Application of Sponge City in China and its Potential Opportunities and Challenges – Shanghai as a Case Study

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Abstract
With rapid urbanization in China, urban flooding has become a frequent and severe threat to the economy and human society. The Sponge City concept was established in 2012 by the Chinese government as a long-term solution to address infiltration, evapotranspiration, and water recycling in cities. Through the study of ten pilot Sponge City projects in Shanghai, which is selected as one of the pilot Sponge cities in 2016, the typical Sponge City facilities (porous pavements, green areas, water pipe networks) are identified. It is judged that it is easier to carry out Sponge City projects in newly built urban areas, where the municipal government could plan before the actual construction takes place. The new Sponge City facilities give positive feedback and have the advantages to reduce surface runoff and Urban Heat Island effect and increase the amount of purified water recycled. Meanwhile, challenges are discovered such as the water storage capacity limitation, the construction financial challenges, and difficulties in proceeding with renewal. These challenges may be mitigated in the future with imminent innovations. In this essay, we argue that Sponge City construction should be continued to meet its maximum potential.

Keywords
Sponge city; Urban flooding; Resilience; Green area; Permeable materials

Introduction

Urban water problems have become increasingly non-negligible because of natural and human causes. Among all, urban flooding is one of the most frequent and dangerous hazards, which significantly impacts the economy, urban infrastructure, and human society. On 25th August 2008, Shanghai experienced heavy rainfall in the densely populated urban areas during peak work hours: more than 11,000 houses were flooded; more than 3,000 traffic accidents occurred; 700 vehicles broke down and more than 100 flights were delayed at the two airports in Shanghai (China Meteorological

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Administration, 2015).

Rapid urbanization-population growth, massive urban development, and outdated infrastructure – create rather vulnerable urban environments when encountering extreme weather conditions. Cities of steel and concrete make it more difficult for rainwater to infiltrate through the ground. With fewer green spaces, farmlands, gardens, etc., the city's ability to regulate itself is weakened, and the problem of urban flooding depends entirely on artificial drainage systems. However, the reality is that the artificial sewerage systems are not effective enough to resolve the water hazards every time.

Global warming exacerbates the risk of flooding in urban areas due to the significant Urban Heat Islands effect. Cities form "heat islands" since pitch and concrete have lower specific heat capacity than green areas; buildings warm up faster and radiate heat into the atmosphere, causing higher temperatures in urban areas than in the surrounding suburbs. Urban Heat islands enhance air convection and raise the precipitation by approximately five to ten percent more than suburban areas (Sheng et al., 2010). As a result, cities are usually faced with a higher possibility of severe rainwater runoff, and hence more severe loss of properties.

This essay focuses on the concept and practice of Sponge City, a counter-flooding measure invented by China. The Sponge City policy appears as a solution to reinforce city drainage capacity by converting a specific Chinese city into a "sponge" and improving its capacity for "infiltration, retention, storage, purification, utilization, and drainage" (Chinese Academy of Sciences, 2017). The following section discusses the urgency to construct Sponge Cities in the context of China. The third section addresses the current situation of pilot Sponge City projects in China, particularly in Shanghai, one of the pilot cities with leading Sponge City implementations. In the end, the discussion argues that, despite the criticisms of the concept and practices of Sponge City, it is still necessary and urgent to carry on the implementation of this initiative. In the long run, the accumulation of Sponge City solutions may increasingly reduce the existing limitations and drawbacks.

Sponge City as a Concept

The accelerated urbanization process brings many environmental problems, and urban flooding has become one of the most urgent urban water ecological issues. In the past twenty years, countries such as the United Kingdom, the United States, and Australia have formed their management systems for sustainable urban rainwater development that follow natural drainage methods in response to the problems arising from the urbanization process. For instance, the United Kingdom established Sustainable Urban Drainage Systems (SUDS) to control rainwater surface runoff. In Australia, Water-sensitive Urban Design (WSUD) was developed with the urban water cycle as its core. In addition, the United States has explored rainwater control methods much earlier, so its laws and regulations regarding Low Impact Development (LID) are relatively more thorough (Ning et al., 2017).

Meanwhile, the rest countries also enthusiastically follow the footprint of the previous predecessors and contribute to inventing systems suitable for their specific situations. For instance, New Zealand has established *Low Impact Urban Design and Development (LIUDD) which makes* references to the context of *LID* and *WSUD* (Che et al., 2015). Although China started slightly later than developed countries in researching rainwater management, China has already established its solution inspired by the existing policies.

Sponge City (SPC), a concept as the result of vast practical experience and the merging of several rainwater management technologies, was first formally mentioned in China at the "2012 Low Carbon City and Regional Development Science and Technology Forum" (Chinese Academy of Sciences, 2017).

There is a consensus among scholars that "Sponge City" is a metaphorical expression. The concept describes an ideal designed city model that addresses flooding risks by "absorbing" water, analogizing its pattern to a sponge. The Sponge City policy is an essential urban planning direction in China to cope with recurrent urban inundation, meanwhile, it also helps to reduce the heat island effect, and water scarcity and construct urban water ecological security (Chen & Chen, 2020). Sponge City solution, which has high resilience and can adapt to environmental changes and respond to natural disasters such as floods, is referred to as a Sponge City. When rain falls, it "absorbs" water using rainwater recycling systems, green roofs, rain gardens, sunken squares, permeable pavements, etc, and then "squeezes" the gathered rainfall for use at other times. The idea behind the design is to make the entire metropolitan system behave like a sponge, absorbing and utilizing rainwater resources as needed. Six measures are used to limit the influence of urban expansion and building on the environment to accomplish the targets- "infiltration, retention, storage, purification, utilization, and drainage" (Chinese Academy of Sciences, 2017). The construction of a Sponge City should emphasize the protection, restoration, and re-establishment of the original urban ecosystem. Maximizing the protection of aquatic ecosystems such as rivers, lakes, wetlands, ponds, forests, and grasslands, and maintaining natural hydrological features are essential requirements for the construction of sponge cities (Reilly & Peng, 2021).

The National Guideline specifies the target that by 2020, 20% of the urban area should be redeveloped to satisfy the Sponge City criteria of absorbing and using 70% of rainwater in situ. When it comes to 2030, the area percentage of Sponge City should rise to 80% (General Office of the State Council, 2015). Guided by the Ministry of Housing and Urban-Rural Development (MOHURD), the Ministry of Finance and the Ministry of Water Resources, the Sponge City pilot program started and selected sixteen cities as the pilot cities of Sponge City trial in 2015, followed by another fourteen cities in 2016 (Li, 2017).

After several years of Sponge City testing and implementations, the ideal concept has transformed into a more solidified solution. The Sponge City policy is flexible when adopted and used in different pilot cities. Due to specific local conditions and geographic characteristics, the scale of Sponge City planning and the financial support received vary across cities. Multiple research projects have demonstrated the efficacy of Sponge City solutions in urban draining and water recycling in different contexts (Zevenbergen et al., 2018).

Urban Flooding in China

China has experienced frequent flooding due to its geographical location. China is located on the east coast of Eurasia. The monsoon circulation has a significant impact on the country's climate (Yan et al., 2020). The eastern and central regions of China are influenced by the Pacific and Indian Ocean monsoons. The precipitation is concentrated and extremely intense in a short period every single year, especially in the summer months from June to September. Due to the severe rainstorms, flooding usually occurs in these months (Tian et al., 2006).

Not only the nature matter, but human activities also need to take responsibility for flooding. In the unexpected rapid urbanization, more and more people migrate from the countryside to cities. According to the National Bureau of Statistics (NBS) in China, the urban population has been climbing considerably since the 1980s, from 19.39% in 1980 to 64.72% at the end of 2021 (NBS, 2022) (see Figure 1). Still, it indicates a steady trend of increase in the coming future. Along with the increasing urban population, many suburb areas are thoroughly reconstructed to meet the urban demand. Roads and architecture now replace the original green areas with soil, grass, and trees. Their impermeable surfaces made of pitch and concrete prevent water from permeating into the underground, and consequently, it is more likely to have a high surface runoff.

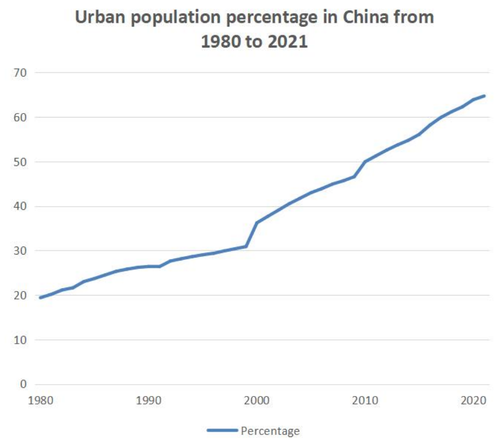

Figure 1. Urban population percentage in China from 1980 to 2021

This graph shows a continuous increasing trend in the urban population percentage in China from 1980 to 2021. National Bureau of Statistics (NBS)

Since 2006, the Ministry of Water Resources of the People's Republic of China (MWR) began collecting data on flooding loss every year. Take 2011, the year before Sponge City Policy was published, as an example, a total number of 89.4 million people were affected by floods nationwide, 640 people died or went missing; 693 thousand houses collapsed; direct economic losses amounted to 102 billion RMB. (MWR, 2011) Recognizing the serious loss caused by urban flooding, a long-term solution was urgently required, thus Sponge City Policy was established.

Pilot Sponge City in China

After the Sponge City policy was established in 2012, the Chinese government devoted many resources to solidifying the expectation.

Three years after, in 2015, the first list of sixteen pilot Sponge City was confirmed by the Ministry of Housing and Urban-Rural Development, the Ministry of Finance, and the Ministry of Water Resources of the People's Republic of China such as Chongqing, Xiamen, Wuhan, Xi'an New Area, and so forth (Li, 2017). The pilot cities selections have broad coverage of cities of different scales, including municipalities directly under the central government, provincial capitals, and prefecture-level cities spreading all over areas of China, indicating the importance of local suitability of the renewal.

In 2016, China published the second list of fourteen pilot Sponge Cities, including the other three provincial-level municipalities - Beijing, Tianjin, Shanghai, and several eastern coastal cities and western inland cities (Li, 2017). These cities have more distinctive geographical characteristics. The pilot projects in every city become a highly contextualized practice based on their location.

Pilot Sponge City in Shanghai

Shanghai, located in the east of China at the mouth of the Yangtze River, is the largest commercial and financial center and has witnessed radical development in the past few decades. The construction of roads and buildings replaces the green area in the original natural environment. The high intensity of land development in Shanghai leads to several problems: high impervious areas with low soil infiltration rate. In addition, Shanghai has high-level groundwater and flat terrain, with a subtropical climate and abundant summer rainfall. The average annual rainfall in Shanghai is about 1,150.6 mm, showing an overall increasing trend after 2000 (Yu et al., 2016). From June to October, consecutive concentrated rainfall occurs frequently, often coupled with typhoons and rainstorms, causing a sharp water level surge. At the time, the water discharge of urban areas becomes extremely difficult, and it is easy to cause urban flooding.

As one of the second batch of pilot sponge cities in 2016, Shanghai has put considerable effort into proceeding to implement the Sponge City renovation. The Shanghai municipal government approved the plan document, "Shanghai Sponge City Special Planning", which specifies the construction details and index requirements of the renovation. The document mentions that the Sponge City in Shanghai contains three types: ecological protection in remote suburbs, ecological restoration in urban-rural fringes, and low-impact development in the central urban area. The renewal is implemented following guideline in the document orderly and effectively and have reached the expected target by 2020 that 20% of Shanghai's built-up area meets the requirements of Sponge City construction (Tian, 2021).

With urban water drainage closely linked to the cities' local river network to facilitate the management of Sponge City construction, Shanghai is divided into fifteen Sponge City control sub-regions (Shanghai Municipal Planning and Natural Resources Bureau, 2016). The renewal of Sponge City in sub-regions may differentiate from each other a little but was still generally guided by six measures in the Sponge City concept – "infiltration, retention, storage, purification, utilization, and drainage" (Chinese Academy of Sciences, 2017).

To further study Sponge City projects, ten project samples containing all three types – ecological protection, ecological restoration, and low-impact development – are selected from ten sub-regions (Feng & Yamamoto, 2020). Comparing the appearances of the ten samples on the map, they are classified into three geometrical categories depending on their sizes and shapes, point-type (limiting to a small scale), lining-type (going a long distance, typically along rivers or main roads), and surface-type (covering a large ground area). There are three point-type and five line-type projects in the existing city areas. Meanwhile, the other two are surface-type projects that take place in the new city areas. In addition, it is summarized that there are four major methods of renewal taking place at those sites. (See Figure 1)

First, porous design is used in road design. Unique permeable pavement materials can permeate more water due to a high effective porosity percentage of about 20% (Guan et al., 2021). In other words, in every cubic meter of the material, there is about 0.2 m^3 hollow volume that allows water to pass through. Meanwhile, water discharge channels are added to transfer rainwater into artificial wetlands to avoid long-term retention of rainwater inside the road. It shows that porous design is the most common method as it is used in all ten samples. The following two, contiguous open green spaces and green roofs, are meant to use the green area to process "retention" and "storage" of rainwater in the soil, as well as natural "purification" of rainwater when passing through soil layers. Among the ten samples, four samples have constructed contiguous open green spaces, and there are two samples equipped with green roofs. Finally, the last method is building water pipe networks for "utilization" and "drainage". After rainwater is restored and purified, the rainwater can be used in situ based on different demands. Maximizing the recycling of rainwater is the primary goal of this method, and it is used in the two samples in the new city areas and two samples in the existing city areas.

Table 1. The categories of the ten pilot Sponge City projects in Shanghai and the methods they used

Project Sample Name	Locating District Name	City area	Geometrical Types	Contiguous Open Green Spaces	Green Roofs	Porous Design	Water Pipe Network
Best practice area Renovation in Expo City	Huangpu	Existing	Point			√	√
Rainbow Bay Park	Hongkou			√	√	√	√
Permeable pavement reconstruction of Wujiaochang Sunken Plaza	Yangpu					√	
Suzhou Creek Slow Trail reconstruction	Changning		Line			√	
Runway Park reconstruction of Yunjin Road	Xuhui			√		√	
Permeable pavement reconstruction	Jing'an					√	
Riverside construction of Zhenru Port	Putuo					√	√
River construction around the airport	Baoshan					√	√
Jiabei Country Park renovation	Jiading	New	Surface	√		√	√
Pocket Park reconstruction	Pudong			√	√	√	√

This table is created based on observations and newspaper articles, categorizing the ten pilot Sponge City projects in Shanghai in geometrical types and verifying which methods they used. From "Preliminary research on Sponge City concept for urban flood reduction: A case study on ten Sponge City pilot projects in Shanghai, China." by S. Feng and T. Yamamoto, 2020, *Disaster Prevention and Management: An International Journal*, *29*(6), 961–985.

After analyzing the ten examples, it is found that the two projects in the new city areas apply most of the four methods, while the others in the existing city area only use one or two methods except the Rainbow Bay Park in Hongkou District, which has applied all the methods. The scales of the projects in the new city areas are more significant than those in the existing city areas. To sum up, it can be judged that it is easier to carry out Sponge City projects in newly built urban areas, where the municipal government could plan before the actual construction takes place. Based on the observations from field trips, there is no doubt that these projects have provided varying degrees of benefits in enhancing drainage capacity and the natural environment in city areas.

Pocket Park renewal in the Lingang area of Pudong New District is a unique example of the Sponge City projects and the most developed sample among the ten projects because of its geographical surface type and all four methods applied. Located in the Lingang area, the Pocket Park renewal is one part of Sponge city renewal in Lingang new city, the first national pilot Sponge City construction in Shanghai as well as the largest Sponge City project among the thirty pilot cities in China (Tang, 2017). With the introduction of "Shanghai Lingang pilot Sponge City area planning", Lingang Sponge City construction formed a well-designed Sponge City natural ecological space pattern (Xu et al., 2016) with the Dishui Lake as the center core and the water system as the skeleton to the periphery of the radial catchment area (see Figure 2). Within the document "Shanghai Sponge City Special Planning", the index requirement specific to the Pudong sub-region that is expected to reach by 2020 was released, which shows the extraordinary ambition towards this sub-region, especially the Lingang area (see Table 2).

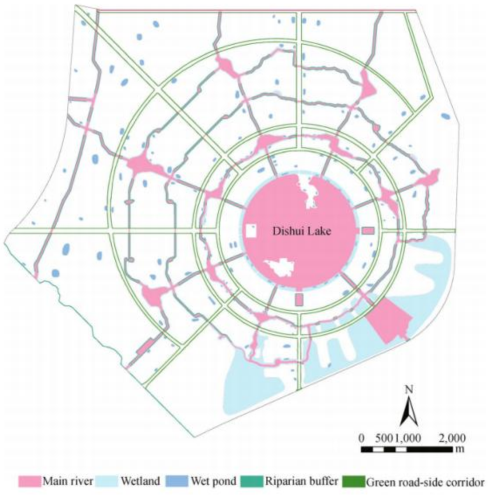

Figure 2. Sponge city ecological pattern in the Lingang area

This diagram shows the Sponge city ecological pattern in the Lingang area. From "Green stormwater infrastructure eco-planning and development on the regional scale: A case study of Shanghai Lingang New City, East China." by H. Xu, L. Chen, B. Zhao, Q. Zhang, and Y. Cai, 2016, *Frontiers of Earth Science*, *10*(2), 366–377.

Table 2. Index requirement of Sponge city infrastructures in the Pudong sub-region

Pudong sub-region index requirement		Indicator values
Water Ecology	Total annual surface runoff control rate	75%
	Water ecological shoreline transformation rate	85%
Water Safety	Flood control design recurrence interval	Once in 3~5 years
Water Environment	Water Quality standard	100% compliance rate of key water function areas
	Annual surface runoff pollution control rate	≥75%
Water Resources	Rainwater resource recycle rate	5%

This table shows the Index requirement of Sponge city infrastructures in the Pudong sub-region. Shanghai Municipal Planning and Natural Resources Bureau.

After more than three years of unremitting efforts, more than 200 hectares of housing estates, 500 hectares of parkland area, as well as several universities (Shanghai Ocean University, Shanghai Maritime University, Shanghai University of Electric Power, etc), underwent the Sponge City renewal in Lingang area (Hu, 2019). The facilities solve the problem of urban flooding and reduce pollution from rainwater runoff into the river. When the projects cope with rainfall at ordinary times, the surface runoff no longer exists or plummets to a negligible level. At the same time, the one in the area without renewal remains its original amount.

In consideration of the performance of the existing pilot Sponge City projects in China, this essay argues for the necessity and urgency of continuing the construction of Sponge cities, especially in metropolises like Shanghai. In the meantime, the essay also acknowledges there are multiple challenges and potential drawbacks of developing Sponge City projects. This section summarizes both significant opportunities and challenges related to Sponge City projects, with a focus on Shanghai.

Potential Opportunities

Reduction of Surface Runoff

The most dominant objective of Sponge City is to reduce surface runoff on rainy days by the methods of reconstructing concrete roads with a porous material, replacing the impermeable roof with green plants as well as creating new green areas. The porous material and soil allow water to pass through layers into the underground, while traditional concrete roads and roofs have most of the rainwater accumulating on their surface, which takes the major responsibility for urban flooding. Thus, the porous material and soil can process "infiltration" of rainwater much better than traditional concrete roads and retain the water for a while, delaying surface runoff formation and reducing surface runoff significantly on rainy days.

To quantize the ability of water absorption in a specific place, a definition is introduced. Surface runoff coefficient (C), is the ratio of surface runoff depth and precipitation depth, which is used to describe the ability of a material's permeability to water, followed by the formula:

Surface runoff depth = Surface runoff coefficient × Precipitation depth

With the same precipitation depth, the surface runoff depths increase with the increase of the surface runoff coefficient in the specific place. Areas with low infiltration percentage and high runoff (concrete pavement≈0.9) have higher surface runoff coefficient, and lower values for permeable, well-vegetated areas (forest≈0.15, green roof≈0.35), thus it explains after urbanization redevelopment, cities become easier to get flooded and have a higher surface runoff.

Take a housing estate beside Dishui Lake in the Lingang area which experienced Sponge City construction as an example (Bao, 2019). It converted from an area original with 75% hard site area and building area and little green area, which suffered from flooding frequently, to an area with 70.9% permeable pavement rate and 33.6% green roofs rate after renewal. Due to the application of porous pavements and green roofs, it is calculated that the comprehensive surface runoff coefficient of the whole estate is reduced from 0.65 to 0.59, which is a relatively considerable reduction, and the total annual runoff control rate reaches 80%. The flooding situations seldom exist anymore in the housing estate and pressure on the drainage system is reduced.

Reduction of the Urban Heat Island Effect

Data from Shanghai Meteorological Service in 1997 and 1998 in July and August clearly shows a trend that the temperature increases gradually towards the city center: 35.5°C isotherms coincided with the outer ring of Shanghai; 36.0°C isotherms overlapped with the inner ring; while Yu Garden area which is a highly-developed tourist attraction in the city center occupied 37.0°C zones (Fang, 2013). However, this Urban Heat Island effect is mitigated by the construction of Sponge City.

The Sponge City facilities such as porous roads and green areas reduce the Urban Heat Island effect through several pathways. With the construction of Sponge City, the percentage of green areas increases significantly in the urban area. First, plants can absorb a lot of heat through transpiration and greenhouse gas, CO_2, through photosynthesis, which suppresses the greenhouse effect, thus achieving a cooling effect. In addition, the water bodies in green areas have a higher specific heat capacity compared to concrete, which controls the rapid temperature rise when absorbing an equivalent amount of heat. Finally, plants can also trap dust in the atmosphere and reduce the absorption of solar heat. Meanwhile, the porous roads also play a non-negligible role. When the rainwater gathering in the hollows of the roads is evaporating, it takes away heat in the air and increases the air humidity as well, so further reducing the Urban Heat Island effect. It is shown that the combination of the Sponge City facilities can lower the average urban temperature by 0.3~3°C on a city scale (He et al., 2019), thus decreasing the difference between the temperatures of the urban area and its surrounding, in another word reduces Urban Heat Island effect.

Increase the Amount of Purified Water Recycled

“Shanghai has sufficient water, but lacks good water, which is a typical water quality type water shortage city." Zhang Jiayi, the director of the Shanghai Municipal Water Bureau, pointed out the dilemma of Shanghai's current water shortage. In Shanghai, water with its quality better than V class which is the worst class, and can be used in daily lives, accounts for less than even half of the total water amount, about only 31.4% (Quan, 2004). In the past, urban clean water resources were simply relying mainly on the supply of waterworks. However, with the appliance of Sponge City facilities, this situation is improved, and resources no longer rely on a single centralized water supply but make full use of recycled rainwater after being purified.

On rainy days, a portion of rainwater fall in green areas such as green roofs, parks, and plants along roads, and is absorbed by the soil. On their way, passing slowly through the underground before being collected by the water pipe network, the rainwater undergoes a thorough purification in all physical, chemical, and biological dimensions with the help of soil, plants, and bacteria. For instance, in Shanghai Gongkang Forest Park, one of the first batches of Sponge City projects in Shanghai, some contaminants in the collected rainwater can be absorbed by specific plants grown in the park (Yu et al., 2016). The tubers of canna (*Canna indica*) can absorb a large number of heavy metal pollutants in rainwater, while the roots of the yellow iris（*Iris pseudacorus*) are effective in absorbing nitrogen oxides contributing to water degradation.

At present, the technical purification capacity of the Sponge City facilities is still limited and the water quality after purification is far from the standard of drinking water. However, this kind of water can still be used in other situations and constitutes a new category of water called reclaimed water. Its quality is lower than domestic tap water but better than V-class water and is only required the absence of pollutants and peculiar smells. The reclaimed water collected from the Sponge City facilities can be used in watering plants, city sanitation, toilet flushes, and so forth. Toilet flushing accounts for one-third of the city's domestic water consumption, and a single person needs more than 100 liters per day (Tongzhou District People's Government of Beijing Municipality, 2018). Therefore, for Shanghai, a metropolis of 20 million people, only one toilet flush will consume thousands of tonnes of water. In these situations, the water use standard is relatively low and can be easily replaced with reclaimed water so that the pressure on water resources can be eased.

Challenges to Sponge City

Limited Water Storage Capacity

In August 2019, with the landing of typhoon Lekima, Shanghai experienced a severe rainstorm: 150 thousand people were relocated in an emergency, and direct economic losses reach nearly 45 million RMB (Luan, 2019). The surface runoff does not reduce much because of the Sponge City renewal and still causes significant loss. What else, according to incomplete statistics from Xinghuanet journalist, among all thirty pilot Sponge cities, more than half of the cities still have witnessed serious urban inundation (Zhang et al., 2016). Consequently, some people doubted whether Sponge City which has invested huge amount sums of money to construct has failed to perform as it should when confronting rainstorms.

However, it is not the Sponge cities that should be blamed. As one part of the minor drainage system, which has its task to ensure the safe discharge of rainwater with a recurrence interval of one to ten years (Che et al., 2013) and ensure the normal operation of cities and settlements, the Sponge City facilities were originally designed to be able to cope with a three to five year rainfall and urban flooding in a small scale. This rainfall by Lekima in Shanghai had exceeded the standards of Sponge City design and could only rely on the major drainage system and the emergency evacuation of people.

While this is a sad reality, it also reflects the limited water storage capacity of Sponge cities. Sponge cities are designed to solve the problem of urban flooding but are not made to cope with extreme weather. The total volume of rainwater that can be infiltrated and stored in the Sponge City facilities such as porous roads and green areas is limited after all. These facilities constitute a system just like a sponge: when the water amount is beneath the volume the facilities can cope with, the system can absorb it all; when the water amount exceeds the volume the facilities can cope with, the system has done their best to reduce the surface runoff, then it becomes a saturated sponge and can no longer absorb any more water.

On the other hand, as Sponge City is a systematic project, currently some of the pilot Sponge City projects have not been accomplished and most of the completed projects are point type and line type. These unfinished and small-scale built-up Sponge cities' water capacity cannot solve the overall urban flooding on a city scale. For instance, in the line-type renovated Suzhou Creek Slow Trail in Changning District in Shanghai, rainwater quickly seeps down due to the permeable roads and pavements on rainy days and there are hardly any traces of the heavy rain; meanwhile, some areas nearby that have not undergone sponge transformation are still waterlogged (Feng & Yamamoto, 2020).

Financial Challenge

Some people may ask why the Chinese government does not improve the Sponge City design standard to a higher recurrence interval so that it should be able to cope with all the extreme rainstorms. The crucial factor is finance, simple but deadly.

The approximate ideal algebraic relationship between the recurrence interval of rainfall that Sponge City can handle and the possible loss caused by flooding is shown in Figure 3 below. As the designed recurrence intervals of the Sponge City projects increase, the possible flooding loss decreases following an inverse proportional pattern due to better protective facilities, while the construction budgets surge exponentially. The sum of possible loss and the Sponge City construction budgets constitutes the total social expenditure cost. The minimum total social expenditure only occurs within the appropriate range of recurrence intervals, neither too low nor too high. This explains why the recurrence interval of three to five years is chosen as the design standard in Shanghai (Shanghai Municipal Planning and Natural Resources Bureau, 2016).

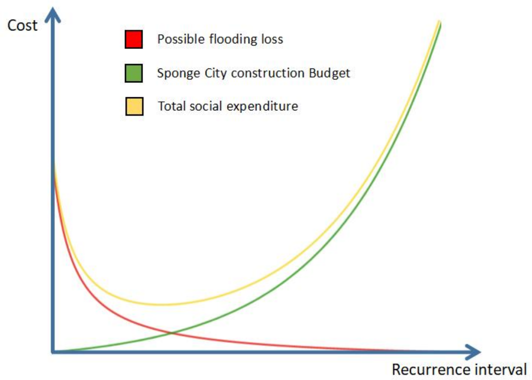

Figure 3. Algebraic relationship between designed recurrence interval of Sponge City and the possible flooding loss

This graph is produced by the author, predicting the approximate ideal algebraic relationship between the recurrence interval of rainfall that Sponge City can handle and the possible loss caused by flooding, and where the minimum total social expenditure occurs.

The finance needed to construct Sponge City projects with a recurrence interval of three to five years is not a small amount as well. Chen Zhenggao, the minister of MOHURD, has publicly revealed that the investment in Sponge City construction is expected to reach about 100~150 million RMB per square kilometer and the total national investment is expected to exceed 400 billion RMB per year (Han, 2016), while the maintenance of the existing Sponge City facilities is excluded which will be another huge expense. Although public sectors contribute to most of the investment, it is clear that the central financial subsidies are not enough to sustain the enormous expenditure. The involvement of private sectors and the creation of public-private partnerships (PPPs) become increasingly important to fill the financial gap (Li et al., 2017).

The fact is that because of the limited revenue-creating capacity of Sponge City construction discourages private sectors to join. Unlike the construction of other civil infrastructures, such as undergrounds, which also provide convenience to citizens and private sectors can gain stable income from part of ticket revenue, Sponge City facilities cannot provide direct revenue. What else, the life cycle costs, containing operation and maintenance, are uncertain, and even the lifespans of certain projects are unknown in some situations (Li et al., 2017). There are plenty of opportunities for investment in Sponge City, but when facing this project with a high technical threshold, no stable revenue income, and uncertain risk, normal private companies usually reject to get involved.

Difficulty of Proceeding with Renewal

Sponge City construction should be a nationwide policy when it was established and is expected to eliminate the inequity of flood control management among all the provinces. During the selection of Sponge City location in the country scale, the inclusiveness of the policy is shown as cities of different categories are chosen to be the pilot projects no matter is developed provinces or less developed provinces. However, when it comes to the implementation of Sponge City construction in specific places within a province, the difficulty of proceeding with renewal is revealed.

China has a very high population density, especially in developed provinces like Shanghai. The original drainage system relies on the sewerage pipes buried under the ground, but proceeding with Sponge City construction needs to increase the green area which will occupy the valuable ground surface and conflict with development targets that is to maximize the use of land to produce financial benefits. What else, instead of the gray infrastructures that belong to the public, the green infrastructures are usually located on private properties (Li et al., 2017). This leads to several issues such as the construction of the green roofs on private housing requires the permission of their hosts which is an uncertainty, and the further maintenance of the facilities is also troublesome.

In addition, the renewal of the old existing city area is much more intricate than constructing a new city area with Sponge City infrastructures. Due to the early years of construction, the original drainage system in the existing city area is insufficient and lacks maintenance, and the pipes are seriously mixed, blocked, broken, and leaking. Meanwhile, the houses are worn and some are in a state of disrepair. These objective conditions increase the difficulty of renewal: careful construction of Sponge City infrastructures is required without causing damage and maintaining the original appearance of the old town. The renewal in these old existing city areas may multiply the budget of the normal amount in other areas and may not reach the expected quality.

Although there are several known challenges at the current stage, they will be mitigated as further Sponge cities are built. Sponge City renewal is a slow gradual process that will last much more than a decade and should proceed step by step. As more and more Sponge cities projects are carried out, experience is gained during the implementation and is likely to bring innovations, which can ease further construction in the future.

Better permeable material may be discovered, and an increasing number of Sponge City projects are constructed. Consequently, the total volume of water the facilities can hold increases, and the limited water storage capacity are offset. When it comes to 2030, if the area percentage of Sponge City does rise to 80% as the target guided, the total water storage capacity may increase to a considerable level.

In addition, as Sponge City projects with high standards on big scales are extremely expensive to construct, the Shanghai government can prioritize the small-scale Sponge City renewals. Due to their lower price advantage, it is easier to carry out some point-type projects spread all over Shanghai. By constructing multiple point-type projects, a Sponge City infrastructure network is formed and may be able to replace a surface-type project with lower expenditure.

Finally, during the further construction of Sponge City, the law about it may be improved. A compulsory requirement can be established to state the minimum percentage of green area in estates. Consequently, the owners of the estates have their duty to help with the construction of Sponge Cities facilities like green roofs and keep the maintenance.

Conclusion

Sponge City policy was established in 2012 as a solution to frequent urban flooding in China by rendering water "resilience" to a city. Due to both natural factors and rapid urbanization, urban inundation becomes increasingly frequent and further emphasizes the urgency of Sponge City renewal. In 2015 and 2016, Sponge City construction is firstly put in an application by selecting thirty pilot Sponge cities. Through the study of the pilot Sponge City projects especially in Shanghai, the four major methods of carrying out the construction are identified, and they are proved to have positive feedback in different mechanisms. After that, the potential opportunities and faced challenges by the projects are discussed. Not only decreasing rainwater surface runoff, but Sponge City facilities also help with the reduction of the Urban Heat Island effect as well as increase the amount of purified water recycled. Meanwhile, the application of Sponge City policy confronts several challenges, including limited water storage capacity of the facilities, problems with financing, and difficulty in proceeding with the construction. However, these challenges may be mitigated with further renewal. In conclusion, China should continue to proceed with the Sponge City policy to meet its maximum potential.

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