Review Article

Application of Sponge City for Controlling Surface Runoff Pollution

ABSTRACT

Nowadays, due to the complexity of urban growth and the frequency of extreme stormwater events, flooding has emerged as a major global problem. Scientists and engineers are competing to find the best and most economical ways to prevent flooding. In 2014, China introduced the concept of a sponge city, similar to the low-impact development (LID) approach, comprising several facilities to prevent flooding. In addition to preventing flooding, this approach offers various benefits such as increasing groundwater levels and expanding green spaces. Sponge city is based on four basic principles: urban water resourcing, ecological water management, green infrastructures, and urban permeable pavement. It involves transforming urban infrastructures into green infrastructures. This review analyzes insights from more than 50 articles focusing on various sponge city facilities and classifying them based on their roles in infiltration, retention, storage, purification, use, and drainage. It also compares Sponge city with traditional runoff management approaches. Overall, this review aims to deepen our understanding of modern urban water management strategies and their implications for sustainable development.

Keywords: Flood, Sponge City, Stormwater, Surface Runoff, Percolation.

1. INTRODUCTION

Individuals are increasingly concerned about water and environmental issues as the social economy grows. Meanwhile, point source pollution is being addressed and managed properly. Rainwater runoff thrown directly into an urban water body without proper safeguards will affect the urban water ecology. Stormwater runoff pollution cannot be solved only by standard stormwater management strategies like drainage system restoration or gray infrastructure building (Jiang et al., 2018). Urban surface runoff pollution is largely caused by rainfall, human activities, and relevant local environmental variables (Luo et al., 2009). As a result, taking action to limit stormwater runoff pollution is crucial for enhancing urban water quality (Si et al., 2022). When discussing sponge facilities and their pollutant removal capabilities, it is critical to define and characterize the types of pollutants being addressed. This specificity helps to emphasize the variations between distinct sponge facilities. Depending on the situation, the following common contaminants should be considered: heavy metals, organic compounds, nutrients, pathogens, suspended solids, oil and grease, acidic and alkaline substances, radioactive substances, and emerging contaminants. The notion of urban drainage may be dated back to 3000 BC, with the primary purpose of swiftly discharging rainfall runoff from the urban region to the downstream channel or other receiving water bodies (Fletcher et al., 2014). However, because of the complexity of urban growth and the frequency of extreme stormwater events, several relatively "new" approaches have emerged in many industrialized countries. LID, Green Infrastructure (GI), and Best Management Practices (BMPs) in the USA, the Sustainable Urban Drainage System (SUDS) in the UK, the Water Sensitive Urban Design (WSUD) in Australia, and Nature-Based Solution (NBS). All these ideas or concepts are similar, but distinct names describe different technological systems, which also differ in application scale, technical measurements, and control aims (Zheng et al., 2020). The term "sponge city" refers to more than just LID. It includes LID at the source, the halfway stormwater drainage pipe system, and the terminal excessive stormwater drainage system, which comprises deep tunnel drainage systems and natural water bodies. Integrating LID methodologies and technologies may improve cities' resilience to environmental threats posed by storm occurrences with varying recurrence intervals (Casal-Campos et al., 2015). The Sponge city program incorporates not just the LID idea and methods, but also a variety of comprehensive urban water management solutions. The Sponge city development promotes water security, environmental preservation, and ecological restoration. Background knowledge and generic SPC program principles are provided (Li et al., 2016). The sponge city idea and its implementation are then thoroughly examined to identify the limits and potential. Sponge city has four basic principles: urban water resourcing, ecological water management, green infrastructures, and urban permeable pavement. The most important issues that might lead to the collapse of the Sponge city idea include ambiguities in sponge city design and planning, and financial inadequacies (Nguyen et al., 2019). Sponge city is a revolutionary concept that may be characterized as a metropolis that can adapt to water environment changes like a sponge and realize free rainwater movement (Sun et al., 2020). When there is external precipitation, sponge city can absorb, infiltrate, hold, and cleanse water; when there is no precipitation, sponge city may discharge water (Guan et al., 2021). Sponge city is made up of wetlands, woods, lakes, green roofs, biological retention, and permeable pavements, among other things (Liang et al., 2020). Sponge city has several goals. The first is to control urban flooding disasters. As a result of climate change and urbanization, many cities in China face extreme urban flooding hazards. To address this issue, sponge city has developed alternative infrastructures such as green roofs, bioretention, and permeable pavements to increase water absorption and reduce water runoff. As a result, urban flooding can be mitigated; however, it must be recognized that an increase in urban flooding is inevitable. Second, Sponge city aims to improve water quality in metropolitan areas through self-purification systems and ecological waterfronts. The following objective is to recycle stormwater for urban water supply. Rainwater is converted into a resource here to address water shortages in cities, which is especially important during droughts (Jia et al., 2017; Wang et al., 2018). the problem statements of sponge city are flooding and urban waterlogging which means heavy rains can create frequent and severe floods, causing property damage, interruptions in transit, and safety issues. Urbanization, industrialization, and population growth are causing water scarcity, pollution, heat island effects, soil erosion, ecological degradation, infrastructure overload, public health concerns, social inequity, and resource inefficiency. Water bodies are polluted due to industrial discharge, stormwater runoff, and inadequate wastewater treatment. Urban heat islands exacerbate temperature extremes and affect urban livability. Inadequate urban planning and land use practices lead to soil erosion and sedimentation in water bodies. Public health issues arise from waterborne diseases and inadequate sanitation. Social inequity affects vulnerable communities. This paper is a review of the sponge city concept; it is important to familiarize people with this, especially in countries that are affected by flooding every year. The fundamental reason for doing this review is to thoroughly evaluate and assess the use of sponge city concepts in mitigating surface runoff pollution. Given the growing issues of urbanization and climate change, assessing the efficacy of sponge city efforts is critical. This study will combine current information, research findings, and practical applications linked to sponge city activities, offering a comprehensive assessment of their influence on surface runoff pollution reduction. It will in addition to identify significant practices, their implementation, and outcomes by reviewing the literature, case studies, and field developments. The purpose is to emphasize the merits and limits of sponge city techniques, giving useful information for researchers, urban planners, policymakers, and practitioners in sustainable urban water management. The relevance of this review stems from its ability to help influence decision-making in urban development and environmental management. Also, this review aimed to provide a framework for evidence-based procedures by consolidating current information about sponge city applications. The findings of this study can inform future research areas, policy formation, and the implementation of sustainable urban water management systems. Finally, the evaluation aims to encourage widespread implementation of sponge city concepts to reduce surface runoff pollution in metropolitan areas, creating resilient and ecologically conscientious urban growth. Sponge city facilities are intended to reduce surface runoff pollution by combining natural and manmade solutions. These projects seek to emulate sponge natural water absorption and retention ability, aiding in the sustainable and ecologically friendly management of urban stormwater. Here are important methods sponge municipal facilities use to manage surface runoff pollution. Table. 1 shows an overview of general measures for surface runoff pollution control, and their practices, effects, advantages, and disadvantages.

2. SPONGE CITY CONCEPT

Sponge city is the chinse concept, similar to the LID system. In recent years, extreme rainfall events and poor drainage infrastructure have frequently resulted in major urban floods in several locations across the world (Myers & Pezzaniti, 2019). Urban flooding is becoming more prevalent worldwide due to climate change and urbanization, to solve this issue, several cutting-edge strategies have surfaced. To create an urban hydrological equilibrium through natural storage, natural infiltration, and natural pomme reification, a sponge city was initially suggested in China in 2012 (Luo et al., 2022). The sponge city concept became more popular after President Xi Jinping Chinese president and the central government promoted it at the central conference on December 12, 2013 (Li et al., 2020). In addition, in 2015 and 2016, the Chinese central government selected 30 pilot cities for sponge city construction exploration based on their diverse natural and social conditions (with an average construction area of 31.3 km2 for each city), and all of them completed performance assessments by the end of 2019 (Jia & Yin, 2021). The term "Sponge City" defines an urban setting that is committed to identifying environmentally appropriate substitutes to change urban infrastructures into green infrastructures so that they might absorb, regulate, and efficiently reuse precipitation, additionally, the goal of sponge city is to encourage the rehabilitation of drainage systems, the enhancement of water system connection, the separation of rainfall and sewage pipe networks, and other contemporary engineering solutions to increase the city's capacity to handle water issues (Liu et al., 2017). Sponge city main goals are to encourage sustainable urban growth, improve water quality, and increase water resilience. Using these techniques, sponge cities want to improve the harmony between urban areas and water resources, resulting in more livable and environmentally friendly communities. To successfully regulate rainfall runoff and lower source emissions, sponge use pays more attention to maintaining the city's natural water system. This is done through natural ecological function recovery and manual intervention in urban water ecology. Additionally, you may lessen the likelihood of disasters and floods, minimize economic losses, offer a safe path for urban growth, and cut local fiscal expenditure. Combining water storage facilities with urban green space will dramatically lower the cost of water pollution management, save money on local environmental governance, and improve the efficient use of finances (Zhang, 2017). The main benefit of sponge city is preventing flooding, nowadays the main problem that faces the cities is flood. The construction of a sponge city emphasizes the full exploitation of previous regions' natural absorption and infiltration ability to regulate stormwater runoff efficiently , hence minimizing water system problems caused by the harm of urbanization-induced hydrological impacts (Yin et al., 2022). Fig. 1 shows a sponge city sketch including most of the facilities.

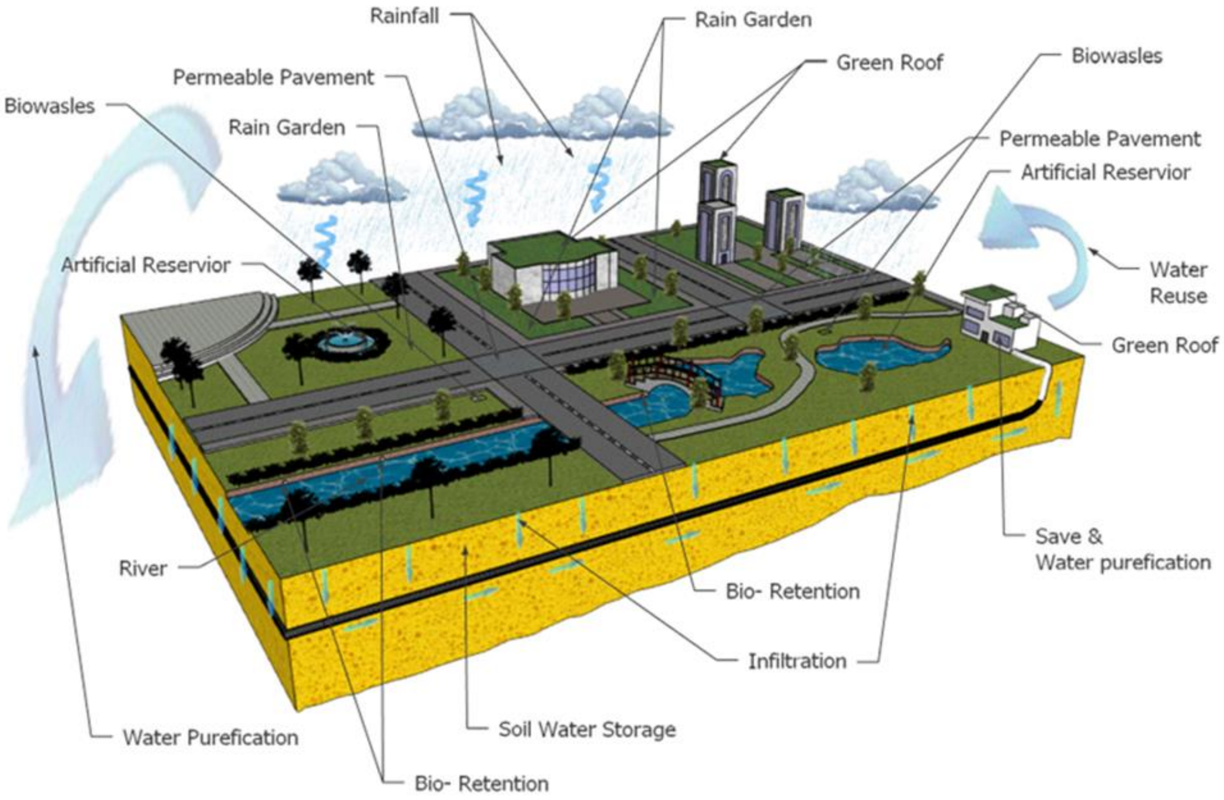
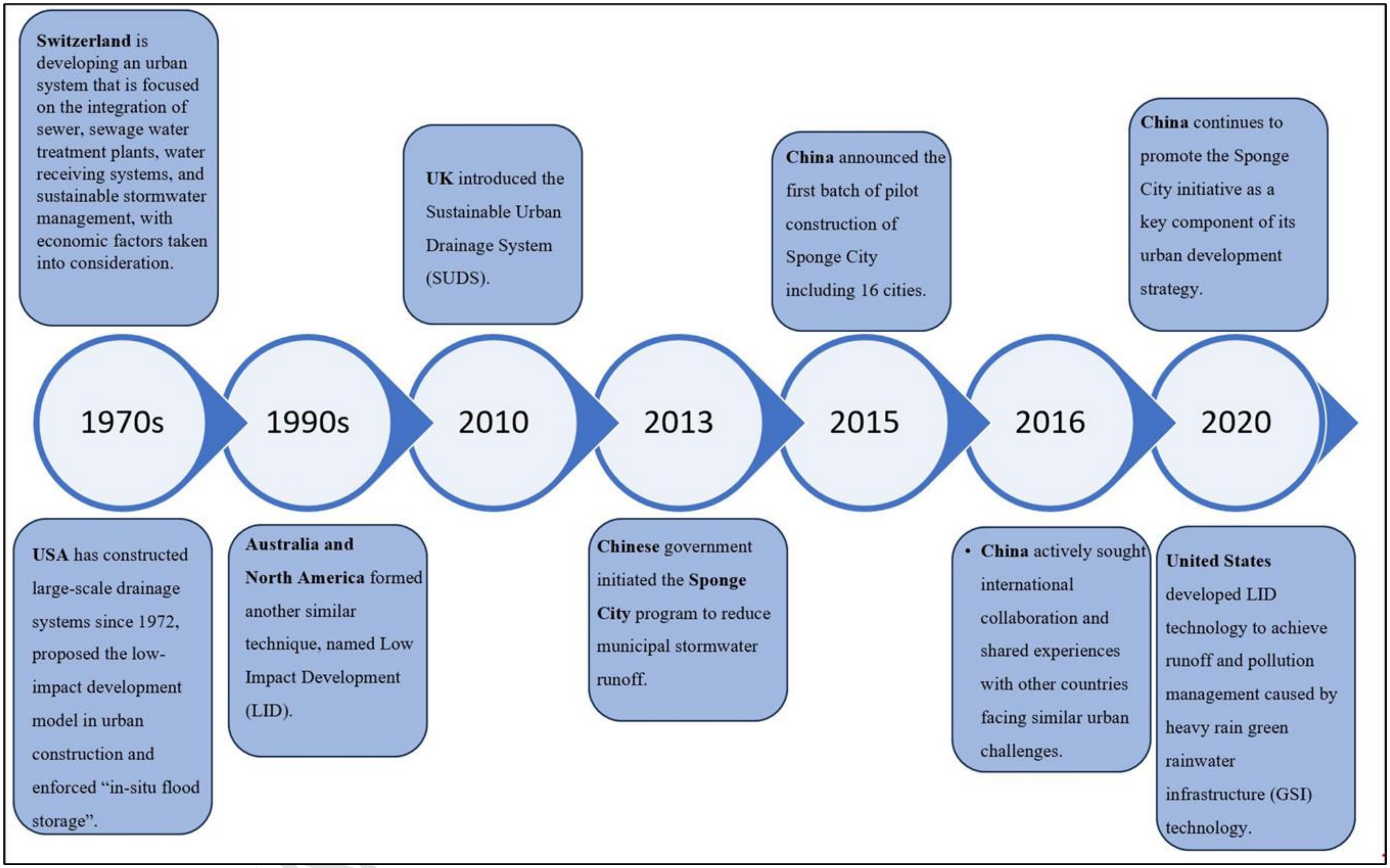


Fig. 1 Sketch of Sponge City.

2.1 THE DEVELOPMENT OF SPONGE CITY

Rainstorms and other extreme weather events are becoming more common because of global warming, resulting in flooding and non-point source pollution (Trenberth et al., 2013). To address this issue, the state of Maryland in the United States developed LID technology in the late 1990s to achieve runoff and pollution management caused by heavy rain, mostly through decentralized, small-scale source control. After nearly two decades of development, it has become the most widely employed urban Green Rainwater Infrastructure (GSI) technology in the United States and many other industrialized nations (Dagenais et al., 2016)Similar technologies include Australia's Water Sensitive Urban Design (WSUD), New Zealand's Low Impact Urban Design and Development (LIUDD), and the United Kingdom's Sustainable Drainage Systems (SuDS). Stormwater harvesting and stormwater management in Japan, as well as rainwater storage infiltration in Japan, are key examples of other nations dealing with urban floods and runoff pollution. Since 1949, China's management of urban rainfall-runoff has traditionally gone through three stages: direct rain (1949 to 2000), joint usage (2000 to 2013), and system management (2013 to present). General Secretary Xi Jinping advocated the creation of "Sponge City" in 2013, indicating that China's urban rainwater management had progressed to the system management level. Since 1989, Beijing has performed research and practiced rainwater utilization. It is China's first city and has achieved success. It has been essential in lowering and regulating urban rainfall-runoff, as well as reducing non-point source pollution and avoiding urban infighting. Reduce non-point source pollution and urban infighting by lowering urban rainwater runoff. Fig. 2 shows a timeline diagram of important events that tallied sponge city occurring.



Switzerland is developing an urban system that is focused on the integration of sewer, sewage water treatment plants, water receiving systems, and sustainable stormwater management, with economic factors taken into consideration.

USA has constructed large-scale drainage systems since 1972, proposed the low-impact development model in urban construction and enforced "in-situ flood storage".

Australia and North America formed another similar technique, named Low Impact Development (LID).

UK introduced the Sustainable Urban Drainage System (SUDS).

Chinese government initiated the **Sponge City** program to reduce municipal stormwater runoff.

China announced the first batch of pilot construction of Sponge City including 16 cities.

- **China** actively sought international collaboration and shared experiences with other countries facing similar urban challenges.

China continues to promote the Sponge City initiative as a key component of its urban development strategy.

United States developed LID technology to achieve runoff and pollution management caused by heavy rain green rainwater infrastructure (GSI) technology.

Fig. 2 Sponge city's important events.

2. APPLICATION OF SPONGE CITY ALIKE APPROACHES AROUND THE GLOBE

2.1 USA

Best Management Practices (BMP) originally appeared in the "Clean Water Act," established by the United States Congress in 1972, and were first applied mostly to sewage discharges or point sources (Keller & Griffin, 1999; Yin et al., 2022)The BMP for stormwater runoff or nonpoint pollution management was implemented after 15 years. Among the key technical measures were several low-cost engineering measures. Furthermore, it stressed non-engineering methods such as facility maintenance norms. Since then, the idea of LID has been incorporated in US EPA publications on urban stormwater management and guidelines from several states. Using a "nature design approach," such as green roofs and rain gardens, has promoted the use of source runoff control facilities. Furthermore, the United States encouraged urban drainage design by employing LID-BMPs, which represented all the BMPs for urban stormwater runoff management using the LID technique, and the frequency of this idea in international literature has quickly expanded in recent years (Jia et al., 2013). As a result, the phrase "green infrastructure," which encompasses classic BMPs and typical LID measures, arose as the word for source control infrastructure for urban runoff. GI can provide several ecological advantages, including reducing urban heat islands (UHI), expanding biological habitats, and promoting biodiversity (Fletcher et al., 2014). Source runoff reduction is also a high goal in sponge city building since it may successfully minimize total runoff and absorb some of it on-site. However, sponge city's source control comprises not just modest, dispersed infiltration and retention structures (green roofs, grass swales, and bioretention), but also large-scale storage facilities like stormwater ponds and wetlands. It is critical to choose appropriate facilities based on the magnitude and features of the individual region's runoff quantity and quality (Yin et al., 2022).

2.2 UK

In the United Kingdom, a SuDS concept was presented in 2007, which not only incorporates the principles of LID-BMPs and GI in the United States but also diversifies the drainage system design to avoid the traditional sewage network being the only drainage outlet (Riechel et al., 2020). Meanwhile, the filtering impact of drainage systems was considered to limit pollution discharge into the receiving water body. Furthermore, rainwater collection and usage were stressed (Lim et al., 2015). As a result, rather than relying primarily on fast runoff discharge, urban stormwater management systems became more functional. Furthermore, significant environmental, social, and economic advantages were realized (Johnson & Geisendorf, 2019). It is easy to observe how SUDS evolved from a classic "rapid drainage" system to a more sustainable and multifunctional drainage system with a high level of benign water circulation. Meanwhile, rather than focusing just on urban drainage systems, it sought to optimize the complete water system, including sewage, and recovered water. This also corresponded to the idea of a sponge city building. The sponge city design considers the quantity and quality of water, and the potential landscape and ecological value of runoff.

2.3 AUSTRALIA

Australia introduced the idea of WSUD in 1994, centered on the technical core of urban stormwater management and based on a comprehensive understanding of the water cycle in the local physical and environmental context (Sharma et al., 2012). It was also the first time stormwater, groundwater, drinking water, sewage, and reclaimed water systems were all considered. WSUD was defined as "a philosophical approach to urban planning and design aimed at reducing the hydrological impact of urban development on the surrounding environment (Lloyd et al., 2002). It stressed the need to consider stormwater management challenges within the context of the complete urban water cycle (Wong, 2015). WSUD employed an integrated technique to achieve stormwater management rather than only micro-scale landscape stormwater control, which differs from LID-BMPs (Taowei, 2021). These overlapped significantly with the sponge city building (Xiufeng et al., 2019). For example, managerial fragmentation and the discretization of linked departments may impede the growth of WSUD. As a result, WSUD encouraged urban water management through institutional development and administrative measures to provide a long-term system for sustainable urban design (Liu, 2021). Regarding sponge city building, it is still required to learn from WSUD and undertake various research to give scientific construction recommendations, such as the runoff regulation capability of various GIs, long-term tracking monitoring, and thorough performance assessment (Gong et al., 2019).

3- SPONGE CITY FACILITIES

Certainly, sponge city facilities can be classified into various categories based on their primary functions related to infiltration, retention, storage, purification, use, and water drainage. Fig. 3 shows a classification of sponge city facilities according to these functions:

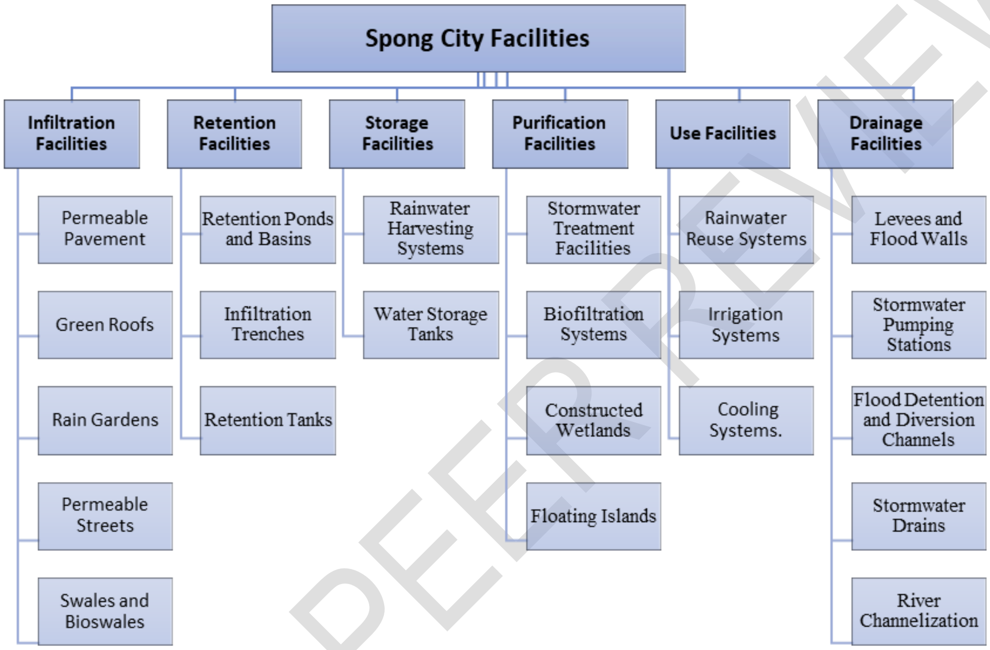


Fig. 3 Sponge city classification.

3.1 INFILTRATION FACILITIES:

- Permeable Pavement: Allows water to infiltrate the ground, reducing surface runoff.
- Green Roofs: Captures and slowly releases rainwater into the environment.
- Rain Gardens: Collects and manages stormwater runoff, promoting infiltration.
- Permeable Streets: Roads and pathways designed for water infiltration.
- Swales and Bioswales: Vegetated channels that capture and facilitate water infiltration.

3.2 RETENTION FACILITIES:

- Retention Ponds and Basins: Store excess stormwater and slowly release it.
- Infiltration Trenches: Underground trenches designed to promote water infiltration.
- Retention Tanks: Underground or aboveground storage for temporary water retention.

3.3 STORAGE FACILITIES:

- Rainwater Harvesting Systems: Collect and store rainwater for various purposes, including irrigation and non-potable water supply.
- Water Storage Tanks: Store harvested rainwater for later use.

3.4 PURIFICATION FACILITIES:

- Stormwater Treatment Facilities: Filter and treat stormwater to remove pollutants.
- Biofiltration Systems: Natural filtration processes to enhance water quality.
- Constructed Wetlands: Natural systems that purify water by removing contaminants.
- Floating Islands: Floating structures with plants that absorb pollutants from the water.

3.5 USE FACILITIES:

- Rainwater Reuse Systems: Collect and treat rainwater for non-potable uses, such as toilet flushing and irrigation.
- Irrigation Systems: Drip or sprinkler systems using harvested rainwater.
- Cooling Systems: Use rainwater for cooling in buildings and industrial processes.

3.6 DRAINAGE FACILITIES:

- Levees and Flood Walls: Control and redirect floodwaters, preventing inundation.
- Stormwater Pumping Stations: Pump and redirect excess stormwater.
- Flood Detention and Diversion Channels: Redirect and temporarily detain excess water.
- Stormwater Drains: Traditional stormwater drainage systems to prevent local flooding.
- River Channelization: Modifications to natural river courses to control water flow.

These classifications are not mutually exclusive; many sponge city facilities serve multiple functions. Integrating these facilities into urban planning and design to create a holistic and resilient approach to water management, flood control, and sustainable urban development is key.

4. PURIFICATION EFFECT OF SPONGE CITY’S FACILITIES FOR REMOVING POLLUTANTS

4.1 THE SUITABLE FACILITIES FOR THE PURIFICATION OF DIFFERENT POLLUTANTS:

Sponge cities are intended to absorb, capture, and manage rainfall to prevent floods, improve water quality, and encourage sustainable urban growth. Sponge city designs might have a variety of facilities for purifying different pollutants. Here are some appropriate sponge city facilities for purifying various contaminants as shown in Table. 2. The efficiency of these facilities may differ depending on local climate, soil conditions, and the unique features of pollutants in the region. A comprehensive approach that includes numerous tactics is frequently advised for the best outcomes in sponge city development. We can cite examples of purification carried out within relevant facilities during performance and implementation, such as:

4.1.1 RAIN GARDEN

The rain gardens’ establishment succeeded in various locations, including the United Kingdom, Japan, Korea, China, and the United States. Rain gardens have been found to decrease surface runoff by 25-69% and peak runoff by 12-71% (Houghton, 2003). The United Kingdom employs a taxonomically diverse selection of plants to enhance habitat quality and aesthetic value. This approach is akin to the strategy implemented in Shanghai, China, where rain gardens are designed with artistic appeal and regional cultural uniformity in consideration. Table. 3 shows the performance and implementation of rain gardens.

4.1.2 GREEN ROOF

They are also referred to as green roofs, living roofs, or vegetated roofs, and can be categorized into three types based on the depth of the planting substrate and the complexity of the landscape and garden design. The green roof mitigates ground drainage resulting from rainfall by approximately 70%, with the peak value being delayed by 20 minutes (Song, 2022). Green roofs have gained widespread adoption in North America and the United Kingdom, whereas Japan lags in both deployment and regulatory measures. For buildings with an area equal to or exceeding 2000 m², regulations stipulate that 20-60% of the total roof area must be designated for green roofing. Japan, on the other hand, mandates the incorporation of green roofs in all new buildings. In the city of Portland, Oregon, an even more stringent requirement is in place, with a mandate for 70% of new buildings to feature green roofs (Shafique et al., 2018). Table. 4 shows the performance and implementation of green roofs.

4.1.3 PERMEABLE PAVEMENT

Permeable pavement technology encompasses various classifications such as permeable brick pavement, permeable cement concrete pavement, and permeable asphalt concrete pavement, distinguished by the specific surface materials, including cobbles and gravel, and the incorporation of grass-embedded bricks or garden pavement. At times, pavements incorporating cobbles, gravel, and garden elements are also categorized as permeable pavements. Table. 5 shows the performance and implementation of Permeable Pavement.

4.2 EFFECT OF FACILITIES ON THE POLLUTION REMOVAL:

The efficacy of different sponge city facilities in removing the same pollution varies depending on several criteria, including the kind of pollutant, local environmental conditions, design considerations, and maintenance procedures. Table. 6 shows a broad comparison of how different facilities can affect the removal of pollutants. It is vital to remember that each facility's efficiency is determined by factors such as its size, local climate, maintenance methods, and special design concerns. Combining numerous facilities in a complete stormwater management plan is frequently advised to efficiently handle diverse contaminants. Furthermore, constant maintenance is required to ensure that these facilities continue to operate properly over time.

4.3 MECHANISMS AND PROCESSES INVOLVED IN SPONGE CITY TO REMOVE POLLUTANTS:

Sponge cities employ diverse strategies to mitigate pollutants in urban runoff and enhance water management. These approaches encompass the utilization of permeable surfaces, such as pavements, facilitating rain absorption into the soil while preventing contaminants from reaching aquatic ecosystems. Green roofs, adorned with vegetation, act as natural filters by absorbing and purifying rainwater. Rain gardens and bioswales, vegetated zones, serve to delay and filter rainwater, facilitating the removal of pollutants. Constructed wetlands function as biological stormwater treatment systems, emulating natural ecosystems. Retention ponds and detention basins briefly retain stormwater, allowing sediment and pollutants to be extracted before controlled release. Vegetated swales, characterized by plant-filled open waterways, aid in pollutant removal and promote infiltration. Urban forestry practices, including tree planting, contribute to rainwater absorption and filtration, thereby reducing pollution. Integration of smart infrastructure, featuring sensors and real-time monitoring, enhances the efficiency of stormwater management. Community engagement is crucial, involving residents in the design and upkeep of green infrastructure, fostering responsible behavior, and endorsing sustainable water practices. The collaborative implementation of these measures enhances the resilience and efficacy of sponge cities in water management and pollutant removal within urban environments. Fig. 4 shows Pollutant removal mechanisms in typical infiltration and purification facilities of sponge cities such as bioretention.

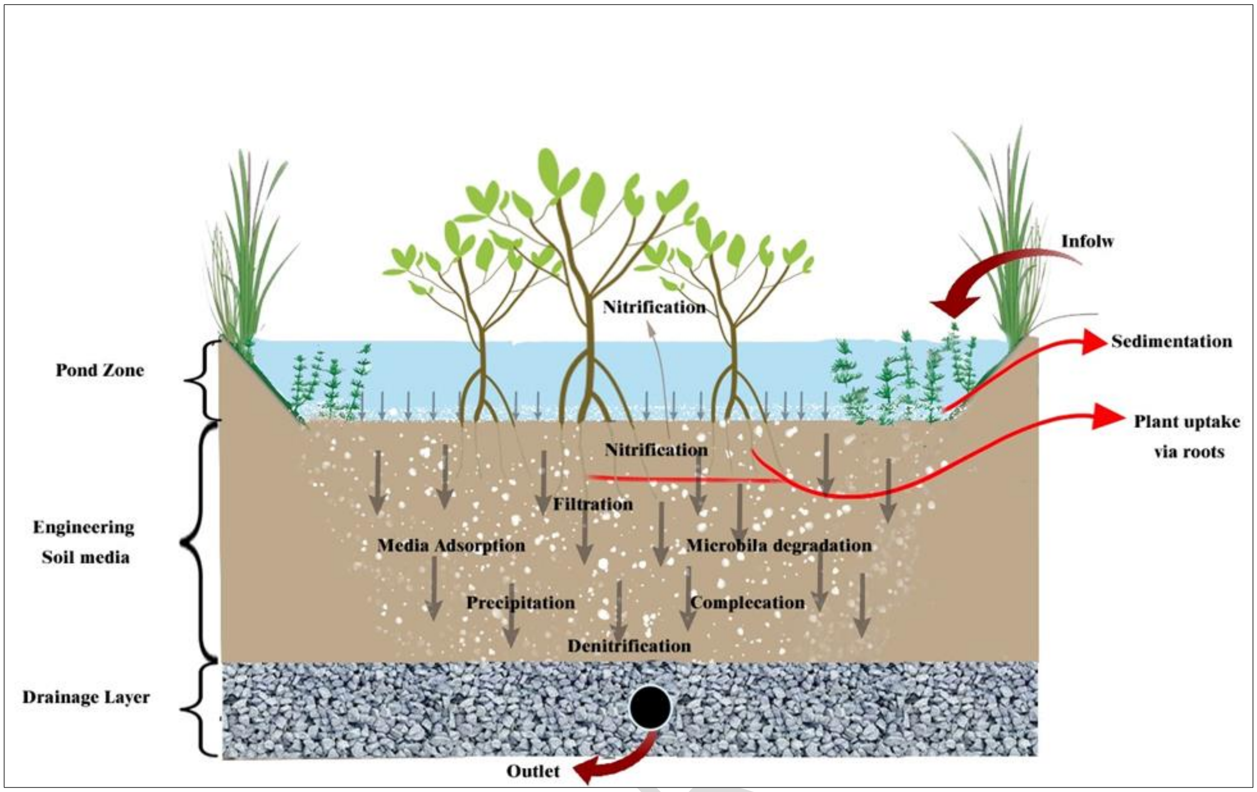


Fig. 4 Bioretention's pollutant removal mechanisms.

5. COMPARISON BETWEEN SPONGE CITY AND NORMAL RUNOFF CONTROL

Urban runoff source control facilities (e.g., bioretention, green roof, permeable pavement, retention pond, infiltration pit, and constructed wetlands) play critical roles in controlling local hydrological conditions, reducing urban runoff pollutants, and alleviating urban flooding as an important part of Sponge city construction(Xu et al., 2022). Sponge city is a concept that intends to emulate the natural water-absorbing qualities of a sponge by absorbing, capturing, and purifying rainwater using various green infrastructure approaches. Its primary goals are to reduce urban floods, improve water quality, and recharge groundwater. Normal runoff management employs structures such as storm drains, concrete channels, and pipes to swiftly remove surplus precipitation from metropolitan areas and release it into rivers or other bodies of water. Its major goal is flood prevention and preventing water from accumulating in urban areas. Green infrastructure such as permeable pavements, green roofs, rain gardens, bioswales, retention ponds, and wetlands are used in Sponge city. These characteristics aid in the absorption and storage of rainfall, enabling it to permeate the earth and, therefore, reduce runoff organically. Normal runoff control relies on concrete infrastructure such as stormwater drains, gutters, and pipes to quickly carry rainfall away from urban areas. These systems are designed to reduce floods by diverting water to centralized bodies of water or sewage systems. Sponge city increases biodiversity, minimizes heat islands, improves air quality, and aids in groundwater recharge. It also improves the visual value of cities and generates leisure zones. Normal runoff control frequently causes increased pollution by transporting trash, chemicals, and contaminants from urban surfaces into bodies of water. The quick flow of water can cause erosion and habitat degradation downstream. Sponge city increases resilience to extreme weather events such as heavy rainfall by absorbing and managing enormous quantities of water, lowering the danger of urban floods and associated damages. normal runoff control may fail to handle heavy rainfall or storm events, resulting in increased floods, property damage, and significant urban disturbances. green infrastructure installation expenses might be greater at first. However, compared to traditional systems, it frequently requires less maintenance and has lower long-term operational expenses. In normal Runoff Control while initial construction costs are cheaper, continuing maintenance and repair expenditures for traditional systems (such as removing blockages in pipes and restoring concrete structures) can be substantial. To summarize, sponge city emphasizes sustainable and nature-based stormwater management solutions, which provide numerous environmental benefits, resilience against extreme weather, and often lower long-term costs than traditional runoff control methods, which primarily focus on quick water removal but may have negative environmental impacts and higher maintenance costs over time.

6. THE COMPARISON OF POLLUTION REMOVES BETWEEN SPONGE CITY AND NORMAL RUNOFF CONTROL:

Sponge city facilities are intended to manage stormwater in a more sustainable and ecologically friendly manner than conventional runoff control systems. The comparison of the removal effects of the same pollutant in sponge city facilities and traditional runoff management strategies is dependent on the individual facilities employed in each method. Table. 7 is a broad overview. Overall, sponge city facilities outperform traditional runoff management methods in terms of pollutant removal and water quality improvement. They use natural processes, vegetation, and artificial technologies to mitigate stormwater runoff's environmental effects. However, the efficiency of both systems is determined by local circumstances, maintenance procedures, and the facility's unique design.

7. BENEFITS OF SPONGE CITY

Sponge City programs provide a comprehensive approach to urban water management that mixes nature-based solutions with traditional infrastructure, benefiting both the environment and the population.,(Nguyen et al., 2020) They review classified Possible benefits of sponge city implementation into three main branches as shown in Fig(5).

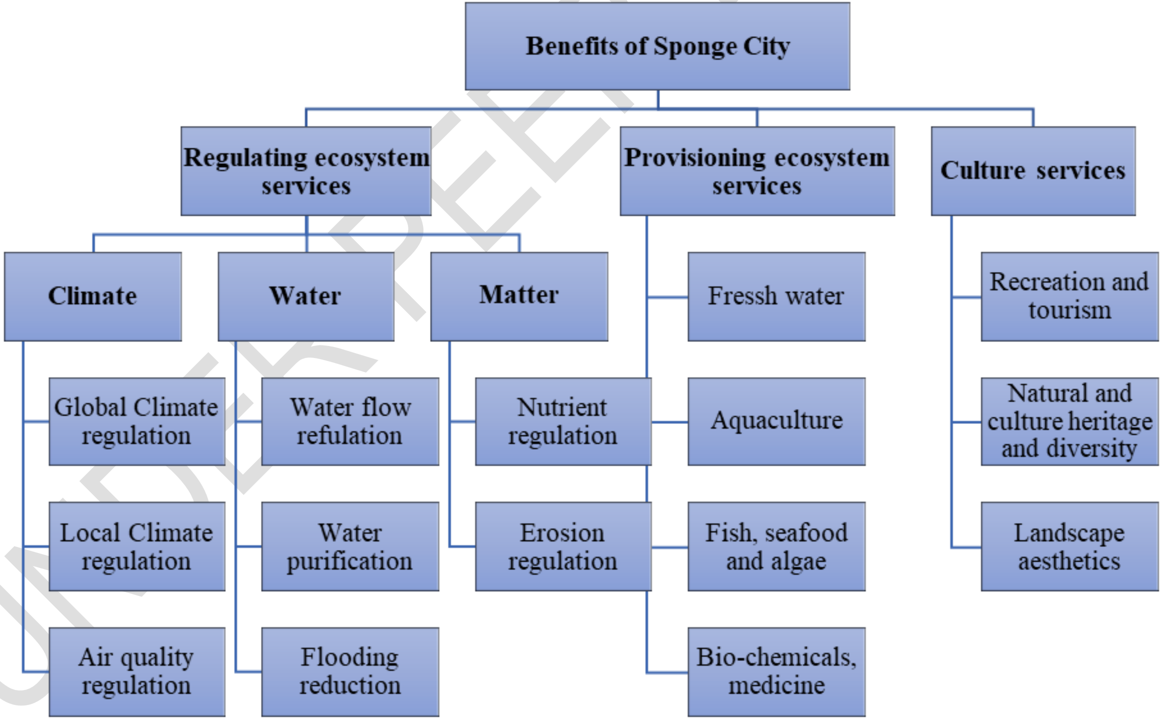
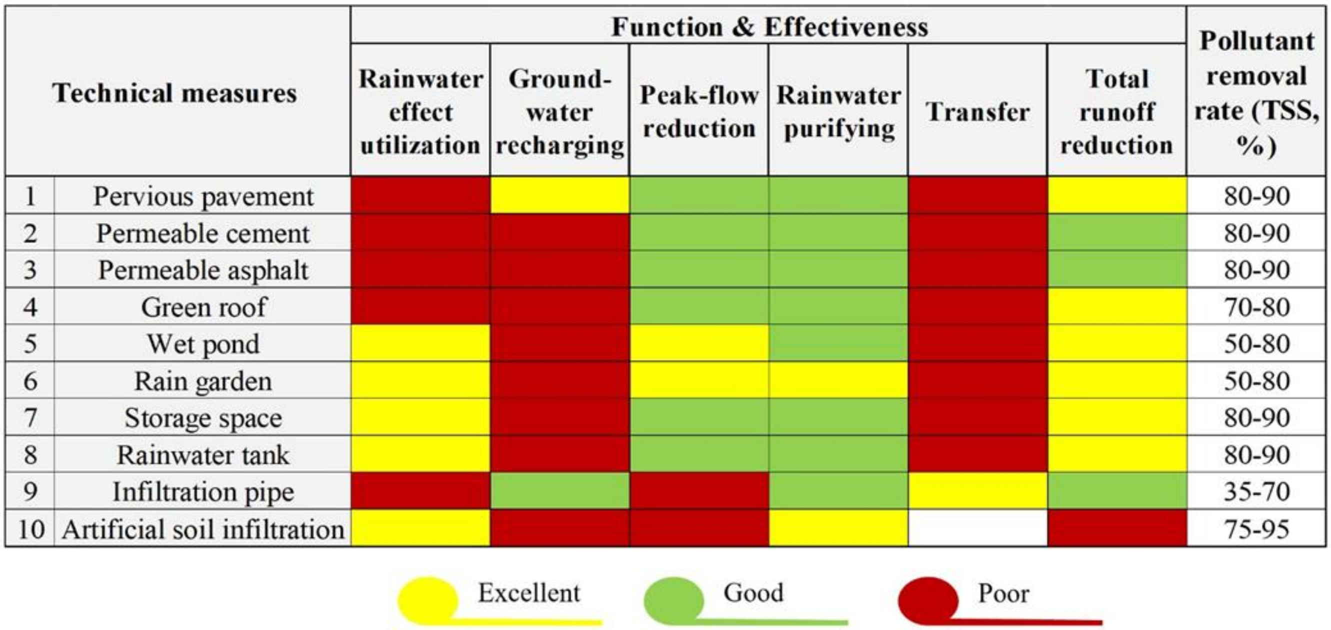


Fig. 5 Possible benefits of sponge city implementation.

Generally, we can summarize sponge city's benefits or advantages as to:
-Flood Prevention: Reduces urban flooding by absorbing and storing rainwater through green spaces and permeable surfaces.
-Water Quality Improvement: Filters pollutants from rainwater, improving water quality before it reaches larger bodies of water or recharges groundwater.

-Biodiversity and Ecosystem Services: Enhances habitats for wildlife, promotes biodiversity, and supports ecosystem services like air purification and temperature regulation.
-Climate Resilience: Adapts to changing weather patterns and extreme events, makes urban areas more resilient to climate change impacts.
-Heat Island Mitigation: Vegetation and green spaces reduce surface temperatures, combating the urban heat island effect and creating more comfortable living environments.
-Community Health and Engagement: Provides spaces for recreation, social interaction, and mental well-being, improving overall community health.
-Economic Benefits: While requiring initial investment, it reduces flood damage costs, increases property values, and potentially saves on water treatment expenses in the long run.
Fig. 6 shows the principal technical indicators of the sponge city Program refer to the primary quantitative metrics employed to assess and gauge the efficacy of the program's engineering and infrastructure measures. Interdependent measures collaborate synergistically to establish an innovative sponge infrastructure. This sponge infrastructure must be seamlessly integrated with conventional drainage systems, with a particular emphasis on regions characterized by moderate to high levels of urbanization(Liu C et al., 2016).



	Technical measures	Function & Effectiveness						Pollutant removal rate (TSS, %)
		Rainwater effect utilization	Ground-water recharging	Peak-flow reduction	Rainwater purifying	Transfer	Total runoff reduction	
1	Pervious pavement	🟥	🟨	🟩	🟩	🟥	🟨	80-90
2	Permeable cement	🟥	🟥	🟩	🟩	🟥	🟩	80-90
3	Permeable asphalt	🟥	🟥	🟩	🟩	🟥	🟩	80-90
4	Green roof	🟥	🟥	🟩	🟩	🟥	🟨	70-80
5	Wet pond	🟨	🟥	🟨	🟩	🟥	🟨	50-80
6	Rain garden	🟨	🟥	🟨	🟨	🟥	🟨	50-80
7	Storage space	🟨	🟥	🟩	🟩	🟥	🟨	80-90
8	Rainwater tank	🟨	🟥	🟩	🟩	🟥	🟨	80-90
9	Infiltration pipe	🟥	🟩	🟥	🟩	🟨	🟩	35-70
10	Artificial soil infiltration	🟨	🟥	🟥	🟨		🟥	75-95

🟨 Excellent
🟩 Good
🟥 Poor

Fig. 6 Principal Technical Strategies within the Sponge City Program.

8. CONCLUSIONS

The implementation of the sponge city concept has emerged as a promising and innovative approach to address the challenges posed by increasing urbanization and the impacts of climate change on surface runoff management. This article provides an extensive review of the literature and case studies to highlight the diverse applications and multifaceted benefits of sponge city initiatives in mitigating surface runoff issues. The integration of green infrastructure, including permeable pavements, green roofs, rain gardens, and retention ponds, has shown remarkable effectiveness in reducing and controlling surface runoff, while simultaneously enhancing urban resilience and sustainability. Furthermore, the utilization of nature-based solutions not only manages stormwater but also contributes to improving urban aesthetics, biodiversity, and overall livability. The sponge city idea is an urban planning and development concept that aims to improve a city's ability to absorb, store, and regulate water. The idea is to emulate the natural water absorption and retention features of a sponge to address challenges like floods, water shortages, and water pollution. sponge city facilities use permeable surfaces, green areas, retention basins, and built wetlands to filter and manage rainwater. These components allow contaminants to be removed naturally through processes such as soil filtering and plant absorption. Furthermore, smart infrastructure and water management systems maximize water treatment, helping to improve overall water quality in cities. The development direction of sponge city focuses on sustainable urban water management. Key elements include enhancing permeable surfaces, green spaces, and water-sensitive design. The direction emphasizes the integration of natural processes like soil filtration and constructed wetlands, along with smart infrastructure for efficient water management. The goal is to create resilient urban environments that mitigate flooding, address water scarcity, and improve water quality, fostering long-term environmental sustainability.

However, despite the demonstrated advantages, successful implementation of sponge city projects necessitates comprehensive planning, stakeholder engagement, sufficient funding, and ongoing maintenance. Challenges related to limited funding, land availability, policy frameworks, and public awareness remain relevant in achieving widespread adoption and long-term success. Looking ahead, further interdisciplinary research, collaboration among stakeholders, and knowledge-sharing platforms are crucial to refining methodologies, addressing challenges, and expanding the adoption of sponge city concepts globally. Additionally, the contextual adaptation of these strategies to different geographic, socio-economic, and climatic conditions is essential for their effective implementation and scalability. As we strive for sustainable urban development, the sponge city concept is a beacon of hope, offering viable solutions to mitigate surface runoff issues, enhance urban resilience, and create more livable and environmentally friendly cities for future generations.

COMPETING INTERESTS

Authors have declared that they have no known competing financial interests OR non-financial interests OR personal relationships that could have appeared to influence the work reported in this paper.

Disclaimer (Artificial intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

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Table. 1 General measures for surface runoff pollution control.

Measures	Practice	Effect	Advantages	Disadvantages
Vegetative buffers	Vegetation planting along water bodies or at the edges of impervious surfaces.	Reduces sediment and nutrient runoff, provides habitat, and stabilizes banks.	Cost-effective, aesthetically pleasing, and promotes biodiversity.	Requires maintenance and may not be effective for certain pollutants.
Permeable pavement	Using porous materials for pavement to allow water infiltration.	Decreases surface runoff, recharges groundwater and minimizes pollutants.	Controls runoff, reduces flooding, and helps with water table recharge.	The initial cost can be high, maintenance is required, and may not be suitable for heavy traffic areas.
Green roofs	Installing vegetation on rooftops to absorb and slow down rainwater.	Reduces stormwater runoff, provides insulation, and improves air quality.	Mitigates urban heat island effect improves energy efficiency and enhances aesthetics.	Initial cost, maintenance, and weight load considerations for existing structures.
Detention and retention basins	Constructing basins to temporarily hold and detain stormwater before controlled release.	Reduces peak flows, controls flooding, and allows sediment settling.	Effective for large areas, helps manage peak flows, and can serve as recreational areas.	May require significant space, and maintenance, and can become sources of stagnant water if not designed properly.
Erosion control measures	Implementing erosion control practices such as silt fences, check dams, and erosion control blankets.	Minimizes soil erosion and sediment transport.	Prevents sedimentation in water bodies, protects infrastructure, and stabilizes soil.	May require frequent maintenance, but effectiveness can vary based on site conditions.
Stormwater management ponds	Constructing ponds to capture and treat stormwater runoff.	Removes pollutants through settling and biological processes.	Effective for multiple pollutants, provides habitat, and can enhance aesthetics.	Requires maintenance, may take up significant space, and can be a drowning hazard.
Street sweeping	Regularly cleaning streets to remove accumulated debris and pollutants.	Reduces sediment, trash, and chemical runoff.	Cost-effective, relatively simple, and helps maintain clean streets.	Limited effectiveness for certain pollutants, requires regular scheduling.
Educational programs	Implementing public awareness and educational campaigns to reduce individual contributions to runoff pollution.	Promotes responsible behaviours, reduces littering, and encourages proper disposal.	Low cost, long-term impact, and fosters community involvement.	Results may take time, challenging to measure effectiveness.

Table. 2 Purification of different pollutants.

Facilities	Purification focus	Function
Green roofs	Heavy metals, particulate matter.	Green roofs with vegetation can filter pollutants from rainwater, reducing heavy metal concentrations and trapping particulate matter.
Permeable pavements	Oil, heavy metals, nutrients.	Permeable pavements allow rainwater to infiltrate, and the materials used can help filter out pollutants such as oil, heavy metals, and nutrients.
Bioretention basins (rain gardens)	Nutrients, sediments, heavy metals.	Designed to capture and treat stormwater runoff, bioretention basins use vegetation and soil to filter out pollutants like nutrients, sediments, and heavy metals.
Constructed wetlands:	Nutrients, organic matter, pathogens.	Wetlands mimic natural processes to treat stormwater by promoting the growth of vegetation that can absorb nutrients, break down organic matter, and filter out pathogens.
Stormwater ponds	Nutrients, sediments, pathogens.	Stormwater ponds capture and detain rainwater, allowing sediments to settle and promoting natural processes that break down pollutants.
Vegetated swales	Nutrients, sediments, pollutants.	Swales are channels with gently sloping sides planted with vegetation. They slow down and filter stormwater, reducing nutrient and sediment loads.
Underground infiltration systems	Various pollutants.	Underground systems, such as infiltration trenches or chambers, allow stormwater to infiltrate the ground, providing natural filtration and reducing the impact of various pollutants.
(WSUD) practices	Various pollutants.	WSUD includes a range of design strategies and technologies that integrate water management into urban planning to reduce pollutants in stormwater runoff.
Floating wetlands	Nutrients, heavy metals.	Floating wetlands consist of vegetation growing on floating platforms. They can absorb nutrients and filter out heavy metals from water bodies.
Biofiltration systems	Nutrients, organic matter.	These systems use engineered media or biological processes to filter out pollutants, particularly nutrients and organic matter, from stormwater.

Table. 3 The performance and implementation of rain gardens.

Location	Performance	Details	Reference
Zhoushan, China	Removal of TSS=82%, COD=42%, NH3- N=66%, NO3 –N=64%, TN=58%, PO4 3-= 65%, & TP=76% in Runoff from the rain Gardens		(Shaoying et al., 2019)
Shanghai, China	The cumulative runoff at the peak time was reduced by 43–63 min, and the total runoff was reduced by 26%~89%.	The objective is to uphold creative integrity, safeguard regional culture, and promote environmental conservation.	(Shaoying et al., 2019)
South Korea	- Removal of TSS with 600 mm media thickness =93%, the removal of Zn= 93%, Pb= 100%, Cu =89%, and Cd =100%. - Removal of TSS with 800 mm media thickness & vegetation =94% with 800 mm, Zn= 97%, Pb=100%, Cu=10% for, and Cd=100%.	The substrate structure comprises a 200 mm layer of topsoil, composed of 40% sand, 30% silt, 15% clay, and 15% organic matter, overlaid on subsoil, which consists of 30% topsoil, 60% sand, and 10% coir fiber.	(Lee et al., 2009)
Japan	Removal of TSS=15%, COD=16%, TN=17%, TP 19%, and a total runoff reduction volume of 46.56 × 106 L.	The adaptability in physical dimensions and integration with the natural landscape facilitates a diverse range of applications in residential neighborhoods, parking lots, roadways, parks, and public access locations	(Zhang et al., 2020)
United States	Average rain gardens delay flow by 5.5 h	Water fluxes are monitored within a two-tier rain garden network.	(Shuster et al., 2017)

Table. 4 The performance and implementation of green roof.

LOCATION	PERFORMANCE	DETAILS	REFERENCE
LUZHOU, CHINA	The green roof exhibited a runoff creation time 5 minutes earlier than that of the intensive green roof. Overall runoff control was notably higher at 64.4%, surpassing the extensive green roof's 61.3%. The impact of rainfall-runoff varied with the following factors: soil substrate thickness, soil tissue type BBB, and gestation volume percentage.	Extensive green roofs generally feature a single layer of vegetation, whereas intensive green roofs may incorporate additional elements such as rockeries, sculptures, and other landscape features.	(Shafique et al., 2018)
UNITED KINGDOM	The investigation analyzed 69 rainstorm events and determined that green roofs retained 65% of the runoff		(Jiuhuan, 2018)

Table. 5 The performance and implementation of permeable pavement.

Location	Performance	Details	Reference

Kunming, China	The road surface exhibits a maximum settlement of 19 mm, whereas the green soil and landscape contribute to a monolithic settlement. The pavement's permeability coefficient is reduced by 13%. No damaged plates or fissures were observed.	Highland regions experience minimal vehicular traffic and encompass non-motorized routes, parking lots, and scenic park landscape walks	(Ball & Rankin, 2010)
Shanghai, China	Reduces temperatures by 6-8°C in comparison to standard road surfaces.	Suitable for applications such as parking lots and walkways.	(Huimin, 2020)
Zhenjiang, China	The annual runoff control rate is 90%, with a suspended solids (SS) removal efficiency of 83.3%.	Permeable structures encompass various types, including asphalt and colored concrete.	(Yadong, 2018)
France	A reduction of 64% in suspended solids (SS) and 79% in lead.	This study aims to compare the quality of runoff water collected at the outflow of a porous pavement with a reservoir structure to that of runoff water from surrounding catchments discharged from traditional stand-alone systems.	(M. Legret et al., 1996)
Canada	Achieved a removal efficiency of 90-96% for solids in the influent.	Both segments of the pavement were approximately 8 meters in length and 6 meters in width, featuring a 3% longitudinal slope.	(Chris Brown et al., 2009)

Table. 6 Effect of facilities on removing pollutants.

Pollutants	Facilities	Effect of removing pollutants
Nutrients (nitrogen and phosphorus)	Bioretention basins (Rain Gardens):	Highly effective in nutrient removal through the action of vegetation and soil microbes.
	Constructed wetlands	Efficient in nutrient uptake by wetland plants and microbial processes.
	Vegetated swales:	Can reduce nutrient loads through plant uptake and soil filtration.
Heavy metals	Green roofs:	Can help in reducing heavy metal concentrations through the filtration action of soil and vegetation.
	Constructed wetlands	Effective in trapping heavy metals through sedimentation and plant uptake.
	Floating wetlands:	Suitable for heavy metal removal through plant uptake.
Sediments	Permeable pavements	Effective in reducing sediment runoff by allowing infiltration and trapping particles.
	Bioretention basins (rain gardens)	Capture sediments through the settling action of vegetation and soil.
	Stormwater ponds	Allow sediments to settle, reducing suspended solids in stormwater.
Pathogens	Constructed wetlands	Provide natural filtration and microbial processes that can help reduce pathogens.
	Vegetated swales	Can contribute to pathogen removal through filtration and adsorption.

	Underground infiltration systems	Some systems may provide natural filtration, helping to reduce pathogens.
Oil and grease	Permeable pavements	Can capture and filter out oil and grease from stormwater runoff.
	Vegetated swales	Effective in trapping and filtering oil and grease.
	Biofiltration systems	Engineered media in biofiltration systems can capture and break down oil and grease.
Organic matter	Constructed wetlands	Efficient in breaking down organic matter through microbial processes.
	Stormwater ponds	Provide a settling area for organic matter, allowing decomposition.
	Biofiltration systems	Can be effective in breaking down organic matter through biological processes.
Temperature	Vegetated swales	Shaded swales can help regulate water temperature by reducing direct sunlight exposure.
	Green roofs	Can provide insulation, reducing the temperature of stormwater runoff.

Table. 7 The comparison effect on the removal effect of pollutants Between Sponge City and Normal Runoff Control.

Measures	Sponge City	Normal Runoff Control
Nutrient removal (nitrogen and phosphorus)	-Bioretention basins, constructed wetlands, and vegetated swales in sponge cities are effective in nutrient removal through plant uptake and microbial processes. - Green roofs and permeable pavements also contribute by allowing water to infiltrate and be filtered through soil, reducing nutrient loads.	- Traditional runoff control measures, such as concrete channels and stormwater pipes, do not provide significant nutrient removal capabilities. - Nutrient runoff in conventional systems can lead to water pollution in downstream water bodies.
Heavy metal removal	-Green roofs and constructed wetlands can help in trapping and reducing heavy metal concentrations. - Vegetated swales and floating wetlands are designed to capture heavy metals through plant uptake and sedimentation.	-Traditional methods often lack specific mechanisms for heavy metal removal. - heavy metals can be transported more readily in runoff from impermeable surfaces.
Sediment control	-Permeable pavements, bioretention basins, and stormwater ponds in sponge cities are effective in trapping sediments through infiltration and settling. -Vegetated swales and biofiltration systems contribute to sediment removal.	Conventional methods may rely on physical barriers or settling basins, but they may not be as effective in promoting natural infiltration and filtration.
Pathogen reduction	-Constructed wetlands and vegetated swales contribute to natural filtration and microbial processes, which can help reduce pathogens. -Underground infiltration systems and biofiltration systems may provide additional pathogen removal.	Traditional systems might not have specific mechanisms to address pathogens adequately.

Oil and grease removal	-Permeable pavements and vegetated swales can capture and filter oil and grease from stormwater runoff. -Biofiltration systems may also help in breaking down oil and grease.	Traditional methods may lack features designed for effective oil and grease removal.
Organic matter decomposition	Constructed wetlands, stormwater ponds, and biofiltration systems contribute to the decomposition of organic matter through microbial processes.	Traditional systems may lack features to actively promote organic matter decomposition.