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# Xiamen:

## Adapting to Climate Change with Sponge City Construction

*Climate Risk and Resilience in China (CRR)*

Project Overview

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# Introduction

Xiamen, a tourist city located in southeast coastal areas of China, comprises a total area of 2089.39 km$^2$ including the Island of Kulangsu, and inland coastal areas. The resident population is 4.29 million (2019) with an urbanization rate of 89.2%. The annual average rainfall in Xiamen is 1530 mm, over 80% of which falls between March and September. Dry seasons usually occur between October and February. In recent years, the characteristics and patterns of rainfall have changed significantly due to climate change and other factors, and therefore urban water-related problems have become more severe and complicated. In 2015, Xiamen was selected as one of the first batches of national pilot sponge cities, which are designated urban areas that are building environmentally sustainable alternatives to traditional flood defenses. The over three-year construction project started a new exploration period of Sponge City adaptation to climate change. This case study introduces detailed plans, measures, and financing mechanisms of Xiamen.

# 1. Water-Related Problems in Xiamen Under Climate Change

## 1.1 Changes in Temperature, Rainfall and Sea Level in Xiamen in Recent Years

Due to various factors such as climate change and urbanization, the temperature in Xiamen has continued to rise since the early 1980s. The annual average temperature rises 0.16℃ per 10 years, and the rate increases after 1989, with an average of 0.56℃ per 10 years. The extreme maximum temperature also showed a significant increasing trend[1]. The inter-annual change of annual average temperature (℃) is shown in **Figure 1**.

The data analysis of weather observation from 1956 to 2015 [2] shows a sizeable inter-annual change in annual precipitation in Xiamen over the past 60 years. The most prominent characteristic is the significant decrease in the number of precipitation days and the increase in the field average precipitation intensity. The number of precipitation days in Xiamen is increasing, and the days above rainstorm level has increased from 3.2 days to approximately 5.7 days. From the middle and late 1980s, the number of days above the average inter-annual rainstorm in Xiamen has increased from 8.3 days to 13 days (an increase of 56.7%). The change in precipitation shows a spatial difference. In southern and northern areas in Xiamen, there are increasing trends of long-term precipitation, and the increasing rates are 43 mm/10a and 21 mm/10a, respectively. The inter-annual changes in the number of precipitation days and field average precipitation intensity in Xiamen (Station) are shown in **Figure 2**.

According to the data analysis of sea-level monitoring from 1960 to 2005 (**Figure 3**), the linear rate of sea-level rise in Xiamen ranges from 0.17 cm/a to 0.20 cm/a, with an average rate of 0.17 cm/a[3]. The simulated data of prediction indicates that the sea level in Xiamen may still maintain a certain degree of rising in the next 50 years. The average rate of rising is 0.17 cm/a. It is estimated that by 2056, the maximum sea-level rise in Xiamen will be 16.9 cm[3].

Monitoring data and research show that climate change has led to rising temperatures, changes in precipitation, increased extreme precipitation days, and sea-level rise in Xiamen City. Although the characteristics of hydrology and water resources in Xiamen are complicated, urban water-related problems are even more complex and comprehensive. Urban water management faces severe challenges.

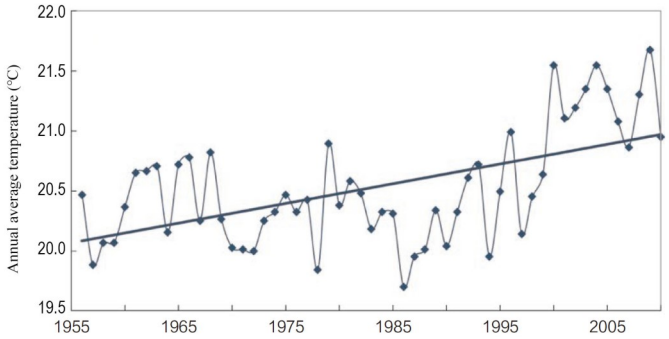


Figure 1. Inter-Annual Change of Annual Average Temperature (℃) in Xiamen [1]

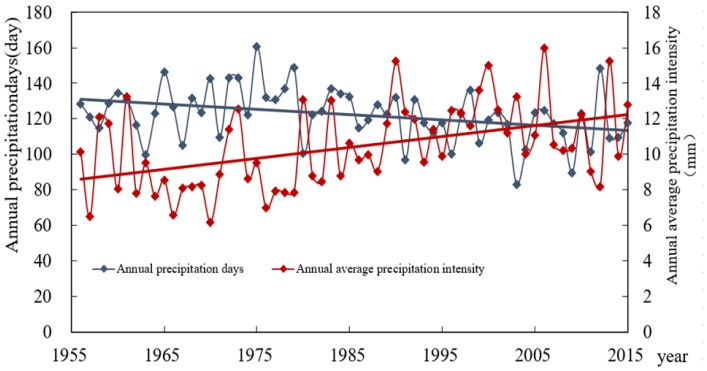


Figure 2. Inter-Annual Changes of Number of Precipitation Days and Field Average Precipitation Intensity in Xiamen [2]

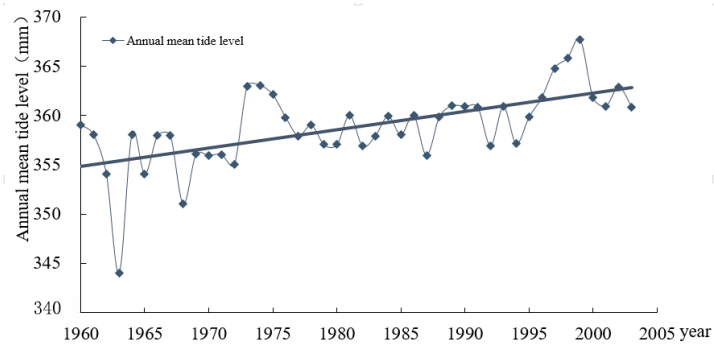


Figure 3. Inter-Annual Change of annual mean tide level in Xiamen

## 1.2 Climate Change Aggravates Water-Related Problems in Xiamen

Xiamen City is facing problems such as urban waterlogging and flooding in the mountain area. The main reasons are as follows: the location of Xiamen on the southeast coast of China; the uneven time distribution of precipitation; and the high intensity of short-term rainstorms due to events like typhoons. Climate change leads to an increase in temperature, the frequent occurrence of extreme weather and climate events, especially the change in characteristics of precipitation, and the increase in extreme rainstorms. Urban floods caused by the factors above have a significant impact on the operation of the city. In September of 2016, a torrential rain due to Typhoon Meranti caused tremendous damage and adverse impacts on Xiamen. According to the available data, 17,907 houses and 700 km$^2$ of crops were damaged. The direct economic loss was 10.2 billion yuan[4]. The construction standards of drainage pipe networks in some old urban areas of

Xiamen are low and the drainage capacity is weak, resulting in frequent waterlogging. Meanwhile, it is difficult to regulate and store the rainfall because of the higher precipitation in summer. Due largely to rapid population growth and economic and social development, Xiamen has become a city with a water shortage. Besides, with the advent of urbanization, some natural water systems, such as the regulation and storage water bodies, have been disrupted by construction and other newly developed urban infrastructure Consequently, the capacities of infiltration, storage, and purification have been reduced. The ecological water quantity is lacking, and the water level of the landscape environment is proving difficult to maintain. The living conditions of aquatic animals and plants are poor, and the ecological water environment outlook is not optimistic. In terms of water quality, the proportion of water that is deemed to be worse than Class V, which is the government designation for the lowest water quality type, of the mainstream in Xiamen is still high, which has been over 80% in recent years.

Sea level rise also brings a series of problems. On the one hand, sea-level rise aggravates the damage from storm surge disasters. It leads to seawater intrusion, soil salinization, coastal erosion, and other problems, resulting in the loss of coastal wetlands, the increase of survival pressure for rare and endangered coastal organisms, and the destruction of ecosystem functions. On the other hand, sea-level rise also reduces the discharge capacity of urban sewage, drainage pipe networks, and river channels, as well as increases the threat of flooding in coastal areas and weakens the function of Xiamen ports.

# 2. Main Measures of Sponge City Construction in Xiamen

## 2.1 Sponge City: A New Idea Dealing with Urban Water-Related Problems

In the past 40 years, economic development in China has promoted rapid urbanization. The urbanization rate had increased from 18% in 1978 to 60% in 2019. Urbanization is accompanied by a series of urban water-related problems, such as urban waterlogging, urban water pollution, water shortage, ecological degradation, and heat island effects. In response to these pressing problems, in December 2013, President Xi Jinping put forward the new concept of "Sponge City" at the Central City Urbanization Conference. This was essentially a proposal to build a series of sponge cities in coastal and flood-prone areas that would have natural storage, infiltration, and purification systems[5]. In 2015 and 2016, thirty pilot sponge cities in two batches were selected, and Xiamen was selected in the first batch.

The underlying objective of building sponge cities is, in a literal sense, to make the city like a sponge –able to absorb water when it rains, and release water when it doesn't rain, achieving regulation of water in dry and rainy seasons. Sponge cities are developed based on Low Impact Development (LID), Water Sensitive Urban Design (WSUD), Low Impact on Urban Design and Development (LIUDD), and Active, Beautiful and Clean Plan (Plan ABC). Sponge city pilot projects comprehensively take

Xiamen City (© GIZ)

into account China's specific national conditions, which is based on China's experience in dealing with urban water-related problems. The sponge city concept emphasizes the principles of "nature does work, minimum disturbance, and ecological priority". It also advocates "quasi-natural design" and "nature-based solution," maintaining and recovering the natural hydrological function of urban underlying surfaces as much as possible[5].

The basic practices of sponge cities are summarized as infiltration, accumulation, stagnation, purification, utilization, and drainage. The overall goal is to adopt a variety of comprehensive measures to make rainwater more stagnant in the city. As a result, the city, like a "sponge", can effectively store rainwater when it rains, and reduce waterlogging and runoff pollution. After the rainfall, the stored water is released to supplement the ecological water and conserve the water source, so as to improve the quality of the ecological environment. Besides, the basic objectives of sponge cities are "no ponding in heavy rain, no waterlogging in light rain, no black-odor water, and mitigation in heat island." The most critical aspect is the total annual runoff control rate. Each region of the country sets different objectives according to its rainfall characteristics, generally no less than 70%[6].

## 2.2 Overall Plan of Sponge City Construction in Xiamen

### 2.2.1 Goals and paths

The sponge city construction in Xiamen was carried out based on fully considering Xiamen's own ecological environment, hydrometeorology, and socio-economic characteristics. The construction not only facilitates urban development, but also promotes ecological protection, economic and social development, and cultural heritage. To build a new image of Xiamen with ecological, safe, and dynamic construction, the city's development strategy of "good water ecology, water safety guarantee, improved water environment, beautiful water landscape, and rich water culture" is being implemented. Also, the sponge city of "green and flexible nature, harmonious ecology, livable culture, and orderly management" will be built[7]. The specific goals are expressed below.

(a) Build a systematic water pollution prevention and control system to ensure that the water quality does not exceed the standard.

(b) Build a complete and reliable water disaster prevention system to ensure that cities and towns are not flooded.

(c) Build a safe and efficient water ecological control engineering system to ensure the continuous flow of the river.

(d) Build a fair and orderly urban-rural basic water supply system to ensure the safety of the water supply and sustainable utilization of water resources. Build a multi-functional integrated urban-rural landscape system to create tourism, leisure, and a livable environment.

(e) Build a water management system to meet development needs, and implement the water management objectives.

(f) Build a coastal culture system with Xiamen characteristics to strengthen the concept of ecological civilization.

Based on the above target setting, the targets are further refined into corresponding indicators, as shown in **Table 1**.

Given the existing problems in Xiamen City, such as lack of water resources, severe water safety, worrying water environment, and degradation of water ecology, a construction pattern of "point, line, and surface" was formed inside and outside the island, relying on mountains, streams, and coasts. A natural ecological spatial pattern of "mountain, water, forest, field, and lake" was constructed. Xiamen has primarily adopted six systems: 1) pollution prevention and control; 2) river and lake water network construction; 3) garden and green space construction; 4) drainage and waterlogging prevention; 5) road traffic construction; and 6) sponge community construction. Among them, the first three constructions are classified as "major sponge," while the rest are classified as "minor sponge" [7].

The construction of the six systems above gives full play to the role of green space, soil, river, and lake systems in natural accumulation, infiltration, and purification of rainwater runoff, to realize the emission of urban rainwater runoff sources, decentralized storage, slow-release, and rational utilization. The construction also accomplishes the absorption and reduction of pollutants, achieving "no ponding in heavy rain, no waterlogging in light rain, no black-odor water, and mitigation in heat island". Moreover, it mitigates or reduces the impact of natural disasters and environmental changes on the city, and protects and improves the ecological environment. Sponge city construction promotes Xiamen to achieve these goals, so as to effectively solve the problem of urban water safety and promote the construction of urban ecological civilization. By the construction of the six systems and combined with the construction support of ecological space outside the urban built -up area, Xiamen will be built as a model of the ecological civilization of coastal cities. The detailed construction path of the sponge city in Xiamen is shown in **Figure 4**[7].

### 2.2.2 Runoff Management and Control System

Runoff management and control is the primary goal of sponge city construction. The rainwater runoff is controlled in the local soil, retention tank, and green infrastructure, which can effectively reduce disasters such as surface waterlogging, improve the local rainwater reserves, maintain the ecological construction, improve the environmental quality, and effectively reduce the Total Suspended Solids (TSS), Total Nitrogen (TN) accumulating to the river and bay. As a result, the goal of pollution control is achieved.

Table 1. Standards of Sponge City Construction in Xiamen

| Categories | Standards | Current Values (2014) | Long-term Target (2030) |
|---|---|---|---|
| Water Ecology | Total Annual Runoff Control Rate | 30% in Built-up Urban Area | Reaches 70% in 80% of Built-up Urban Area |
| | Ecological Shoreline Restoration | 20% | 80% |
| | Urban Heat Island Effect | Apparent | Significant Mitigation |
| | Urban Water Surface Ratio | 6% | 8% |
| Water Environment | Surface Water Quality Standard | 85.1% of the main river with a water quality worse than Grade V. Several Black-odor waters | No lower than Grade IV of *Environmental Quality Standard of Surface Water.* Basically eliminating black-odor water |
| | Water Quality in Estuaries and Coastal area | Some waters are worse than Grade V. Some sea areas are seriously polluted | Eliminates water worse than Grade V. Good water quality in the nearshore area reaches 70% |
| | Urban Non-point Source Pollution Control | Combined systems in old cities, separate systems in new cities | Rainwater runoff pollution and combined canal overflow pollution effectively controlled |
| Water Resource | Rainwater Utilization Rate | < 0.5% | 3% |
| | Wastewater Recycling Rate | < 1.0% | 30% |
| Water Safety | Standard Rate of Urban Waterlogging Control | 20-yr return period | 50-yr return period |
| | Drinking-Water Safety | Most of the drinking water sources are above Grade II; some are Grade III | All drinking water sources are Grade II |
| | Leakage rate of Water Pipe Network | 15% | 10% |
| System | System Construction | - | Complete management system |

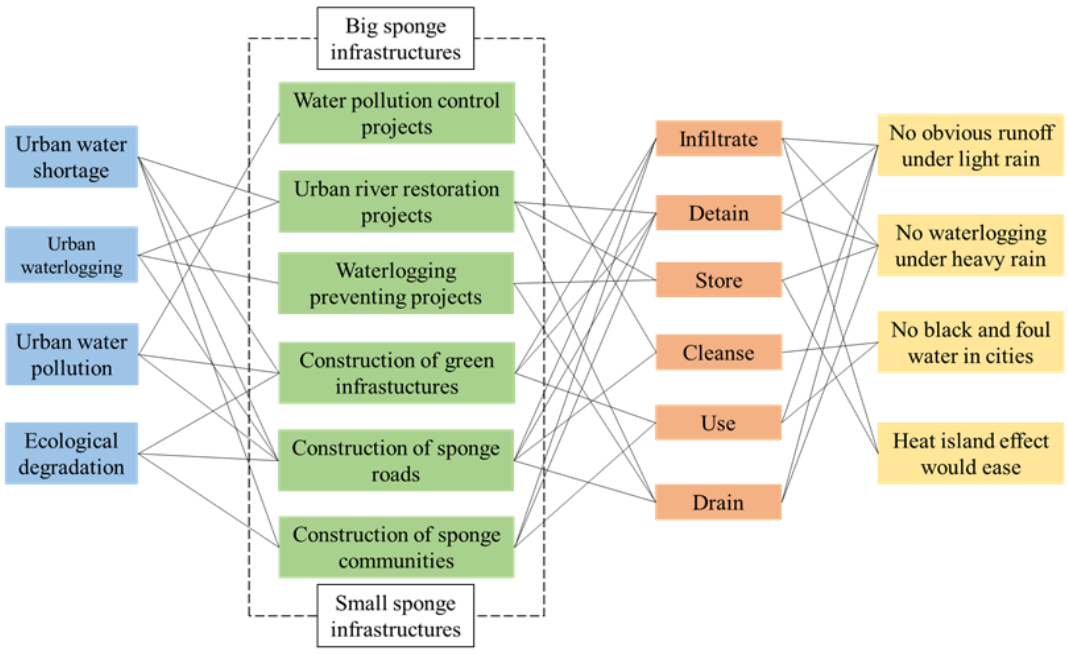


Figure 4. Construction Path of Sponge City in Xiamen

According to precipitation analysis, the target of the annual total runoff control rate in Xiamen is 70%. The city is divided into 16 sponge city construction units, as shown in **Figure 5**. Based on the goal, the annual total runoff control rate of the whole city varies with each unit. The current annual runoff control rates of each land use category are 35% - 50% for residential land, 60% for road and square land, 70% for park and green land, and 45% for other land[7].

In order to achieve the goals, different regions can make different plans. In the new urban area, the implementation of construction should be strengthened according to the situation of various types of urban underlying surfaces, and the types and layout of low impact development facilities should be reasonably distributed. Due to the high density of previous construction in the old urban area, the sponge city construction should be implemented step by step, period by period. Considering these circumstances, hardened sidewalks and parking lots can be reconstructed, and the permeable pavement and green land can be built.

### 2.2.3 Drainage and Waterlogging Prevention System

The construction strategies of drainage and waterlogging prevention system in Xiamen include:

(a) **Combination of urban vertical and manual storage facilities.** In the construction of the new urban area, the hydrological unit should be reasonably demarcated, and the site vertical, with the drainage direction and waterlogging discharge channel arranged scientifically. The three systems: flood control and damp-proof, rainwater discharge, and waterlogging prevention and control should be appropriately connected with the site vertical. The waterlogging discharge channel should be reasonably arranged in combination with the urban vertical and receiving water body distribution as well as the urban waterlogging prevention and control standard. The temporary rainwater storage space should be arranged by using wetland, sunken green space, and sunken square.

(b) **Combination of drainage and flood prevention facilities with the natural river system.** There are many rivers and lakes in Xiamen. Rivers and lakes are the most effective places for flood discharge. The drainage and waterlogging prevention facilities in each region should make full use of rivers and streams as drainage channels, and harbors and lakes as storage capacities. The drainage pipes, channels, and sluices in the city should be reasonably arranged to improve drainage performance, shorten drainage length, and reduce investment.

### 2.2.4 Construction of Ecological Water System

The ecological water system planning is designed to improve the water safety of rivers and lakes in Xiamen and reduce flood risk through the construction of flood control and river ecological restoration. Also, the construction restores the natural river landscape by strengthening the ecological bank protection of nine rivers flowing into the sea alone outside the island. Moreover, the ecological water system pattern of Xiamen is built by the reuse of renewable water sources and photovoltaic water extraction. The construction includes:

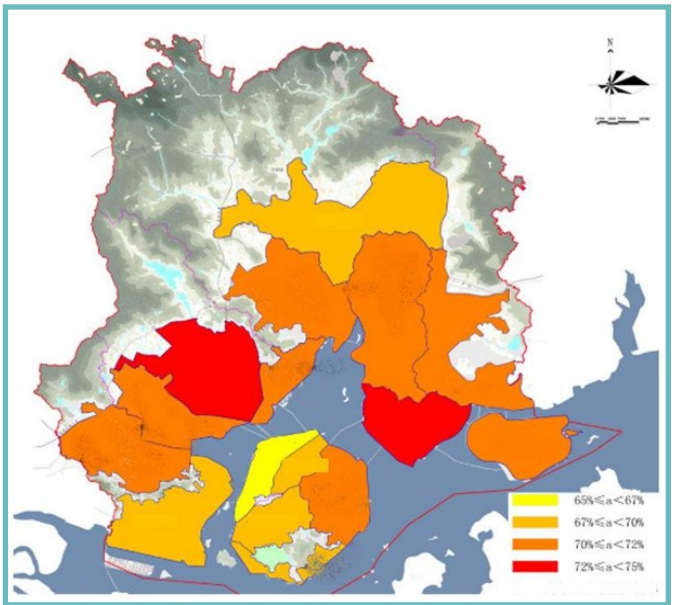


Figure 5. Distribution of Annual Total Runoff Control Rate of Each Unit in Xiamen ( a refers to annual total runoff control rate in the figure)

(a) **River cross-section restoration.** The river cross-section restoration is an essential part of river ecological restoration. The changeable river cross-section in the natural mountain area should be restored in order to restore the overall river ecosystem. According to the location of different river reaches and the planning of surrounding areas, the ecological water restoration should adopt various river cross-sections to create a variety of river habitats, including multiple, slope, and rectangular cross-sections.

(b) **Construction of ecological bank protection.** Based on engineering mechanics, ecology, soil science, and botany, the revetment can be effectively protected. The protection technology consists of plant-only technology and a combination of engineering and plant technology. For example, the gabion revetment uses lead wire to fix pebble and block stone into a whole, more massive block to prevent scouring by the larger flood. It is suitable for the reproduction and habitat of aquatic plants, fishes, and amphibians.

(c) **Construction of riverside buffer zone.** A riverside buffer zone refers to all kinds of vegetation zones along rivers, lakes, streams, and valleys, including forest belts, grassland, or other land use categories. It refers to one of the flexible bioengineering approaches and is suitable for water and soil conservation and non-point source pollution control.

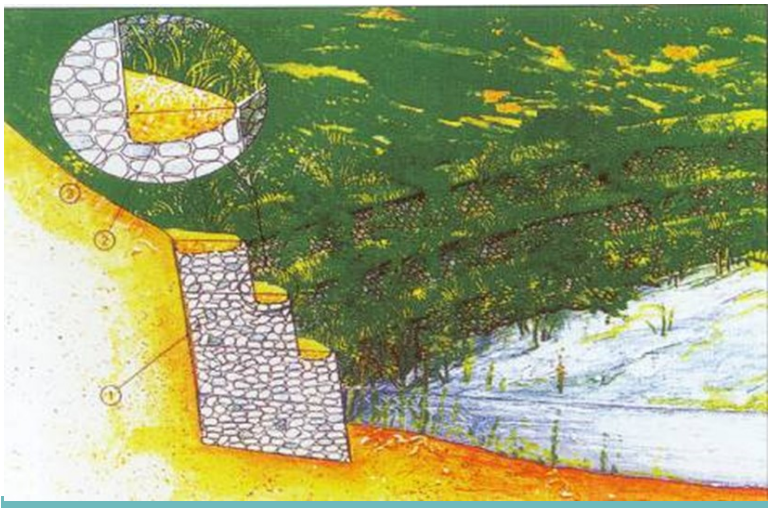

Figure 6. Sketch of Gabion Revetment

### 2.2.5 Construction of Sponge Community

As an essential part of sponge city construction, the sponge community plays a crucial role in connecting the preceding and the following. Compared with the traditional old residential area, the sponge community can effectively store and allocate rainwater and establish a sufficient connection between the hard building landscape and the natural environment. These advantages solidify its role as a primary direction for residential landscape construction and development in the future. Sponge city planning in Xiamen promotes sponge community construction, which includes site, building, community road, and community green space construction.

Reconstruction of the old community. By making full use of the advantages of the cultural resources of the old urban area, the relevant facilities adopted in the construction are gradually improved based on the overall protection of the historical city and not destroying its original historical heritage. The permeable pavement rate of the reconstruction should not be less than 40%. Besides, through the structural transformation of permeable parking space, the construction of grass planting shallow ditch, among other things, the rainwater from the parking space is introduced into the green belt, or the appropriate amount is introduced underground to regulate the rainstorm peak value.

Construction of the new community. According to the requirements of sponge city construction in Xiamen, all roads and squares in all new residential areas need to be paved with permeable pavement, with the permeable pavement rate not less than 70%. For projects with a hardened area of more than 2000m$^2$, rainwater regulation and storage facilities such as retention basin and landscape water body shall be built. The biological detention facilities such as green roof and rainwater garden shall be added to enhance the water conservation capacity. As a result, the accumulated water can be used for road sprinkling, greening irrigation, and building water recycling.

## 2.3 Typical Case of Sponge City Construction

The Yangtang residential area, the pilot area of sponge city in Xiamen, with a total area of 620,000 m$^2$, is located in the central area of Xiang'an new town. This area was newly developed in 2010. The comparison of remote sensing images before and after development is shown in **Figure 7.** Before the development, villages, bare soil, farmland, and ponds were the main areas. At present, due to rapid high-intensity development, the underlying surface with good permeability has been damaged to a certain extent, and the impervious area has increased significantly. Due to development, several urban water-related problems such as surface runoff pollution, road water accumulation, and heat island effect gradually arose [8].

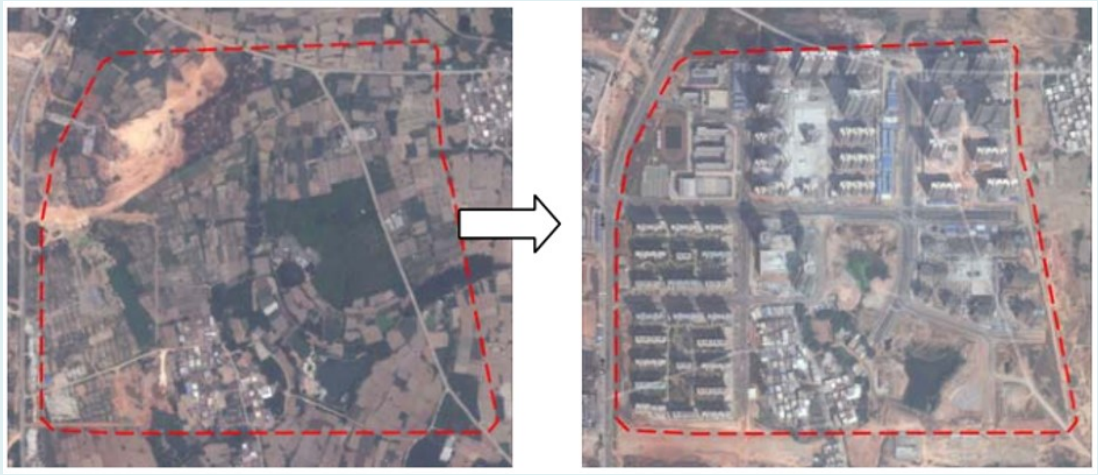

Figure 7. Comparison of Remote Sensing Images Before and After the Development of Yangtang Residential Area

In 2015, the Yangtang area was selected as a pilot project of sponge city construction in Xiamen. The construction objectives are 45% of the annual suspended solids removal rate, 75% of the annual runoff control rate, and 50-year return period of waterlogging control[8]. The management and control of runoff include source reduction, intermediate transfer, and terminal regulation and storage. The source reduction mainly relies on an underground pipe network, and the terminal regulation and storage are achieved by two artificials in the Yangtang area. The overflow is discharged through the municipal pipe network.

The spatial layout of sponge city construction in Yangtang residential area is shown in **Figure 8**. The facilities used include a wetland park, artificial wetland, biological detention basin, green roof, rainwater tank, artificial lake, and rainwater pipe network. The specific number of facilities is shown in **Table 2,** and the scene after the completion of facilities is shown in **Figure 9** [8].

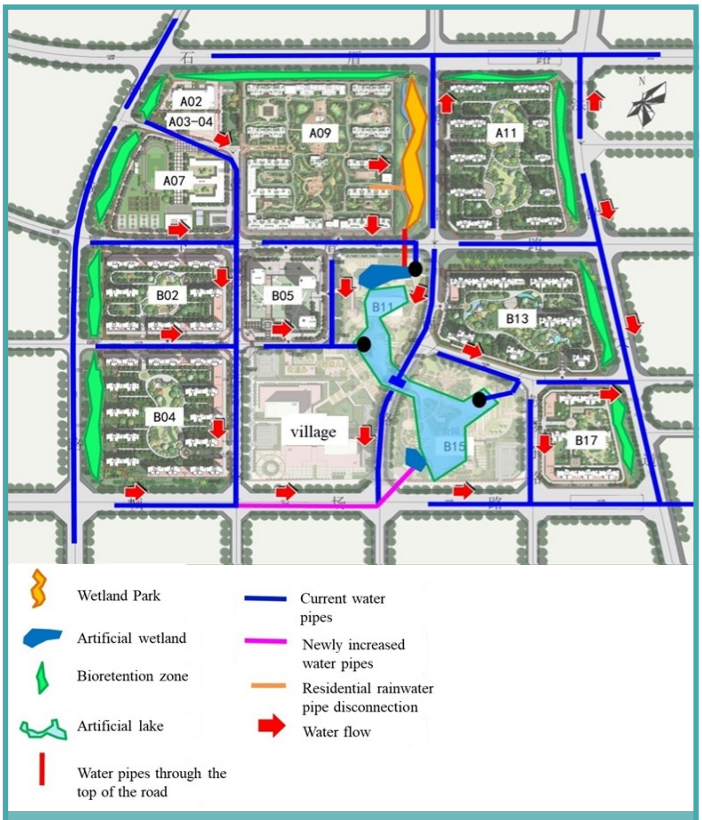


Figure 8. The layout of Sponge City Construction in Yangtang Residential Area

Table 2. Number of Facilities in Yangtang Residential Area

| Category | Number | Category | Number |
|---|---|---|---|
| Sunken green space/m² | 4809.6 | Grassing ditch/m² | 11096.4 |
| Permeable pavement/m² | 23755.2 | Wetland/m² | 4916.4 |
| Rainwater tank (1.5m³) | 60 | Rainwater leader disconnection | 1 |
| Green roof/m² | 26600.4 | Pipe network reconstruction | 1 |
| Biological retention zone/m² | 42326.8 | Artificial lake | 1 |
| Rain garden/m² | 7132.4 | Landscape improvement | 1 |

# 3. Investment and Financing Mechanism and Operation Mode

## 3.1 Cost and Investment and Financing Mechanism

The total planned investment for the construction of sponge city in the central urban and key areas of Xiamen is 35.35 billion yuan[7]. The project includes pollution prevention and control, ecological water system, drainage, and waterlogging prevention, garden and green land, road and traffic, sponge community, and information management and control platform. The planned total investment of recent construction (2016 – 2020) is 29.99 billion yuan, accounting for 84.8% of the total investment. The budget of recent construction is shown in **Table 3**.

There are three primary sources of investment:

(a) **Subsidies from the government for pilot cities**. Xiamen received a subsidy of 300 million yuan per year from the government for the three-year period, in total 900 million yuan.

(b) **Local government financial revenue investment**, which makes up the central part of the overall investment. In the construction stage of the pilot period (2016 – 2019), except for PPP projects, 100% of the project investment came from government investment. After that three-year period, the government is now promoting the concept of sponge city to various construction projects through legislation, planning, and approval, and the government undertakes the chief investment of public welfare construction.

(c) **Adopt PPP investment mode.** Government and social capital cooperate, study, and explore overall outsourcing, franchise and other modes in construction and


Figure 9. The layout of Sponge City Construction in Yangtang Residential Area

Table 3. Investment Estimate of Recent Construction

| Number | Project | Investment (100 million yuan) |
|---|---|---|
| 1 | Pollution prevention and control | 77.90 |
| 2 | Ecological water system | 28.75 |
| 3 | Drainage and waterlogging prevention | 12.54 |
| 4 | Garden and green land | 14.91 |
| 5 | Road and traffic | 98.55 |
| 6 | Sponge community | 67.25 |

operations, widely attract social capital to participate in sponge city construction; encourage relevant financial institutions to provide various credit support for sponge city construction on the premise of controllable risk and sustainable business. The structure of the PPP mode for sponge city construction is shown in **Figure 10**. All parties involved in the PPP project cooperate in an orderly manner according to the project contract. The government (public institutions) mainly carries out sponge city planning and conducts public bidding to the society according to the planning. After winning the bid, the enterprise (consortium) shall establish a sponge city project company as the initiator, obtain the franchise right of sponge city construction from the government, and take the sponge city project company as the main body in the financing. Generally, the construction period is 2 years, and the operation period is 8-15 years. As the user of sponge cities, the government will pay relevant expenses to the operating company in the way of a "purchase service" during the operation period of the project. The company will purchase relevant insurance during the construction and operation period from the insurance company according to the construction laws and regulations.

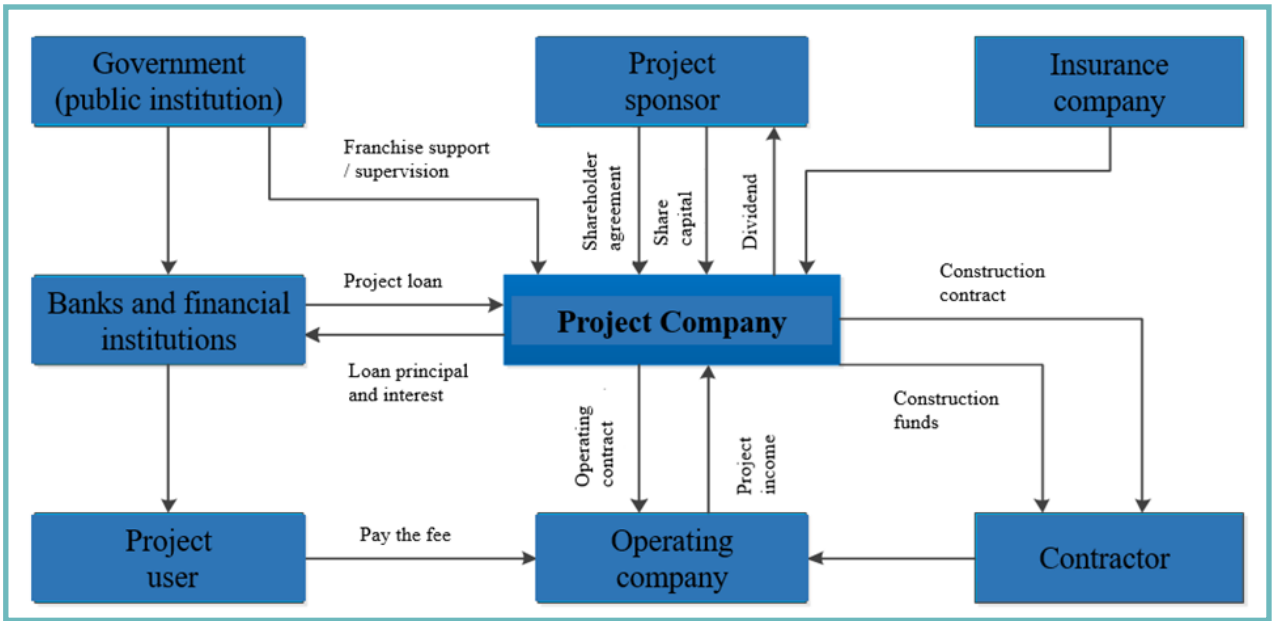


Figure 10. Schematic diagram of PPP Mode of Sponge City Construction

Xiamen has formulated an insurance program for catastrophe to make up for the government's insufficient investment in natural disasters, such as urban floods. The executive meeting of the Xiamen municipal government passed the Xiamen catastrophe insurance plan on December 1, 2016. The insurers were determined through a bidding process that month. The insurers include several companies, and the representative of coinsurance is the Xiamen Branch of PICC (The People's Insurance Company (Group) of China Limited). The insurance system was officially implemented in May 2017. Xiamen adopts the mode of "government leading, commercial insurance agency, and socialized participation," takes commercial insurance as the platform, multi-level risk sharing as the guarantee, and constructs a catastrophe insurance system suitable for Xiamen. Xiamen Municipal Finance has invested about 29.31 million yuan every year, and from insurance companies, purchased the insurance of housing and property loss with compensation limit of 1 billion yuan, and the insurance of personal injury, death, and medical assistance with compensation limit of 1 billion yuan. During the underwriting period, if losses are caused by typhoons, earthquake, rainstorm, flood, and other natural disasters, compensation of up to 200,000 yuan for personal injury and death, 100,000 yuan for housing loss, and 500 yuan for property loss can be obtained.

## 3.2 Cooperation Mode of Stakeholders

The stakeholders of sponge city construction mainly include government, enterprises and individuals. As public welfare facility investment and construction, sponge city construction has no clear beneficiaries, including all stakeholders: government, society, enterprises and individuals.

## 3.3 Operation of Measures Maintenance

Xiamen has set up the sponge city information management and control platform. The overall maintenance of facilities is achieved with a combination of online monitoring and offline operation.

The monitoring system monitors the data from urban hydrology, waterpower, and drainage pipe networks. The management and control platform adopts geographic information system (GIS) as the core technology, comprehensively uses advanced technology such as online monitoring, model analysis, GPS and Web technology. As a result, the sponge city intelligent management cloud platform is formed, which integrates simulation, evaluation, operation, monitoring, dispatching and emergency management.

# 4. Achievements and Benefits after Implementation

## 4.1 Achievements: Analysis Based on Monitoring Results

Taking Maluan Bay, the pilot area of sponge city construction in Xiamen as an example, the effectiveness of its implementation was evaluated based on the monitoring results[9]. The pilot construction area of the Maluan Bay was 8.63 $km^2$, and the water area was 7.45 $km^2$. The construction complied with the general requirements of the Xiamen Sponge City Special Planning. The target annual total runoff control rate was 70%. One hundred twenty-seven projects were arranged and implemented in 2016 – 2019, with a total investment of 4.599 billion yuan[9].

Table 4. Stakeholders of Sponge City Construction

| Stakeholders | Institutions/Individuals | Duty/Obligation |
|---|---|---|
| Government (Public institution) | Municipal Development and Reform Commission, Finance Bureau, Housing and Urban Rural Development Bureau, Water Affairs Bureau, Municipal Landscape Bureau, Ecological Environment Bureau, Natural Resources Bureau, Civil Affairs Bureau, Information Office, governments of all districts. | Initiators, investors, organizers and regulators. Establishing various sponge city construction projects in a certain area and investing or cooperating with enterprises by formulating special plans. |
| Enterprise (Legal person) | Planning and design, engineering construction, investment and operation, construction materials, gardening, water treatment, scientific research and other enterprises and institutions; Franchise enterprises of some PPP projects | Investment in sponge city construction projects. Obtaining various sponge city- related businesses through bidding. Gaining profits by participating in sponge city planning, construction and maintenance. Undertaking certain social responsibilities. |
| Citizens | All residents of the city | Enjoying the good ecological environment brought by the construction of sponge city. Having an obligation to provide convenience and share their own views in the planning, suggestions and maintenance of sponge city construction to promote the construction of sponge city. |

The monitoring results showed that the cumulative rainfall in Maluan Bay area was 1311.9mm in the year of 2018. The Haitou Science and Technology project area had a cumulative rainfall of 56,563.34m$^3$, rainwater discharge of 48,279.43m$^3$, and an annual average runoff control rate of 85.35%, which meets the design target[9].

In the area of Maluan Bay, there were 51 annual accumulated rainfall events at Cascade waterlogging point, with a maximum intensity of a 30-year return period. The monitoring results showed that the depth of water accumulation in the monitoring point was below 15cm, the maximum depth of water accumulation was 11.7cm, the maximum time of accumulation was 23 minutes, and the waterlogging was significantly alleviated.

The water quality monitoring results of Xinyang main flood discharge channel in Maluan Bay area showed that after the construction, the water quality in the channel was obviously improved, the transparency was maintained above 25cm, the dissolved oxygen index was above 2.0mg/l, the redox potential was higher than 50mV, the ammonia nitrogen index was lower than 8.0mg/l, the condition of black-odor water body was obviously improved, and the water ecosystem was gradually restored [9].

The drainage pipe network of Xin'an Village in Maluan Bay area was a combined rain and sewage system. Before the construction, there was an overflow situation even in the dry season. The results showed that after the construction, the overflow situation in the dry season was eliminated, and the overflow frequency in the rainy season was also significantly reduced to less than ten times. The overflow pollution of the pipe network was effectively controlled[9].

## 4.2 Other Indirect and Comprehensive Benefits

(a) Reduce waterlogging disasters, and reduce urban water disaster losses;

(b) Reduce water pollution, improve water environment quality, and enhance water source safety;

(c) Alleviate the urban heat island effect and improve the city's livability;

(d) The urban ecological environment has been improved, and the residents' well-being has been enhanced;

(e) The project construction drove market investment and promoted regional economic development;

(f) Improve the goodwill of urban residents to the government and maintain social harmony and stability;

(g) Improve the overall quality of the city, increase the reputation of the city, and increase the attractiveness of tourism.

# 5. Highlights and Inspiration

## 5.1 Highlights of Sponge City Construction in Xiamen

Ecological ideas and measures can successfully resolve urban water-related problems. Xiamen sponge city construction adopts the principle of ecological priority to minimize the disturbance to the urban ecological background. When building new facilities, "quasi-natural design" and "nature-based solutions" are adopted. For the source reduction of rainwater runoff, green infrastructure, such as green roof, rainwater garden, ecological detention basin, and ecological bank protection, is preferred. In terms of facility maintenance, solar photovoltaic water extraction technology is creatively used to achieve ecological water supply and reduce energy consumption. Based on the ecological concept, ecological measures are taken to maximize the recovery of the city's natural water cycle function, so as to achieve the goal of "no ponding in heavy rain, no waterlogging in light rain, no black-odor water body, and mitigation in heat island."

Realizing the city's three-dimensional slow release of rainwater. Taking Xiamen city as a "three-dimensional" structure, we should give full play to the role of urban three-dimensional space to retain rainwater. With green roofs, rainwater gardens, underground pipe networks, and other facilities to realize the three-dimensional interception, detention, and regulation of rainwater. Besides, with the idea of "source reduction, intermediate transfer, and terminal regulation and storage" the rainwater can be dispersed and detained in different steps as much as possible. The goal of slow-release regulation of rainwater based on urban vertical space can be achieved.

Various facilities are constructed according to different policies. Sponge city is not a project, but a concept, which combines different urban infrastructure construction to form different sponge facilities. In Xiamen, sponge road, community, school, park, and ecological water system have been built, which are examples of combining sponge city concepts with specific projects. To maximize the role of sponge cities, the concepts of "natural storage, infiltration, and purification" and "nature does its work" shall be promoted to the public through pilot construction and promotion. The concepts have been applied in all aspects of urban planning, facilities, management and development.

## 5.2 Enlightenment to the Adaptive Response to Urban Climate Change

Responding to climate change by enhancing urban flexibility. The response of a single city cannot wholly reverse or mitigate the trend of climate change. Therefore, cities need to be enabled to adopt flexible actions and policies to face the issues surrounding climate change. Sponge city has a more significant applicable threshold for the change of precipitation, reducing the vulnerability of cities and people to climate change. As a result, the concept of sponge cities helps allow cities and people achieve their goals of survival and development in the context of climate change.

Integration of the concept of sponge cities into urban development. As a concept of a comprehensive response to urban problems, sponge city is also a practical path to an adaptive response to climate change. Based on the ecological concept and measures, sponge city makes nature do more work, makes it so there is less interference from people, and tries to adopt a "quasi natural design". Therefore, the concept of sponge city has the potential to spur a deep awareness among residents, society, and governors. With this awareness and public consciousness, all aspects and steps of urban construction and development in the sponge framework can be realized. Eventually, people and rainwater, society and nature can share urban space, achieving the improved adaptability of cities to climate change.

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