

Opportunities and challenges of the Sponge City construction related to urban water issues in China

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Abstract Waterlogging is one of the major water issues in most cities of China and directly restricts their urbanization processes. The construction of Sponge City is an effective approach to solving the urban water issues, particularly for the waterlogging. In this study, both the urban issues emerged at the stage of rapid urbanization in China and the demands as well as problems of Sponge City construction related with the water issues were investigated, and the opportunities and challenges for the Sponge City construction in the future were also proposed. It was found that the current stormwater management focused on the construction of gray infrastructures (e.g., drainage network and water tank) based on the fast discharge idea, which was costly and hard to catch up with the rapid expansion of city and its impervious surface, while green infrastructures (e.g., river, lake and wetland) were ignored. Moreover, the current construction of Sponge City was still limited to low impacted development (LID) approach which was concentrated on source control measures without consideration of the critical functions of surrounding landscapes (i.e., mountain, river, wetland, forest, farmland and lake), while application of the integrated urban water system approach and its supported technologies including municipal engineering, urban hydrology, environmental science, social science and ecoscape were relatively weak and needed to be improved. Besides, the lack of special Sponge City plan and demonstration area was also a considerable problem. In this paper, some perspectives on Good Sponge City Construction were proposed such as the point that idea of urban plan and construction should conform to the integral and systematic view of sustainable urban development. Therefore, both the basic theoretical research and the basic infrastructure construction such as monitoring system, drainage facility and demonstration area should be strengthened, meanwhile, the reformation and innovation in the urban water management system and the education system should also be urgently performed. The study was expected to provide a deeper thinking for the current Sponge City construction in China and to give some of suggestions for the future directions to urban plan and construction, as well as urban hydrology discipline.

Keywords Sponge City, Waterlogging, Integrated water system approach, Opportunities and challenges, China

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1. The demands of Sponge City construction in China

As the biggest developing and most populous country in the world, China is now at a stage of rapid urbanization. After the liberation of People's Republic of China in 1949, the urbanization rate of this country increased from 10.64% to 56.10% in 2015 with a surge of 0.68% per year (Figure 1) (Pan et al., 2015). In particular, the speed reached 0.98% per year after the implementation of reform and opening-up policy in the late 1970s. Meanwhile, as the total population of the country ascended to 1.4 billion at the end of 2015 with more than 90% crowding in East and Middle China, six megalopolis cities whose population reached 10 million (i.e., Shanghai, Beijing, Chongqing, Guangzhou, Tianjin and Shenzhen) emerged in the world. However, the urbanization rate of China was far behind that of the developed countries (e.g., USA, England, Germany and Japan), and the urbanization was still one of the core tasks in China's development.

The urban issues caused by blind urbanization, disorderly resource utilization and excessive exhaust emissions have gradually emerged since China stepped into the rapid urbanization stage in 1998. The typical issues are the high housing price, environment deterioration (water and air pollution, rain island and heat island), resource shortage, traffic jam and urban waterlogging, which would directly threaten human health, social stability and economic development. For example, 90% of urban waterbodies were polluted seriously, and most provincial capital cities as well as developed coastal cities were experiencing water shortages. In particular, the urban waterlogging after rain has become the most severe and universal phenomenon, and hundreds of cities have suffered the disasters almost every year since 2008 according to the statistical data from the Office of State Flood Control and Drought Relief Headquarters of China. For instance, a severe waterlogging occurred in Beijing on July 21th 2012 and caused huge losses of lives and properties (79 victims

and 11.64 billion RMB economic loss). Worse conditions appear in Wuhan despite the existence of hundreds of lakes in the city, where the urban waterlogging happens every summer and has been dubbed as "seeing sea in the city". The primary reason for these disasters is that the urbanization totally changed natural hydrological process (Xue and Tan, 2009), and that the rapid expansion of urban impervious area remarkably increased runoff yield amount which was increasingly difficult to be drained away through the outdated gray infrastructure system. Moreover, the surface subsidence boosted the possibility of waterlogging, and the design standard of urban drainage system was quite low (only once per one to three years).

Since the 1970s, lots of developed countries (e.g., USA, Germany, United Kingdom, Japan, Singapore and Australia) have devoted considerable attention to the urban waterlogging and stormwater pollution (Fletcher et al., 2015). A number of concepts and theories were proposed to address the rapid urbanization and related environmental problems, e.g. "smart growth city", "green city" and "city garden". Moreover, several representative design approaches were proposed to guide the urban plans, e.g., best management practices (BMP), low impact development (LID), green infrastructure (GI), sustainable urban drainage systems (SUDS) and water sensitive urban design (WSUD). The BMP was first proposed and implemented to control stormwater pollution in North America (USA and Canada) in the 1970s. Based on the BMP, the LID was put forward in the 1990s and was then widely accepted in North America and New Zealand (US EPA, 2000), while the GI was proposed as a strategic plan framework for environmental, social and economic sustainability in 2000 (Benedict, 2000), which could be used interchangeably with LID. The SUDS idea was proposed in the 1970s in the United Kingdom, dealing with flood disaster and stormwater pollution caused by the sewage systems (Jefferies, 2004). The WSUD was proposed in the 1990s in Australia aimed to protect nature environment, and to improve life quality

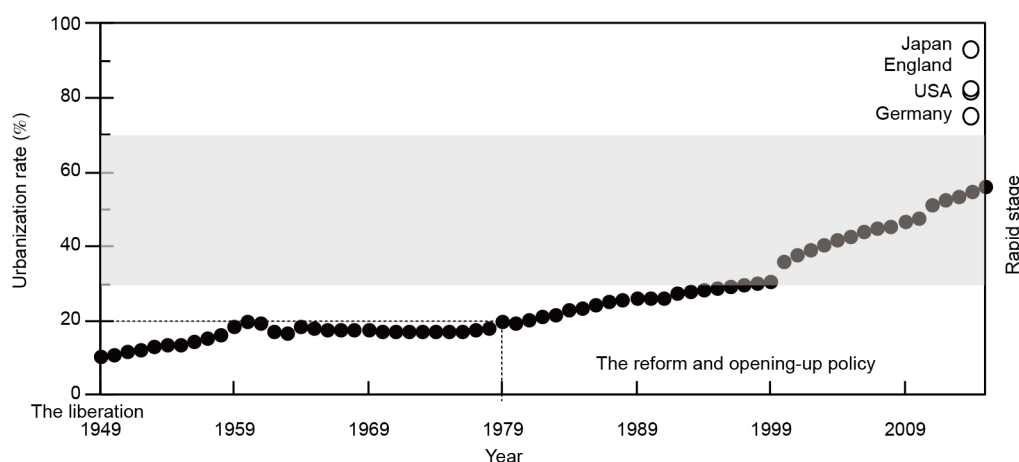


Figure 1 The urbanization stage in China from 1949 to 2015.

(Coombes et al., 2000). Japan also paid much attention to the construction of Sponge urban infrastructures not only because of its climate characteristics but also the severe scarcity of water resources. In New Zealand, the low impact urban design and development (LIUDD) was proposed as an integrated development of LID and WSUD, which emphasized the rational development of both city and surrounding villages and took overall consideration of water quality and quantity, biodiversity, land utilization, and so on. In Singapore, Active Beautiful and Clean Waters Programme (ABC), a scientific design with rational distribution of rainwater collection and drainage system was proposed. As a result, the urban inland inundation scarcely occurred in this tropical island despite its abundant rainfall. Moreover, many successful projects were constructed in the world, such as Green Street in Portland, USA, Potsdamer platz in Berlin, Germany, and Ryogoku District in Tokyo, Japan. Nevertheless, most of these concepts, theories and approaches focused on the source control of stormwater because populations were comparatively low in the developed countries and green ratios were usually high enough to absorb the stormwater increased by the developed impermeable area (Ministry of Housing and Urban-Rural Development, 2014).

In China, most cities have large population density and are experiencing intensive development with numerous impermeable roads and hard rooftops. Focusing on these severe urbanization issues, however, solutions implemented by different government departments were fragmented, outdated and inefficient. For example, the stormwater simulation was usually reported by simple & constant runoff coefficient method or foreign mature models (e.g., SWMM, MIKE-URBAN) (Beijing General Municipal Engineering Design & Research Institute, 2006). In over 90% of cities in China, the current design conception of stormwater drainage system was based on the fast discharge idea and focused on the construction of gray infrastructures (Qiu, 2015), which was costly and hard to catch up with the rapid expansion speed of city and impervious surface. As a result, numerous man-power and investments were cost for this pollution control on constructions of sewage treatment plants and development of their treatment technologies. Although the foreign approaches (e.g., LID, GI) were gradually used in the urban stormwater management in China, their targets mostly focused on source control, which were difficult to maintain the identical hydrological characteristics (e.g., total quantity, peak flow and time) before and after development. Midway and terminal control approaches should be adopted (Ministry of Housing and Urban-Rural Development, 2014). Therefore, comprehensive concepts, theories and approaches should be further developed to meet the urban development and address the urbanization issues in China.

The concept of Sponge City was first proposed in 2012 Low-Carbon Urban Development and Technology Forum.

And the construction of Sponge City in China was first formally put forward by Xi Jinping, President of P.R.China at Central Urbanization Working Conference in 2013. The State Council issued “Opinions of the State Council on Strengthening Urban Infrastructure Construction” (Guo Fa [2013] No.36), “a notice to improve the construction of urban drainage and waterlogging facilities” (Guoban Fa [2013] No.23). The Ministry of Housing and Urban-Rural Development proposed the construction guideline of sponge city in China-low impact development of stormwater system in 2015. The Ministry of Finance, Ministry of Housing and Urban-Rural Development, and Ministry of Water Resources chose 16 and 14 urban districts across the country as the first and second batches of pilot Sponge Cities respectively, including megalopolis (e.g., Beijing, Shanghai, Tianjin, Shenzhen) as well as middle and small cities (e.g., Zhenjiang, Changde, Guyuan, Qingyang) under various climate conditions (e.g., cold or hot, dry or wet). In the following three years, 1.20–1.80 billion RMB were invested for each city to construct the Sponge measures for stormwater infiltration, retention, storage, purification, utilization and drainage. The construction of Sponge City became a significant national strategy to achieve the goals of “new-type urbanization” and “overall construction of well-off society” of China in the 2020s. Although huge investment was thrown into these construction, “seeing sea in the city” still happened in most of southern cities in the summer of 2016. The adaptability of the technologies focused on source control that have gained powerfully effective performances in the developed countries should be further assessed according to the actual situations of China. Besides the source control measures (e.g., LID, GI), the entire measures of Sponge City should contain the gray infrastructure system for the midway control (e.g., sewage drainage network, pump) and the surrounding landscape (e.g., river, wetland, forest, farmland and lake) as well. In particular, China has kept rapid increase in economy for over three decades with the largest population in the world, but the construction of urban infrastructures in China was poor and still needed to be improved. China is facing new opportunities and challenges in the Sponge City construction.

The Sponge City construction will also be a hot topic in the future of China. In this study, the urban water issues were addressed related to the Sponge City construction, and the major objectives are as follows: (1) to clarify the demands of Sponge City construction, particularly its hydrological knowledge system, (2) to investigate the cause of problems in Sponge City construction, (3) to propose some suggestions on opportunities and challenges of Sponge City construction, particularly on hydrological foundation. It was expected to provide a deeper thinking for the construction of Good Sponge City in China and to give future directions to the urban plan and construction, as well as the urban hydro-

ogy discipline.

2. The problems of Sponge City construction in China

(1) Need of integrated urban water system theory. In China, current Sponge City construction mostly focuses on LID approach at the scale of city cell, such as residential area. For urban waterlogging, LID approach plays a key role in enhancing rainwater infiltration and storage in urban area through bio-retention, rain garden and others at the initial stage of small or middle intensity rainfall. However, if the rainstorm intensity is very high to exceed storage capacity of city cell, the role of LID at small scale will be quite limited. Urban water system approach will have a better performance which considers not only the roles of LID and storage functions of the city lake and river system, but also the water issues of water quantity, quality and ecosystem as well as alterations from human components in the whole urban water system (Figure 2). Thus, the core of Sponge City is the concept of water system, including urban runoff generation with complex nonlinear relation between rainfall and runoff, relative flood, water pollution and utilization under changes of eco-environmental system & urban system. These closely interrelated issues belong to an integrated water issue, which involves numerous relevant sectors and departments of urban plan, construction, monitoring and management, as well as urban residents and production (Xia et al., 2014; Ministry of Housing and Urban-Rural Development, 2014). A sensible solution is multi-department cooperation and multi-discipline study among municipal engineering, hydrology, environmental science, social science and ecology according to the theory of hydrological cycle. However, the fast discharge idea was limited to the flood drainage and ignored other runoff components such as evapotranspiration, infiltration and uti-

lization. The basic discipline of current urban plan and design was municipal engineering while hydrological knowledge was still weak as well as the plan of basic monitoring system. Although the construction guideline of Sponge City was proposed, the widely-used control rate of annual average runoff amount only focused on the storage and infiltration measures of source controls with deficient capacities. For example, the total runoff reductions were about only 150–200 mm for sunken green space, 40mm for permeable pavement, and 14mm for green roof (Ministry of Housing and Urban-Rural Development, 2014). Several critical hydrological processes including evapotranspiration, river routing, and storage of ponds, wetlands and lakes were not considered, which consumed a large part of annual average precipitation amount, particularly for the evapotranspiration. Moreover, the urban integrated water system contains three components, i.e., hydrology, water pollution and water management, which involve all the physical and social processes of water and its accompanying pollutants.

(2) Need of special Sponge City plan. Numerous master or special plans were established for the urban development and construction. The related plans included urban master plan, urban flood control and waterlogging plan, urban garden and landscape plan, urban road special plan, urban river and lake plan. Most of these plans focused on only a specific problem, which made it difficult to solve entire urban water issues. In October 2014, the Ministry of Housing and Urban-Rural Development issued “the construction guideline of Sponge City in China-low impact development of stormwater system” (Ministry of Housing and Urban-Rural Development, 2014). Most contents of this guideline emphasized the development of low impact practices (i.e., small Sponge measures), which belonged to the source control measures. Less importance were attached to the renovation of rivers and lakes (i.e., big Sponge measures) in and around cities which were

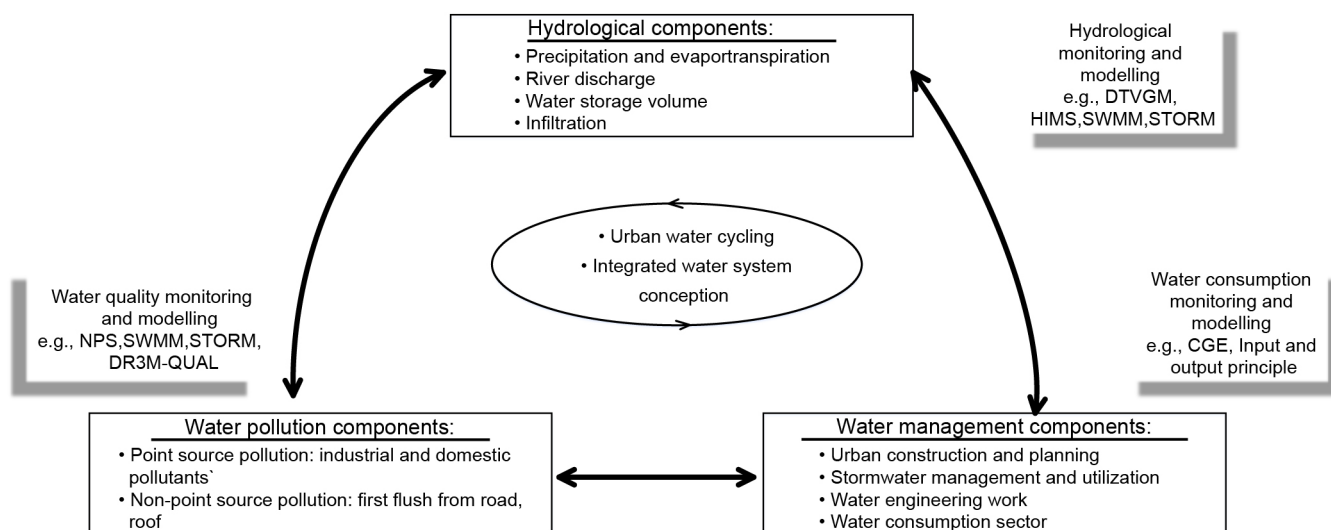


Figure 2 The framework of integrated urban water system.

the terminal storage and discharge measures and had much greater potential to discharge stormwater than the source control measures. Moreover, some cities were impatient for achievements spending great efforts and investments to blindly construct the low impact development practices. The prospective guideline for the whole Sponge City construction was still missing, especially the Sponge City plan.

(3) Outdated supporting technologies of Sponge City plan. The widely-used approach was a simple & constant runoff coefficient method for the designing of stormwater drainage and utilization system with an outdated theoretical foundation of integrated water cycling (Beijing General Municipal Engineering Design & Research Institute, 2006). Actually, the runoff generation mechanism is rather complex as a non-linear relation with precipitation intensity, soil moisture and underlying surface cover condition (Xia et al., 2005). The integrated water system simulation was still not reported in the urban area. Although some classical stormwater models such as TRRL, ILLUDAS, UCURM, SWMM, STORM, MIKE-SWMM, MIKE-URBAN, InforWorks and MOUSE were developed in the developed countries, these models with simple mechanisms of runoff generation needed to be improved to capture runoff processes of complicated urban underlying surface in China. The present model functions were not able to fully meet the requirements of the Sponge City design in China. Moreover, manual adjustment was still the main approach at cell scale for the current LID design, which was time-consuming and laborious (Liu et al., 2016), while the auto-optimization technology was not used despite its wide acceptance in other fields, such as economy and finance (Coello and Lamont, 2004), power dispatch (Abido, 2006), engineering shape design (Deb and Goel, 1993), water resources and environmental management (Suen and Eheart, 2006).

(4) The demonstration area constructions of Sponge City are far from enough. Currently, the successful Sponge City cases are not common in China, especially in the developing cities. Although some megalopolis cities (e.g., Beijing, Shanghai and Shenzhen) have already constructed successful demonstration cases, they were just ornaments distributed in the large urban central areas. The demonstration areas and rainwater absorption functions were far from enough to meet the requirement of waterlogging control and stormwater utilization in the cities. The famous cases are the central zone of Olympic park and CBD Core Area of Chaoyang District in Beijing, and Daming Palace in Xi'an. According to the guideline of Sponge City construction, the construction area should cover more than 20% of the whole urban city. However, the existing infrastructures and plans are contradictory with the Sponge City construction severely, which makes it difficult and costly to reconstruct the outdated infrastructures. By estimation, the construction cost will be 0.10–0.15 billion RMB/km².

3. The opportunities and challenges of Sponge City construction in China

3.1 Integral and systematic view of sustainable development

The Sponge City construction firstly requires holistic thinking. The objective of Sponge City is to eliminate the negative impact of urbanization on hydrological cycle and create a virtuous water cycle system by learning from the advanced approaches in the developed countries and depending on the actual conditions of China, rather than only fragment man-made landscapes. The main issues of Sponge City are related to hydrological problems such as the stormwater generation and control, and water pollution protection. These problems were solved well by systemic method and the integration of ecological technologies with the idea of harmonious coexistence between human and water. A good way for implementation of stormwater management is to change the single objective of flood control to the multi-objectives of flood control, environment improvement, ecological water requirement and reutilization in the cities. Meanwhile, the Sponge City construction also requires systemic thinking, which consists of three systems, i.e., gray infrastructure system, natural ecosystem and urban construction system from a designed point of view. Therefore, it is necessary to break the tendency of independence in various professional designed processes. From the perspective of construction and operation, the Sponge City construction requires a comprehensive integration of multiple aspects, including policies, regulations, designs, guideline, training, certification, construction management, construction monitoring, property management, operations monitoring, social communication and other subsystems.

3.2 Strengthening the scientific and application basic research

The Sponge City involves the interests of various administrative departments, such as urban plan, water conservancy, gardening, municipal and other departments, but the core theory is the urban water system approach originated from the hydrology discipline, which focuses on the interactions and feedbacks among the physical, environmental, ecological and social water cycles. The water processes involves urban rainfall-runoff process, complicated water interchange among land surface, drainage network, rivers and lakes, migration and transformation processes of first flash pollution, ecological water consumption process of vegetation, rainwater resource utilization and other manual intervention processes. The basic research areas include plans and designs of urban drainage, waterlogging control, black and odorous water restoration, Sponge measures at various spatial scales, monitoring and assessment systems. In addition, remote

sensing technology (RS), computer technologies (GIS and mathematical models) also play important roles in many aspects such as high-precision data acquisition of underlying surface, urban stormwater and pollution processes simulation, land surface evapotranspiration and LID optimization. For example, if the underlying surface characteristics are quite different in the urban area, it is necessary to obtain the high-precision information of underlying surface through advanced satellite RS technology so that the LID measures will be established in different regions according to local conditions. Besides, considering the large number of LID design parameters, all the proposed design schemes should be optimized and evaluated repeatedly with the help of the computer technology in flood control, pollution control, rainwater utilization, economic cost and other aspects.

3.3 Strengthening the urban plan and the monitoring system

The construction of Sponge City is problem-oriented in the inner cities but goal-oriented in the new cities or developing cities. It is better to fully utilize the information technologies (e.g., internet, cloud computing and big data) in many aspects of urban stormwater plan and managements. Some smart devices of drainage and rainwater collections could be implemented by integrating small Sponge measures (e.g., LID for the source control), gray infrastructures (e.g., sewage pipes, pumps and storage tanks for midway migration and control) and big Sponge measures (e.g., mountain, river, forest, farmland and lake for the terminal control). Moreover, the online and real-time monitoring including runoff and water quality monitoring in the drainage system, urban surface and surrounding river network are essential parts for the Sponge City construction. For example, flood situation in the road could be informed timely by means of flood warning and forecasting system. The real-time emergency response should be made to deal with the short-term heavy stormwater according to the information of real-time monitoring. The stormwater should be controlled and managed by combination of centralized and decentralized pollution treatments to make its cyclic utilization and reuse. Besides, with more and more frequent extreme climate events caused by climate change (Chen, 2013), the combination of urban stormwater simulation and city weather forecast monitoring in order to enhance the capacity for dealing with climate change and sudden-onset disasters would be one of the most important research fields in alleviating the impact of urban rainstorm floods.

3.4 Strengthening the demonstration area construction of Sponge City

At present, the demonstration area of the Sponge City is still limited, which is deficient to absorb the stormwater amount corresponding to the control rate of annual average runoff

amount (over 60%) in the whole urban area. The construction area of Sponge City should be taken seriously in the urban master plan of the whole city, as well as other special plans. For example, the designer could add the value of the Sponge City to the real estate industry in the future to create a luxuriant public space for the community. The demonstration area not only relieves the frequency and effects of the urban waterlogging, but also makes the urban resident closer to green plants and clean water bodies, which would make the residents more pleasant in the busy urban life. Besides the aesthetic function, it also increases biodiversity, relieves the effect of heat island, and increases its surrounding housing prices. Nevertheless, we should be careful to avoid developing demonstration area blindly, particularly the source control measures.

3.5 Innovation of urban water management system and the education system

The reformation and innovation need to be urgently performed in the urban water management system. A coordinate and innovative mechanism of “production, learning, research, use and administration” is formed for the Sponge City construction. For example, economic structure, water resource management and water pollution control would be adjusted to focus on the demand of Sponge City in the macroscopic aspects, while water-saving taps and toilets would be popularized in the microscopic aspects. Meanwhile, extensive economic measures should be implemented for water usage, such as ladder water price policy, recycled water utilization system, tax reduction for water saving, penalty for over standard discharge and encouragement of private investment. Furthermore, the government should not only focus on the cultivation of professional talents of Sponge City plan and construction, but also enhance the public education about water saving and water protection in order to upgrade the public perception of environment and water issues, in which the education system (e.g., schools, colleges, universities) should play an important role. It is a sensible way to encourage the citizens to participate in the design and construction of Sponge City as well as to realize the co-construction of harmonious home. Moreover, international cooperation is a convenient approach to localizing and fully-utilizing the advanced concepts, theories and methods in the international arena.

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References

- Abido M A. 2006. Multiobjective evolutionary algorithms for electric power dispatch problem. *IEEE Trans Evol Comput*, 10: 315–329

- Beijing General Municipal Engineering Design & Research Institute. 2006. Water Supply and Sewerage Engineering Design Handbook. Vol 5. 2nd ed (in Chinese). Beijing: China Architecture & Building Press
- Benedict M A. 2000. Green Infrastructure: A Strategic Approach to Land Conservation. American Planning Association. Chicago: Planning Advisory Service Memo
- Chen H P. 2013. Projected change in extreme rainfall events in China by the end of the 21st century using CMIP5 models. *Chin Sci Bull*, 58: 1462–1472
- Coello C A C, Lamont G B. 2004. Applications of Multi-Objective Evolutionary Algorithms. Singapore: World Scientific. 761
- Coomes P J, Argue J R, Kuczera G. 2000. Figtree place: A case study in water sensitive urban development (WSUD). *Urban Water*, 1: 335–343
- Deb K, Goel T. 2001. A hybrid multi-objective evolutionary approach to engineering shape design. *Lect Notes Comput Sci*, 1993: 385–399
- 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, Mikkelsen P S, Rivard G, Uhl M, Dagenais D, Viklander M. 2015. SUDS, LID, BMPs, WSUD and more—The evolution and application of terminology surrounding urban drainage. *Urban Water J*, 12: 525–542
- Jefferies C. 2004. SUDS in Scotland-The Monitoring Programme of the Scottish Universities SUDS Monitoring Group. Environment Agency
- Liu C M, Zhang Y Y, Wang Z G, Wang Y L, Bai P. 2016. The LID pattern for maintaining virtuous water cycle in urbanized area: A preliminary study of planning and techniques for Sponge City (in Chinese). *J Nat Resour*, 31: 719–731
- Ministry of Housing and Urban-Rural Development. 2014. The construction guideline of sponge city in China- low impact development of stormwater system (trial)
- Pan J H, Li E P, Shan J J, Wang Y Q, Shen G Y. 2015. Urban Blue Book: City Development Report of China (in Chinese). Beijing: Social Sciences Literature Press
- Qiu B X. 2015. The connotation, approach and perspective of Sponge city and LID (in Chinese). *Water Wastewater Eng*, 41: 1–7
- Suen J P, Eheart J W. 2006. Reservoir management to balance ecosystem and human needs: Incorporating the paradigm of the ecological flow regime. *Water Resour Res*, 42: W03417
- United States Environmental Protection Agency (US EPA). 2000. Low impact development (LID): A literature review. EPA-841-B-00-005
- Xia J, Wang G S, Tan G, Ye A Z, Huang G H. 2005. Development of distributed time-variant gain model for nonlinear hydrological systems. *Sci China Ser D-Earth Sci*, 48: 713
- Xia J, Zhai X, Zeng S, Zhang Y. 2014. Systematic solutions and modeling on eco-water and its allocation applied to urban river restoration: Case study in Beijing, China. *Ecohydrol Hydrobiol*, 14: 39–54
- Xue L F, Tan H Q. 2009. Flood and waterlog and rainwater hydrological cycle rehabilitation during urbanization (in Chinese). *J Agric Sci*, (23): 11058–11061