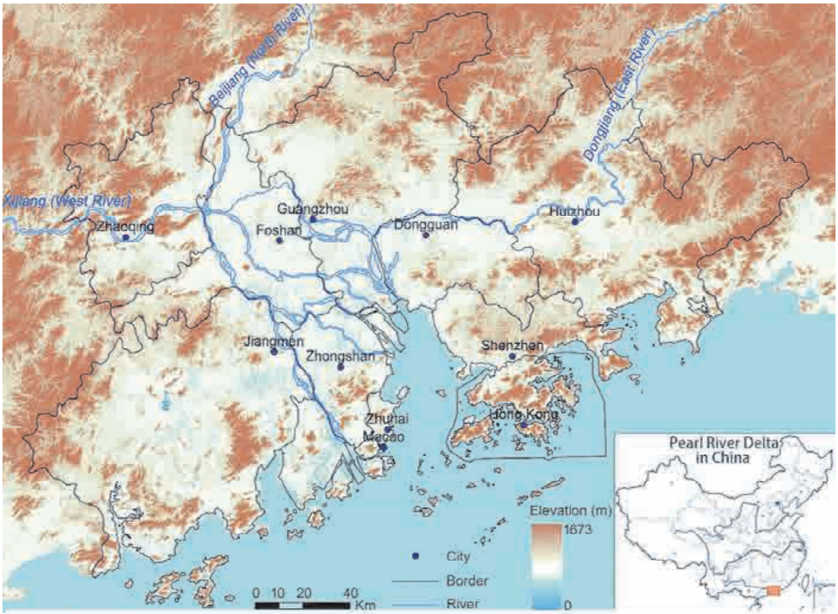

Figure 1: Topography, the river system, and the eleven cities of the Pearl River Delta, China.

abundant precipitation. The long-term annual mean precipitation is approximately 1800 mm and about 85 % of the precipitation occurs between April and September. The topography of the PRD has mixed features of crisscrossing river networks, channels, shoals, and river mouths (so-called “gates” in Chinese). Water flow at the estuary is influenced by both the river runoff and sea tide, with water level variation between 0.86 m and 1.63 m with a half-day return period.

The PRD includes eleven cities, nine in the Guangdong Province (Shenzhen, Dongguan, Guangzhou, Foshan, Jiangmen, Zhongshan, Zhuhai, and parts of Zhaoqing and Huizhou) plus Hong Kong and Macau (Figure 1). Comprising 81.61 million inhabitants in 2016, the PRD is rapidly urbanizing and is now among the most prosperous metropolitan areas of the world. The GDP of the PRD cities reaches roughly 1428 billion US$ in 2016 with an average annual growth rate of 16.2 % in the first decade of this century. This rapid development is accompanied by intense land use change, e. g. built-up areas increased from 4.14 % in 1988 to 20.61 % in 2008 (Ye et al. 2012), and this trend is still continuing.

The natural environment of PRD is sensitive and variable due to the strong monsoon, the dense river network, and significant effects of erosion and deposition. Rapid economic development and population growth have further intensified the fragmentation of the natural environment. The combination of these factors makes the PRD prone to natural disasters, of which floods are the most serious. Although increasing hydraulic engineering (mainly reservoirs and dams) in the upstream area prevent certain fluvial floods for the PRD, local extreme weather and poor drainage in the context of climate change and urbanization still make the flood threat a substantial concern for the government and stakeholders (Peng et al. 2008; Chan et al. 2012).

Climate change and impacts on the water system

Flood risks

Flood implications of climate change trends are pronounced in most of the cities in the PRD. The frequency and intensity of extreme weather and climate events have triggered some significant change – together with continuing development in flood-prone areas, which increase both the scale and degree of urban flood risk. Climate change is expected to lead to increases in extreme rainfall, especially in places where mean rainfall is already expected to increase. Such extreme precipitation will threaten many areas, buildings, infrastructure, and people and is likely to result in great losses.

Flooding in the Pearl River basin is caused primarily by local or upstream rainstorms during the rainy season from May to September in the year. The stream flow variations show remarkable relations with precipitation changes in the West and East River basins, implying a tremendous influence of climate change on hydrological processes (Zhang et al. 2009). Large-scale flood impacts (economic loss and population flooded) coincide well with the occurrence of intense precipitation most of the years, while low precipitation means fewer flood impacts. However, floods are not only related to total precipitation but also to extreme rainfall. In 2003, the total precipitation was relatively low but the population flooded was substantial because a devastating typhoon (Dujuan, with international No. 0313) hit the PRD directly with extreme rainfall and strong winds (Yang et al. 2015).

The principle also applies to typhoons. What usually matters more is the intensity rather than the typhoon frequency. As previously stated, annual precipitation, extreme rainstorms, and typhoons are all projected to continue to become more frequent in the PRD area during this century, thus the probability of flood occurrence is expected to increase accordingly.

Flooding in cities is also called waterlogging in local areas, which occurs frequently in PRD cities like Guangzhou, Shenzhen, and Hong Kong. Heavy rainfall over a short period of time is the main reason for waterlogging. In addition, large parts of land

Figure 2: Photographs showing the rapid development and urbanization in the low coastal areas of the PRD. Source: Photos taken by Liang E. Yang in November and December, 2011.

are covered by buildings and concrete, which increases the surface runoff and rainwater accumulation for waterlogging. PRD cities have experienced rapid development and urbanization in the low coastal areas and this is not slowing down in recent years (Figure 2). In the context of expected extreme precipitation and continuing urbanization, waterlogging is increasingly possible for city centers due to fast rainwater accumulation and in old city areas due to poor local drainage.

While the eastern areas of the PRD face many local small-scale floods caused by intensive rainfall, the western and northern parts suffer more from river flooding. River flooding is usually caused by large-scale precipitation. A sharp increase in precipitation would require further water storage capacity for flood control along the river, while unexpected precipitation reduction would affect the impoundment. Indeed, the decrease in flood frequency and increase in flood-affected population or assets in the Pearl River basin during the last decades have been noticed by Chen, Zhang, and Chen (2012). Given that the frequency and intensity of extreme weather have shown significant change, tremendous influence on hydrological processes can be expected and further basin-wide flood risks are implied.

Water shortage

Water resources are unevenly distributed throughout the PRD. The highly urbanized PRD area gets relatively little water compared to the upstream areas, based on per capita water availability. In addition, not all cities can easily take advantage of using the Pearl River water as cities such as Hong Kong and Shenzhen are not located near the river mainstream. Both cities rely highly on natural rainfall and regional water transfer and are therefore more vulnerable to the impact of weather factors. Uneven patterns of precipitation also cause droughts in certain subareas. Higher drought risk can be observed in the lower Pearl River basin and lower drought risk in the upper Pearl River basin (Zhang et al. 2012). Due to the uncoordinated distribution of water resources and population, the highly urbanized PRD area is under higher pressure when drought and water shortage occur. Projected climate change is expected to aggravate the uneven pattern of precipitation, which will bring about further water stress.

In the context of global climate change, the sea level is expected to keep rising in the future, which would increase saltwater intrusion, the invasion of seawater into inland freshwater systems. Saltwater intrusion affects the quality of river water, resulting in reduced availability of freshwater resources. The river water level declines due to reduced surface runoff, which therefore allows sea-water to intrude and spread in the Pearl River inland river channels. The situation deteriorates when tides occur and tidal water intrudes further into the costal river system, thereby creating a super saltwater intrusion. In addition, a rising sea level would push saltwater into inland groundwater systems. If there were not enough surface runoff injected to groundwater system, ground water would eventually become unusable.

Large amounts of rainfall in the wet season help to take away or dilute water contaminants significantly. However, less water will lead to a higher concentration of water contaminants. As wastewater and sewage are increasing rapidly in the PRD cities along with fast population growth and urbanization, climate-related water shortage would aggravate water pollution. Serious water pollution would deteriorate the aquatic environment and cut down the amount of useable water. Natural and human made water pollution can spread with transboundary water diversion. Research shows that increased depositions of cadmium, copper, and zinc in Hong Kong's reservoirs are positively correlated with their depositions in the downstream of Dongjiang River during the period of 1994–2001. There are also many other substances transported to Hong Kong through the water supply project, which may cause health problems (Ho, Chow, and Yau 2003).

The impact of climate change on available water resources, including the quantity, quality, and distribution, is very complicated and often unclear. Furthermore, the development, utilization, and planning of the local water facilities are also involved, which adds a lot of exposure to climate change impacts. Long term and severe droughts could cause failures of water supply facilities. Extreme hot weather can depreciate the entire social infrastructure including water supply, flood control, and pollution treatment. In addition, floods are a major initiator in destroying human facilities and welfare. And finally, the health sector may be also affected by damages in water supply facilities and sewage systems of the PRD basin, mainly in form of an increase in the incidence of water-related diseases and may influence the cities and their people.

Vulnerability to climate-related water hazards

Flood vulnerability of PRD cities

Flood risks emerge from the interaction of flood hazards and vulnerability (Merz et al. 2010). The vulnerability to flood hazards can be identified by its three components: exposure, sensitivity, and adaptive capacity. In this study, the methodology consists of a vulnerability indicator system with 15 indicators to quantitatively evaluate the PRD cities' vulnerabilities, as introduced in Yang et al. (2015).

Primary data for the vulnerability assessment were collected from the Statistical Yearbooks of Guangdong Province (2002–2011), statistical yearbooks of each city (2002–2011), the sixth census of each city (2010, except Hong Kong and Macau), and government publications and news reports in related cities in 2010. It has to be mentioned that a few indicator values (e. g. economic sector and drainage system) are not exactly comparable due to different statistical criteria of individual cities. A more appropriate approach is to describe the three components of vulnerability in detail and also combine them into one flood vulnerability index. Of all the eleven cities examined, Zhongshan, Dongguan, and Macao are the three most vulnerable cities in this area (Figure 3) while Hong Kong, Shenzhen, and Guangzhou rank in the middle. Therefore, even though the exposure and sensitivity indicators are still significant in the most developed cities, flood risks and potential damages can be mitigated greatly by improving flood-control measures (i. e. the adaptive capacity).

The results suggest that the exposure and sensitivity of Hong Kong, Macao, Shenzhen, and Guangzhou are very high because of highly exposed populations and assets located in lowland areas. However, the potential vulnerability and risk can still be low due to high adaptive capacities with regard to both hard and soft flood-control measures. A novel framework on flood responses is proposed to identify vulnerable links and response strategies in different phases of a flood event. It further suggests that the flood risks can be reduced by developing an integrated climate response strategy, releasing accurate early warning and action guidance, sharing flood related information to the public, and applying the advantages of social network analysis.

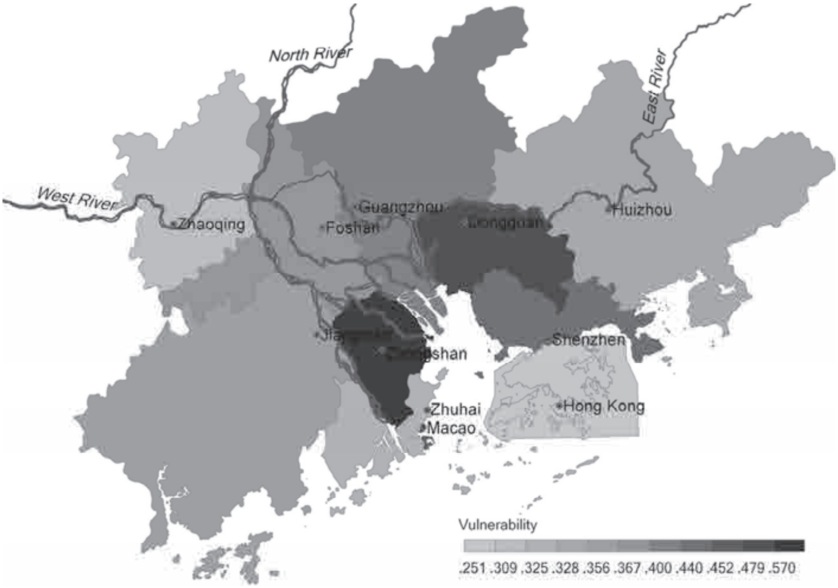

Figure 3: Relative flood vulnerabilities of PRD cities. Source: Yang et al. 2015.

As a river delta, the PRD has frequently suffered from flooding in the past. Urban settlements in the PRD are typically located and developed along shorelines and the river estuary, putting them at particularly high risk of flooding and an expansion of the water's edge. At the macro level, the PRD has a higher frequency of floods and a more severe flood risk in general because it is highly impacted by the combination of urbanization effects and climate-related changes in the future. Adding to this is the fact that a large number of existing tidal flood defenses are below the standard set by the provincial government (Chen and Chen 2002), increasing the probability of flooding of the local population. If the PRD region fails to take precautions, it will suffer multiple serious impacts of inundation, storm surges, dike failure, and drainage difficulties.

Climate-related impacts are not the only causes of flood hazards in the PRD area. Since 1980, the coastline of PRD has undergone extraordinary changes due to urbanization and economic development. Such developments also increase the likelihood of flooding due to human-induced hydrological changes, which include:

– Urbanization changes land surface characteristics, thus altering the rainfall-runoff relationship, which leads to increased and earlier flood peak flow, shorter flood duration, and increased flood volume.

- In order to meet the water demand of an increasingly dense population, excessive exploitation of groundwater in the PRD has led to land subsidence, making the delta more vulnerable to flooding (Huang, Zong, and Zhang 2004).
- Rapid urbanization drives significant riverbed dredging for construction materials. Although river dredging could potentially increase the channel cross-section and reduce the flood risk, intensive dredging and abnormal riverbed excavation exacerbates river bank erosion and therefore increases the probability of riverbank outburst (Luo et al. 2007).
- The growing population occupies an increasing river beach by land reclamation along the Pearl River estuary, which seriously narrowed the river channel and reduced the river's natural capacity for draining and regulating floodwater. Flood threats will very likely increase in this situation if no remedial action be taken. Moreover, natural floodwater storage has been sacrificed, as seen in the drainage of large natural wetlands for urban development around the Shekou Peninsula in Shenzhen.

Vulnerability to water shortage

The Pearl River Delta is quite often portrayed as a subtropical area with abundant water resources. However, this is only part of the full picture of the complicated water issues. Although the current water supply system supports the water demand effectively, water shortage is still of general concern in this area (Gu and Yang 2005). Furthermore, global climate change adds new challenges from another dimension, together with population growth and development activities, making water supply issues more complicated. Water system management is both complex and politically difficult, requiring the best expert knowledge available for decision-making (Hunt et al. 2007). In order to enrich the adaptive capacity in the PRD area, it is necessary to understand the characteristics of the water supply system and the associated risks.

The usable river water in the PRD originates in the upstream part of the river and is influenced greatly by any changes in quality or quantity. Although the absolute amount of water available to the PRD seems sufficient, per capita water availability is relatively small considering the intense population and economy (Yang 2014). Especially, the East River has been nearly fully developed to serve the water demands of cities along it. It is hardly possible to increase supply. Taking into account potential droughts and increasing upstream water consumption, the further development of water supply has become one of the most important and urgent tasks facing PRD city governments. Accelerated urbanization also dramatically changes water use patterns. During 1980–2003, the share of agricultural water consumption with respect to the total annual amount of water consumption declined from 87.6 % to 54.3 % (Yang 2014). During the same period, the share of industry water consumption increased from 12.4 % to 44.5 %. This altered pattern exposes further contradictions in water supply and demand: agricultural water consumption shows seasonal, temporary features and therefore can be well prepared for peak demand period while urban water consumption is constant at a certain high amount. Thus urban water supply is more sensitive to climate-related water fluctuations and there is a significant potential that it is threatened by droughts (Liu, Liu, and Wang 2005).

Extensive water consumption contributes to a large amount of wastewater, which pollutes the river system and reduces the usable fresh water. This can be considered a vicious circle of the water system because the expansion of the sewage treatment system significantly lagged behind the pace of urbanization. According to a water resource report, the characteristics of the PRD are the worst water quality, highest water consumption, and largest sewage volume in the country (PRWRC 2011). About half of the PRD streams are polluted, with river water quality classified as IV, V or worse than V (I to V indicates best water quality to worst). Zhu and colleagues analyzed the water environment and pollution sources in the PRD and point out that domestic sewage is the main source of water pollution (Zhu et al. 2002). Although the estimated amount of pollution-caused water loss seems negligible throughout the PRD, the situation in certain sub-areas is worse (Gong 2012). In addition, seasonal salty-tidal brings saltwater and marine pollution to the inland parts of the river system, which aggravates already existing water pollution. Furthermore, contaminants deposited in the riverbed could be transported to other areas by water transfer and pose potential risks in the destination areas as well (Ho, Chow, and Yau 2003).

The most severe impact of water shortage and drought is its disaster-chain effect (Liu, Liu, and Wang 2005), which considers not only a lack of water as a primary effect but also many indirect consequences such as pests, diseases, forest fires, ground subsidence, crop reduction, and even social instability (Figure 4). First, water shortage is a disaster for the environment. As the river water level drops during a drought, saltwater intrusion occurs more readily and pollutes the already stressed freshwater resources; thus, the drought situation is further exacerbated. Moreover, water shortage reduces human-wellbeing due to difficulties in the drinking water supply. In addition, some infectious bacteria and viruses have a strong biological activity in arid environments and may disperse diseases among humans if there are water shortages. For example, the warm and long-lasting dry spell benefited the spread of SARS (Severe Acute Respiratory Syndrome) in 2002/2003 in Guangdong province (Chen et al. 2004). The emergence of diseases not only affects people's physical and mental health, it is also likely to cause social panic: severe water shortage or drought leads to huge economic

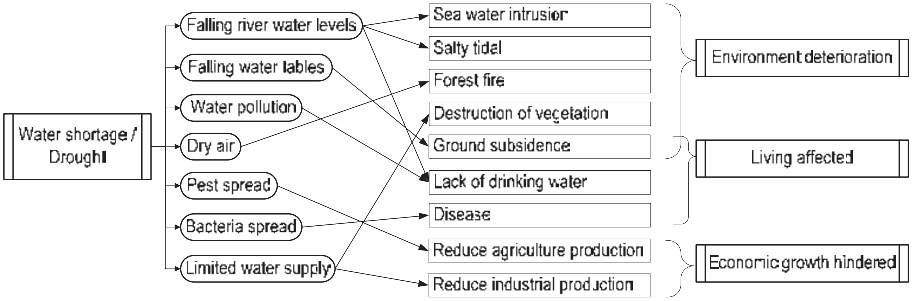

Figure 4: Disaster chains of water shortage and drought. Own representation based on Liu, Liu, and Wang 2005.

losses. Drought-introduced pest infestations are the most direct harm to agricultural production. Severe drought also affects industrial production, by reducing production or discontinuing it. In 1991, the drought forced most of the food, beverage, and textile factories in Shenzhen to shut down their production totally or partially, causing a direct loss of about 200 million Chinese Yuan (37.59 million US Dollars) (Liu, Liu, and Wang 2005).

Furthermore, changes or a reduction in water availability may cause, bring back, or prolong social conflicts between municipalities or between people and authorities on access to water, water use, or water consumption (Yang, Zhang, and Ngaruiya 2013). Three main reasons have been identified as critical factors influencing the occurrence of water related social conflicts: 1) aggravation of water shortages, a trigger that strains the competition for the resource; 2) public rejection of government decisions that may be perceived as unpopular (e. g. reduction of subsidies, increase of tariffs, scheduled reductions in water supply); and 3) additional causes related to local (geographic or sectorial) circumstances, e. g. recurrent drought periods affecting local agricultural activities, lack of infrastructure, or inequitable supply (Brun 2007).

Framing the community resilience in the PRD cities

Community resilience to natural hazards in general

To ensure the delta's communities can adapt well to climate and water threats, it is clear that it is important to invest in building community resilience for the most vulnerable. The essential issue in this respect is that social and ecological vulnerability to disasters and long-term consequences of any particular extreme event are influenced by the buildup or erosion of resilience (Adger et al. 2005). Specific studies explored resilience from both theory and methodology perspectives and in doing so moved beyond looking at resilience merely in terms of vulnerability, risk, and capacity. Recently, the concept of resilience was increasingly explored to offer a more systemic and cross-cutting approach to disaster risk reduction. The Sendai Framework for Disaster Risk Reduction 2015–2030 (Sendai Framework) further promoted the studies since it set forth "investing for resilience" as one of the four main priorities for action at different levels (UNISDR 2015). Although the study is prosperous, the identification of standards and metrics for measuring disaster resilience is still one of the challenges faced by local, state, and federal agencies (Paton and Johnston 2017).

A recent literature review indicated that community resilience is an amorphous concept that is understood and applied differently by different research groups (Patel et al. 2017). In essence, depending on one's stance, community resilience can either be seen as an ongoing process of adaptation, the simple absence of negative effects, the presence of a range of positive attributes, or a mixture of all three (Patel et al. 2017). Although expressed differently, community resilience generally emphasizes the capability to absorb, adapt, and transform in the face of hazards, shocks, and stresses (Zakour and Swager 2018). Evidence was found of nine core elements of community resilience that were common among the definitions used in different studies, which include local knowledge, community networks and relationships, communication, health, governance and leadership, resources, economic investment, preparedness, and mental outlook (Patel et al. 2017).

Building on these elements, community resilience aims at solving the root causes of vulnerability and at evolving the systematic stability of functions. The connotation of community resilience is the inherent state and structural characteristic, in which the community itself exists before a disaster occurs. In summary, the approach here is to understand community resilience in terms of relationships and action processes of individual, household, and public services in a community. In other words, "resilience" is not so much a response to a given hazard itself but is an emergent characteristic of the way, in which the responses and subsequent recovery processes are managed (Whittle et al. 2010).

Understanding vulnerability to enhance resilience

In the context of climate change, vulnerability is a function of "systemic exposure, sensitivity, and adaptive capacity" (IPCC 2014). Vulnerability research can help us understand where people and places are at risk and propose strategies for adapting governance. Social vulnerability and community resilience can be viewed as separate but often linked concepts. Vulnerability speaks to the inherent qualities of a social system that contribute to the amount of risk of exposure as well as the degree of harm, while resilience refers to the conditions that help social systems to absorb, cope with, and adapt to hazards and disasters (Cutter et al. 2008). While numerous scholars note the conceptual links between these two indices, few have empirically investigated the relationship between community resilience and social vulnerability (Bergstrand et al. 2015; Sherrieb, Norris, and Galea 2010). Findings indicate a correlation between high levels of vulnerability and low levels of resilience, although not all areas have parity concerning vulnerability and resilience levels.

Studies on climate change impacts increasingly focus on not only assessing the vulnerability of social systems that reflects the negative aspects but also on increasing resilience that reflects the positive and initiative aspects of human societies. The reason for this shift of focus of climate impact research is mainly due to the fact that experts and scholars have noticed that a large number of the published vulnerability research results have not made various mitigation strategies and measures work as expected (Cutter et al. 2008). In other words, the recent findings of vulnerability knowledge are not sufficient to be of practical use for disaster risk management. Enhancing community resilience is thus necessary to fill the knowledge gap. This can be achieved by investigating possible practical measures. Studies indeed have suggested that a strong social resilience can be developed as long as there is a strong relationship in social networks that offers immediate and in-need help when fighting against external disturbances (Chelleri, Minucci, and Skrimizea 2016; Bergstrand et al. 2015). In general, the current sustainable development movement tends to rely on resilience as the main concept if it is based on a well-founded understanding of the associated vulnerability and risks.

As far as the PRD cities are concerned, different communities certainly have different issues and challenges such as flooding, sea level rise, water pollution, ageing of population, new immigrants, or the industrial transition. Some of these issues are internal issues within the communities; some of them belong to a larger scale of socio-economic structural problems. Nevertheless, they all contribute to the vulnerability of the city systems and they must also put efforts to community building and local development in order to construct resilient communities and a resilient society. Climate change impacts are also an urgent problem in the PRD area. An important issue that PRD cities should pay greater attention to is how to identify areas that are highly vulnerable in order to focus on building resilience and impact mitigation there. If local communities can identify specific areas with high vulnerability promptly, then these regions can be used as priority areas to promote mitigation planning and adaptation actions. Consequently, these areas are more likely to be built into resilient communities. Proposing resilience plans will not only reduce vulnerability but also integrate formal and informal networks to respond to the climate change impacts and move towards a true sustainable development.

Increasing community resilience in the PRD cities

The consequences of water-related hazards depend on both the hazard itself and the response behaviors. It is indeed of paramount importance to discuss the resilience building measures in the PRD cities and the necessary improvements based on the flood/water shortage vulnerability and risk analyses. In this context, framework for community resilience building consisting of four phases is introduced that could help to reduce the vulnerability of local communities to water-related hazards. Implementation of such a framework could have direct and indirect positive impacts on enhancing the resilience of urban communities in the PRD. Though many other measures could be considered for community resilience building as well, this study emphasizes specific procedures based on the vulnerability analysis above.

First, precautionary measures should always be considered as basics in building community resilience to water hazards as it is more effective and cheaper to invest in early rather than late actions (Yang et al. 2018). These include:

– Identification of local vulnerability and risk and informing of all community residents. Knowledge of vulnerability and risks in surrounding environments enables community members to identify context-specific adaptation actions and allows policymakers to engage community members in urban resilience planning. The ability of urban communities to remain resilient to water hazards is rooted in their understanding of the potential risks and vulnerabilities. The primarily suggested channels for achieving these aims were school programs and media campaigns.
– Investments into new and refurbishment of existing infrastructure to build community resilience. The primary goal is to strive towards a greener and more resilient city environment and implement standards about the continuity and long-term reliability of infrastructure. Moreover, multi-level, distributed, replicated networks of key facilities should be constructed to distribute risks over space and time. Regarding flood threats, the concept of a Sponge City is a promising option that involves the principle of harmonizing human and water systems in urban conditions (Xia et al. 2017). In addition, diversified drainage methods and redundant storage capacity could enhance the resilience to floods.

- Effective and precise early warning systems are considered to be an important component of disaster preparedness and response. There must be a clear emphasis on improving both the technological "hard" elements of such systems and the "soft" components, such as appropriate mechanisms for the communication and dissemination of early warning information to end-users and the linkages with community-based disaster preparedness activities.
- Finding of effective ways to inform and engage in communities to build resilience. Effective communication and engagement are best carried out through strategies that are appropriate to community needs, create partnerships and trust, and provide continuity of information. Particularly in poor communities, the enhancement of climate resilience requires an understanding of the residents' needs, resources, and capabilities (Yang et al. 2018).

Second, warning with forecasting and guidance is the necessary measure in case disaster strikes.

- Clarify shared responsibilities. To ensure shared responsibilities are equitable and effective, both institutions and communities need a good understanding of their communication and cooperation. This applies to both vertical (between authorities and communities) and horizontal (between community members) cooperation.
- Improvement of the instant warning system with prediction that is more accurate, longer lead-time, and more frequent information release. A flood warning system, which provides timely, accurate, and broad rain coverage warning can reduce flood losses by 30 %-40 % (Yang et al. 2018). To achieve this goal, further research on the mechanisms of rain triggered floods and appropriate channels for the release of warning information are highly recommended.
- Social media networks can be used very well to offer immediate information of any extreme events occurring. Given the rapid development of communication technology, the widespread individual use of cell phones, and the cost effectiveness of text messages to individuals, transparent disaster information and prevention services should be explored in more detail.

Third, relief through emergency management is the most appropriate measure particularly for external agencies to help building resilience of the communities.

- The local government and outside aid should be better organized to reinforce the adaptive capacity of the people in local communities. Random and unorganized response actions help very little to reduce total flood losses.

The relief system of treating flooding as a public problem should stress the increased organizational role in managing relief activities. This includes improving individual capabilities, coordinating their initiatives, and making full use of their efforts in the overall relief systems.

– Emergency response institutions and systems must be readily established and maintained to respond quickly and address the needs at the community level. An emergency plan should have been exercised in advance to ensure that timely and effective disaster relief can be offered in an emergency.

Fourth, post-disaster recovery measures contribute to improving community resilience in general so that the community can better cope with possible future hazards.

– Assessments of damages and remaining property are important to obtain information on the existing conditions and establish a baseline for subsequent steps. This baseline must consider the existing vulnerabilities, the state of recovery, the built environment, and nature itself.
– Repairing and upgrading of the remaining infrastructure, facilities, networks, livelihoods, as well as improving the early warning systems and evacuation procedures according to the observed inefficiencies.
– Investments into and construction of new infrastructure, facilities, and networks based on new information, experiences, and lessons learned from the disaster. These measures not only help in the recovery process but also aim at enhancing resilience with regard to future hazards. It is important to consider the capacity of ecosystems to buffer possible impacts of extreme events.
– Integration of disaster risk reduction into sustainable development strategies. There is an urgent need to develop strategies that integrate, more strongly, disaster risk reduction with water resource management, poverty reduction, and sustainable development. It is significant to incorporate the building of systematic ecological and social resilience to environmental and other shocks with a long-term comprehensive perspective.

Summary and conclusions

This paper presents an integrated analysis and overview on both flood threats and water shortage risks to the Pearl River Delta, China, in the context of climate change. It discusses and further emphasizes assessment methods for climate impacts and social responses (vulnerability and resilience) in urban communities. A comprehensive study on the climate change trends in the area of the PRD indicates increasing mean temperatures by around 3 °C and slightly more precipitation by end of this century while the sea level is likely to rise with an annual rate of 0.33cm to 1cm in the near future. The inter-annual variability of precipitation is much more notable relative to its trend variability, which means that extreme precipitation events occur frequently. These impacts potentially amplify hydrological variation in the PRD, which means an increasing frequency of droughts and floods. Such challenges increase both the vulnerability and the importance of resilience building in the PRD metropolitan area.

On the one hand, the study suggests that earlier investments in disaster responses are more efficient than late activities, and real-time, accurate, and large-scale flood warnings play a significant role in reducing flood vulnerabilities. It is increasingly recognized that the nature of coupled socio-environmental problems such as floodings require innovative institutional arrangements to address the complex physical processes occurring at local, regional, and global scales, while fitting within the economic, socio-cultural, and political constraints of decision making. On the other hand, response measures for coping with water shortages include rainwater harvest, seawater desalination and utilization, wastewater treatment and reuse, and water demand management. Actually, Hong Kong has done very good work in rainwater collection and seawater utilization, which can be considered to be a role model for the other cities. A long-term response strategy may also be implemented to both improve the self-sufficiency rate of water supply and diversify water source options.

The integrative analysis above suggests that the coastal areas of the PRD exhibit the full range of possible combinations of vulnerability and resilience. Therefore, suggestions are made to develop an integrated resilience building strategy, which includes specific measures of precautionary methods, warning with forecasting and guidance during extreme events, external relief through emergency management, and post-disaster recovery measures. It is very important that a chain of various measures must be established to enhance community resilience dynamically and from multiple dimensions.

As experience from history indicates, most cities that have experienced catastrophic damages show strong resilience, continued to exist, and developed even more prosperously. However, for those individuals deceased and suffering because of the disaster, the resilience of the city system is still far from sufficient. Therefore, resilience building includes two layers of meaning: to ensure the individual safety and to maintain system functionality. This is very challenging. In many ways the impacts of climate change are unavoidable up to certain extent. The human-water systems in coastal and delta cities are always subject to anthropogenic stress and all parts of the system adapt to each other to maintain a balanced systematic function. Actually, the stability of a given system is a relative stability in periods of dynamic changes. Therefore, the ultimate goal of water system management of the PRD cities shall be to limit damages as much as possible and recover functions as soon as possible, which is the essential argument for vulnerability reduction and resilience building in this paper.

References

Adger, W. N., T. P. Hughes, C. Folke, S. R. Carpenter, and J. Rockstrom, 2005: Social-ecological resilience to coastal disasters. Science, 309(5737): 1036–1039.

Bergstrand, K., B. Mayer, B. Brumback, and Y. Zhang, 2015: Assessing the Relationship Between Social Vulnerability and Community Resilience to Hazards. Social Indicators Research, 122(2): 391–409.

Brun, J. C. A, 2007. Adapting to impacts of climate change on water supply in Mexico City In: Fighting climate change: Human solidarity in a divided world. Human Development Report 2007/2008: Oxford: Oxford University Press.

Chan, F. K. S., G. Mitchell, O. Adekola, and A. McDonald, 2012: Flood Risk in Asia's Urban Mega-deltas: Drivers, Impacts and Response. Environment and Urbanization Asia, 3(1): 41–61.

Chelleri, L., G. Minucci, and E. Skrimizea, 2016: Does community resilience decrease social-ecological vulnerability? Adaptation pathways trade-off in the Bolivian Altiplano. Regional Environmental Change, 16(8): 2229–2241.

Chen, J.-Y. and S.-l. Chen, 2002: Estuarine and coastal challenges in China. Chinese Journal of Oceanology and Limnology, 20(2): 174–181.

Chen, Y. D., Q. Zhang, and X. Chen, 2012: Flood, Drought and Typhoon Disasters over the Last Half-Century in Guangdong Province, China (In Chinese). Journal of Water Resources Research, 1: 169–174.

Chen, Z., D. Ye, H. Yang, and G. Feng, 2004: On Relationship between SARS Epidemic and Weather Conditions in China (In Chinese). Meteorology, 30(2): 42–45.

Cutter, S. L., L. Barnes, M. Berry, C. Burton, E. Evans, E. Tate, and J. Webb, 2008: A place-based model for understanding community resilience to natural disasters. Global Environmental Change-Human and Policy Dimensions, 18(4): 598–606.

Dewan, A., 2013: Floods in a Megacity: Geospatial Techniques in Assessing Hazards, Risk and Vulnerability: Dordrecht: Springer.

Gong, Q., 2013: Dongguan has become the most risky city in water use in the Pearl River Delta. Dongguan Daily, 2012-03-27 2012. http://news.h2o-china.com/html/2012/03/1331332824183_1.shtml, last accessed 5 November 2013.

Gu, J. and J. Yang, 2005: Features of climatic and environmental changes in the South China (In Chinese). Resources Science, 27(1): 128–135.

Ho, K. C., Y. L. Chow, and J. T. S. Yau, 2003: Chemical and microbiological qualities of The East River (Dongjiang) water, with particular reference to drinking water supply in Hong Kong. Chemosphere, 52(9): 1441–1450.

Huang, Z., Y. Zong, and W. Zhang, 2004: Coastal Inundation due to Sea Level Rise in the Pearl River Delta, China. Natural Hazards, 33(2): 18.

Hunt, J. C. R., M. Maslin, T. Killeen, P. Backlund, and H. J. Schellnhuber, 2007: Introduction. Climate change and urban areas: research dialogue in a policy framework. Philosophical Transactions of the Royal Society-A. Mathematical Physical and Engineering Sciences, 365(1860): 2615–2629.

IPCC, 2012: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press.

IPCC, 2014: Climate Change 2014: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press.

Jevrejeva, S., J. C. Moore, and A. Grinsted, 2010: How will sea level respond to changes in natural and anthropogenic forcings by 2100? Geophysical Research Letters, 37, L07703.

Li, Y., 2009: Water supply and demand in the Pearl River Delta under a changing global climate (In Chinese), Beijing: Capital Normal University of China.

Liao, K. H., 2012: A Theory on Urban Resilience to Floods-A Basis for Alternative Planning Practices. Ecology and Society, 17(4), 48.

Liu, J., H. Liu, and Y. Wang, 2005: Causes and the chain of Guangdong drought disaster (In Chinese). Guangdong Water Resources and Hydropower, 2, 3–5.

Luo, X.-L., E. Y. Zeng, R.-Y. Ji, and C.-P. Wang, 2007: Effects of in-channel sand excavation on the hydrology of the Pearl River Delta, China. Journal of Hydrology, 343(3–4): 230–239.

Meerow, S., J. P. Newell, and M. Stults, 2016: Defining urban resilience: A review. Landscape and Urban Planning 147: 38–49.

Merz, B., J. Hall, M. Disse, and A. Schumann, 2010: Fluvial flood risk management in a changing world. Natural Hazards and Earth System Sciences, 10: 509–527.

Nitivattananon, V., T. T. Tu, A. Rattanapan, and J. Asavanant, 2012: Vulnerability and Resilience of Urban Communities under Coastal Hazard Conditions in Southeast Asia. In: D. Hoonweg, M. Freira, M. Lee, P. Bhada and B. Yuen, eds., Cities and Climate Change: Responding to an Urgent Agenda. Washington D. C.: World Bank, 752–775.

Patel, S. S., M. B. Rogers, R. Amlôt, and G. J. Rubin, 2017: What Do We Mean by Community Resilience? A Systematic Literature Review of How It Is Defined in the Literature. PLOS Currents Disasters, 1.

Paton, D. and D. Johnston, 2017: Disaster Resilience: An Integrated Approach (2nd Ed.). Springfield: Charles C Thomas Publisher.

Peng, T., X. Chen, X. Liu, and L. Wang, 2008: Flood Response to Changes of Flood Disaster Formative Environment in the Pearl River Delta (In Chinese). Journal of China Hydrology, 28(5): 343–351.

PRWRC, 2011: Pearl River Water Resources Bulletin 2011. Guangzhou: Pearl River Water Resources Commission.

Schewe, J., J. Heinke, D. Gerten, I. Haddeland, N. W. Arnell, D. B. Clark, R. Dankers, S. Eisner, B. M. Fekete, F. J. Colón-González, S. N. Gosling, H. Kim, X. Liu, Y. Masaki, F. T. Portmann, Y. Satoh, T. Stacke, Q. Tang, Y. Wada, D. Wisser, T. Albrecht, K. Frieler, F. Piontek, L. Warszawski, and P. Kabat, 2014: Multimodel assessment of water scarcity under climate change. Proceedings of the National Academy of Sciences, 111(9): 3245–3250.

Sherrieb, K., F. H. Norris, and S. Galea, 2010: Measuring Capacities for Community Resilience. Social Indicators Research, 99(2): 227–247.

UNISDR, 2015: Sendai framework for disaster risk reduction 2015–2030. Geneva: United Nations International Strategy for Disaster Reduction.

Whittle, R., W. Medd, H. Deeming, E. Kashefi, M. Mort, C. Twigger Ross, G. Walker, and N. Watson, 2010: After the Rain - learning the lessons from flood recovery in Hull, final project report for 'Flood, Vulnerability and Urban Resilience: a real-time study of local recovery following the floods of June 2007 in Hull'. Lancaster: Lancaster University.

Xia, J., Y. Y. Zhang, L. H. Xiong, S. He, L. F. Wang, and Z. B. Yu, 2017: Opportunities and challenges of the Sponge City construction related to urban water issues in China. Science China-Earth Sciences, 60(4): 652–658.

Yang, L, 2014: Climate change, water risks and urban responses in the Pearl River Delta, China, Institute of Geography, Universität Hamburg, Hamburg, Germany.

Yang, L., J. Scheffran, H. Qin, and Q. You, 2015: Climate-related flood risks and urban responses in the Pearl River Delta, China. Regional Environmental Change, 15(2): 379–391.

Yang, L., C. Zhang, and G. W. Ngaruiya, 2013: Water supply risks and urban responses under a changing climate: A case study of Hong Kong. Pacific Geographies, 39: 9–15.

Yang, L. E., F. K. S. Chan, and J. Scheffran, 2018: Climate change, water management and stakeholder analysis in the Dongjiang River basin in South China. International Journal of Water Resources Development,34(2): 166–191.

Yang, L. E., J. Scheffran, D. Susser, R. Dawson, and Y. D. Chen, 2018: Assessment of Flood Losses with Household Responses: Agent-Based Simulation in an Urban Catchment Area. Environmental Modeling and Assessments 23(4): 369–388.

Ye, Y., H. Zhang, K. Liu, and Y. Su, 2012: Spatial Analysis of Construction Land Expansion in the Pearl River Delta during 1988–2006 (In Chinese). Tropical Geography, 32(5).

Zakour, M. J. and C. M. Swager, 2018: Chapter 3 - Vulnerability-plus theory: The integration of community disaster vulnerability and resiliency theories. In M. J. Zakour, N. B. Mock and P. Kadetz, eds., Creating Katrina, Rebuilding Resilience: Lessons from New Orleans on Vulnerability and Resiliency. Oxford: Butterworth-Heinemann, 45–78.

Zhang, Q., M. Xiao, V. Singh, and X. Chen, 2012: Copula-based risk evaluation of droughts across the Pearl River basin, China. Theoretical and Applied Climatology, 111, 119–131.

Zhang, Q., C.-Y. Xu, Y. D. Chen, and J. Jiang, 2009: Abrupt behaviors of the streamflow of the Pearl River basin and implications for hydrological alterations across the Pearl River Delta, China. Journal of Hydrology, 377(3–4): 274–283.

Zhang, W., Y. X. Yan, J. H. Zheng, L. Li, X. Dong, and H. J. Cai, 2009: Temporal and spatial variability of annual extreme water level in the Pearl River Delta region, China. Global and Planetary Change, 69(1–2): 35–47.

Zhu, Z., Q. Deng, H. Zhou, T. Ouyang, Y. Kuang, N. Huang, and Y. Qiao, 2002: Water Pollution and Degradation in Pearl River Delta, South China. Ambio - A Journal of the Human Environment, 31(3). 226–230.