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Review article

Comments and recommendations on Sponge City — China's solutions to prevent flooding risks

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ABSTRACT

Background: /Objective: Flooding risk is a global issue, and various approaches have been established to prevent flooding risk around the world. China is one of the heavily flood-affected countries and has been implementing the Sponge City program since 2015 to defend against flooding. Unfortunately, flooding has been common in China in recent years, causing severe health risks to citizens. This research mainly focuses on (a) evaluating the implementation of China's Sponge City program and the associated impacts on human health and (b) exploring the future improvement of the Sponge City program in China.
Methods: The Interpretive Document Approach was used to explore an inclusive review of the Sponge City program and its implications on human health.
Results: /Findings: The Sponge City program in China is still insufficient to prevent flooding risks effectively. In the past eight years, 24/34 provinces have recorded flooding, which caused a total of 4701 deaths and over 525.5 billion RMB (around 72.9 billion US$) in economic loss. Till now, only 64/654 cities have promulgated local legislation to manage sponge city construction, although the Sponge City was implemented in 2015. Besides, the completed Sponge City program constructions cannot fully prevent flooding risks, the flood prevention capacity is limited. The Sponge City program is not granted priority, lacking national legislation hinders Sponge City program implementation in China.
Conclusions: China needs to make national legislation on the Sponge City program and update the Sponge City program technology guidelines. Local governments should implement Sponge City construction according to local geographic environments.

1. Introduction

Urban flooding, seen as a natural disaster, ensues when rainfall cannot quickly and adequately be drained through drainage channels and other water bodies [1,2]. There is an increase in impervious surface area, runoff, and flood recurrence rate [3–5]. Today, flooding has become a serious disaster around the world, including the US, Europe, South East Asia, and Africa [4,6,7]. Some countries have become very vulnerable to flooding mainly because of their geographic location and climatic conditions [8,9]. India is the most

Abbreviations: BMP, Best Management Practices; CNKI, China National Knowledge Infrastructure; GI, Green Infrastructure; IDA, Interpretive Document Approach; LID, Low Impact Development; SCP, Sponge City Program; SUDS, Sustainable Urban Drainage Systems; WoS, Web of Science Database; WSUD, Water-sensitive Urban Design.

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flood-susceptible country globally and accounts for one-fifth of global deaths by flooding [10,11]. The core reasons for flooding in India are high-intensity rainfall in a short period, poor and inadequate drainage capacity of rivers and failure of flood control structures [6]. Pakistan suffered major floods in 2022, affecting almost one-third of the territory.

China has also suffered severe water problems, including water scarcity [12], flooding, and water pollution [13]. They intertwin and escalate in urban areas and threaten human health, socio-economic development, among others [14]. Flooding risk is a more serious water security issue in China, several studies show nearly 98% of China's 654 leading cities have problems with flooding and waterlogging because of the rapid growth in recent years creating urban sprawls that enclosed floodplains with waterproof concrete [14,15]. The rate of urbanization led to increased susceptibility to flooding [16,17], which means China needs to pay more attention to urban flooding prevention than other countries.

To deal with the wide-ranging urban water problem, the Chinese government has adopted the policy of Sponge City. According to the General Office of the China State Council, the target of the Sponge City Program (SCP) is to improve urban water management. By adopting measures such as "infiltration, stagnation, storage, purification, use, and discharge", SCP can maximize the use of precipitation and reduce the impact of urban development and construction on the ecological environment (Guiding Opinions of the General Office of the State Council on Advancing the Construction of Sponge City). The SCP could enhance city neatness and aesthetics for the living environment and water supplements, enhancing residents' sense of life satisfaction [18]. China launched the SCP on October 11, 2015, and two batch cities were selected, 16 in 2015 and 14 in 2016.

As a measure of water management, SCP could reduce urban flooding risk. SCP is a relatively new concept for China. Considerable research efforts have been devoted to exploring the concept of Sponge City and its various implications. Nguyen examined the approaches associated with conventional urban water management while assessing the concept, limitations, and opportunities of Sponge

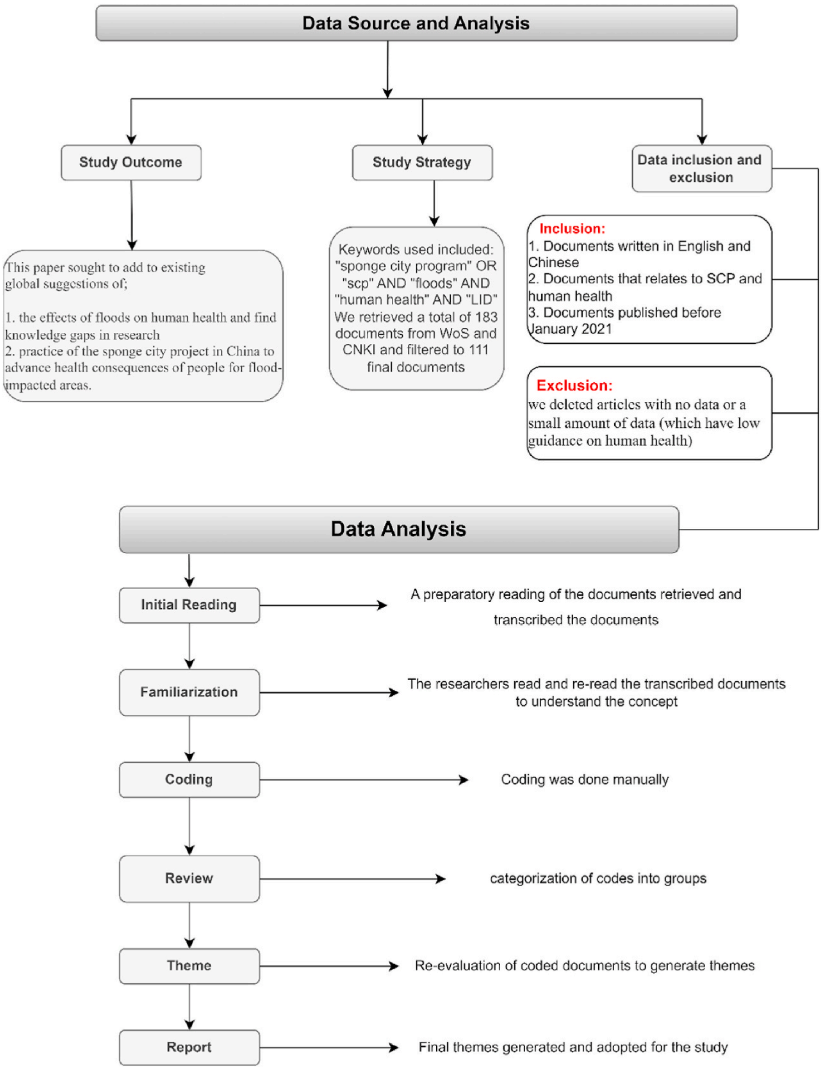

Fig. 1. The flow chart of review procedures.

City [1]. Chan aimed to explain the concept and development of Sponge City and consider the transformation of urban-water management practices in China [19]. Guan reviewed the initiative and actions of Sponge City, analyzed the problems faced by Sponge City construction, and proposed possible solutions [20]. Li surveyed the progress of all 30 pilot sponge cities and identified a broad array of technical, physical, regulatory, and financial challenges to communities and institutions [21]. Zhang summarized the status quo of urban rainwater flooding, and the development and application of flooding control technology [22].

Various methods were proposed to estimate the effectiveness of SCP. Zhang assessed the implementation of SCP in Beijing [22]. Wang developed an assessment methodology from a social equity perspective [23]. Nguyen critically compared the effectiveness of SCP with conventional urban water management [1]. Zhou developed an Emergy Ecological Model for evaluating the ecological benefits and sustainability of the urban stormwater system [24]. Qiao examined how the prominent national policy on SCP is interpreted and implemented locally [25]. Recent developments in SCP reflected its important role in urban water management, including urban flooding risk prevention.

Among all the research conducted on Sponge City, very little was found in the literature on the question of the implementation and the legislation of Sponge City in China. The flooding issue continues to persist, and the research on this subject is insufficient. The "7.20″ heavy rain disaster in Zhengzhou, Henan province, which killed 380 people in 2021, highlights the importance of a Sponge City for public health in China [26,27]. Against the backdrop, this paper sought to: (a) evaluate the implementation of China's Sponge City program and the associated impacts on human health and (b) explore the future improvement of the Sponge City program in China.

2. Methods

2.1. Literature analysis

This study adopted the Interpretive Document Approach (IDA) to make an inclusive review of Sponge City and its implications on human health. We used this approach to reflect a logical pattern that demonstrates fairness in analyzing the data gathered to understand this study. This approach confirmed the reliability and validity of the data examined [28]. Hence, the researchers had the chance to read and assess the documents multiple times [29].

Fig. 1 shows the main context of the flow of this study. Initially, the researchers searched the literature on SCP and Low Impact Development (LID) by using keywords or applicable information from current papers. Secondly, there was the identification and categorization of all examined papers' themes and removing invalid input based on in-depth analysis. Then, a comprehensive assessment was made from two aspects, specifically: (a) the effects of flooding on human health; (b) knowledge gaps in research and practice of the SCP in China. In this study, the Web of Science (WoS) database and China National Knowledge Infrastructure (CNKI) were both databases that contain the most influential related research; where we searched the keywords "Sponge City" and "human health" in either English or Chinese before October 2022. For English literature, we added supplementary keywords of "China/Chinese" as constraints to ensure that all research is based on cases in China.

2.2. Flooding disaster data collection

Flooding disaster data were searched in the National Disaster Reduction Center of China, http://www.ndrcc.org.cn/zqtj/index.jhtml. [Assessed time: 2022.10].

Legislation data were searched in China's National Laws and Regulations Database, https://flk.npc.gov.cn/. [Assessed time: 2022.10.]

Due to the limitation of the data update frequency, we selected data during 2015.01–2022.08 for analysis.

2.3. Mapping

ArcGis 10.2 was used to visualize flooding distribution and the Sponge City legislation in China.

3. Results

3.1. Literature analysis result

In the initial literature search, we found 102 papers in English and 81 articles in Chinese. Since the scope of this review aims to summarize SCP results, we further screened the documents based on two criteria: (a) both quantitative and qualitative research and related national standards with literature review or policy discussion; (b) literature which included research about Green Infrastructure (GI) and LID facility operation. At the same time, we deleted articles with no data or few data in relation to human health. As a result, we identified 78 papers in English and 33 papers in Chinese in our scoping review.

3.2. The flooding records of China from 2015 to 2022

Although the Chinese government has undertaken all preliminary activities to ensure the success of SCP, there are yearly records of flooding across China. Fig. 2 visually displays flooding distribution around China from 2015 to 2022. It can be seen that Jiangxi and Hunan, which shares a border, recorded the highest 7 and 6, respectively. However, a lot of provinces recorded 1 flooding case in this period. Fig. 3 shows the spatial distribution of pilot cities of Sponge City and annual water disaster frequency in China.

As shown in Table 1, though China implemented SCP in 2015, flooding caused hundreds of deaths every year. However, the National Disaster Reduction of China only reported the total number of disaster-related deaths annually. Hence, we cannot distinguish the exact number of deaths in urban and rural flooding. However, the data for 2021 is quite intuitive, with 590 deaths due to flooding, of which 64% was caused by the Zhengzhou "7.20″ heavy rain disaster. Flooding also caused large annual economic losses, and some provinces have experienced flooding for many years. The number of deaths and economic loss caused by flooding are shown in Table 1.

3.3. *The implementation of sponge city from 2015 to 2022*

Fig. 4 shows the local implementation and legislation of Sponge City from 2015 to 2022. Generally, provinces with more than one flooding case over the period have several corresponding legislations enacted to help control flooding risks. But not all flood-affected provinces have implemented SCP.

4. Discussions and implications

4.1. *Inadequate nationwide SCP implementation*

Based on the data collected, there is an inadequate priority for Sponge City in China, both from the policy-making and scientific research perspectives. Since China implemented the SCP in 2015, we could only gather 183 research articles and 64 local regulations for this study. In contrast, the Carbon Neutrality, another national plan initiated in 2020, has gained more attention currently. More than 4000 research articles have been published already and a powerful carbon control institution has been established in China in the last two years [30]. The slow implementation of SCP and the limited research on Sponge City reflect the Chinese government's minimum attention given to SCP.

Few cities in the north implemented SCP, and most SCP pilot cities are located in China's central and southern regions (Fig. 4). Historically, precipitation in China was mainly distributed in the central and southern regions [31]. This is why SCP implementation is concentrated in the central and southern regions and inadequate in the northern regions of China. Notwithstanding, cities in northern China also need SCP to store precipitation to fully use water resources due to dry climate. Meanwhile, with climate change, rainfall in northern China is gradually increasing [32], which also requires the implementation SCP to prevent flooding risks. But not every flood-affected province has undertaken SCP. To prevent flooding risk, it is necessary to implement SCP nationwide.

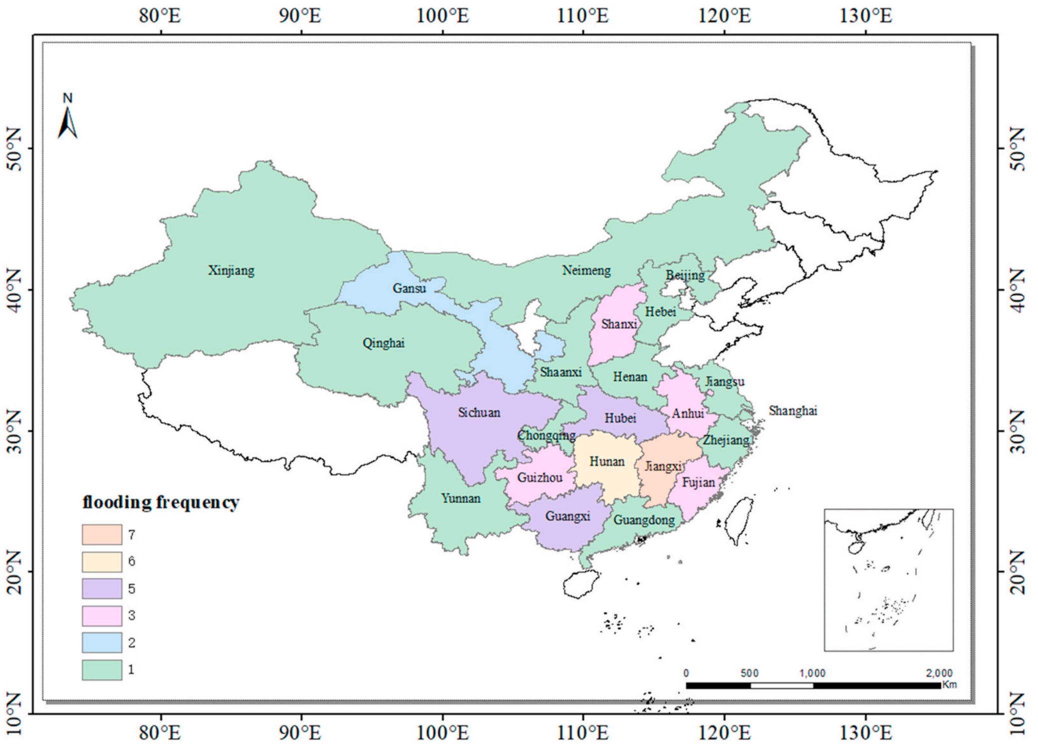

Fig. 2. The flooding records of China from 2015 to 2022. The map showed that China is suffering heavy flooding risk, for 24/34 provinces recorded huge flooding disasters. Flooding occurs every year in some provinces, such as Jiangxi province. The analysis data period is from January 2015 to August 2022.

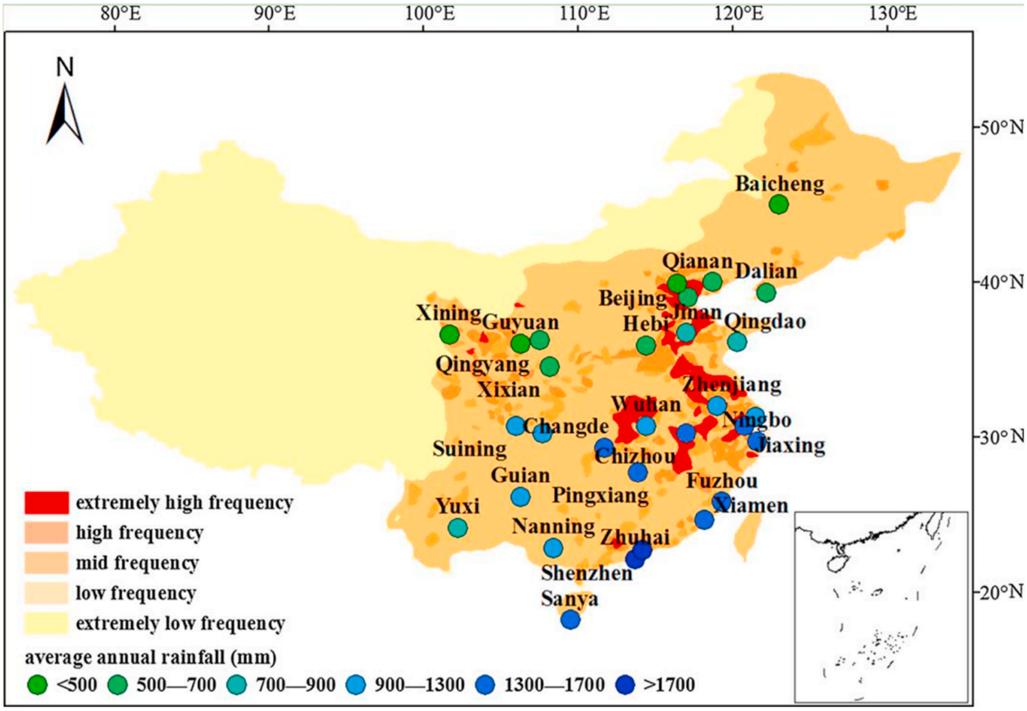

Fig. 3. The spatial distribution of pilot cities of Sponge City and annual water disaster frequency in China (adopted from Ref. [49].

Table 1
The flooding damage in China from 2015.01 to 2022.08

Year	The worst affected provinces	Death and missing/ Individual	Amount of economic loss/ Billion
2015	Anhui, Fujian, Jiangxi, Hubei, Hunan, Guangxi, Xichuan, Guizhou, Yunnan, Shanghai	679	67.9
2016	Hebei, Hubei, Anhui, Jiangxi, Shanxi, Jiangsu	1182	118.2
2017	Hunan, Jiangxi, Guizhou, Guangxi, Sichuan	749	74.9
2018	Zhejiang, Fujian, Jiangxi, Hubei, Hunan	380	38
2019	Guangxi, Jiangxi, Hunan, Guizhou, Sichuan	680	68
2020	Anhui, Sichuan, Jiangxi, Hubei, Chongqing, Gansu, Hunan, Guangxi	279	27.9
2021	Henan, Shanxi, Hubei, Shaanxi	590	59
2022	Qinghai, Neimeng, Shanxi, Xinjiang, Gansu, Jiangxi, Hunan, Guangdong, Fujian, Guangxi	162	71.6
Total	24 provinces	4701	525.5

4.2. The SCP construction can not fully prevent flooding risk

Flooding disasters that occurred in recent years indicated that the implementation of SCP in China is insufficient to effectively prevent flooding risks. The SCP aims to manage sustainable water resources [33]. With the success of the Sponge City pilot, the number of cities implementing SCP in China has increased from 16 in 2015 to 64 in 2022. Noteworthy, also from 2015 to 2022, floods caused a total of 4701 deaths and more than 72.9 billion US$ loss. Despite the rapid development of several flooding risk mitigation strategies, flooding still caused an annual loss of about 10 billion US$ in China, and every year could cause human death [34]. Flooding became the top-influenced natural disaster that caused the highest number of accidental deaths in China [35].

It is necessary to mention Zhengzhou "7.20″ heavy rain disaster again. Zhengzhou, the capital of Henan province, implemented the SCP in 2016 and planned to invest 58.4 billion RMB (around 8 billion US$) to construct the SCP. Most of the construction was completed before 2021 (*Zhengzhou Sponge City Special Plan (2017–2030)*). Zhengzhou is located in central China, with low annual average rainfall. Under normal conditions, the SCP constructions in Zhengzhou can handle average rainfall. But on 20 July 2021, Zhengzhou was hit by the heaviest rain on record. The casualties exposed the city to risks beyond its capacity to handle. The cause of this flooding risk was an excessive rainfall in a short period, which significantly exceeded the design capacity of the SCP. By implication, SCP has an upper limit to its preventive capacity.

Urban water management has been proven to prevent flooding risks and help protect people's health, which is one of the intentions of China in implementing the SCP. The construction of SCP can store and purify rainwater. Thus, it reduces the possibility of germs and

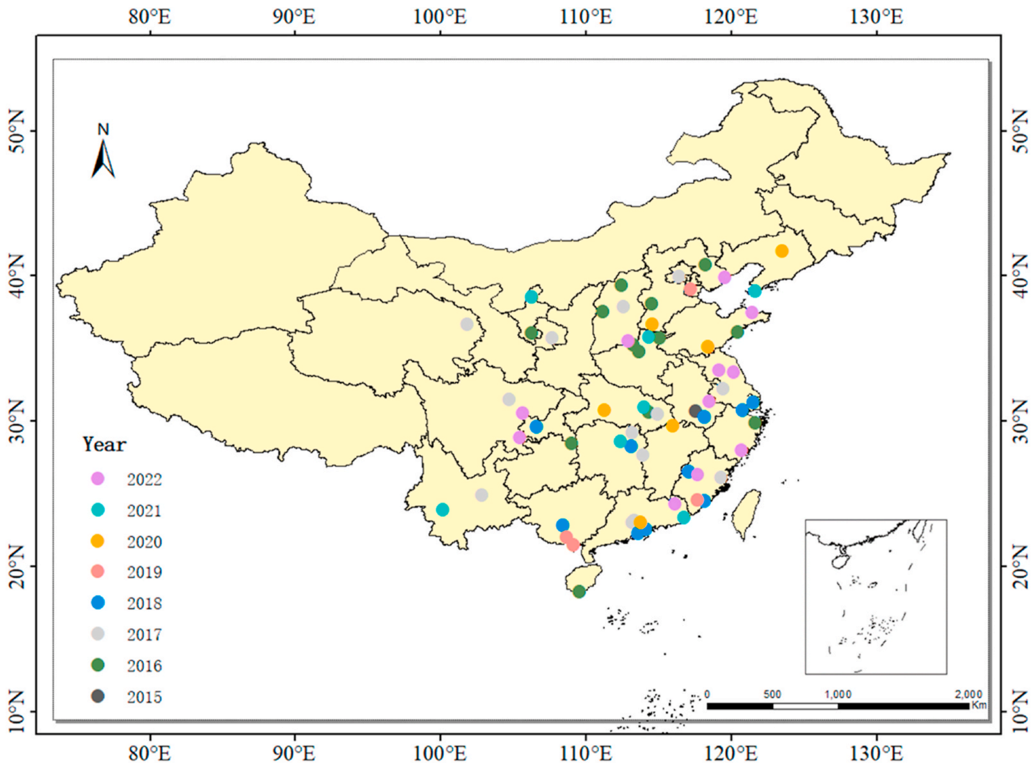

Fig. 4. The local legislation on Sponge City of China from 2015 to 2022. China lacks national legislation on Sponge City, which means the implementation of Sponge City relies on local legislation. This map showed there are only 64/654 cities have promoted the construction and local legislation on the Sponge City Program from 2015 to 2022.

mosquitoes being deposited in low-lying areas, reducing the public's exposure to health risks from the spread of disease. Simultaneously, it can store rainwater and prevent direct flooding as a safety mechanism for residents [36]. For example, Wuhan, a city in Hubei, suffered a severe storm with eventual flooding in 2016, killing 30 people just in the year when SCP was being piloted but the construction was not completed. Governments official then formulated the Guidelines of SCP. The results of the evaluated SCP in Wuhan showed that the SCP effectively controlled flooding threats and eventually could protect human health [37,38]. SCP has been touted as the most reliable and efficient solution in China to help control flooding risks now.

4.3. Inadequate learning from other countries

The data of 4701 deaths in China only refers to direct flood deaths. Persistent health effects caused by flooding are relatively common globally. In the US, flooding is seen as the prevailing cause of death associated with natural disasters, where most deaths are caused by drowning [39,40]. In the United Kingdom (UK), there are increased rates of diarrhea (with cholera and dysentery), respiratory infections, typhoid fever, and illnesses borne by insects that have been defined as occurring after flooding [2]. In Bangladesh, about 70% of the indigenes live in flood-prone areas where diarrhea is the primary illness [41]. Indirect health problems caused by flooding require attention as well.

To control the flooding risk, several strategies were launched earlier in some countries, such as the US [42]. In the US, water management was intended to prevent pollution — as part of the *Clean Water Act*, initially drafted in 1972 and was called best management practices (BMPs). With technology and scientific development, water management has turned to Low Impact Developments (LIDs) from BMPs in the US [43]. LIDs mean the construction of a Sponge City should build and operate under a low change in developed urban areas. LIDs refer to GI, such as green roofs, roads, etc. Some urban areas in US also constructed lots of green parks to reserve rain. GI can have less impact on the city while playing a role in preventing flooding risk [43,44]. LIDs were implemented in the US and later adopted in Germany, Japan, England, France and other countries [1,44,45]. Many implementations of water management measures have shown some positive effects on flooding risk prevention and protection for residents' health. More information about water management around the world is shown in Fig. 5 and Table 2.

Compared with the above, the water management measures in China are insufficient, not only because China has not carried out nationwide SCP but also because China has developed only one water management scheme, while the United States has developed a variety of water management schemes such as BMP, LID and GI [43,46,47]. Late-mover advantage theory advocates that later movers can learn from first movers and reduce costs [48]. China holds the late-mover advantage in many dimensions but not in water management measures. Many foreign practices in water management are worthwhile for China.

4.4. Inadequate legal enforcement on SPC

The lack of legislation from the central government is one of the major factors that hinder the nationwide implementation of SCP in China. Local legislation played a major role in the construction of SCP, but at the same time local legislation is fragmented and duplicated the Chinese legal system, making it difficult for the central government to achieve nationwide coordinated management of SCP [49,50]. The US promoted the nationwide implementation of LID under the *Clean Water Act*, *Disaster Management Act*, *Municipal Finance Management Act*, *Public Finance Management Act*, and so on. States have also promulgated local laws, such as *Virginia Stormwater Management Act*, to implement LID practices. But in China, only local legislation on Sponge City is available. Sponge City has been the goal of China's future urban development. To promote the further implementation of SCP in China, national legislation for Sponge City must be put into the legislative plan.

The impact of flooding varies by geographical location [51]. Hence, geographical complexity may be one of the reasons why China has not yet carried out a national Sponge City legislation. China has a wide geographical area, and the urban regions for piloting the SCP are distributed in different provinces, representing different climates and geographic features around China. Due to the difference in the environmental and economic factors, there is no national law from the central government level in China to manage the SCP. Only guidelines and Sponge City building standards are promulgated by the State Council and the Ministry of Housing and Urban-Rural Development. There is a gap between policy implementation and legal protection [23]. Since there is no national legal enforcement, local governments have to promulgate their local regulations to promote the construction of SCP, but this is not a permanent solution for China.

Since 2015, China has begun to promote Sponge City pilots, and evaluations in several cities have shown that SCP can prevent flooding risks. For the past 8 years, only 64 cities enacted local laws, regulations, and construction plans for SCP. The national Sponge City legislation may be the compelling factor that will improve the implementation of SCP in China. Based on the flooding disaster in Zhengzhou, China also needs to consider redefining standards on Sponge City construction, improving the design and construction standards and responding to emergencies that exceed the capacity limit. With particular relevance to water management measures worldwide, the recommendations to raise standards and establish emergency response initiatives are not just for China.

5. Future research for sponge city in China

Based on the discussion above, future development of SCP in China should focus on national legislation research, engineering and construction standards research, and management according to the local situation. It is necessary to improve flooding risk ability by making huge investments in technology, science, and communications, which have the prospect to enhance and augment the SCP that has already been established to control flooding risks. To further augment the construction standards, data should also be gathered through observation and monitoring to aid decision-makers and engineers in developing the current mitigation actions and improving the new ones [52]. Additionally, research is required in flooding risk awareness to achieve a more comprehensive knowledge of how risk perceptions impact the susceptibility, capacity, and strength of individuals and regions facing flooding.

On the policy dimension, it is important to raise the priority of SCP and give it more attention. A powerful policy-making and a strongly enforced institution are useful for risk prevention. As a national flooding risk prevention plan, a higher priority could promote the implementation of SCP.

On the legal dimension, enacting national legislation also benefits the implementation of SCP and improve the flooding risk prevention ability.

On the construction dimension, some scholars have shown that the building structure has a large impact on water flow [53] and affects flood defense effectiveness [54]. Thus, China needs to update the SCP technology guideline, and the local government should conduct the SCP construction according to the local geographical environment. More so, local SCP construction design should initially consider the highest historical rainfall situation and build an appropriate flood prevention capacity. Changes in precipitation distribution in China due to climate change also need to be considered for SCP implementation in China.

6. Conclusions and limitations

Flooding risk is a global issue, and many countries have undertaken urban water management measures to promote urban water use and flooding prevention. This study analyzed the implementation of SCP in China, and the results showed that currently SCP in China is still insufficient to effectively prevent flooding risks.

SCP was launched later in China, and as a national plan, China lacks national legislation to promote SCP implementation. Noteworthy, just a Sponge City guidance issued by the General Office of the State Council and a Sponge City technology guideline promulgated by the Ministry of Housing and Construction has been applied nationwide. Currently, the Chinese government has not prioritized the Sponge City program enough.

The inadequacy of SCP implementation is demonstrated by: (a) Insufficient coverage of Sponge City construction. Many provinces in China are affected by floods, but not every flood-affected province undertakes SCP. (b) Inadequacy of regulations. China lacks national SCP law; thus, local legislation plays an important role in local SCP management. There are over 600 cities in China, but as of 2022, only 64 cities have promulgated local Sponge City regulations. (c) Insufficient flooding risk prevention. Flooding had caused fatalities every year since 2015, when SCP was launched. Cties that completed their SCP construction still can not fully control flooding

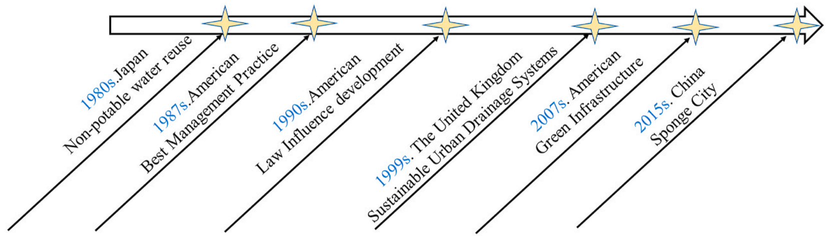

Fig. 5. Various timeline of approaches to control urban flooding risk worldwide. The timeline showed that urban flooding risk prevention has long been practiced in many countries. It is observed that China launched the Sponge City Program later.

Table 2
Various approaches to prevent urban flooding risks worldwide.

Approach/Plans	Implication	Scale	Main facilities	Reference
Sponge City Program (SCP, China)	A systematical outline with methods to develop urban water syndrome	new urban area	LID amenities, terminal treatment facilities, and natural elements	Wang et al., 2020 [36]; Kumar et al., 2021 [56]
Low Impact Development (LID, The US)	An environmentally based development and industrial design approach to controlling the stormwater runoff	all-inclusive urban region	Porous concrete, green roof, rain garden	Eckart et al., 2017 [43]; Bhatt et al., 2019 [47]
Best Management Practices (BMPs, The US)	A type of water pollution control practice	Individual engineering practices (both urban and rural)	Stormwater pond, stormwater marshland, and open-channel systems	Petit-Boix et al., 2017 [60]; Antolini et al., 2020 [46]
Green Infrastructure (GI, The US)	A system offering the "components" for solving urban and climatic challenges by building with nature	In and around towns and cities	Urban forest, constructed wetland, green roof	Mell, 2017 [58]; Leal Filho et al., 2021 [57]
Non-potable water reuse (Japan)	A water management system to reuse systems in several cities mainly for urban applications	Urban areas	Flushing toilets, Irrigation	Takeuchi and Tanaka, 2020 [61]
Water Sensitive Urban Design (WSUD, Australia)	A land planning and engineering design approach that integrates the urban water cycle, including stormwater, groundwater, and wastewater management and the water supply, into urban design	Urban areas	urban waterways	Meng, 2022 [59]
Sustainable Urban Drainage systems (SUDS, The UK)	Collection of water management practices that aim at align modern drainage systems with natural water processes and are part of a larger green infrastructure strategy	Urban areas	physical structures built to receive surface water runoff	Jiménez Ariza et al., 2019 [55]

risk, such as Zhengzhou. (d) Insufficient attention on public health. China is heavily affected by flooding, and flood-related deaths of residents occur every year. Although one of the goals of the Sponge City program in China is to prevent flooding risks, few regulations related to the health department are addressed in the existing local Sponge City regulations. Thus, the research on Sponge City in China needs to be further strengthened.

Despite the discussions above, this research still has some limitations. Since the documents gathered for this study were based on WoS Core Collection and CNKI, there is the possibility of risk of selection bias, although these two databases are reliable and extensive. However, integrating more sources of databases like Google Scholar and Scopus can highlight all-inclusive information for discussion. Notwithstanding, if these challenges are resolved, the researchers do not expect a huge difference in results from this current study.

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Author contribution

Chen Zeng: Formal analysis, Data curation, Visualization, Writing–original draft; Emmanuel Mensah Aboagye: writing review and editing; Huijun Li and Shirui Che: Formal analysis, Data curation. All authors listed have significantly contributed to the development and the writing of this article.

Data availability statement

Data included in article/supp. material/referenced in article.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Abbreviations Table

BMP	Best Management Practices
CNKI	China National Knowledge Infrastructure
GI	Green Infrastructure
IDA	Interpretive Document Approach
LID	Low Impact Development
SCP	Sponge City Program
SUDS	Sustainable Urban Drainage Systems
WoS	Web of Science Database
WSUD	Water-sensitive Urban Design

Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.heliyon.2022.e12745.

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