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Review

Sponge City Practices in China: From Pilot Exploration to Systemic Demonstration

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Abstract: In recent years, China has been committed to strengthening environmental governance and trying to build a sustainable society in which humans and nature develop in harmony. As a new urban construction concept, sponge city uses natural and ecological methods to retain rainwater, alleviate flooding problems, reduce the damage to the water environment, and gradually restore the hydrological balance of the construction area. The paper presents a review of sponge city construction from its inception to systematic demonstration. In this paper, research gaps are discussed and future efforts are proposed. The main contents include: (1) China's sponge city construction includes but is not limited to source control or a drainage system design. Sponge city embodies foreign experience and the wisdom of ancient Chinese philosophy. The core of sponge city construction is to combine various specific technologies to alleviate urban water problems such as flooding, water environment pollution, shortage of water resources and deterioration of water ecology; (2) this paper also introduces the sponge city pilot projects in China, and summarizes the achievements obtained and lessons learned, which are valuable for future sponge city implementation; (3) the objectives, corresponding indicators, key contents and needs of sponge city construction at various scales are different. The work at the facility level is dedicated to alleviating urban water problems through reasonable facility scale and layout, while the work at the plot level is mainly to improve the living environment through sponge city construction. The construction of urban and watershed scales is more inclined to ecological restoration and blue-green storage spaces construction. Besides, the paper also describes the due obligations in sponge city construction of various stakeholders.

Keywords: sponge city; low-impact development; pilot exploration; systematic demonstration; construction scale; stakeholders

Citation: Yin, D.; Xu, C.; Jia, H.; Yang, Y.; Sun, C.; Wang, Q.; Liu, S. Sponge City Practices in China: From Pilot Exploration to Systemic Demonstration. *Water* **2022**, *14*, 1531. https://doi.org/10.3390/w14101531

Academic Editor: Pankaj Kumar

Received: 31 March 2022
Accepted: 9 May 2022
Published: 10 May 2022

1. Introduction

The rapid urbanization process in China has effectively driven the development of the national economy [1]. However, it has also exposed the risk of urban water issues due to the increase in impervious underlying surface and a decrease in green space and water areas [2–5]. This led to a significant reduction in the amount of rainfall runoff absorbed in the processes of plant interception, infiltration, depression detention, and evapotranspiration [6–8], and then increased the flooding risk [9–11]. When the rainfall runoff is large enough and exceeds the capacity of the drainage networks, it will bring more serious urban water safety and water environment issues [12,13]. Many cities in China have suffered a variety of water related problems such as frequent flooding, water environment pollution, water resources shortage and water ecology deterioration, which have seriously impacted the quality of people's life [14–16].

In order to improve the status quo, on the basis of learning from the stormwater management experiences in developed countries, China initiated the development of sponge city in 2013. This became a new solution for urban stormwater management. Whereafter, the government issued a series of related policies and guidelines for the sponge city development in an effort to improve the sponge city construction [17,18]. In addition, China central government selected 30 pilot cities considering their different natural and social conditions (with the average construction area of 31.3 km^2 for each city) for the sponge city construction exploration in 2015 and 2016, and all of them have completed performance assessment in the end of 2019 [19]. Furthermore, in 2021, based on the experiences of pilot cities, China began to systematically promote the sponge city demonstration on a national scale.

The construction of sponge city emphasis the full utilization of the natural absorption and infiltration capacity of pervious areas to effectively control stormwater runoff, thereby minimizing water system problems caused by the damage of urbanization-induced hydrological effects. The philosophy of sponge city is to transform the traditional "fast drainage" principle to a systematic implementation of "infiltration, detention, retention, purification, utilization and discharge" [13]. It aims to achieve stormwater runoff control from source reduction and process control to systematic remediation through planning, design, construction, operation, and management, which would lead to a sustainable approach for urban development.

At present, various sponge city related studies have become more and more extensive, including the analysis of various green infrastructures' performance, the interpretation of policies, and the optimization of green-gray infrastructure layout at the planning level. Based on the analysis of relevant references, government reports and actual sponge city projects, we present a comprehensive review of the sponge city from the inception to the development. In particular, construction modes, achievements, lessons learned during the pilot exploratory phase are all identified and analyzed. Then, we try to provide an outlook of the next stage work, which can be a guide for the promotion of sponge city systematic demonstration, especially the working contents at different scales and obligations of various stakeholders.

2. Inception of Sponge City

2.1. Foreign Advanced Experiences

The urban drainage concept can be traced back to the 3000 BC, with the most important goal being to quickly discharge the rainfall runoff from the urban area to the downstream channel or other receiving water bodies [20]. However, with the complexity of urban development and the frequent occurrence of extreme stormwater events, a series of relatively 'novel' concepts have appeared in the different developed countries. These concepts mainly include the Low Impact Development (LID), Green Infrastructure (GI) and Best Management Practices (BMPs) [21] in US, the Sustainable Urban Drainage System (SUDS) in UK [22], the Water Sensitive Urban Design (WSUD) in Australia [23] and Nature-Based Solution (NBS) [24]. These concepts attempted to combine urban drainage with natural processes to reduce rainfall runoff through various nature-based solutions and therefore, achieved a benign urban water cycle. All of these concepts are closely related, but different terms represent different technical systems, which also have certain differences in the field of application scale, technical measures and control objectives [25]. This section describes the concepts related to drainage proposed by the US, the UK and Australia, and explores the relationship and connection between these concepts and sponge city construction.

2.1.1. LID-BMP and GI for Source Control in US

BMP first appeared in the "Clean Water Act", enacted by the US Congress in 1972 and was first applied mainly in the field of sewage discharges or point sources [26]. After 15 years, the BMP for stormwater runoff or nonpoint pollution control was implemented. The main technical measures included different low-cost engineering measures. Besides, it also emphasized the non-engineering measures, such as facility maintenance rules. Since then, the concept of LID has been used in the reports related to urban stormwater management issued by the US EPA and in the related design manuals of various states.

The application of source runoff control facilities has been promoted by taking a "nature design approach", such as green roofs and rain gardens. Moreover, the US also promoted urban drainage design by using LID-BMPs, which represented all of the BMPs for urban stormwater runoff control using the LID strategy, and the frequency of this concept rapidly increased in international literature in recent years [27]. Subsequently, green infrastructure or GI, which covers traditional BMP and typical LID measures, was evolved as the term represented source control infrastructure for urban runoff. GI can bring multiple ecological benefits, such as alleviating the urban heat island (UHI) effect, increasing biological habitat, and improving biodiversity [20]. In the sponge city construction, source runoff control is also a top priority since it can effectively reduce the total amount of runoff and absorb part of the runoff on-site. However, the source control of sponge city includes not only small, decentralized infiltration and retention facilities (green roofs, grass swales and bioretention), but also large-scale storage facilities, such as stormwater ponds and wetlands. It is important to select appropriate facilities according to the scale and characteristics of runoff quantity and quality of the specific region.

2.1.2. SUDS for Multifunctional Drainage System Design in UK

In UK, a sustainable drainage concept was proposed in 2007, which not only includes the concepts of LID-BMPs and GI in the US, it also diversifies the design of the drainage system to avoid the traditional sewer network being the only drainage outlet [28,29]. Meanwhile, the filtering effect of drainage facilities was taken into account to reduce the discharge of pollutants into the receiving water body. In addition, rainfall collection and utilization were also emphasized [30–32]. Thus, strategies for the urban stormwater management became more functional rather than focusing solely on rapid runoff discharge. Besides, various corresponding environment, social and economic benefits were also obtained [33,34]. These benefits were reflected not only in the overall reduction of urban runoff, the improvement of air quality, and the CO_2 storage, but also in the burden reduction of the stormwater fees and the energy consumption [33,35–37]. It is not difficult to see that SUDS rose from a traditional "rapid drainage" system to a more sustainable and multifunctional drainage system that maintains a high level of benign water circulation. Meanwhile, it began to optimize the entire water system including urban drainage, sewage, and reclaimed water system rather than that of only urban drainage facilities. This also coincided with the concept of sponge city construction. In the sponge city design, the water quantity and quality, potential landscape and ecological value of runoff are all comprehensively considered.

2.1.3. WSUD for Urban Water System Optimization in Australia

Around the technical core of urban stormwater management, Australia put forward the concept of WSUD in 1994 through a whole understanding of the water cycle in the local physical and environmental context [38,39]. It was also the first time that stormwater, groundwater, drinking water, sewage and reclaimed water system were comprehensively considered together. WSUD was described as "a philosophical approach to urban planning and design aimed at reducing the hydrological impact of urban development on the surrounding environment" [23]. It emphasized the consideration of stormwater management issues within an integrated framework of the entire urban water cycle [40]. Different with LID-BMPs, WSUD used integrated method to achieve stormwater management rather than only micro-scale landscape stormwater control [41]. All of these had a higher overlap with sponge city construction [42]. For example, the fragmentation of management and the discretization of related departments might hinder the evolution of WSUD. Thus, WSUD promoted urban water management through institutional construction and administrative measures to build a long-term mechanism for sustainable urban design [41]. As far as the sponge city construction is concerned, it is still necessary to learn from WSUD and conduct various studies to provide scientific construction guidance, including the runoff regulation capacity of different GIs, long-term tracking monitoring, and comprehensive performance evaluation [31,43–45]. All of these actions play a vital role in the development of sponge city construction and its promotion in the future.

2.2. Chinese Historical Inheritance

The idea of "natural storage, natural infiltration, and natural purification" in sponge city is derived from the wisdom of the ancient Chinese people using nature approaches to discharge and collect stormwater. As early as the Qin and Han dynasties (221 BC–220 CE), China began to build strip-shaped or wave-shaped terraced fields along the contour lines on the hills for farming [46]. This was also an effective measure for controlling soil erosion on sloping farmland. The terraced fields has been listed as a United Nations Educational, Scientific and Cultural Organization (UNSCEO) heritage since 2013 [47]. We can see that people in ancient times have been able to combine the living environment with the natural environment to realize the recycling of stormwater. In the settlement development, Chinese ancients also took advantage of natural power to harvest stormwater for utilization, to drainage stormwater for safety.

2.2.1. Ancient Stormwater System of Courtyards and Villages

The domestic studies on ancient Chinese drainage system are mostly including structure, composition, and operation mode. In China, the quadrangle is one of the most common buildings in ancient times, but the styles are slightly different to adapt local climate. The ancient wisdom and concepts contained in the ancient courtyard drainage system also can be a valuable reference for the current sponge city construction. In northern China, the rainfall depth is much less than that in the southern region. However, the rainfall is more turbulent, and the instantaneous rainfall intensity is stronger, which requires the drainage system to have a good drainage capacity. The quadrangles are all built with walls. Along these walls, flowers and trees are planted (Figure 1a), so that people can enjoy the natural scenery while utilizing rainwater. Usually, as the rain falling down the eaves, part of the runoff is absorbed on the permeable surface in the courtyard, and the rest is discharged out of the courtyard along the ditches into the drainage system.

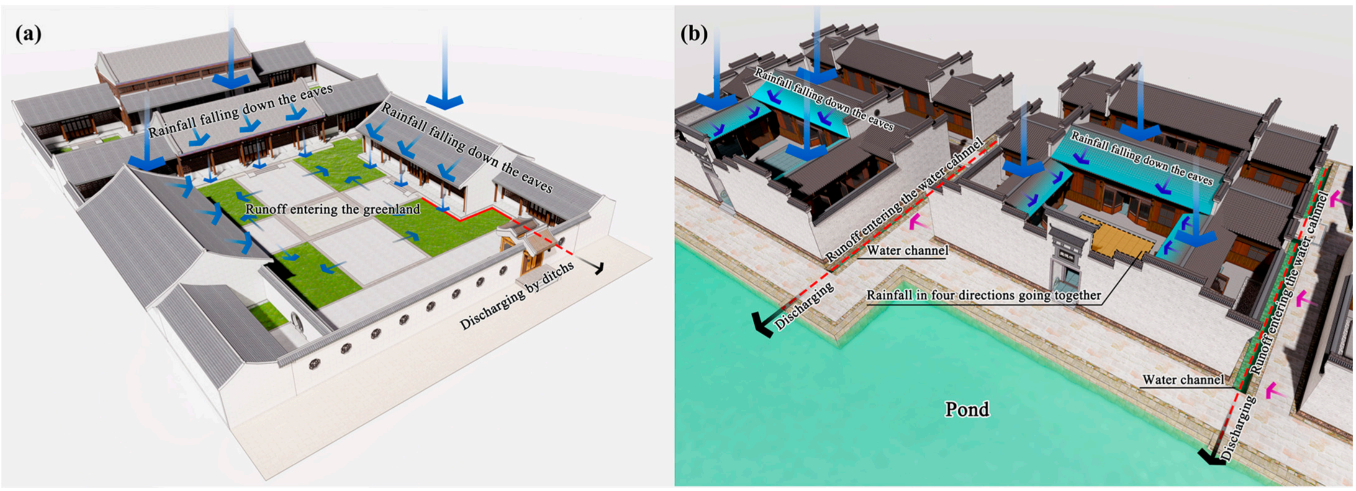

Figure 1. Drainage systems in ancient southern and northern China: (**a**) Typical courtyard buildings in northern China; (**b**) Ancient villages in southern China.

In the southern China, courtyard is more restrained and smaller compared with northern region due to the scarce land resources. Therefore, patios are often used as a substitute for courtyards. The average annual rainfall in the southern region exceeds 800 mm, which is generally higher than that in northern area.

Taking Hongcun which located at the south of Huangshan City, Anhui Province, as an example, it was built in the Southern Song Dynasty (1127–1279 CE) and was also selected as an UNESCO heritage. Based on historical records, Hongcun was unscathed and unaffected by heavy rainfall events in history [48,49]. The reason is that Hongcun includes a smart drainage system that combines storage and drainage facilities together, so that it can retain stormwater runoff on-site first and drain the extra stormwater to downstream water bodies safely. As can be seen in Figure 1b, when rainfall events occur, the stormwater is flowing down the eaves, entering the courtyard, and then drains into the river from the trenches around the patio. Thus, stormwater runoff in Hongcun can be merged into the channel and spread throughout the village. The runoff from the channel then flows into the pond for midway regulation and storage along the terrain, and finally flows into the receiving water body. Hongcun solves the problem of water shortage in the dry season and can reduce flood peaks and runoff flow volume through the rational use of channel, pond and receiving water body at the raining time. The villagers use part of the collected stormwater for production and living. In addition, the management system in Hongcun clearly states that domestic sewage water cannot be directly discharged into the channel and needs to be infiltrated through the soil. This measure ensures the water environment of the stormwater system is not affected by domestic sewage water.

There are also examples for larger areas to deal stemwater rationally, such as Ganzhou in Jiangxi province, China [48]. The urban drainage system of Ganzhou also make reasonable use of ditches, ponds and city walls to achieve source reduction and resource utilization of a large amount of runoff generated by rainfall events, and quickly discharge excess runoff into downstream receiving water bodies [50]. All of the above are good references for sponge city construction and modern stormwater management.

2.2.2. Ancient Drainage System of Architectural Complex

In addition to the smart stormwater management in courtyard and village, the stormwater system in architectural complex was also well designed in ancient China. Taking Tuancheng (Figure 2), Beijing, which was constructed during the Ming Dynasty (1368–1644 CE), as an example, its area is about 0.5 hectares with an average annual rainfall depth of 560 mm [48]. On 21 July 2012, Beijing suffered the extraordinary stormwater event in the past 60 years, with an average rainfall depth of 210.7 mm. According to data, approximately 1.602 million people were affected, and the economic loss was about 11.64 billion Yuan. However, the drainage system in Tuancheng was still in service, and there was no report of flooding there. In Tuancheng, there are no open ditches. The ground of Tuancheng is paved by bricks with good water permeability, and the shape of these bricks is an inverted trapezoid. When rainfall occurs, the stormwater runoff infiltrates into the ground through the gaps between adjacent bricks (Figure 2). When the runoff quantity is large enough that cannot be absorbed locally, it will flow into the surrounding water holes from north to south according to the terrain. The vertical shafts are directly below the water holes, and connected by culverts with a height of 80–150 cm. Therefore, the runoff flows into the water holes can be stored among the culverts, this design cleverly solves the local drainage problem, which can be used for reference when dealing with urban flooding issues.

There are countless historical sites similar to Tuancheng scattered in China, which contain extremely rich scientific and technological value. They are the concrete reflection of ancient scientific thinking, water culture, and technological progress. Besides, these architectures also embody the ingenuity of ancient people and demonstrate historical process of social science and technology development. Traditional culture is the source of modern culture. In order to better understand the modern urban stormwater management system, traditional culture must be learned. The historical site faithfully records the traditional way of stormwater utilization with high cohesion of traditional culture and is also a window for scholars to explore the symbiosis of human and water. At the same time, it provides the possibility for people to experience the broad, profound, and splendid traditional culture.

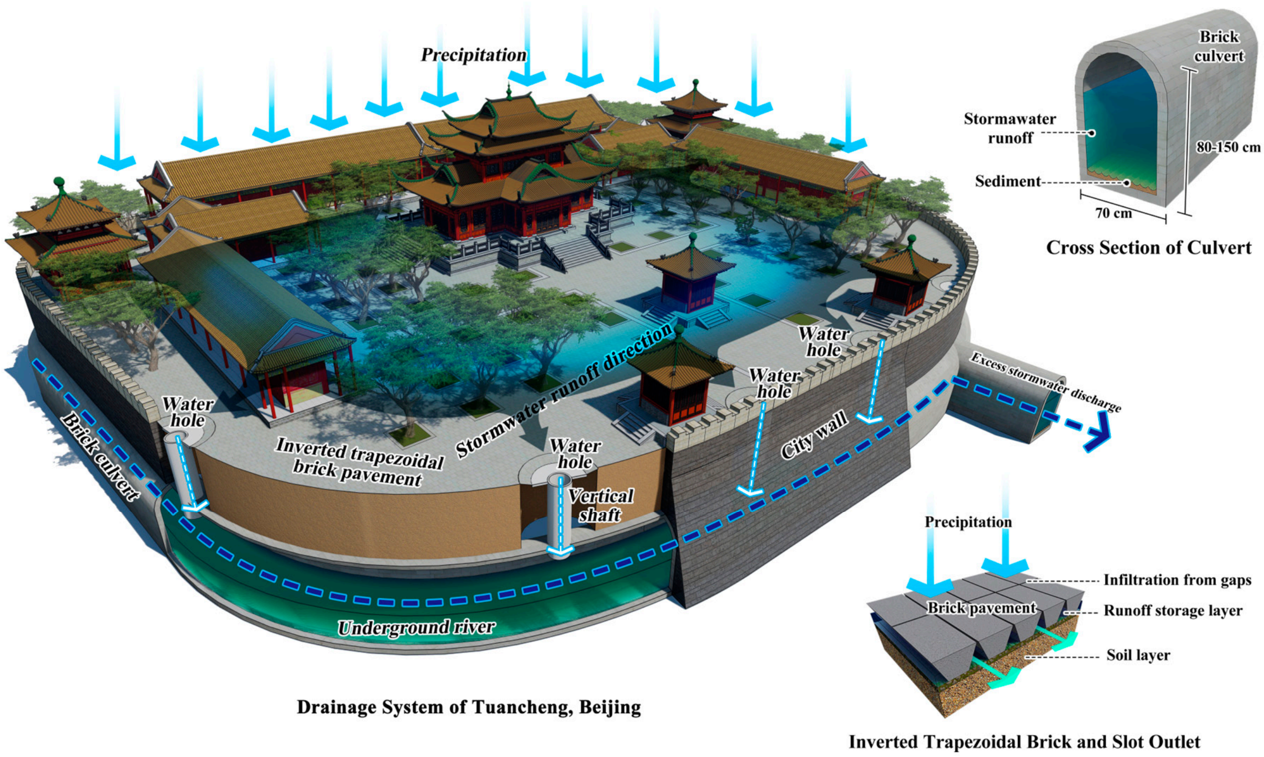

Figure 2. Typical ancient drainage system of Tuancheng, Beijing in northern region.

However, with the onset of rapid urbanization, some ancient drainage systems have been gradually replaced by a large number of engineering pipe systems in urban area which led to urban water quantity and quality issues. In order to avoid the aggravation of such problems, it is urgent to carry out sponge city constructions in urban area to reverse these kinds of situations.

3. Sponge City Pilot Exploration

3.1. Sponge City Construction Implementation Mode in China

Based on the several years' exploration of sponge city construction, the Chinese implementation mode was formed (Figure 3). In the implantation mode, the government carries the main responsibility. Central government acts as the promoter and local municipal governments are organizers of sponge city construction and management. Usually, a sponge city construction office or committee would be setup, which includes the officers from the related municipal bureau or agencies of urban planning, construction, landscaping, transportation, environment protection, water resources, and so on. The sponge city construction office or committee organizes all of the related issues on sponge city construction and management.

During the planning stage, all of the different levels of planning are oriented by technology. For overall city planning level, the concept and the target of sponge city construction should be included, and the implementation strategy should be proposed. For special planning level, the main principles focus on "flooding control, water environment improvement, water resources conservation and water ecology rehabilitation". The objectives are "no ponding in light rain, no flooding in heavy rain, no black and odorous urban water, and mitigating the heat island effect". The schemes which can meet the above objectives should be proposed related with infrastructure space layout, water system, green space and road system.

As of the design, construction and operation stage, the role of different stakeholders in sponge city construction are emphasized. The Public-Private Partnership (PPP) mode is encouraged. Typically, it involves private capital financing government projects and services up-front, and then drawing profits from taxpayers and/or users over the course of the PPP contract. In sponge city construction, usually the related projects are bundled up by municipal government and sign PPP contract with the qualified enterprises. The enterprise will have responsibility for design, construction, and operations.

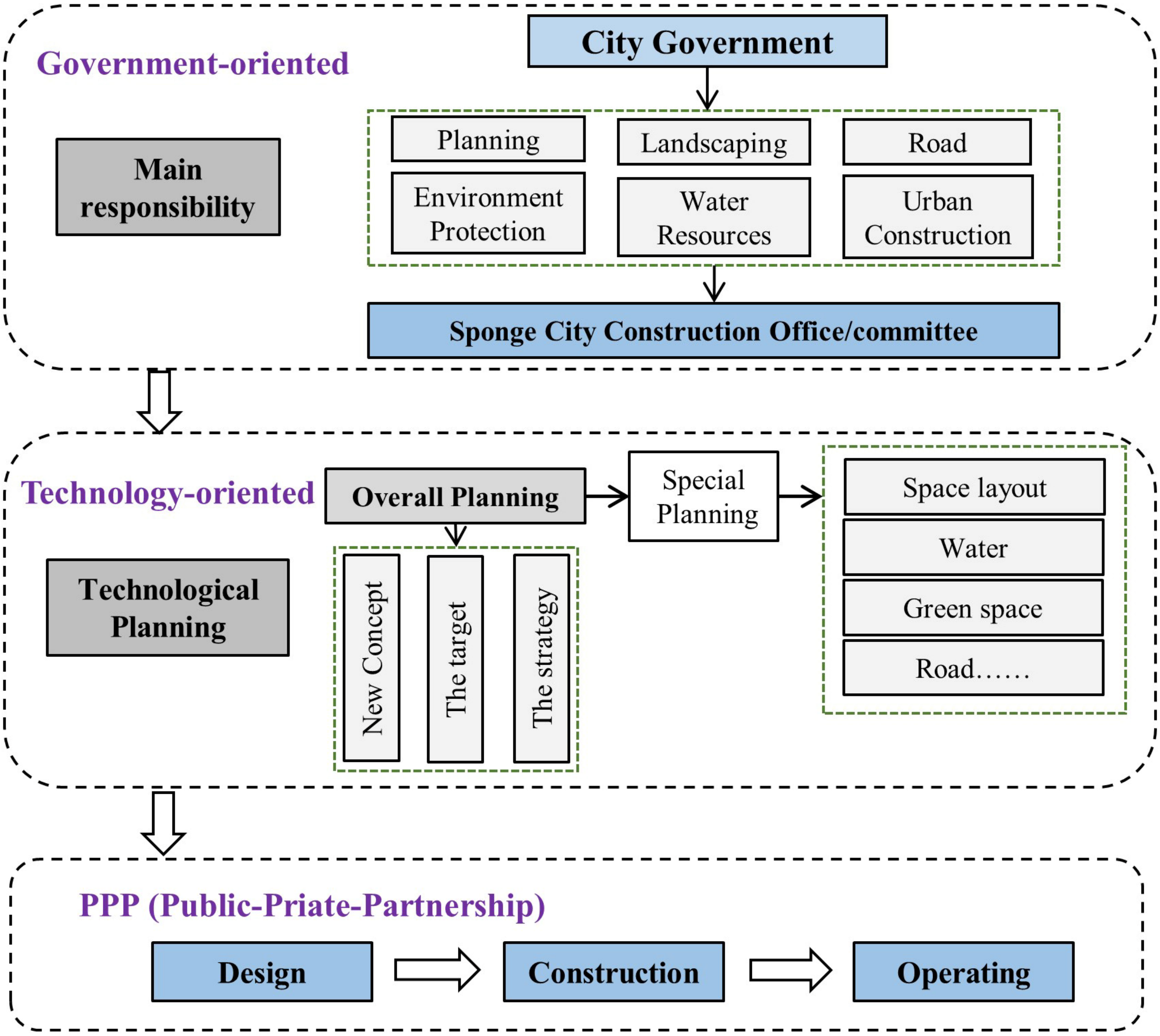

Figure 3. Chinese implementation mode of sponge city pilot construction.

3.2. National and Local Pilot Sponge Cities

To explore the specific development model of sponge cities construction in different regions of China, the Ministry of Finance (MF), the Ministry of housing and urban-rural development (MHURD) and the Ministry of water resources (MW) of China coordinately promoted the national pilot sponge cities construction. According to the characteristics of China's geographical climate, average annual rainfall, and urban development intensity, 30 cities were selected as national pilot sponge cities with different annual rainfall volume capture ratio targets in 2015 and 2016 (Figure 4). Each pilot city constructed a pilot region with no less than 15 km^2 in 3 years. The main task of pilot cities was to explore a development model which is suitable for the construction of sponge cities in the specific region, and to form a set of practices, experiences, policies, and systems which can be promoted in similar cities. In addition to the national pilot construction, provinces and cities have also carried out their own sponge city pilot construction. According to statistics, 13 provinces have carried out local pilot programs in 90 cities, 28 provinces have issued requirements of sponge city construction, and two-thirds of the cities in China have formulated special plans for sponge city construction [51].

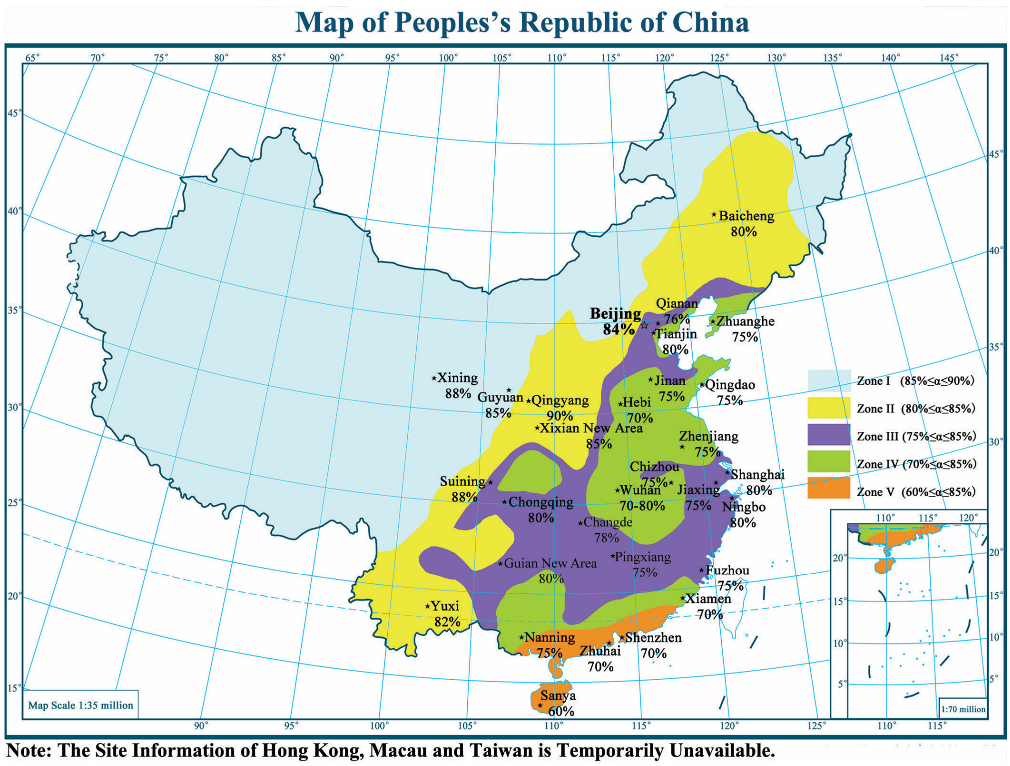

Figure 4. Location of 30 national pilot sponge cities in China (reprinted with permission from Ref. [13]. 2020, Haifeng Jia).

3.3. Achievements

The 30 national pilot sponge cities have passed the joint acceptance check of MHURD, MF, and MW in 2019. After summarizing the national pilot experiences and practices, it was found that many impressive achievements have been obtained.

3.3.1. Worldwide Influence

Sponge city has gained worldwide attention due to its innovative concepts, huge implementation plan and strong performance in improving water quality and controlling flooding situation. To strengthen the academic communication, there are many books, journal papers, international conferences, workshops, and other academic activities on sponge city. The most attractive international conferences are the 2016 International LID Conference held in Beijing and the 2018 International sponge city conference held in Xi'an. Statistical results showed that more than 1200 attendants from more than 20 countries and regions attended the 2016 International LID Conference, and more than 2000 attendants (more than 800 thousand persons online) attended the 2018 International sponge city conference. The internationally renowned journal, *Nature* and *Science*, also reported that sponge city is crucial for many cities which suffer severe flooding and water shortage [52,53]. These studies pointed out that the green sponge infrastructure should be combined with conventional drainage systems, particularly in areas of medium- and high intensity urbanization.

In recent years, related literatures have been rapidly growing. The literature of China National Knowledge Network (CNKI) from 1995 to 2021 showed that sponge city related (for example, sponge city, permeable pavement, low impact development, rain garden, LID, sunken green space, green roof) has reached more than 2000 papers. These papers cover engineering cases, reviews, experimental studies, planning schemes, efficiency evaluation, and so on. Moreover, many books, such as typical cases of sponge city construction, sponge city construction and operation technology system, theory and practice of urban sponge green space planning and design, etc. have been published to help people further understand sponge city [54–56].

The International Water Association (IWA) published many articles (for example, getting to Climate Resilient and Low Carbon Urban Water) about the performance of sponge city in controlling urban runoff and avoiding water scarcity. Major international journals, such as Water Research, Resources, Conservation & Recycling, Journal of Cleaner Production, Science of the Total Environment, Journal of Hydrology, Journal of Environmental Management, and etc. published a large number of papers which are related to sponge city [13,57–60].

3.3.2. Sponge City Performance

In recent years, a large amount of data on sponge city performance has been accumulated. However, these data have various sources, diverse formats, and uneven quality, making it difficult to fulfill relevant research and design needs directly. Thus, Xu et al. establishes a China sponge city database with a clear structure and convenient management schemes [61]. It includes facility size and cost information under various environmental conditions. At present, 1066 urban runoff source control facilities parameters from 30 pilot sponge cities are included in the database. The database can provide useful guidance information to other countries with similar environmental and fiscal conditions for the construction of urban runoff source control facilities.

Sponge city urban runoff source control facilities can achieve good water quality control performance. The average pollutant removal rates of urban runoff source control facilities are presented in Table 1. Results showed that these facilities have good removal performance in COD, SS, NH_3-N, TP, TN, Pb, and Zn.

Table 1. Pollutants average removal rate of urban runoff source control facilities (reprinted with permission from Ref. [51]. 2020, Changqing Xu).

Urban Runoff Source Control Facilities	**Pollutants Average Removal Rate (%)**						
	COD	**SS**	**NH_3-N**	**TP**	**TN**	**Pb**	**Zn**
Concaved green space	51.65	-	60.39	54.88	33	-	-
Constructed wetland	86.23	71.18	67.07	70.56	85.33	62.71	-
Bioretention	59.10	79.15	65.45	72	73.90	-	-
Permeable pavement	62	34.93	39	57	53	60	60
Detention pond	41.88	59.32	21.62	20.05	15	-	-
Buffer strip	77.97	90	-	85.11	69.93	-	-
Grassed swale	26.70	46.25	44.70	51.40	-	98	97

As mentioned before, the 30 national pilot sponge cities have passed the joint acceptance check by MHURD, MF, and MW. The 30 cities all achieved the pilot objectives of water environment, water ecology, water resources, and water security. For example, performance evaluation of sponge city construction in Qian'an city is good [62]. The scores of water resources, water security, water ecology and economic benefits are high, indicating Qian'an has made positive progress in rational utilization of water resources, water security, and economic benefits after sponge city implementation. Similar to Qian'an, Jiaxing's sponge city construction performance is at a "relatively high" level [63]. From the performance evaluation results, the sponge city construction in Jiaxing has achieved remarkable results, indicating the rationality and feasibility of its overall implementation plan and related policies. Specifically, the environmental performance, which includes water ecology, water environment and water resources indicators (for example, volume capture ratio of annual rainfall, groundwater level, water resource utilization rate, water environmental quality), has higher index weight coefficient than social performance and management performance. Therefore, Jiaxing should focus on the control of the above factors in the future construction of sponge city. The Science and Education Channel of China Central Television (CCTV-10) reported that Nanning City implemented permeable pavement, rain garden, green roof and other practices in sponge city pilot areas, these made Nakao River change from a gutter to an ecological wetland park. The citizens living in Nanning have experienced the significant positive changes in the urban water environment around them.

3.3.3. Education and Talent Training

To further promote the sponge city construction sustainably, strengthening professional expertise and social publicity are necessary. Apart from building information promotion platforms and implementing community demonstration projects, letting sponge city enter the campus and training sponge city talented people are key strategies. At present, there are some teaching materials (for example, Designing Our Sponge Community, Sponge Castle Adventure (primary school version), Sponge city Exploration (middle school version) and activities have been promoted in schools [64–66].

The comprehensive practice series instruction book "Designing Our Sponge Community" was based on the Primary Science Curriculum Standards for Compulsory Education issued by the Ministry of Education. This textbook becomes the "China's first STEAM (Science, Technology, Engineering, Arts, and Mathematics) project teaching guide for primary and secondary schools". Besides the textbooks, many schools launched activities to help students have a comprehensive understanding of sponge city and feel the great changes sponge city has brought to the city. In Suzhou, sponge city course taught on campus has aroused the students' interest in knowing the theory of sponge city. Field trips were organized to guide students to understand the design of bioretention, a permeable pavement, and a green roof etc. In Jinan, the students carry out some experiments in campus by themselves to help them better understand the principle and function of SPONGE CITY. In fact, the active promotion of sponge city construction allows everyone to develop an environmental protection and sustainable thinking mode.

Sponge city construction is a multi- and cross-disciplinary project that involve the majors of water supply and drainage engineering, environmental engineering, water conservancy engineering, urban planning, land use, landscape, transportation and ecology [67]. In the process of sponge city construction, close cooperation across all these disciplines is very important. Wide academic discussion and collaboration are needed. The summary of achievements, such as books, handouts, papers, atlas, manuals, and etc. are significant in education and talent training.

3.3.4. Public Awareness

As a national scale public project to address environmental issues, sponge city project is subject to public financial support and perception. Willingness to pay (WTP) is an effective tool to explore public behavioral intention and evaluate integrated benefits of a project. Wang et al. examined public perceptions of sponge city construction, as well as the public's willingness to support sponge cities in Zibo and Dongying City, Shandong Province [68]. A total of 1800 questionnaires were distributed with 900 each in Zibo and Dongying City, finally 1443 were valid returns. Results indicated that most respondents knew about sponge city projects and supported sponge city construction in residential areas. Respondents also accepted 17% of the domestic water price as a surcharge to be used for sponge city construction. Results also showed that educational level, income, and occupation were main factors affecting respondents' WTP to support sponge city initiatives. Wang et al. made a questionnaire survey in the flood affected communities with 656 respondents in Guyuan City [69]. Survey results showed that most respondents accepted an 8.3% surcharge of domestic water tariff for sponge city development. The results provide practical implications for government and developers to optimize financing and operation of sponge city developments and thus can improve the sustainable performance of sponge city.

During the process of sponge city construction, public dissent has arisen over the effectiveness of sponge cities, the most common dissent is "Omnipotence" and "Uselessness" of sponge city [70]. This is mainly because the public holds unrealistic expectations to the effect of sponge city construction, hoping to solve all water problems in one way, once and for all. In addition, some sponge city construction projects exaggerate the implementation effect in the early publicity, undoubtedly contributing to the public misjudgment. Besides, the public has a partial understanding of the nature of sponge city construction, thinking only source reduction LID facilities represent sponge city construction. Another reason is that the public only cares about sponge city construction projects when flooding occurs, and they are more concerned about the quality of outdoor built environment. Whether sponge facilities are effective depends largely on construction quality, which is consistent with the public's perception of built environment quality. For some sponge facilities, the poor engineering quality has been criticized for a long time. sponge city construction should focus on improving residents' well-being. Only when residents feel the urban water problem is alleviated and observe the improvement of living environment quality, can they support the continuation of more such work, and sponge city construction can be promoted systematically.

3.4. Some Lessons Learned

Although pilot sponge city construction presented much experience for future implementation, there are still some problems that need to be addressed. To further promote sponge city construction, the following lessons learned need to be emphasized.

3.4.1. Lacking Local Sponge City Technical Parameter for Planning & Design

The theory research and practice of urban runoff control in China started late. In the Technical Guide for Sponge city Construction issued in 2014, the definition, construction requirements, typical structures, scale calculation methods, usability, advantages, and disadvantages of individual facilities are given, but the descriptions are relatively simple and general. Urban runoff characteristics are very site-specific. In practice, the technical guide of sponge city should be formulated according to local conditions.

However, since sponge city practice has only begun in China in recent years, there are few literature reports on monitoring data of sponge city in the actual operation process, and most of them are for individual facilities. Domestic studies on optimization of design parameters of runoff control facilities are also in the initial stage, some of which are based on model simulation. For example, Xu et al. simulated optimization of design parameters of low impact development facilities on urban roads based on SWMM model [71]. Meng et al. used SWMM model to simulate the performance of grassed swale and found that the rainfall return period and slope ratio were negatively correlated with the hysteresis capacity of grassed swale [72].

Studies that analyzed the influence of design parameters on the effectiveness of runoff control facilities through experiments are also quite few. Only a few researchers made some attempts, such as Sang et al. used a green roof test device composed of six different substrates to conduct a simulated rainfall test, and found that the green roof composed of light materials had a better control effect on TN, and different substrates had obvious leaching loss of TP and COD [73]. According to the special environment of the red soil area in Southern China, Li optimized the design of the rain garden from the aspects of filler ratio, plant selection, internal water storage area setting, and obtained the appropriate filler ratio and plant type [74]. Zhang determined artificial rainfall parameters according to the special hydrological characteristics and water quality of Xuzhou, selected experimental groups with different ratio of cushion layer, base layer and permeable material, and compared the permeability of permeable pavements in different experimental groups [75].

Although many pilot cities had issued some so-called local guidelines, most lacked solid research but a copy of national technical guideline or foreign experience. Lacking in-depth analysis of design, monitoring, and performance evaluation system is a main issue in sponge city construction of China.

3.4.2. Lacking Professional Managers and Technicians

From the previous sponge city pilot construction experiences, many mistakes were caused by misunderstanding of sponge city. Many misconceptions still exist, for example, LID can solve all urban flooding problems, or LID is useless for flooding control. The main reason is that current education and training do not provide the necessary skills for designing and implementing sponge city. To successfully implement an sponge city project, knowledge from various disciplines is required. For example, planning/design of LID facilities would need skills in stormwater management, urban hydrology and hydraulics (scales from site to region and to watershed), water quality modeling, optimization techniques, landscaping, etc. However, the specific system education and outreach programs are still lacking in universities and colleges. Professional training is also missing.

To implement the sponge city construction nationwide smoothly, a large number of qualified professionals in all stages of sponge city construction are essential. Enough managers, planners, designers and construction workers are required to support this colossal initiative [52]. Firstly, there is a shortage of "specialized technicians" who can provide depth into a certain field. At present, sponge city construction is short of qualified professionals in every post, whether it is design, construction or operation and maintenance. Secondly, there is shortage of general managers who can carry out in-depth professional communication and realize the knowledge and technology links of various professional processes and fields. In future, as to various practices related to sponge city construction, the problems to be solved will become more complex. Cross-field and cross-professional team collaboration will become much more common. Therefore, it is necessary and urgent to strengthen interdisciplinary exchange and cooperation and cultivate comprehensive talents in professional education.

3.4.3. Lacking Policy Coordination

Sponge city is a new paradigm of urban construction and governance; it has multi-benefits in many aspects. Besides runoff control and water environment improvement, sponge city construction can alleviate the urban heat island effect and promote building energy consumption reduction. It also contributes to carbon dioxide reduction and is consistent with the China's "dual carbon" target. In context, nearly all of the policies are related and can impact each other. For example, design of the bioretention needs input from both stormwater and landscape architect professionals. Such a coordinated effort has not been the norm because the responsibilities for stormwater management and roadside vegetation management are belonging to different agencies. Currently, there are close coordination attempts among the key ministries (MHURC, MF and MWR) for implementing the sponge city plan at the national level. However, conflicts still exist among many current policies issued by difference ministries.

At the city level, many agencies are involved in sponge city construction, such as the urban planning, construction, water conservancy, and environment protection bureaus, etc. A smooth and efficient sponge city implementation requires a great effort for inter-agency coordination. To facilitate such efforts, some sponge city pilot cities have created the "Sponge city Offices," which include representatives from all bureaus related. However, during the real operation of the sponge city Offices, there are still many inconsistences exist because of a difference in interests and responsibility.

The normalization of sponge city construction needs to seek institutional breakthrough under the support of national and local policies. The kernel is the harmony among all of the related national and local technical standards and management regulations issued by different agencies. Therefore, it is important to review all of these current technical standards and management regulations. Then all the inconsistences and conflictions among them should be identified. After that, a cross-field and cross-professional team is needed to improve these standards and regulations.

4. Sponge City Systematic Demonstration

During the 14th Five-year Plan period (from 2021 to 2025) in China, the MF, MHURD, and MWR planned to facilitate systematic demonstrations at various "representative" cities. In 2021, 20 sponge city demonstration cities had been selected according to their basic conditions. For these selected sponge city demonstration cities, a fixed subsidy range from 700 million to 1.1 billion Yuan were provided by the central government [76]. Another 25 sponge city demonstration cities will be selected in 2022.

4.1. Multi Sponge City Scale Implementation

For the systematic sponge city demonstration, the focus of implementation strategies varies at different scales. The objectives, corresponding indicators, key contents and needs under difference construction scale are illustrated in Figure 5. The construction of sponge city is committed to comprehensively strengthen the flooding mitigation, the water environment improvement, the water resources recycling and the water ecology restoration. These four objectives can be quantified by several indicators, such as non-point source pollution control ratio and volume capture ratio. In order to achieve these goals, different engineering contents and requirements need to be implemented at various scales. Besides, in order to systematically establish and promote a long-term operation and maintenance mechanism for the overall construction period, demonstration cities should also make full use of the previous working experiences and achievements of sponge city pilot construction [76]. In this way, the sponge city strategy can be effectively implemented, thereby promoting the construction of national sponge cities to a new level. This section gives an overview of the engineering content and requirements that need to be performed at each scale.

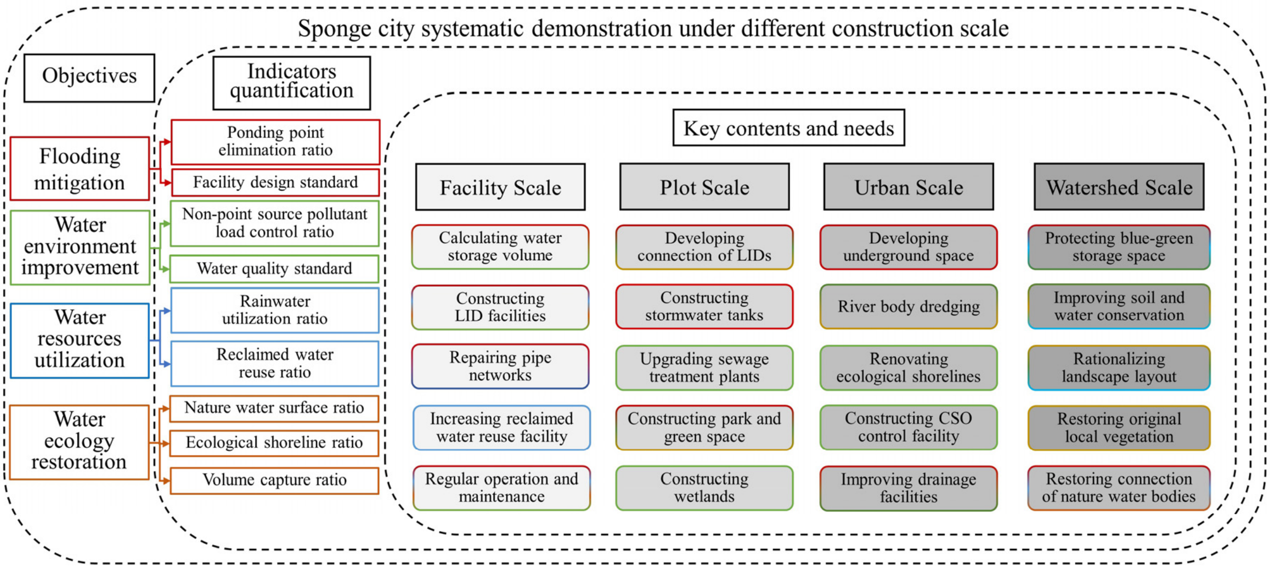

Figure 5. Objectives, indicators, key contents and needs for systematic demonstration of sponge city. Note: The colors of the boxes with different content and needs indicate that they can be used to improve the objectives or indicators under the same corresponding colors.

4.1.1. Facility Scale

The facilities mainly include green infrastructure (LID facilities at the source) such as rain gardens and green roofs, gray infrastructure (transit facilities at mid-way) such as drainage pipe networks and pumps, and blue infrastructure such as receiving water bodies (terminal storage facilities) [44]. The planning layout of green, gray and blue facilities should fully consider the needs of the storage volumes and how to deal with urban water issues [57]. Besides, the renovation and construction of drainage pipe networks should be coordinated with the construction of LID facilities to achieve better performance [77–79]. A full use of green and blue infrastructures is more sustainable and environmental-friendly, it also enhance the resilience of the drainage system [80]. Therefore, how to reconcile the proportion and scale of green-gray-blue infrastructures requires further analysis based on local conditions. Compared with flooding and water quality control, it is also important to increase unconventional water resources (rainwater and reclaimed water) utilization [81]. Currently at facility scale, the most common unconventional water reuse facilities in cities are rain barrels. Li showed that a 25.74 m^2 roof can bring potential benefits of about 1.0903 to 1.2474 million Yuan per year in an area with an annual rainfall depth of about 520 mm–600 mm [82]. Therefore, a lot of economic and environmental benefits can be brought about by rationally arranging rain barrels.

After the facility construction, it is necessary to conduct long-term real-time monitoring, operations, and maintenance of typical facilities for better understanding the relationship between facility capacity and multiple influencing factors [13,45,83,84]. The operation and maintenance of infrastructures is indispensable in sponge city construction. Better operation and maintenance methods can greatly improve the construction effect of sponge city [13]. The operation and maintenance management system of sponge city needs to clarify the operation and maintenance content, risk management, funding source and supervision method. To understand the operation status of a facility, monitoring data is essential. Therefore, the monitoring of typical infrastructures is very important for sponge city effect evaluation since it can provide real-time feedback on facilities' runoff control capacities [85]. the monitoring content of these facilities should include total runoff volume, peak flow, runoff pollution, soil medium infiltration rate, moisture content, and emptying time [86]. Besides, the monitoring data also can be used to calibrate and validate certain urban hydrologic and hydraulic models [87]. Only after the model has been calibrated and validated through monitoring data can it be used to evaluate the effectiveness of sponge city construction [45].

4.1.2. Plot Scale

At plot scale, how to improve the living environment through sponge city construction is one of the most important problems that need to be considered. Measures such as "infiltration, retention, storage, purification, utilization and discharge" should be fully implemented as a priority to solve the problem related to the stormwater and sewage networks [88]. Meanwhile, the vacant land in the plot also needs to be utilized to increase the public activity space, such as parks and green space. The land use types of the plots are mainly divided into community, commercial land, industrial land, green space, and square land.

Communities can be further divided into old and new communities [89,90]. The old community renewal is an important issue in the process of sponge city construction [88]. At present, the common renewal arrangement of old community is problem-oriented, putting residents' demands first to solve local specific problems. Taking an old community in Beijing, China as an example, the overall guiding ideology is to repair the old infrastructures and make full control of the runoff (Figure 6). In accordance with the concept of sponge city construction, the existing stormwater infrastructure were fully used to avoid excessive modification. According to the vertical terrain in the plot, the connection of different types of LID facilities, such as bioretention or sunken green spaces were designed, so that the runoff can be discharged in an organized manner. Meanwhile, the damaged infrastructure was renovated, and the road was reorganized. Some damaged roads or parking spaces were converted into a permeable pavement. Then, several small stormwater tanks were built to store excess stormwater runoff and reuse. It is easier to construct a new sponge community than an old one which is usually goal oriented. New communities often construct under strict sponge city target and combine with the district or city planning. For example, Beijing has incorporated the permeable area and storage volume requirements into local standards of newly built communities [91].

Industrial land is one of the main types of urban construction land and an important area for sponge city construction [92]. Distinct from residential areas, it typically has lower greening rates and a higher risk of runoff pollution. Therefore, the sponge city construction method should be different from that in communities. Firstly, green roofs can be used when the load requirements of building roofs are met. The green roof can not only absorb and store roof runoff and use the soil infiltration process to purify some pollutants, but also reduce the overall stormwater runoff coefficient of the underlying surface of the industrial site. This can reduce the intensity of stormwater discharge and slow down the speed of stormwater concentration. It should be noted that green roofs can only be built on flat roofs since sloping roof buildings with greater inclination may cause the structural layer of green roofs to slip [93]. As for the more polluted industrial land, sewage treatment plants or wetlands can be considered to use for regulation, storage and collection of initial stormwater.

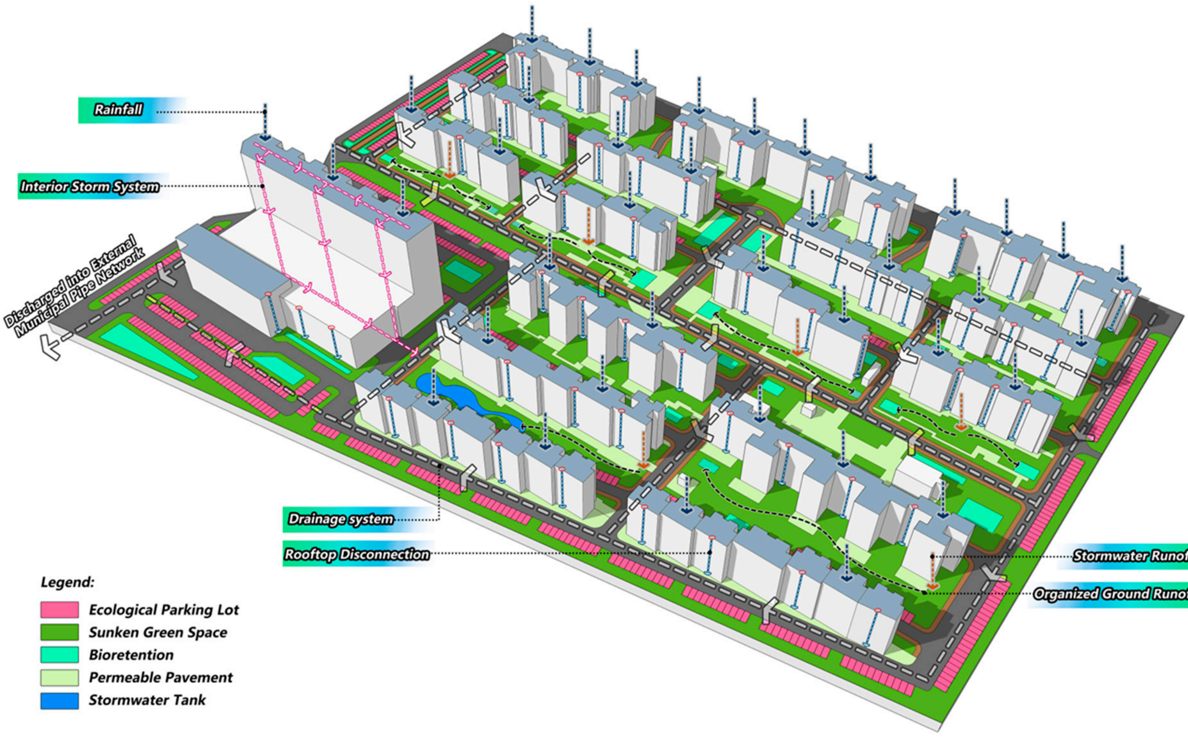

Figure 6. Community renovation under sponge city concept in Beijing, China.

With the continuous acceleration of economic development and urban expansion, commercial complexes have become an important part of urban construction. At present, commercial lands not only require to fully meet the needs of aesthetics and functions, but also needs to consider ecological functions, such as the effective use of natural resources and the promotion of the overall urban environment [94]. During sponge city construction, permeable pavements cannot be used in areas with high traffic loads, such as highways. However, they can be widely used in commercial pedestrian streets. It can not only increase the penetration rate of stormwater runoff, but also reduce the pollutants. In addition, it is also a good runoff control measure to build some high-level flower beds and ecological tree boxes in the commercial square. Although such a flower bed or tree box occupies a small area, its capacity to purify runoff should not be underestimated. The combined use of ecological tree boxes, permeable pavement and the municipal pipe network in the commercial land partly solves the contradiction between rapid discharge and sewage interception.

As for the land type of green and square space, their own conditions enable them to achieve better infiltration, retention, or storage of rainfall runoff than other types of plots. Therefore, for this type of plots, the requirements for runoff quantity and quality control capacity are higher than other types of plots in sponge city construction [18]. The main method is to combine green space, surrounding buildings and roads through vertical terrain adjustment, so that stormwater runoff can be absorbed locally. For the stormwater runoff that exceeds the storage capacity of the facility, it should be merged into the municipal stormwater pipe network through the transfer facilities.

To sum up, in the construction of sponge city at the plot scale, the joint utilizations of different types of green, gray and blue infrastructures can greatly improve the runoff quantity and quality control capacity and enhance people's satisfaction degree. Different types of plots need to be systematically arranged according to specific problems. With the construction of sponge cities in multiple plots, the sponge effect of the whole urban can be improved.

4.1.3. Urban Scale

At the urban scale, it is necessary to build an ecological, safe, and sustainable urban water circulation system to improve the overall level of water resources security, disaster prevention and mitigation capabilities. In the new and renewal projects of urban green space, buildings, roads, squares, etc., not only should various stormwater infiltration and storage facilities be constructed according to local conditions, but urban permeable pavement also need to be promoted to expand the urban permeable area.

The focus of flooding mitigation at the urban scale mainly focuses on the drainage system and the layout of LIDs [18]. Urban drainage system construction needs to be systematically managed on the premise of reducing external influences for the existing storage and drainage channels, such as the main rivers and lakes. Besides, such rivers and lakes are also the important link between the drainage facilities and the plot-scale sponge project [95]. The drainage capacity can be improved by means of diversion, interception, regulation, storage, etc., [96]. A proper GI layout needs to refine the sub-catchment of the region and achieve a certain degree of runoff reduction and drainage efficiency improvement through sponge projects at facilities and plot scale. It is also important to develop underground space in addition to the layout of LID facilities. Reasonable underground space construction can be used to store excess stormwater when a storm event occurs, and then slowly discharge or reuse it after the event.

The improvement of the urban water environment needs to be managed through a variety of engineering or non-engineering measures from two aspects: reduction of pollutants and sediment and increasing water environment capacity. Pollutants may come from urban non-point source pollution or combined sewer overflow (CSO) pollution, which can be alleviated by improving urban drainage facilities and constructing CSO control facilities [97,98]. The urgent need of sponge city construction at urban scale is to alleviate the urban non-point source pollution and CSO problems [18].

Moreover, regular dredging and ecological shoreline rehabilitation of urban rivers and lakes can be implemented for better water ecological restoration. Sediment dredging, however, aims to solve the problem of internal source pollution [99]. Through ecological shoreline rehabilitation, a diversified living environment and natural habitats for living things can be created. Many cities have carried out the transformation and restoration of ecological shorelines in the process of water ecological restoration. For example, during the pilot sponge city construction period, Wuhan, China has restored more than 50% of ecological shoreline. Besides, it is also essential to implement comprehensive management, monitoring, surveillance, and early warning of the ecological environment of the entire ecosystem to achieve better performance.

In addition, along with the global climate change, the frequent extreme storm and drought events have threatened human survival [13]. The consideration of climate change in sponge city construction is first reflected in the resilience of the city to control stormwater. Extreme rainfall events increase the drainage pressure of the city. The sponge city construction at the urban scale can reduce the threat of storm events to the city through the linkage of various green, gray, and blue infrastructures, so as to increase the resilience of the city. Another impact caused by climate change is UHI effect. Studies have shown that the larger the green area, the higher the temperature reduced by transpiration [100]. So, green infrastructures used in sponge city construction also can effectively alleviate the UHI effects [35]. Studies also found that green infrastructures such as green roofs can not only increase urban greening rates, but also reduce greenhouse gases [101]. The use of permeable pavements instead of impervious ground covers can also greatly reduce the UHI effect [102]. In the evaluation system of sponge city construction, the mitigation of UHI effect is also one of the important evaluation indicators.

4.1.4. Watershed Scale

At a watershed scale, it is necessary to aim at protecting nature blue-green storage space to build an ideal spatial pattern of landscape layout and improving connection of natural water bodies to increase the nature storage and drainage capacity. The spatial distribution of mountain, forest, field, river, lake, and grass needs to be accurately identified to protect the natural features. Besides, it is also important to improve soil and water conservation to protect the existing stormwater storage space and expand the natural storage space outside the urban built-up area.

Taking the capital city of Inner Mongolia Autonomous Region, Hohhot, as an example, an urban water system with healthy circulation has been constructed. First, the important ecological elements, such as surface water system and local vegetation in the watershed, are identified and protected. It is important to strengthen the connection of the natural water bodies and protect the blue-green storage space in the watershed to maximum the water storage and drainage capacity and, therefore, prevent flooding or non-point sources pollution. Secondly, considering the actual water shortage problems, the existing green space resources in Hohhot are fully utilized to build an LID system so that they maximize the utilization of stormwater resources. Then, by restoring the drainage pipe and pump networks, the current drainage system can be revitalized. Through the synergy of the above green, gray, and blue systems, a healthy and sustainable water resource utilization system can be created. Although the sponge city is promoted as a whole in the watershed, the natural and historical conditions of each area are different. It is very important to drive the overall construction of sponge city in the watershed through small typical demonstration areas. There are a total of 9 demonstration areas in Hohhot with an area of about 81.21 km^2.

On the whole, the sponge city construction at the watershed scale focuses more on the coordination of macroscopic blue-green storage spaces to improve water and soil resources conservation and enhance purification capabilities. The entire sponge city planning can provide mutual guidance and feedback to jointly ensure the healthy operation of the water system and, thus, maximize the overall benefits of the whole watershed.

4.2. The Roles of Different Stakeholders

In order to promote the sponge city construction in an orderly manner, the main responsibility of different stakeholders must be brought into full play (Figure 7). Stakeholders can be divided into promoters, implementers, and protectors. The central government act as the promotor. Currently, the related ministries of central government are changing their thinking and fully realizing that the sponge city is a new way of urban development. In the implementation stage, local governments, planners, designers, and constructors assume corresponding responsibilities, and no gaps should appear in each section. After the construction is completed, maintenance and the protection of the facilities by the public have also become the necessary conditions for the continuous and normal operation of various facilities in sponge city. This section discusses the obligations of each stakeholder.

Firstly, the central government has a guiding role in the formulation of planning ideas and the selection of directions. The central government has integrated the concept of sponge city into the process of urban planning and development to play an effective role in the work of systematically promoting sponge city construction since 2013. Besides, relevant policies were also issued since the central government can promote the construction and transformation of sponge city through policies and corresponding laws and regulations. Urban infrastructure is usually an important part of financial investment. Therefore, doing a good job in fundraising and investment control is of great significance for the sponge city construction. On the one hand, the central government absorbed social capital to participate in the sponge city construction, and on the other hand, it increased financial investment to ensure the smooth implementation of the project during sponge city construction. In terms of investment control, the central government strengthened not only the process control to ensure the normal payment of funds, but also the role of audit supervision to ensure the rational and efficient use of funds. National technical standards were also issued so that the concept and top-level design of sponge cities can be deeply rooted in the hearts of implementers and protectors. Finally, it is necessary to establish a sound supervision system for the whole process of sponge city construction to ensure that various problems can be discovered and solved in time.

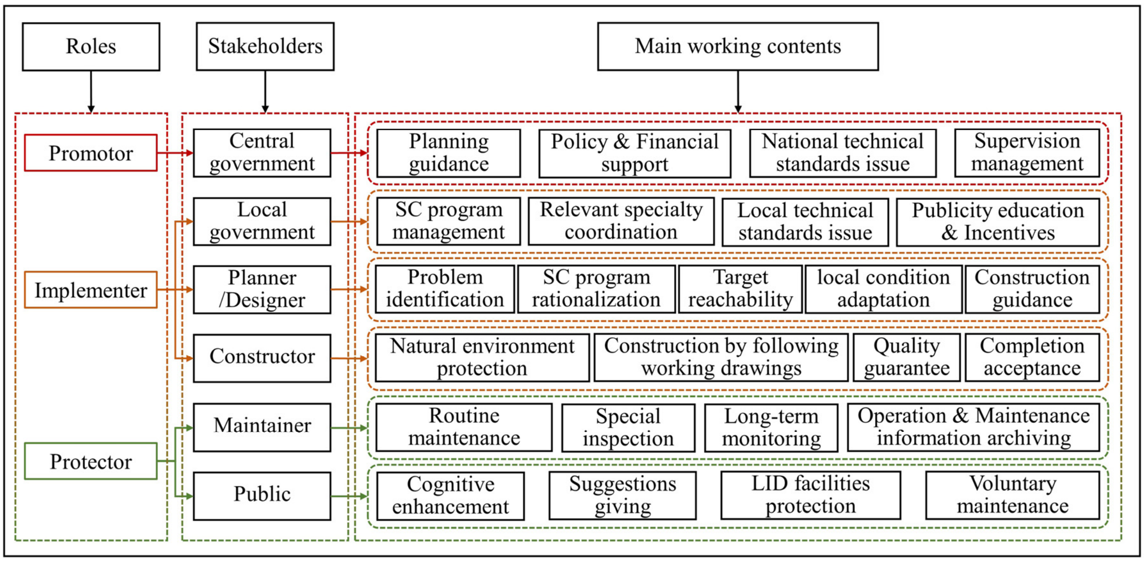

Figure 7. Main working contents for different stakeholders in sponge city construction.

Secondly, local governments, planners, designers, and constructors act as the implementers to construct sponge cities. Local governments formed a normalized sponge city program management and control workflow during the whole process including project establishment, planning, design, construction, acceptance and assessment, etc., so that relevant specialties can be better coordinated. Further, local governments also incorporated the compliance of sponge city construction into the local urban development performance assessment system and issued corresponding technical, management, and operation and maintenance standards adapted to their own regions on the premise of fully understanding the national technical standards. Carrying out publicity education activities and issuing corresponding incentives also played a positive role in the smooth development of sponge city construction. At the same time, local government explored diversified and multi-channel investment and financing modes, attracted social capital input, and encouraged relevant financial institutions to increase credit support for sponge city construction. It is also necessary to use demonstrative projects as a carrier for experience promotion for other regions and local citizens.

Planners and designers then fully identified the local problems before sponge city related planning and designing to ensure rationalization and adaptation of all sponge city programs. After completing the design scheme, it is also necessary to carefully analyze the feasibility. More importantly, planners and designs were supposed to guide construction scheme. Therefore, designers and constructors can coordinate and cooperate with each other to reduce conflicts. This requires designers to understand the actual situation of construction, listen to relevant opinions and suggestions humbly, and figure out if the design need improve, in order to make design economical and practical. Construction following design drawing was also one of the most important jobs because it was the embodiment of the designer's intention. After construction is completed, a systematic acceptance check was implemented.

Finally, maintainers carry out routine maintenance of the sponge city facilities, and special inspections were required for the key parts before and after the occurrence of storm. The operational effect of the facilities can be judged by long-term online or manual monitoring. According to long-term monitoring, facilities should be checked whether it meets the design requirements. If met, the next routine maintenance would continue as usual; if not, special maintenance would be required to make sure the design requirements are met [13]. In addition to relevant maintainers, public also needs to be brought into play to raise the awareness of sponge city construction, and then, guiding them to develop environmental-friendly living habits, and mobilizing the enthusiasm of all social parties to participate in sponge city construction. In daily life, the public strived to improve their own cognition, strengthened their awareness of environmental protection, and actively participated in the construction of sponge cities. At present, many people live in the sponge city renovated communities have already benefited from sponge city construction. Besides, the public can also protect the facilities in the community, for example, no littering, trampling on the lawn, and not destroying the sponge city facilities, etc. At the same time, public can also carry out voluntary activities spontaneously or in an organized manner to help maintaining the facilities in the community.

In summary, the sponge city construction is a large program, which also involving many fields, and it needs the joint efforts of many parties to achieve better results. Only on the premise that all stakeholders enhance their sense of responsibility and strengthen organizational management, it is possible to promote systematic demonstration of sponge city.

5. Conclusions

With the national scale exploration of sponge city pilot projects, we have summarized experiences and lessons learned to help improve future sponge city implementation. The sponge city initiative has made some achievements so far, in the long-term, it still needs more efforts in the urban water system management. Future directions can be summarized as follow:

Increasingly serious water security, water ecology and water environment problems add much more pressure to the traditional gray engineering infrastructure. Sponge city construction (specifically refers to green infrastructures), in some extent, can alleviate part of pressure on traditional gray infrastructure. However, when considering safety during extreme storm events, traditional gray infrastructures is still an essential part in sponge city construction. Appropriately controlling construction scale of gray infrastructure is necessary to avoid excessive artificial interference to the ecological environment. Accordingly, the green and gray infrastructures should be coupled to play an effective role in urban water system management.

Many studies reported that sponge city performed well in flood control, stormwater harvesting, and water quality purification. However, sponge city implementation includes many stages (for example, production and transportation of raw materials, operation, maintenance, labor, and decommissioning). Each stage can have different environmental and economic impacts or benefits. To provide useful and reliable information for policy- and decision-makers with regard to sponge city construction, a quantitative evaluation for both environmental and economic burdens through life cycle perspective is highly needed.

A large amount of data has been accumulated during the implementation phase of sponge city in recent years. To effectively organize, store, and apply these datasets in the assessment of urban runoff control is a great challenge.

Author Contributions: Writing—Original Draft Preparation, D.Y., C.X. and H.J. Writing—Review & Editing, D.Y., C.S., Y.Y., Q.W. and S.L.; Supervision, H.J.; Funding Acquisition, C.X. and H.J. All authors have read and agreed to the published version of the manuscript.

Funding: This work was funded by China Postdoctoral Science Foundation (Grant No. 2021M691769), Shuimu Scholar Programme of Tsinghua University (No. 2019SM125), and the National Nature Science Foundation of China (Grant No. 52070112 and 41890823). The research is also supported by Ningxia Hui Autonomous Region Key R&D Project "Research and Demonstration of Key Technologies of Full Digital Water Control Based on Water Network" (2020BCF01002) and the GEF Hai Basin Integrated Water and Environment Management Project (GEF ID 5561/WB ID P145897).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Jiang, C.; Li, J.; Liu, J. Does urbanization affect the gap between urban and rural areas? Evidence from China. *Socio-Economic Plan. Sci.* 2022, *101271*. *in process*. [CrossRef]
2. Yin, D.; Evans, B.; Wang, Q.; Chen, Z.; Jia, H.; Chen, A.S.; Fu, G.; Ahmad, S.; Leng, L. Integrated 1D and 2D model for better assessing runoff quantity control of low impact development facilities on community scale. *Sci. Total Environ.* **2020**, *720*, 137630. [CrossRef] [PubMed]
3. Wu, J.; Cheng, D.; Xu, Y.; Huang, Q.; Feng, Z. Spatial-temporal change of ecosystem health across China: Urbanization impact perspective. *J. Clean. Prod.* **2021**, *326*, 129393. [CrossRef]
4. Xu, C.; Jia, M.; Xu, M.; Long, Y.; Jia, H. Progress on environmental and economic evaluation of low-impact development type of best management practices through a life cycle perspective. *J. Clean. Prod.* **2018**, *213*, 1103–1114. [CrossRef]
5. Cheng, M.; Qin, H.; Fu, G.; He, K. Performance evaluation of time-sharing utilization of multi-function sponge space to reduce waterlogging in a highly urbanizing area. *J. Environ. Manag.* **2020**, *269*, 110760. [CrossRef]
6. Pumo, D.; Arnone, E.; Francipane, A.; Caracciolo, D.; Noto, L.V. Potential implications of climate change and urbanization on watershed hydrology. *J. Hydrol.* **2017**, *554*, 80–99. [CrossRef]
7. Mei, C.; Liu, J.; Wang, H.; Yang, Z.; Ding, X.; Shao, W. Integrated assessments of green infrastructure for flood mitigation to support robust decision-making for sponge city construction in an urbanized watershed. *Sci. Total Environ.* **2018**, *639*, 1394–1407. [CrossRef]
8. Guan, X.; Wang, J.; Xiao, F. Sponge city strategy and application of pavement materials in sponge city. *J. Clean. Prod.* **2021**, *303*, 127022. [CrossRef]
9. Liu, K.; Li, X.; Wang, S. Characterizing the spatiotemporal response of runoff to impervious surface dynamics across three highly urbanized cities in southern China from 2000 to 2017. *Int. J. Appl. Earth Obs. Geoinf. ITC J.* **2021**, *100*, 102331. [CrossRef]
10. Mahmoud, S.; Gan, T.Y. Urbanization and climate change implications in flood risk management: Developing an efficient decision support system for flood susceptibility mapping. *Sci. Total Environ.* **2018**, *636*, 152–167. [CrossRef]
11. Chan, F.K.S.; Griffiths, J.A.; Higgitt, D.; Xu, S.; Zhu, F.; Tang, Y.-T.; Xu, Y.; Thorne, C.R. "Sponge city" in China—A breakthrough of planning and flood risk management in the urban context. *Land Use Policy* **2018**, *76*, 772–778. [CrossRef]
12. Qi, Y.; Chan, F.K.S.; Griffiths, J.; Feng, M.; Sang, Y.; O'Donnell, E.; Hutchins, M.; Thadani, D.R.; Li, G.; Shao, M.; et al. Sponge city Program (SCP) and Urban Flood Management (UFM)—The Case of Guiyang, SW China. *Water* **2021**, *13*, 2784. [CrossRef]
13. Yin, D.; Chen, Y.; Jia, H.; Wang, Q.; Chen, Z.; Xu, C.; Li, Q.; Wang, W.; Yang, Y.; Fu, G.; et al. Sponge city practice in China: A review of construction, assessment, operational and maintenance. *J. Clean. Prod.* **2020**, *280*, 124963. [CrossRef]
14. Wang, C.; Hou, J.; Miller, D.; Brown, I.; Jiang, Y. Flood risk management in sponge cities: The role of integrated simulation and 3D visualization. *Int. J. Disaster Risk Reduct.* **2019**, *39*, 101139. [CrossRef]
15. Hasan, H.H.; Razali, S.F.M.; Zaki, A.Z.I.A.; Hamzah, F.M. Integrated Hydrological-Hydraulic Model for Flood Simulation in Tropical Urban Catchment. *Sustainability* **2019**, *11*, 6700. [CrossRef]
16. Li, J.; Zhang, B.; Mu, C.; Chen, L. Simulation of the hydrological and environmental effects of a sponge city based on MIKE FLOOD. *Environ. Earth Sci.* **2018**, *77*, 32. [CrossRef]
17. MHURD. *Technical Guide for Sponge Cities-Construction of Low Impact Development*; China Architecture Publishing & Media Co., Ltd.: Beijing, China, 2014.
18. MHURD. *Assessment Standard for Sponge city Effect*; China Architecture Publishing & Media Co., Ltd.: Beijing, China, 2019.
19. Jia, H.; Yin, D. Green Infrastructure for Stormwater Runoff Control in China. In *Oxford Research Encyclopedia of Environmental Science*; Oxford University Press: Oxford, UK, 2021. [CrossRef]
20. Fletcher, T.D.; Shuster, W.; Hunt, W.F.; Ashley, R.; Butler, D.; Arthur, S.; Trowsdale, S.; Barraud, S.; Semadeni-Davies, A.; Bertrand-Krajewski, J.-L.; et al. SUDS, LID, BMPs, WSUD and more—The evolution and application of terminology surrounding urban drainage. *Urban Water J.* **2015**, *12*, 525–542. [CrossRef]
21. DoER. *Low Impact Development Design Strategies: An Integrated Design Approach*; U.S. Environmental Protection Agency: Washington, DC, USA, 1999.
22. Woods-Ballard, B.; Kellagher, K.; Martin, P.; Jefferies, C.; Bray, R.; Shaffer, P. *The SUDS Manual*; CIRIA: London, UK, 2007.

23. Lloyd, S.D.; Tony, H.F.W.; Chesterfield, C.J. *Water Sensitive Urban—A Stormwater Management Perspective*; Cooperative Research Centre for Catchment Hydrology: Melbourne, Australia, 2002.
24. European Commission. Policy Topics: Nature-Based Solutions. Available online: https://ec.europa.eu/research/environment/index.cfm?Pg=nbs (accessed on 21 April 2017).
25. Yang, Z.; Li, J.; Wang, W.; Che, W.; Ju, C.; Zhao, Y. The advanced recognition of low impact development and sponge city construction. *Environ. Eng.* **2020**, *38*, 10–15. (In Chinese) [CrossRef]
26. Keller, B.D. Griffin, Georgia's Stormwater Utility "A Non Structural Best Management Practice (BMP)". In Proceedings of the 1999 Georgia Water Resources Conference, the University of Georgia, Athens, Georgia, 30–31 March 1999.
27. Jia, H.; Yao, H.; Yu, S.L. Advances in LID BMPs research and practice for urban runoff control in China. *Front. Environ. Sci. Eng.* **2013**, *7*, 709–720. [CrossRef]
28. Riechel, M.; Matzinger, A.; Pallasch, M.; Joswig, K.; Pawlowsky-Reusing, E.; Hinkelmann, R.; Rouault, P. Sustainable urban drainage systems in established city developments: Modelling the potential for CSO reduction and river impact mitigation. *J. Environ. Manag.* **2020**, *274*, 111207. [CrossRef]
29. Eckart, K.; McPhee, Z.; Bolisetti, T. Performance and implementation of low impact development—A review. *Sci. Total Environ.* **2017**, *607–608*, 413–432. [CrossRef] [PubMed]
30. Lim, H.S.; Lim, W.; Hu, J.Y.; Ziegler, A.; Ong, S.L. Comparison of filter media materials for heavy metal removal from urban stormwater runoff using biofiltration systems. *J. Environ. Manag.* **2015**, *147*, 24–33. [CrossRef] [PubMed]
31. Gong, Y.; Yin, D.; Li, J.; Zhang, X.; Wang, W.; Fang, X.; Shi, H.; Wang, Q. Performance assessment of extensive green roof runoff flow and quality control capacity based on pilot experiments. *Sci. Total Environ.* **2019**, *687*, 505–515. [CrossRef]
32. Zubelzu, S.; Rodríguez-Sinobas, L.; Andrés-Domenech, I.; Castillo-Rodríguez, J.; Perales-Momparler, S. Design of water reuse storage facilities in Sustainable Urban Drainage Systems from a volumetric water balance perspective. *Sci. Total Environ.* **2019**, *663*, 133–143. [CrossRef] [PubMed]
33. Johnson, D.; Geisendorf, S. Are Neighborhood-level SUDS Worth it? An Assessment of the Economic Value of Sustainable Urban Drainage System Scenarios Using Cost-Benefit Analyses. *Ecol. Econ.* **2019**, *158*, 194–205. [CrossRef]
34. Joshi, P.; Leitão, J.P.; Maurer, M.; Bach, P.M. Not all SuDS are created equal: Impact of different approaches on combined sewer overflows. *Water Res.* **2020**, *191*, 116780. [CrossRef] [PubMed]
35. Li, J.; Gong, Y.; Li, X.; Yin, D.; Shi, H. Urban stormwater runoff thermal characteristics and mitigation effect of low impact development measures. *J. Water Clim. Chang.* **2018**, *10*, 53–62. [CrossRef]
36. Guptha, G.C.; Swain, S.; Al-Ansari, N.; Taloor, A.K.; Dayal, D. Assessing the role of SuDS in resilience enhancement of urban drainage system: A case study of Gurugram City, India. *Urban Clim.* **2022**, *41*, 101075. [CrossRef]
37. Maqbool, R.; Wood, H. Containing a sustainable urbanized environment through SuDS devices in management trains. *Sci. Total Environ.* **2021**, *807*, 150812. [CrossRef]
38. Sharma, A.K.; Cook, S.; Tjandraatmadja, G.; Gregory, A. Impediments and constraints in the uptake of water sensitive urban design measures in greenfield and infill developments. *Water Sci. Technol.* **2012**, *65*, 340–352. [CrossRef]
39. Tjandraatmadja, G. Chapter 5—The Role of Policy and Regulation in WSUD Implementation. In *Approaches to Water Sensitive Urban Design*; Sharma, A.K., Gardner, T., Begbie, D., Eds.; Woodhead Publishing: Cambridge, UK, 2019; pp. 87–117.
40. Wong, T.H.F. Water sensitive urban design—The journey thus far. *Australas. J. Water Resour.* **2006**, *10*, 213–222. [CrossRef]
41. Liu, D. A Comparative Research on LID and WSUD from the Perspective of Rainwater Management. *Archit. Cult.* **2021**, 93–96. (In Chinese) [CrossRef]
42. Sun, X.; Qin, H.; Lu, W. Evolution of Water Sensitive Urban Design in Australia and Its Enlightenment to Sponge city. *Chin. Landsc. Archit.* **2019**, *35*, 67–71. (In Chinese) [CrossRef]
43. Mitchell, V.; Deletic, A.; Fletcher, T.; Hatt, B.; McCarthy, D. Achieving multiple benefits from stormwater harvesting. *Water Sci. Technol.* **2007**, *55*, 135–144. [CrossRef] [PubMed]
44. Leng, L.; Mao, X.; Jia, H.; Xu, T.; Chen, A.S.; Yin, D.; Fu, G. Performance assessment of coupled green-grey-blue systems for Sponge city construction. *Sci. Total Environ.* **2020**, *728*, 138608. [CrossRef] [PubMed]
45. Yin, D.; Chen, Z.; Yang, M.; Jia, H.; Xu, K.; Wang, T. Evaluation of runoff control effect in sponge city construction based on online monitoring + simulation modeling. *Environ. Eng.* **2020**, *38*, 151–157. (In Chinese) [CrossRef]
46. Zhang, Y. *Inspiration from Traditional Wisdom of Rainwater Utilization to Contemporary Urban Landscape Design*; Nanchang University: Nanchang, China, 2018. (In Chinese)
47. UNSCEO. Honghe Hani Rice Terraces Inscribed on UNESCO's World Heritage alongside an Extension to the uKhahlamba Drakensberg Park. Available online: https://www.unesco.org/en/articles/honghe-hani-rice-terraces-inscribed-unescos-world-heritage-alongside-extension-ukhahlamba (accessed on 22 June 2013).
48. Cun, C.; Zhang, W.; Che, W.; Sun, H. Review of urban drainage and stormwater management in ancient China. *Landsc. Urban Plan.* **2019**, *190*, 103600. [CrossRef]
49. UNSCEO. Ancient Villages in Southern Anhui-Xidi and Hongcun. Available online: https://whc.unesco.org/en/list/1002 (accessed on 30 November 2020).
50. Xu, Y.-S.; Shen, S.-L.; Lai, Y.; Zhou, A.-N. Design of sponge city: Lessons learnt from an ancient drainage system in Ganzhou, China. *J. Hydrol.* **2018**, *563*, 900–908. [CrossRef]

51. Xu, C. *Research on Life-Cycle Environmental and Economic Benefits Assessment of Sponge city Source Control Facilities*; Tsinghua University: Beijing, China, 2020.
52. Liu, D. China's sponge cities to soak up rainwater. *Nature* **2016**, *537*, 307. [CrossRef]
53. Larsen, T.A.; Hoffmann, S.; Lüthi, C.; Truffer, B.; Maurer, M. Emerging solutions to the water challenges of an urbanizing world. *Science* **2016**, *352*, 928–933. [CrossRef]
54. Zhang, L. *Typical Cases of Sponge city Construction*; China Architecture Publishing: Beijing, China, 2017.
55. Huang, M.; Shen, R.; Yan, D.; Huo, D. *Sponge City Construction and Operation Technology System*; China Architecture Publishing: Beijing, China, 2019.
56. Xu, H. *Theory and Practice of Urban Sponge Green Space Planning and Design*; Southeast University Press: Nanjing, China, 2021.
57. Jia, H.; Liu, Z.; Xu, C.; Chen, Z.; Zhang, X.; Xia, J.; Yu, S.L. Adaptive pressure-driven multi-criteria spatial decision-making for a targeted placement of green and grey runoff control infrastructures. *Water Res.* **2022**, *212*, 118126. [CrossRef] [PubMed]
58. Liu, Z.; Xu, C.; Xu, T.; Jia, H.; Zhang, X.; Chen, Z.; Yin, D. Integrating socioecological indexes in multiobjective intelligent optimization of green-grey coupled infrastructures. *Resour. Conserv. Recycl.* **2021**, *174*, 105801. [CrossRef]
59. Xu, C.; Tang, T.; Jia, H.; Xu, M.; Xu, T.; Liu, Z.; Long, Y.; Zhang, R. Benefits of coupled green and grey infrastructure systems: Evidence based on analytic hierarchy process and life cycle costing. *Resour. Conserv. Recycl.* **2019**, *151*, 104478. [CrossRef]
60. Zhu, Y.; Xu, C.; Yin, D.; Xu, J.; Wu, Y.; Jia, H. Environmental and economic cost-benefit comparison of sponge city construction in different urban functional regions. *J. Environ. Manag.* **2021**, *304*, 114230. [CrossRef]
61. Xu, C.; Shi, X.; Jia, M.; Han, Y.; Zhang, R.; Ahmad, S.; Jia, H. China Sponge city database development and urban runoff source control facility configuration comparison between China and the US. *J. Environ. Manag.* **2021**, *304*, 114241. [CrossRef]
62. Chen, Z.; Tang, Q.; Liang, C. Performance Evaluation of Sponge city Construction in Qian'an City. *Hebei Province Water Conservancy* **2021**, 33–37. (In Chinese)
63. Cao, D.; Wei, Y.; Xu, R.; Chen, Q. Performance Evaluation of sponge city Construction—A case study of Jiaxing City. Spatial Governance for High-quality Development. In Proceedings of the 2021 China Urban Planning Annual Conference (08 Urban Ecological Planning), Chengdu, China, 25–30 September 2021. [CrossRef]
64. Cheng, J.; Wang, Y.; Guo, X. *Sponge Castle Adventure*; Jinan Publishing Press: Jinan, China, 2017.
65. Cheng, J. *Sponge city Exploration*; Jinan Publishing Press: Jinan, China, 2017.
66. Lu, H.; Chen, Y.W. *Design Our Sponge Community*; Shanghai Education Press: Jinan, China, 2018.
67. Zhang, W.; Che, W. Connotation and multi-angle analysis of sponge city construction. *Water Resour. Prot.* **2016**, *32*, 19–26. (In Chinese)
68. Wang, Y.; Sun, M.; Song, B. Public perceptions of and willingness to pay for sponge city initiatives in China. *Resour. Conserv. Recycl.* **2017**, *122*, 11–20. [CrossRef]
69. Wang, Y.; Liu, X.; Huang, M.; Zuo, J.; Rameezdeen, R. Received vs. given: Willingness to pay for sponge city program from a perceived value perspective. *J. Clean. Prod.* **2020**, *256*, 120479. [CrossRef]
70. She, N.; Xie, Y.; Li, D. Reflections and Suggestions on China's Sponge city Construction. *Landsc. Archit. Front.* **2021**, *9*, 82–91. (In Chinese)
71. Xu, P.; He, J.; Ren, X.; Tang, Z.; Zhang, Y.; Huang, J. Optimization of LID facility design parameters of urban roads based on SWMM. *Water Resour. Power* **2016**, *34*, 21–25. (In Chinese)
72. Meng, Y.; Chen, M.; Zhang, S. Experiment and simulation of stagnant Stormwater storage in urban road by planting grass ditch. *Adv. Water Sci.* **2018**, *29*, 32–40. (In Chinese)
73. Sang, M.; Zhang, W.; Zhong, X. Effects of common substrates on water quality characteristics of rainwater retention and outflow of extensive green roofs. *Water Conserv. Hydropower Technol.* **2018**, *49*, 166–173. (In Chinese)
74. Li, Y. *Research on Design OPTIMIZATION and Application of Rain Garden in Red Soil Region of South China*; Nanchang University: Nanchang, China, 2017.
75. Zhang, W. Test on permeable pavement technology of sponge green space. *Hortic. Abstr. China* **2018**, *34*, 37–39. (In Chinese)
76. MF. *Notice on Carrying Out Demonstration Work of Systematic Global Promotion of Sponge City Construction*; Ministry of Finance: Beijing, China, 2021.
77. Leng, L.; Jia, H.; Chen, A.S.; Zhu, D.Z.; Xu, T.; Yu, S. Multi-objective optimization for green-grey infrastructures in response to external uncertainties. *Sci. Total Environ.* **2021**, *775*, 145831. [CrossRef]
78. Chen, W.; Wang, W.; Huang, G.; Wang, Z.; Lai, C.; Yang, Z. The Capacity of Grey Infrastructure in Urban Flood Management: A Comprehensive Analysis of Grey Infrastructure and the Green-Grey Approach. *Int. J. Disaster Risk Reduct.* **2021**, *54*, 102045. [CrossRef]
79. Bakhshipour, A.E.; Dittmer, U.; Haghighi, A.; Nowak, W. Hybrid green-blue-gray decentralized urban drainage systems design, a simulation-optimization framework. *J. Environ. Manag.* **2019**, *249*, 109364. [CrossRef]
80. Fu, X.; Hopton, M.E.; Wang, X. Assessment of green infrastructure performance through an urban resilience lens. *J. Clean. Prod.* **2020**, *289*, 125146. [CrossRef]
81. Karimidastenaei, Z.; Avellán, T.; Sadegh, M.; Kløve, B.; Haghighi, A.T. Unconventional water resources: Global opportunities and challenges. *Sci. Total Environ.* **2022**, *827*, 154429. [CrossRef]
82. Li, F. *Comprehensive Benefit Evaluation of Roof Rainwater Reuse System Based on the Perspective of Sponge city—A Case Analysis in Fengxixincheng District*; Xi'an University of Architecture and Technology: Xi'an, China, 2021.

83. Razzaghmanesh, M.; Borst, M. Monitoring the performance of urban green infrastructure using a tensiometer approach. *Sci. Total Environ.* **2018**, *651*, 2535–2545. [CrossRef]
84. Cheng, Y.-Y.; Lo, S.-L.; Ho, C.-C.; Lin, J.-Y.; Yu, S.L. Field Testing of Porous Pavement Performance on Runoff and Temperature Control in Taipei City. *Water* **2019**, *11*, 2635. [CrossRef]
85. Geberemariam, T.K. Post Construction Green Infrastructure Performance Monitoring Parameters and Their Functional Components. *Environments* **2016**, *4*, 2. [CrossRef]
86. MHURD. *Standard for Sponge city Effect Monitoring*; China Architecture Publishing & Media Co., Ltd.: Beijing, China, 2020; *in preparation and to be submitted*.
87. Alizadehtazi, B.; Montalto, F.A. Precipitation and soil moisture data in two engineered urban green infrastructure facilities in New York City. *Data Brief* **2020**, *32*, 106225. [CrossRef] [PubMed]
88. Liu, W.; Zhen, K.; Cai, D.; Yuan, H.; Li, X. Reconstruction Method of Old Residential Quarters in North China under the Concept of Sponge city—Taking Tongzhou District of Beijing as an Example. *Constr. Sci. Technol.* **2019**, 54–58. (In Chinese) [CrossRef]
89. Li, D.; Du, B.; Zhu, J. Evaluating old community renewal based on emergy analysis: A case study of Nanjing. *Ecol. Model.* **2021**, *449*, 109550. [CrossRef]
90. Chang, Y. Analysis on the Scheme Design of the Sponge city in the Newly-built Community of Xixian. *Sci. Technol. Innov.* **2021**, 152–153. (In Chinese)
91. BMCoPNR. *Code for Design of Stormwater Management and Harvest Engineering*; Beijing Municipal Bureau of Quality and Technical Supervision: Beijing, China, 2013.
92. Xie, S.; Wu, C.; Lv, Y. Standards and technical points of sponge city construction in industrial project. *Water Purif. Technol.* **2021**, *40*, 118–121. (In Chinese) [CrossRef]
93. Jin, Y.; Wang, H.; Shi, C. Application of Sponge city Design in Different Underlying Surfaces of Industrial Factories. *Constr. Des. Proj.* **2021**, 62–65. (In Chinese) [CrossRef]
94. Xia, Q. The "Sponge city" Concept in the Landscape Design Practice of Commercial Office Areas-Taking the Community Service Center Project of Airport 3rd Road, Nanfang Xincheng, Nanjing as an example. *Creat. Living* **2021**, 18–19. (In Chinese)
95. Li, X. *Research on Urban Vertical Planning Based on Major Drainage System*; Beijing University of Civil Engineering and Architecture: Beijing, China, 2020.
96. Zhang, Z.; Miao, Y.; Li, J.; Liu, D.; Fang, X. Improvement effect of rainfall source control facilities on urban drainage capacity in different regions of China. *J. Hydrol.* **2019**, *579*, 124127. [CrossRef]
97. Yang, W.; Zhang, J.; Mei, S.; Krebs, P. Impact of antecedent dry-weather period and rainfall magnitude on the performance of low impact development practices in urban flooding and non-point pollution mitigation. *J. Clean. Prod.* **2021**, *320*, 128946. [CrossRef]
98. Rizzo, A.; Tondera, K.; Pálfy, T.; Dittmer, U.; Meyer, D.; Schreiber, C.; Zacharias, N.; Ruppelt, J.; Esser, D.; Molle, P.; et al. Constructed wetlands for combined sewer overflow treatment: A state-of-the-art review. *Sci. Total Environ.* **2020**, *727*, 138618. [CrossRef] [PubMed]
99. Yin, D.; Xu, T.; Li, K.; Leng, L.; Jia, H.; Sun, Z. Comprehensive modelling and cost-benefit optimization for joint regulation of algae in urban water system. *Environ. Pollut.* **2021**, *296*, 118743. [CrossRef] [PubMed]
100. Sanchez, L.; Reames, T.G. Cooling Detroit: A socio-spatial analysis of equity in green roofs as an urban heat island mitigation strategy. *Urban For. Urban Green.* **2019**, *44*, 126331. [CrossRef]
101. Moghbel, M.; Salim, R.E. Environmental benefits of green roofs on microclimate of Tehran with specific focus on air temperature, humidity and CO_2 content. *Urban Clim.* **2017**, *20*, 46–58. [CrossRef]
102. Ferrari, A.; Kubilay, A.; Derome, D.; Carmeliet, J. The use of permeable and reflective pavements as a potential strategy for urban heat island mitigation. *Urban Clim.* **2019**, *31*, 100534. [CrossRef]