

## Study on countermeasures and spatial potential of China's coastal cities in response to heatwave and flood hazards

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**Abstract:** Global warming has caused frequent occurrences of various extreme events. Coastal cities are facing a series of severe flood hazards led especially by rising of sea level and threats caused by severe heat island effects and extreme heat waves. This article first summarizes the shortage of planning actions in coping with extreme climate of flood and extreme heat wave hazards faced by coastal cities in China. Then sorting out international experience of technologies and policies in mitigating and adapting to flood and heatwave hazards, and focuses on the main problems solved by applied technologies and the indicators involved (including time, costs, etc.). Through the identification of quantitative techniques, the spatial potential of the two major types of extreme climate disasters in downtown Shanghai and the priority application of mitigation and adaptation technologies are identified. Finally, from the technical and policy aspects, suggestions for mitigating and adapting to two types of extreme climate disasters in Shanghai's central urban areas are proposed.

**Keywords:** heatwave and flood hazards; mitigation and adaptation technology; downtown Shanghai

### Introduction

Issues such as rising sea levels, global warming, and frequent extreme weather have become common challenges for cities around the world. China's coastal cities are areas of strong economic activity and key areas for the construction of marine ecological civilization, facing the dual challenges of natural and human activities. At present, flood hazards has become a major economic loss in coastal cities, and heatwave has affected the health of people. In the face of these hazards, coastal cities have made some planning actions in the context of national

policies, such as the construction of hazards prevention facilities. However, these cities still lack detailed and scientific technological framework and policies to mobilize enthusiasm and implementation. Therefore, from the perspective of international experience, this article expounds how international cities respond to flood hazard and heatwave in terms of technology and policy. Finally, taking Shanghai as an example, this article studies the spatial distribution of hazards in downtown Shanghai, and give suggestions on how to deal with the heatwave and flood hazards from two aspects of technology and policy, combining international experience. At present, the research on climate change in the field of urban planning in China mostly focuses on national macro-policy research, urban design methods under the background of climate change, trade-offs of mitigation and adaptation actions, and planning technology and policy research for specific hazards or specific urban types is still lack. Other fields are targeted at hazard risk assessment, hazard distribution characteristics, quantitative estimation of hazard intensity, etc., strategies and methods for dealing with hazards are also lack. Therefore, this article combines the two aspects to enrich the technical and policy research on specific hazard types in the urban planning field.

### **1. Heatwave and flood hazards faced by coastal cities in China and insufficient planning actions**

Under the background of global climate challenges, China's coastal cities face severe climate hazard risks. On the one hand, China's coastal cities have some characteristics, such as high population density, intensive economic activity, and high levels of urbanization. Cities with more populations, resources, industries, and infrastructures are more negatively affected by climate change. Large-scale human activities make the region more vulnerable to climate hazards. Climate change overlaps with urbanization. The Organization for Economic Cooperation and Development ranked coastal cities exposed to global flood risk by population and social assets in 2070. The results showed that the coastal cities of China, such as Guangzhou, Shanghai, Tianjin, Ningbo, Hong Kong and Qingdao, were listed in the top 20 cities with the greatest risk (Yuanyuan Zhang *et al.* 2017). On the other hand, China's coastal cities are affected by complex hazards due to the interaction between land and sea. China's coastal areas are close to the Pacific Ocean. Due to the subtropical monsoon climate, floods caused by extreme weather such as typhoon and rain are highly prone to occur. In particular, coastal cities such as Tianjin, Shanghai, and Guangzhou are high-risk areas threatened by floods and submerged in lowlands. Based on the three aspects of ecological environment vulnerability, climate change impact risk and socio-economic exposure, a study on natural hazard risk assessment of coastal cities in mainland China shows that the high-risk areas of natural hazard are concentrated in Liaodong Bay, Laizhou Bay, Hangzhou Bay, some coastal areas of Zhejiang, Eastern Guangdong, Pearl River Delta and Haikou Sea Port (Figure 1). These areas are not only the areas with high vulnerability of natural ecological environment, but also the high-risk areas affected by climate change. They are vulnerable to more serious natural disasters (Hui Chen and Chenyan Ma, 2018). The following is a brief introduction to flood hazards, urban heat island effects and heatwave hazard faced by coastal cities in China.

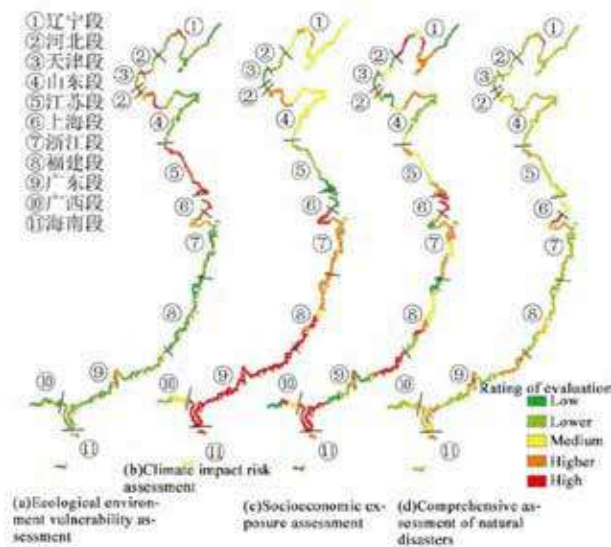


Figure 1 Results of natural hazard risk assessment in coastal cities of mainland China (Hui Chen and Chenyan Ma, 2018)

### 1.1 Flood hazards

China's coastal cities are facing the risk of flooding in the low-lying areas of coastal cities on the background of rising sea levels. According to the China Sea Level Bulletin, the sea level changes in China's coastal areas are generally fluctuating upward trend. From 1980 to 2018, the sea level rise rate in China's coastal areas was 3.3 mm/year, which was higher than the global average of the same period. Internationally, coastal areas below 5 m above sea level are considered to be dangerous areas for climate change, sea level rise and storm surge disasters. Most of the coastal cities in China, such as Shenzhen, Guangzhou, Shanghai, Suzhou, Qingdao, Tianjin, etc., have an elevation of only 2.0 to 3.0 m. The Yangtze River Delta is a low-lying area with an elevation of 11,000 square kilometers below 2.0 m. Most of the Pearl River Delta has an elevation of less than 1.0 m (Suocheng Dong *et al.* 2010). As a result, most coastal cities in China are at risk of submergence due to rising sea levels. In addition, sea level rise will increase the extent of intrusion into the ground freshwater layer of land. Coupled with the problem of over-exploitation of groundwater in coastal cities such as Dalian, the contradiction between supply and demand of freshwater in coastal cities has intensified.

In addition, storm surges and floods are major sudden hazards that threaten coastal cities. In 2018, there were 16 storm surges on the coast of China (the statistical scope was the storm surge process reaching the blue and above warning levels), resulting in direct economic losses of 4.456 billion yuan, accounting for 93% of the total direct economic losses of marine hazards in 2018. Storm surges can cause seawater backflow, they can also cause urban flooding when meet the river flood peaks. Coastal cities are generally rich in water systems, which aggravates the chain hazards caused by storm surges (Yue Zhao and Baishi Zhang, 2017). In addition, the

coastal cities have a large population and the urban area is expanding constantly. In the process of urbanization, a large number of reclaimed development activities such as reclamation, over-exploitation, and disorderly development of rivers have destroyed the ecologic and resilience of coastal areas. During the 30 years from 1980 to 2010, the reclamation area was as high as 3577.93km<sup>2</sup>, and the large-scale extensive behavior has produced many negative effects. The urban ground's ability to cope with short-term heavy rainfalls is reduced, and the flood risk is increased (Honglei Yu 2015).

## 1.2 Heatwave hazards

China's coastal cities are an important area for China's economic development. High-density cities such as Shanghai, Guangzhou and Shenzhen are all located in coastal areas. The urban heat island effect has become a common problem in high-density urban centers. Some scholars used daily temperature range to quantitatively assess the intensity of urban heat island in remote sensing. They found that the intensity of urban heat island in eastern coastal areas of China was increasing (Zhongli Lin and Hanqiu Xu, 2018). The heat island effect can exacerbate the negative effects of heatwaves. During the period of extreme heatwaves, the effect of heat island is obvious at night, which will reduce the temperature difference between day and night in the urban center. The heat island effect also creates a low-pressure vortex that causes the accumulation of atmospheric pollutants and exacerbates air pollution. Under the background of global warming, there are more and more heatwave events, which have brought enormous adverse effects on human health, agriculture and ecosystems. Heatwave are characterized by variability, sustainability, and predictability, and are related to weather-scale circulation systems, urban heat island effects, subsidence warming, and topography. Heatwave can cause discomfort to residents, fires, endanger crops, increase water and electricity consumption. Among the coastal areas of China, the southeast coastal cities are affected by the subtropical high-pressure climate and become an area with sweltering heatwave hazards. Due to the short coastline, northern coastal cities often suffer from dry heatwave hazards (Xinyu Wang 2017).

According to the distribution map of China's high temperature days published by the China Meteorological Administration (Figure 2), it can be seen that the high temperature phenomenon in the southeast coastal cities is relatively serious, especially in the Zhejiang section, which can last for nearly 30 days. The distribution characteristics of coastal cities can be seen from the temporal and spatial variation characteristics of heatwaves in China (Figure 3, Figure 4, Figure 5, Figure 6). The frequency of heatwave and the number of days of high temperature have both showed higher in southeastern coastal cities and Zhejiang ranked the highest. In the linear variation trend of frequency and number of days of heatwave, the southeastern coastal cities showed a significant increase trend, while the northern coastal cities showed an increasing trend

(Dianxiu Ye *et al.* 2013). Combined with the heatwave warnings that have appeared in China's meteorological bureaus in recent years, the heatwave phenomenon in China's coastal cities has increased and the coastal cities need to take measures to face them positively.

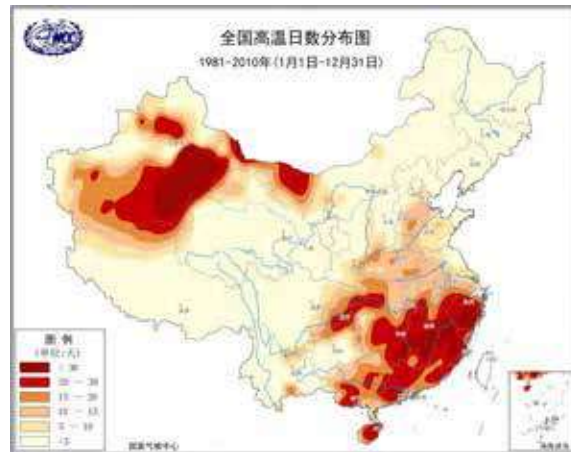


Figure 2 Distribution of high temperature days in the country (1981-2010)  
(<http://www.cma.gov.cn/>)

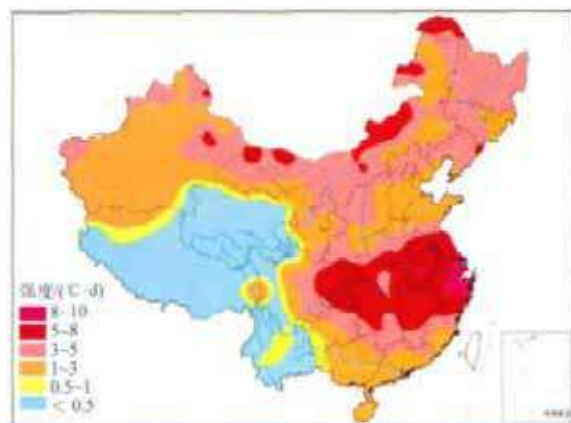
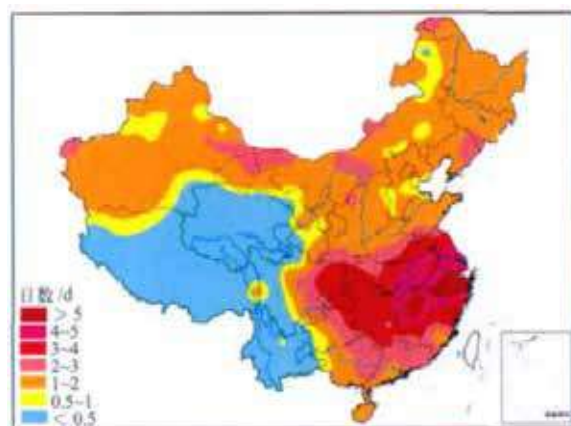


Figure 3 Distribution of mean summer heatwave intensity in china (1961-2010)  
(Dianxiu Ye *et al.* 2013)



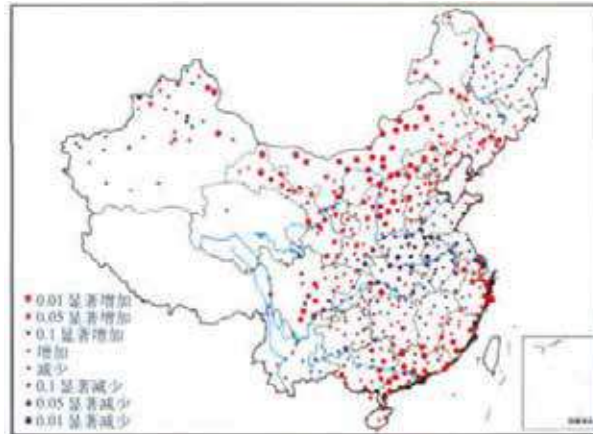


Figure 5 Linear variation trend of heatwave intensity in single station in summer in China (1961-2010) (Dianxiu Ye *et al.* 2013)

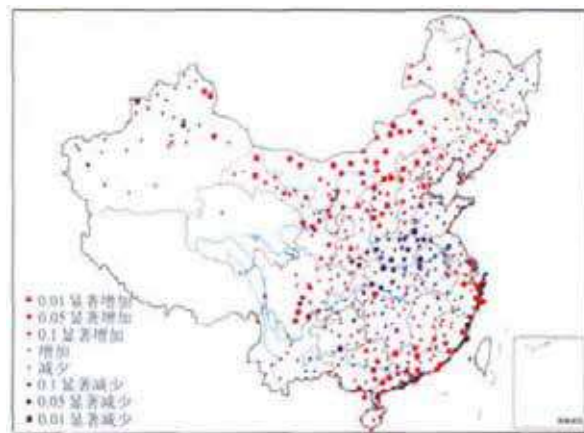


Figure 6 Linear variation trend of heatwave days in single station in summer in China (1961-2010) (Dianxiu Ye *et al.* 2013)

### 1.3 Insufficient planning actions

In the face of global climate change, China has been proactive in taking action. For example, the state has launched the National Climate Change Plan (2014-2020) and provincial-level special plans, China's Special Action on Climate Change Science and Technology, China's National Independent Contribution to Enhancing Action on Climate Change, and the Action Plan for Cities to Adapt to Climate Change. Coastal areas have actively carried out the construction of marine ecological civilization and the construction of climate-adapted cities, as well as the pilot work of climate-adapted urban construction. China has made some progress in mitigating climate change, adapting to climate change, improving institutional mechanisms, strengthening capacity building, encouraging local action, and raising public awareness. Coastal cities are actively responding to national strategies, such as Shanghai drew up “13th Five-Year Plan for Energy Conservation and Climate Change in Shanghai”. However, there are still many shortcomings in Chinese cities in terms of planning actions to address climate change.

In the planning and management system, the Shanghai 2035 Master Plan proposes to build a more sustainable and resilient city of ecology, and clearly articulate measures to deal with sea level rise, to mitigate extreme climate impacts, and urban heat island effects. However, the task of coping with global climate change has not yet been clearly stated in the urban planning and management for many coastal cities. Urban planning does not refine and deepen specific planning techniques and methods (Zuda Ye 2017). The lack of technical content will affect the planning response to climate change.

In the planning of macro-policies and local actions, the content of energy-saving emission reduction and low-carbon actions is too much, and the content of improving infrastructure adaptability is relatively little (Quan Zhou *et al.* 2016). There is a lack of integrated regional coordination mechanisms among local governments (Dongfeng Yang *et al.* 2017). Some local governments have taken into account the financial shortage, other economic and social problems, cost of human capital, risk of damage to their own economic interests, and relatively less serious climate hazards. They are not active in facing regional cooperation (Yan Song *et al.* 2011). In addition, national or local policies lack classified guidance, while different cities in coastal cities face different status and challenges.

At the level of planning control and design, domestic cities mostly carry out the construction planning of low-carbon city, resilient city and sponge city, which responds to the ecological concept from the aspects of land use, traffic planning, infrastructure planning, open space design, ecological green space system planning, wind corridor planning, green building, municipal engineering system planning, hazard prevention and mitigation planning, etc. Such as low-impact development, roof greening, and cold microclimate construction. However, in addition to hazard prevention and mitigation planning, these control designs are often fragmented, and there is a lack of systematic, direct and in-depth guidance and linkages with specific climate disasters. Some designs are too microscopic and formal, and it is difficult to exert effects (Weiwen Zhang and Liangjiang He, 2009). Planning and climate change are likely to be tightly integrated if there is a framework for multi-level planning and design control that responds to climate change mitigation.

In short, faced with heatwave and flood hazards, China's coastal cities lack legal, scientific, cooperative, proactive, targeted and systematic planning. These coastal cities need to draw lessons from other countries' technical and policy strategies.

## **2 International experience in mitigating and adapting to heatwave and flood hazards**

There is growing recognition and awareness that nature can help provide viable solutions that use and deploy the properties of natural ecosystems and the services that they provide in a smart,

'engineered' way. These nature-based solutions provide sustainable, cost-effective, multi-purpose and flexible alternatives for various objectives. The European Union (EU) defines it as Nature-Based Solutions (NBS), it refers to the sustainable management and use of nature for tackling socio-environmental challenges. In Table 1 and Table 2 , a series of relatively mature NBS solutions are collected and sorted out according to internet sources.

## 2.1 Heatwave hazard solving technology

Table 1 summarizes the technical indicators and construction costs and effectiveness of different scales to mitigate and adapt to heatwave. As can be seen from Table 1, although the scale of solutions for heatwave hazard is different, the construction of green facilities plays an extremely important role, and the greening of the surface is particularly emphasized from the building, the block to the city scale. The small-scale greening facilities are more suitable for the transformation of the built-up areas, and generally can achieve significant results in a short period of time, and are easier to be implemented. The common greening method is to provide more green vegetation coverage. It is generally divided into two major types of plants, planting trees and grass. The average effective time for increasing tree coverage is shorter than the average effective time for increasing grass. Studies have shown that there is an extension effect on the cooling effect of the green area. Although it is not clear whether there is a minimum scale, the effect of cooling extension with the increase of green area has been verified. The cooling extension effect of a 156-hectare park can even be reach the park boundary 1 km away (Diana E. Bowler *et al.*, 2010). This extension and cooling effect beyond the boundary of the green area indicates that the cooling effect of parks of different scales can be preliminarily considered in the urban park system planning to effectively reduce the heat island effect. Another study also shows that mosaic-style dense and frequent small green space improves the urban thermal environment better than large concentrated green space (Xinyu Wang and Jian Zeng, 2017). Therefore, for the dense construction area, the green transformation is more suitable for increasing the horizontal or vertical green vegetation coverage through the dense plaque method.

In addition to the green transformation, providing different cooling spaces are also effective strategies for heatwave, especially for the more vulnerable groups (such as the elderly over 65 years old, the poor, the population with low educational level). The cooling space can be used effectively not only to provide a sufficient amount of cooling space (air-conditioned indoor space and shaded outdoor space), but also ensure accessibility to these spaces, especially vulnerable people (Babak J.Fard *et al.*, 2016). The elderly group is at a disadvantage in terms of physical fitness, and they are inconvenient to move. It is easy for them to be limited by the distance cost and cannot reach the cooling space far away for them. The poor and low-educated people are more likely to be low-income people, and the accessibility to air-conditioned indoor

space for low-income people is often subject to cost constraints. The accessibility to cooling space is thus often limited by cost. Therefore, adequate cooling space and good accessibility must be seriously considered.

Table 1 Technical methods and reference indicators for mitigation and adaptation to heatwave at different scales

Scales	Methods	Costs	Expected efficacy (year)	Descriptions
Building	Wetland roofs	—	< 1	A special type of extensive green roof which is evenly planted with wetland or marsh plants. It can help slow things down and spread the impact of heavy rain out over a longer period along with rainwater collectors.
	Green roofs	Initial costs: 100-250 €/mq Maintenance: 10-15 €/mq per year	< 10	It refers to the space on the top of a building that is covered partially or entirely with vegetation that is planted in a growing substrate.
	Green facades	—	< 1	It is comprised of plants grown in supported vertical structure attached to an internal or external wall or freestanding.
District	Shade provided by trees	Initial costs: \$50-80 per tree Maintenance: \$.10 - \$.22	< 1	Planting vegetation on streets, squares, parks creates shade and evapotranspiration and therefore has a cooling effect.
	Green bus shelters	Initial costs: \$14.500	< 1	Bus shelter provided with green roof for water retention and cooling and with all the smart facilities that make waiting times more comfortable.
	Tree-lined streets	Initial costs: \$50-80 per tree	< 10	It is the street that has trees on either side.

		Maintenance: \$.10 - \$.22		
	Community gardens	Initial costs : \$3,750 to \$7,500 Maintenance: \$50-\$100 per year	< 1	It is an urban, suburban or rural piece of land in which it can grow flowers, vegetables or a community. It can be one community plot or many individual plots which are located at different scales.
Overall city	Increasing total vegetation index	Initial costs: \$50-80 per tree Maintenance: \$.10 - \$.22	Trees: < 10 Grass: < 1	Increasing green areas by planting trees or growing grass.
	Access to cooling facilities	—	—	Cooling facilities refer to indoor buildings with air conditioners and outdoor spaces shaded by vegetations.

## 2.2 Flood hazard solving technology

On the scale of building, the usual solution is still the green transformation of the roof. It not only achieves the cooling effect, but also fully utilizes the rainwater. It is a low-cost solution that can effectively solve the heatwave and flood hazards at the same time. It should be noted here that different forms of the roofs have significantly different effects on the speed of the stormwater runoff. The rainwater flow rate on the sloping roof is much faster than that on the flat roof. Therefore, in order to achieve efficient mitigation and full utilization of the stormwater runoff, the flat roof and slope roofs take different forms of treatment, which is evident in the solution of wetland roofs as is seen in Figure 7 (retrived from website).

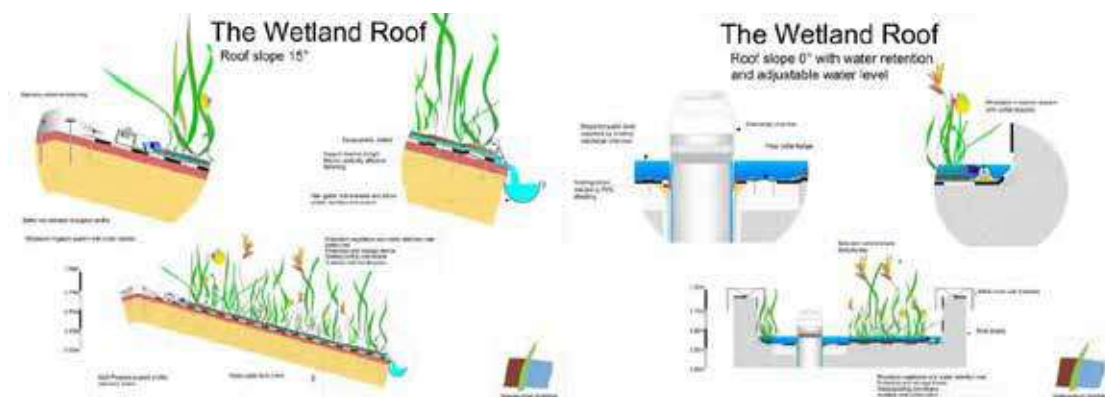


Figure 7 The wetland roof

The block-scale accommodates more diverse flood disaster resolution technologies, which are characterized by increasing surface permeability and slowing down surface runoff and runoff velocity during rainstorm periods. Most of these measures are low-cost and easy to implement, and can achieve results in the short term. This method can be summarized into two categories: one is to increase the vegetation cover on the surface, while playing a role in mitigating heatwave; the other is to design small-scale surface engineering, such as building infiltration ditches.

Overall city scale. Such measures are usually applied to large-scale urban ecosystems, such as suburban parks, wetlands, etc., and require a large amount of technical and engineering quantities and financial support. What's more, the general construction period is longer. However, once such measures are successfully implemented, they can greatly improve the overall capacity of cities to cope with disasters.

Table2. Technical methods and reference indicators for mitigation and adaptation to flood hazards at different scales

Scales	Methods	Costs	Expected efficacy (year)	Descriptions
Building	Wetland roofs	—	< 1	A special type of extensive green roof which is evenly planted with wetland or marsh plants. It can help slow things down and spread the impact of heavy rain out over a longer period along with rainwater collectors.
	Green roofs	Initial costs: 100-250 €/mq Maintenance: 10-15 €/mq per year	< 10	It refers to the space on the top of a building that is covered partially or entirely with vegetation that is planted in a growing substrate.
District	Permeable paving	Initial costs: €4 - €8/ sqft Maintenance: 0,5-2 euro cents / sqft annually.	< 1	It is a type of paving that allows fluids to seep through them and are commonly used on pedestrians and light vehicle pathways.

	Bioswales	Initial costs: €5,17/m <sup>2</sup> (Bioswale) ; €8,97/m <sup>2</sup> (Sewage) Maintenance: €0,37/m <sup>2</sup> (Bioswale); €0,26/m <sup>2</sup> (Sewage)	< 1 or < 10	It is a long, channeled depression or trench that receives rainwater runoff and has vegetation and organic matter to slow water infiltration and filter out pollutants.
	Living Garden	Initial costs: solar panel 3 € per watt, green area 20 € Per sqm and structure 40 € per sqm	< 10	Concept developed by the Dutch Garden and Landscape Contractors Association in which green and sustainable gardens for private or public spaces are proposed, in which water, energy, soil and edible greenery are concentrated.
	Rain garden	—	Depends on the scales	A low-cost rain garden can be built to prevent rainwater runoff from the roof, the various impermeable surfaces of the building and its perimeter from being directed into the stormwater drainage system (Mélissa Giguère <i>et al.</i> 2016).
	Gutter	—	< 1	Gutters are wide and shallow simple form of channels, which are above ground that carry the storm runoff in excess of the capacity of the minor drainage system from streets and squares.
	Infiltration strips and meadows	Initial costs: 1,73 €/lineal foot	< 1	Infiltration strips and meadows are green or permeable areas that provide opportunities for slow transportation and infiltration of water.
Overall city	Urban wetland	—	< 10	A wetland is a zone where the distribution of living beings is mainly characterized by the presence of water, whatever its degree of



				salinity or its persistence during the year.
	Re-meander rivers	Initial costs: £ 100-300/m	< 10	Re-meander rivers (where they have been artificially straightened) to help reduce speed and height of flood peaks.
	Rainwater run-off ponds	—	< 10	A system for purifying polluted rain and run-off water, preventing direct infiltration.

### 2.3 Policies for urban mitigation and adaptation to heatwave and flood hazards

Policy on heatwave hazard solutions. The most common action is the heatwave warning system, the most important of which is when to issue an early warning. In determining publication time, the most effective method is comparing historical local daily mortality data with complex weather data for time periods when mortality rates exceed normal averages (Carlson and Ann E., 2008). Heatwave are closely related to the age of the population. As the health of the elderly is more fragile, they are more vulnerable to heatwave. Heatwave can lead to more health problems for the elderly. By investigating the effect of urban heatwave early warning for the elderly population, some scholars found that when cities issue heatwave early warning to the elderly population through traditional media, the effect of early warning is significantly improved than that without heatwave early warning for the elderly population (Carlson and Ann E., 2008). In the cities surveyed, the heatwave warning awareness rate is between 83% and 91%. Therefore, there are three important technical indicators in the heatwave early warning system: historical local daily mortality data, complex weather data for time periods when mortality rates exceed normal averages, elderly population distribution data.

Policy on flood hazard solutions. Private flood protection measure has long been implemented in the German Rhine River, which has received increasing attention in flood risk management measures across Europe and even at the global level. Private flood protection measures are long-term flood mitigation and response measures maintained by private households. They can be understood as a private sector's liability system for flood damage, such as flood-adapted building use or the deployment of flood barriers. The key to the long-term sustainability of the system is that a series of major flood events have become an important trigger for the implementation of accelerated mitigation measures. An analysis of private sector actions after the floods in the Rhine section of Germany in 1993-1995 and 2011 confirmed that flood experience has a strong impact on pre-disaster precautionary measures. Moreover, there is a strong positive correlation between the number of flood incidents reported each year and the

number of flood response measures adopted, which continuously strengthens the private households' sense of responsibility to solve flood problems (P. Bubeck *et al.*, 2012). Interestingly, in the process of implementing pre-disaster preventive measures, personal preventive behavior is often strongly influenced by the behavior of others, which makes the flood experience not only enhance the sense of responsibility through its own experience, but also expand the positive behavior of pre-disaster prevention through upstream and downstream flood events in the waters. The three important positive aspects of flood hazard experience, key reports, and preventive behavior impacts have played a very positive role in maintaining the long-term effectiveness of the private flood control responsibility system.

### 3 Study on countermeasures and spatial potential of China's coastal cities in response to heatwave and flood hazards

#### 3.1 Spatial distribution of heatwave and flood areas and potential areas in downtown Shanghai

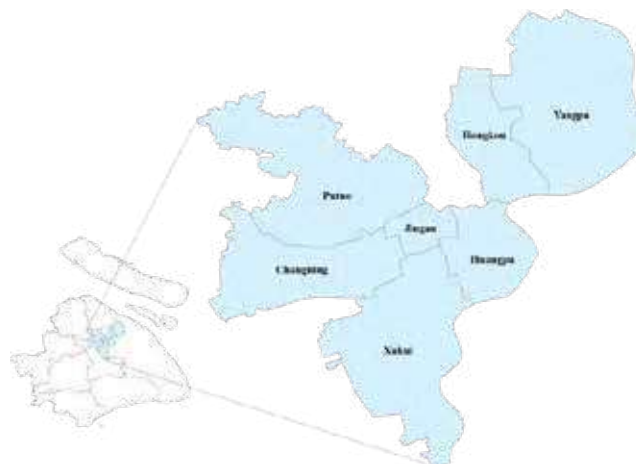


Figure 8 Administrative district map of downtown Shanghai

The research scope of this study is the central area of Shanghai (Figure 8), including Xuhui, Changning, Jing'an, Putuo, Huangpu, Yangpu and Hongkou.

Spatial distribution of vulnerable areas of heatwaves. Figure 9 and Figure 10 respectively show the surface temperature changes in downtown Shanghai from 1989 to 2013 (Rong Jiang, 2016) and surface temperature retrieval in 2014 (Jian Cai, 2017). It can be seen from Figure 9 that the overall thermal environment increase in Shanghai is mainly concentrated in the central area of the city and its marginal areas. Only Changning District and Xuhui District have plaques with greatly reduced temperature, and the remaining areas are only show slightly and scattered plaques of temperature reduction. The overall thermal environment changes slightly, indicating that the heat island effect has not been significantly improved.

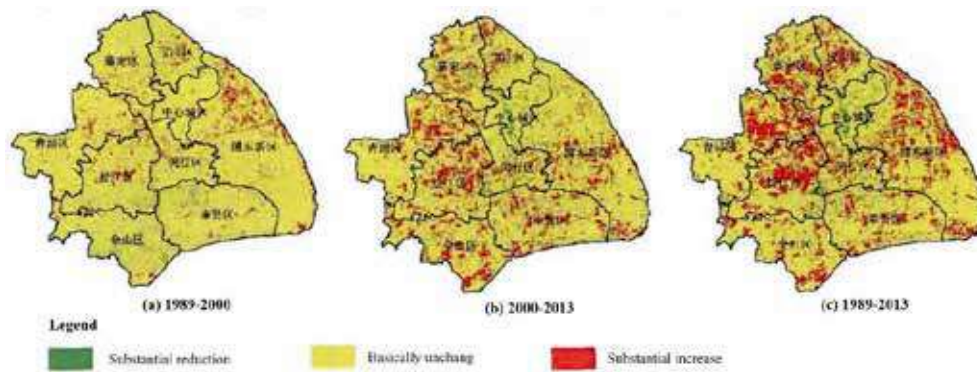


Figure 9 The changes in Shanghai's land surface temperature

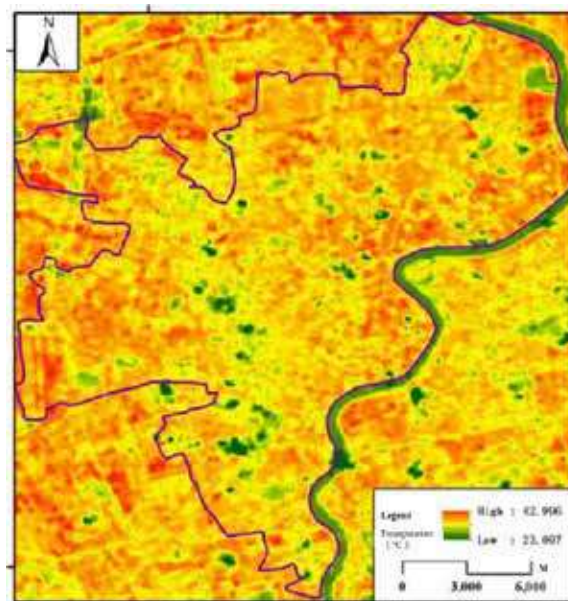


Figure 10 Land surface temperature retrieval of Shanghai

According to the data downloaded from the OSM map, the natural waters and different types of green spaces within the central area of Shanghai are extracted. The green space shown in Figure 11 is urban green space. As is seen in Figure 11, the total amount of green space in the central urban area of Shanghai is extremely scarce. There are not enough large green spaces or dense plaque green spaces. The lack of green space is particularly acute in Jing'an District, Huangpu District and Xuhui District. There are a large number of buildings in the downtown area that have not been remodeled with any green roofs and green facades, but it must also be noted that there are also a large number of slope roof buildings in this area. Due to the lack of accurate building roof data, the buildings with 6 floors and below were initially considered as sloping roofs based on the Shanghai building data provided by the Urban Data Party. The rest were considered as flat roofs, which can roughly estimate the distribution of the two types of buildings. When the green roof is reconstructed, the cost and difficulty of the renovation of the flat roof is lower, so it can be considered as the object that can be prioritized for transformation.

In contrast, the proportion of flat roofs in Yangpu District, Hongkou District, Putuo District and Changning District is higher, and the proportion of slope roofs in Huangpu District, Jing'an District and Xuhui District is higher.

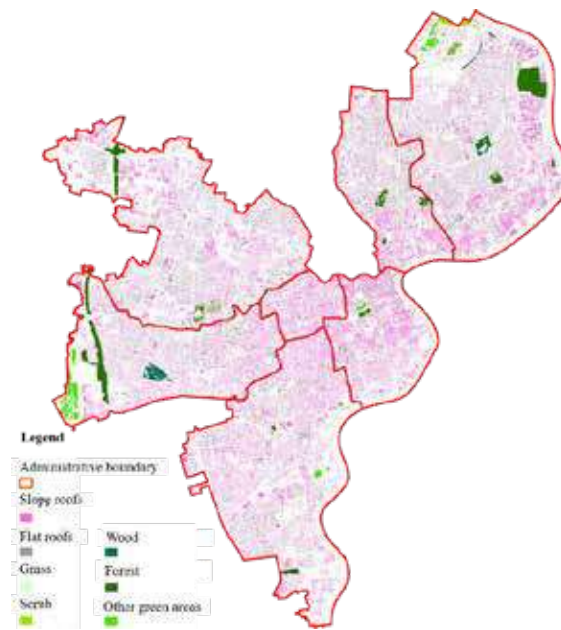


Figure 11 Distribution of Shanghai's green areas

Spatial distribution of vulnerable areas of floods. The 2017 Shanghai Digital Elevation Model (DEM) data with a precision of 30m\*30m is downloaded from the Geospatial Data Cloud. Based on this data, the distribution of river networks in the central city of Shanghai was analyzed through ArcGis hydrological analysis tool (Figure 12). Firstly, the data is padded to reduce the error caused by the concave area of the image data; then the water flow direction data is extracted; for the next step, the cumulative amount of confluence of water flow direction data is calculated according to the natural water flow from the place where the elevation is large to the place where the elevation is small; finally, the streamnet is obtained by extracting grids with a cumulative amount greater than 100. Excluding the flood period of the Huangpu River, according to this data processing principle, it can reflect the distribution of the largest surface runoff value in the central city of Shanghai. The greater the density of the river network, the more likely it is that urban flooding is likely to occur. As can be seen from Figure 12, the density of the river network can be divided into two levels: the denser areas are Xuhui District, Putuo District, Changning District and Yangpu District; and the sparse ones are Huangpu District, Hongkou District and Jing'an District. However, for the Yangpu District, Hongkou District, Huangpu District and Xuhui District along the banks of the Huangpu River, the huge flood threats of the Huangpu River during the flood season cannot be ignored. Although Changning District and Xuhui District have more natural river channels than other districts, it can be found in comparison with Figure 12 and Figure 13 that the natural river network and the streamnet accumulated by the convergence do not overlap, indicating that the river network is not the only important reason that easily leads to the waterlogging in these two districts. The causes of flood vulnerability reflected by different districts vary.

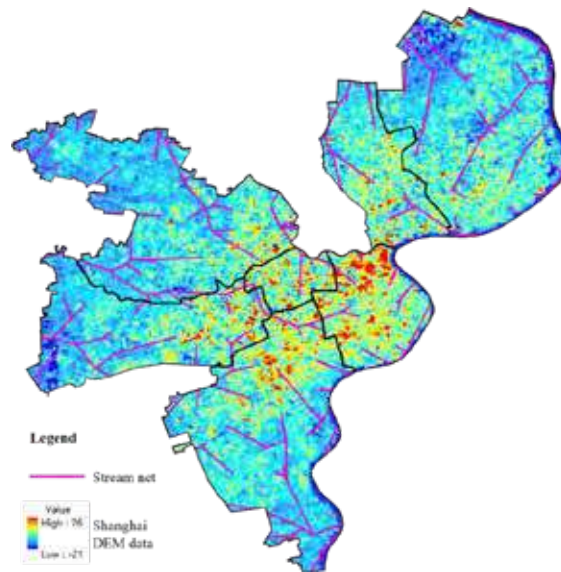


Figure 12 Analysis of river network in downtown Shanghai

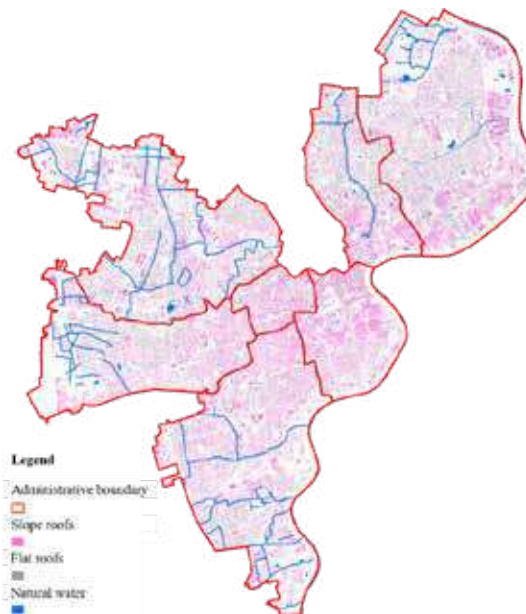


Figure 13 Distribution of Shanghai's natural river

### 3.2 Countermeasures and suggestions to solve the heatwave and flood hazards in downtown Shanghai

Different districts in downtown Shanghai face different major disasters. In addition to the threat of floods in the flood season that may be brought by the Huangpu River, Changning District, Putuo District, Yangpu District, Hongkou District and Pudong District are facing more flood threats. The heatwave hazard in Huangpu District and Jing'an District are more severe, while Xuhui District faces the challenges of both hazards. Each district should propose different and targeted measures to adapt to and mitigate extreme climate disasters based on the primary problems it faces. In addition, for technical measures such as green roofs that can

simultaneously solve heatwave and flood hazards, more cooperation should be carried out between administrative districts, which should be incorporated into one system and effectively implemented from planning and design to planning implementation and regulation.

In order to effectively implement a series of measures to adapt and mitigate heatwave and flood hazards, each department should first make accurate survey about the distribution of vulnerable population (such as people more than 65 years old, low-income groups, etc.), not just consider engineering technology. By this way, departments of downtown Shanghai can determine the priority implementation area, reduce time and cost waste, and improve the efficiency of problem solving.

In addition, government departments must provide a corresponding set of supporting implementation policies, make full use of and mobilize the power of social resources, and ensure that all adaptation, mitigation of heatwave and flood hazards can be effective in the long run, rather than just construction, regardless of subsequent maintenance.

#### **4 conclusion**

Through the analysis of the internationally adopted technical measures for mitigating and adapting to heatwave and flood hazards, the green-oriented solution plays a very important role in solving both hazards, both on the micro and macro scales. The technical method can solve two kinds of hazards at the same time, effectively reduce the repeated implementation costs, and achieve two goals. Therefore, the green-oriented solutions must receive sufficient attention in the future when coastal cities in China responding to extreme climate hazards. In the application of technology, we must first clarify the scope and type of different technology adaptations, and systematically summarize correspond requirements according to the technical details, in order to achieve efficient mitigation and adaptation to heatwave and flood hazards. For different districts of the city, unified technology cannot be fully adopted, and each city must have its own targeted classification guidance program. The technical considerations for adapting to and mitigating heatwave and flood hazards should be incorporated into the planning and design system and management system at the same time, so that design, implementation and maintenance are closely integrated. Disaster mitigation and adaptation measures are not the final result of the application of technology. Subsequent maintenance is an important link as well. Therefore, in the process of dealing with extreme climate disasters, planning, design, implementation, and planning management must attach great importance to mobilizing the enthusiasm and participation of the society from the beginning, shaping the sense of responsibility of individuals and collectives, and learning from the long-term maintenance effectiveness of the German private households. Actively supervise the mechanism and implement responsibility to individuals. China's coastal cities face serious challenges of heatwave and flood hazards. The methods of adapting to and mitigating hazards are also extremely complicated to operate. They must pay special attention to the legality and scientificity, systematicness, cooperation and initiative in the implementation process.

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