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Combining Stormwater Management and Park Services to Mitigate Climate Change and Improve Human Well-Being: A Case Study of Sponge City Parks in Shanghai

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Abstract: Due to climate change and rapid urbanization, contemporary cities face the dual challenges of providing sufficient stormwater management and adequate park services, which potentially conflict over limited space and resources. To solve these problems, cities are increasingly combining stormwater infrastructure with park space in ways that create new efficiencies. To date, most research has focused on the stormwater management performance aspect of these combinations and not the techniques employed to achieve the combined goals. To fill this gap, 23 sponge city parks in Shanghai were investigated to examine the combination of stormwater and park services. Our findings show that stormwater techniques were primarily combined with the park facilities of water areas, paved open spaces, and pathways. Additionally, we found that larger parks employed a wider range of techniques for managing stormwater runoff and supported broader sets of park activities, while those at smaller scales prioritized infiltration, detention, and purification measures, as well as concentrated on social and economic activities. This study is the first to explore SPC parks that integrate stormwater management and park services, thereby providing implications for SPC development in China and insights into the ways that the two properties can be combined in other cities.

Keywords: sustainability; climate change; rapid urbanization; stormwater management; urban parks

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1. Introduction

Contemporary cities are facing mounting challenges to their sustainability, with improved stormwater management being key to promoting ecological civilization and enhanced park services being a central step in improving human settlement [1–3]. More intense and frequent urban flooding, exacerbated by climate change, has created an urgent need for better management of water in cities [4,5]. The increased volumes and intensity of stormwater are causing frequent loss of property, safety problems, and worsening environmental degradation, all of which take a toll on cities' economies and disrupt the lives of their residents [6]. Since the 1980s, the increased frequency and severity of flooding events have led to a shift in stormwater management methods which now seek "as much as possible to retain precipitation in the area where it falls" [7]. Today, scholars and practitioners have recognized the importance of rising demand for stormwater management in mitigating flooding risk, recycling rainwater and stormwater runoff, greening the urban environment, and improvement of human well-being [2,3,8]. To solve these problems, over the past two decades cities have begun to implement initiatives to combine stormwater management and park space to mitigate the impacts of climate change and rapid urbanization, such as the Low Impact Development in the United States, the Sustainable Urban Drainage Systems (SUDSs) in the United Kingdom, and the Sponge City (SPC) in China [1]. A response to the changing views on ecologically sensitive management of stormwater and the 1972 passage of the Clean Water Act in the United States, Low Impact Development and later Green Infrastructure (together described as LID in this research) were developed in North

America [7]. LID has swiftly been adopted by cities worldwide and stimulated LID-like initiatives with varying ramifications, with the main goal of managing stormwater runoff on-site before discharging into the urban environment [9–12].

Concurrently, many cities are recognizing the need to provide residents with adequate park space and services. Globally, it is acknowledged that cities require more and better parks that provide access to nature and outdoor activities, all of which can improve health, economic development, and social sustainability [13]. Four key outdoor activities in urban parks have been identified, which includes social activities [14,15], economic activities [16,17], cultural activities [18,19], and educational activities [20,21]. Studies have revealed that increasing access to park facilities has the potential to improve residents' mental and physical health, reduce mortality rates, and improve human health [13,22–24]. Based on the properties and activity zones that accommodate different outdoor activities, park facilities have been categorized into water areas, buildings and other areas, pathways, paved open spaces, sports fields, children's playgrounds, lawn areas, and other natural spaces (vegetation with no spatial access) [25]. In addition to recreational use, urban parks provide access to open green space, which offers solutions to the impacts of rapid urbanization and climate change on human well-being. However, rapid urban growth has precipitated a substantial increase in land values and density of urban settlement and led to a land transition from vegetation cover and bare soil into built-up areas [26]. This enormous and unsustainable urbanization induces the degradation and even reduction of green spaces while also making it more expensive to provide new and expanded public parks [13,27]. The dual challenge for cities described above, to provide sufficient stormwater management and park services, is potentially in conflict with limited urban land and constrained financial resources.

However, these two urgent needs also have the potential to be combined in ways that can improve stormwater management and park services, saving costs and land while deriving additional social, economic, environmental, and health benefits. While notable efforts have been made as of late to integrate stormwater management techniques and park space, most projects and research remained focused on the stormwater management component over its combination with park recreational services [28,29]. For instance, the LID Urban Design Tools website hosted by the US EPA only provides descriptions and examples of drainage infrastructure designs based on the physical and regulatory environment of different states, while no document provides specifications on how the park facilities and stormwater management techniques are combined in practice to reinforce each other [29]. This limited focus is also true for research on the topic, with little research investigating the combination of stormwater management and park services [30]. For instance, numerous models have been developed to simulate extreme weather scenarios and assess the applications or functions of LID techniques, including the capacity of infiltration [31], purification [32], detention [33], and retention [33] but none look at its interaction with park services. This gap in research and practice calls for more empirical studies that focus on the ways that these two necessary and potentially synergistic investments in sustainability, stormwater management and park services, have been combined in urban green space.

To better understand the combined implementation of stormwater management and park services as practiced, this research investigated its implementation in the leading site of SPC development in China. Since 2014, China has been implementing the national initiative on SPC development to improve stormwater management and water quality by integrating stormwater techniques in urban environments [9]. Shanghai was one of the three cities selected to pilot best practices for SPC's later expansion throughout China. As part of this pilot project 23 SPC projects in Shanghai have combined stormwater management and park services, here referred to as "SPC parks," using an array of techniques in a variety of urban contexts. These sites were investigated to answer three research questions:

1. What are the most common stormwater management techniques and measures employed in SPC parks?
2. What are the most common park facilities and activities available in the selected SPC parks to implement park services?
3. What are the configurations of combined stormwater management and park services in the selected SPC parks?

By investigating the combination of stormwater management and park services in Shanghai, this research provides knowledge and insights that can help urban planners, designers, and engineers to better adapt urban systems to urban flooding issues and insufficient park space in urban areas.

2. Methods

2.1. Study Site

The impacts of climate change on urban stormwater management and rapid urbanization on park services have been pronounced in China. Hundreds of China's cities have been impacted by flooding disasters annually since 2008 [34]. Studies have shown that the likelihood and intensity of flooding have increased in urban areas with a constant decrease in permeable surfaces (which allows stormwater runoff to percolate through the soil, filter out pollutants, and run into the nearest water body) and exacerbated by increased intensity of precipitation due to climate change [35]. In 2013, China introduced the national SPC Development Initiative inspired by the concepts and devices of LID. Since then, SPC projects have been built across 30 pilot cities in China to control frequent flooding, water pollution, and other environmental problems. The SPC program is premised on the idea that a city can function as a sponge to "absorb, infiltrate, retain and purify the runoff for different utilization purposes before it is discharged" [28]. The SPC program describes the ability to manage water onsite as "the sponge effect" of the site. Both the Assessment Standard of Sponge City Effects that guides SPC development (See Table 1) and scholars (see Table 2) divide stormwater management into techniques and measures [28,36–38]. Techniques are the specific infrastructure tools that include permeable pavement, green roofs, complex bio-detention, artificial ponds, artificial wetlands, rain gardens, bio-swales, and vegetation buffers. Measures describe the six different ways that water is handled by the techniques. This provides a key method to categories the stormwater management approaches of SCP projects.

Table 1. Definitions of stormwater measures and techniques employed in SPC development.

Term	Subcategory	Definition
Stormwater techniques	Permeable pavement	Permeable pavement reduces surface runoff and alleviates the impact of stormwater runoff.
	Green roofs	Green roofs can retain and filter stormwater runoff, which is then transpired into the air before being released into the surrounding environment.
	Complex bio-detention	Bio-detention systems help retain the peak flow of stormwater runoff and slowly discharge it after a heavy storm.
	Artificial ponds	Artificial ponds help to store, detain, and filter stormwater runoff.
	Artificial wetlands	Artificial wetland helps to purify stormwater runoff, encourage ecological diversity, and provide habitats for diverse organisms.
	Rain gardens	The rain garden is constructed in lowland and designed to retain and treat part of stormwater runoff, as well as recharge groundwater.
	Bio-swales	Bio-swales are shallow open channels filled with vegetation to collect, purify, and discharge stormwater runoff into the sewer systems.
	Vegetation buffers	Vegetation buffers can intercept stormwater runoff and reduce the quantity of suspended soil sediments using strips of vegetation.

Table 1. *Cont.*

Term	Subcategory	Definition
Stormwater measure	Infiltration	This is the very first step through which rainwater sinks into the land and supplies plantings [28].
	Retention	The measure is used to reduce the peak flow of stormwater, channel overflows to downstream drainage infrastructure, and filter larger particulates [28].
	Detention	The measure collects upstream overflows which will be decanted in the impounded lakes or ponds [28].
	Purification	Vegetations will be used to filter organic and inorganic matter to meet the standards of reused water [28].
	Utilization	The filtered water is used for irrigation and waterscape [28].
	Discharge	The purified stormwater is discharged into reservoirs or waterscapes, and finally flows into waterways [28].

Table 2. Stormwater techniques and the associated stormwater measures.

Stormwater Techniques	Stormwater Measures					
	Infiltration	Detention	Retention	Purification	Utilization	Discharge
Permeable pavement	✓	✓	×	✓	×	×
Green roofs	×	✓	×	✓	✓	○
Complex bio-detention	○	✓	×	○	✓	✓
Artificial ponds	×	○	✓	○	○	×
Artificial wetlands	×	○	○	○	✓	○
Rain gardens	×	✓	○	✓	○	○
Bio-swales	○	✓	×	✓	×	✓
Vegetation buffers	×	○	×	○	×	○

✓ Above average, × Below average, ○ Average.

Shanghai, one of the first pilot cities for SPC development in China, was selected as the site in this study. The city is located in the Yangtze River Delta in East China and covers an area of approximately 6340 km^2. It has a subtropical monsoon climate typical of subtropical continents' eastern coasts, with temperatures ranging between 25° and 35° [39]. With a mean annual precipitation of 1158.1 mm and more than 60% of rainfall occurring between May and September, the region has historically been confronted with the challenge of peak stormwater management. With the combined impacts of climate change and the expansion of intensive use of urban land, flood disasters in Shanghai now occur more frequently and with greater intensity [40,41]. The city has a rising need for managing stormwater, mitigating of flooding risk, and recycling of rainwater and stormwater runoff to reduce potential challenges to dense urban populations.

With a population of approximately 24.89 million, Shanghai is one of the most densely populated cities in the world. The scope and intensity of urbanization in Shanghai since the 1980s has created enormous pressure on the provision of park space. According to the 2020 Shanghai Municipal Statistical Yearbook, the current green area of Shanghai is 157,800 hm^2 covering 18.9% of the built city, with a green space of only 8.5 m^2 per capita [42]. In 2015, the Shanghai municipal government announced the goal of increasing park space per capita to 13 m^2 by 2035 by establishing an urban-rural park system, such as adding 600 public parks and 1000 km of greenways [43]. To address the increasing stormwater challenges and achieve the goal of adding green space concurrently, the government launched the sponge city program with the Shanghai Sponge City Special Plan [37]. With a leading effort to use SPC to address both stormwater management and park services across the city, Shanghai presents a unique opportunity to explore the contemporary practice of combining the two priorities.

2.2. Selected Projects

To investigate the combination of stormwater management and park services, this research first identified SPC parks in Shanghai. According to the official reports and news that listed the pilot SPC projects, we screened SPC projects to identify those that also are publicly accessible parks [44,45]. Twenty-three SPC parks that combined the two goals were identified across 15 districts of Shanghai (see Figure 1).

Figure 1. Locations of the selected SPC parks.

Table 3 shows the size, scale, and location of each selected SPC park. In the selected sites, the largest park is Jiabei Countryside Park, which encompasses 731.9 hectares in the suburban area, and the smallest one is Wujiaochang Sunken Square, which encompasses 0.52 hector of land in the central city area. Based on their scales and locations, the majority of the selected sites at regional or city scales are located in the new town and suburban areas, and those in the central city areas are smaller at community or sub-district scales.

2.3. Research Methods

First, on-site observations were conducted to document the most common techniques employed in the selected sites, including the configurations of stormwater techniques and park facilities as well as their combination. Second, we developed an analytical framework focused on the implementation of stormwater management (based on the employed stormwater measures) and park services (regarding access to park activities).

Last, we categorized the stormwater measures and park activities according to each site's scale and location to understand their applications.

Table 3. The overview of the selected sites.

No	Park Name	Size (ha)	Scale	Location
1	Pujiang Countryside Park	1306.13	4	Suburban
2	Liuzao Community Park	0.70	1	Suburban
3	Dongtan Avenue Green Buffer	29.20	3	Suburban
4	Suzhou River Landscape Gallery	27.85	3	Central City
5	Zhenrugang Binghe Park	3.34	2	Central City
6	Yangpu Riverside	3.74	2	Central City
7	Popular Pugang Binhe Greenland	2.61	2	Central City
8	Xuhui Runway Park	9.42	2	Central City
9	Xuhui Middle Ring Road Park	27.52	3	Central City
10	Caihong Bay Park	1.64	1	Central City
11	Daning Middle Ring Road	8.39	2	Central City
12	Sichuan North Road Park	4.72	2	Central City
13	North Bund Green Land	12.65	2	Central City
14	Wujiaochang Sunken Square	0.52	1	Central City
15	City Best Practice Area	6.38	2	Central City
16	Nanda Park	15.77	2	Central City
17	Shanghai Zhiyu	214.39	4	New Town
18	Jinshan Newtown Park	7.20	2	New Town
19	Dishui Lake Waterfront Landscape (section C)	9.17	2	New Town
20	Linggang Homeland Service Station and Green	1.91	1	New Town
21	Guangfulin Country Park	314.93	4	New Town
22	Jiabei Countryside Park	731.39	4	New Town
23	Wulonghu Park	36.62	3	New Town

To examine the combination of stormwater management and park services in SPC projects in Shanghai in practice, we employed an observational method to investigate the techniques used by the SPC parks in the process of combining the two goals. On-site observations of the 23 selected sites were conducted between June and July 2022 to identify the specific stormwater techniques and park facilities employed. Since most park infrastructure serves for long periods, we only recorded the presence of stormwater techniques and park facilities in a single visit to each selected SPC park during the daytime. An observational assessment matrix was developed to record the type of stormwater techniques and park facilities combined in the selected sites. After that assessment, the authors further examined the specific park facilities that directly incorporated stormwater techniques to better understand the ability of those amenities to achieve both goals simultaneously.

Based on the observational results, we developed an analytical framework to explore the implementation of stormwater management and park services in the selected sites. In the framework, the first variable was the stormwater technique, as described in Table 1, which was determined by examining the specific stormwater infrastructure of each site. The second variable was the types of park activities available in each park. The types of park activities were determined by the presence of park facilities or amenities (such as athletic fields) and the events gathered from each park's website. Table 4 presents the four categories of outdoor activities used with examples in contemporary parks [13,15].

Finally, the selected sites were compared to investigate the configurations of stormwater management and park services regarding each site's scale and spatial location. The scale of each site was categorized based on its size and sorted into community scale (0.5–2 ha), sub-district scale (2–20 ha), regional scale (20–100 ha), and city scale (over 100 ha) [46,47]. Then, the spatial locations were categorized according to the city planning areas consisting of the central city area, suburban area, and five new town areas (emerging sub-city centers in Shanghai) [48].

Table 4. Type and examples of outdoor park activity in urban parks.

Type of Park Activity	Definition	Examples
Social activity	Activities associated with entertaining facilities [15].	Biking, fishing, swimming, skating, hiking, etc.
Economic activity	Activities associated with park services or facilities on which visitors need to spend money [15].	Boating, fishing, dining, bookstore, market, etc.
Cultural activity	Activities associated with obtaining educational and research opportunities, as well as promoting ecological awareness and environmental consciousness [15].	Art exhibitions, museums, traditional festival events, etc.
Educational activity	Activities associated with the experience of the cultural value embedded in the landscape or architectural design [15].	Outdoor classroom, wildlife viewing, education program, etc.

Note: some examples may involve multiple types of park activities.

Data management and analysis were performed using SPSS 22.00. Frequency analysis was conducted to identify the use of stormwater techniques and park facilities, their combinations, and the applications of stormwater management and park services in the selected sites based on their scales and locations. All data were obtained during on-site observations and categorized according to the categories described above. Photos of the park infrastructure were taken and retained for verification purposes.

3. Results

3.1. Stormwater Management in the Selected Sites

3.1.1. Employment of Stormwater Techniques

After examining the stormwater management techniques used in the 23 selected SPC parks (Figure 2), we found that the most commonly used stormwater techniques were permeable pavement (n = 23) followed by bio-swales (n = 18), and artificial ponds (n = 16), with green roofs (n = 7) being the least commonly used. This is not surprising, considering the relatively low cost of constructing and maintaining the stormwater techniques of permeable pavement and bio-swales, which by extension, provides a cost-effective way of filtering and conveying the stormwater runoff. However, while bio-swales and permeable pavements can play an important role in the process of reducing stormwater volume and velocity, these techniques are possibly insufficient as a singular tool to manage stormwater.

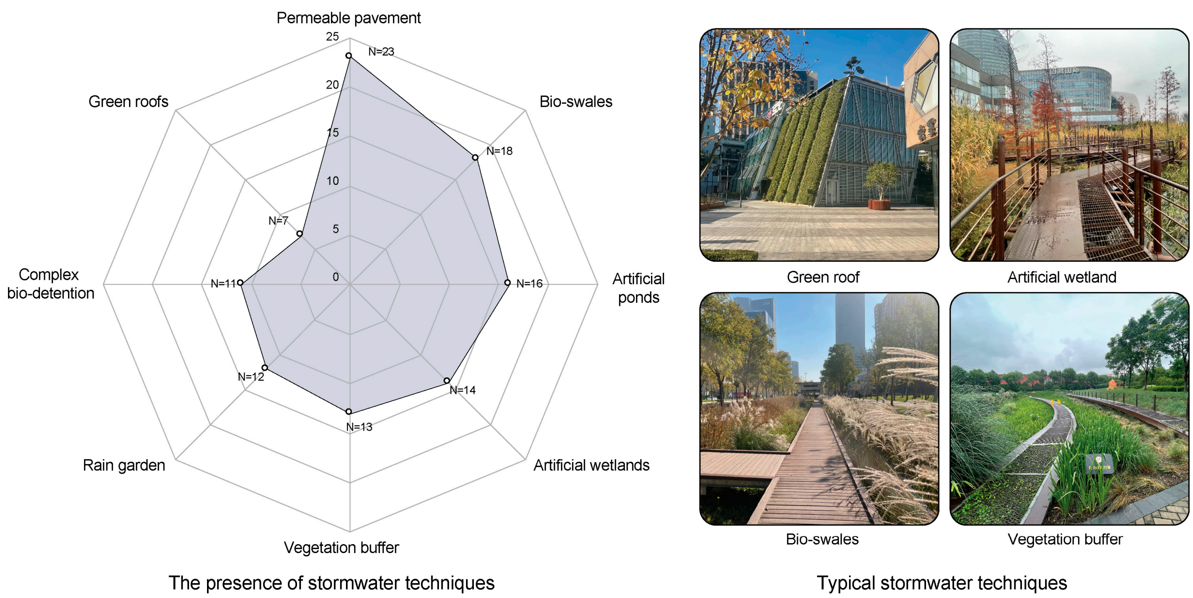

Figure 2. The configurations of applied stormwater techniques.

Contrary to permeable pavement and bio-swales concentration on filtering and conveyance of stormwater runoff, artificial ponds (n = 16) provide the unique attribute of a large water body, the use of which allows for the treatment of more significant volumes of stormwater runoff on-site. However, while the artificial pond is a great technique to hold the stormwater runoff on-site, building a large water body is highly constrained by the available land. Lastly, the least commonly used stormwater technique was green roofs (n = 6). It can significantly reduce the amount of stormwater and contribute to the green space through the rooftops. Although most parks have buildings or other structures with rooves, few of them employed green rooves as stormwater techniques.

3.1.2. Implementation of Stormwater Measures

Based on the analytical framework, we examined the employed stormwater techniques to understand the implementation of stormwater management measures. As shown in Figure 3, infiltration (n = 23), detention (n = 23), purification (n = 23), discharge (n = 19), and utilization (n = 17) were the most commonly utilized stormwater measures, while retention (n = 12) was the least commonly used measure. The results show that most of the selected SPC parks focused on the sponge effects of filtering and conveying stormwater, which has the attendant benefit of reducing the volume and velocity of runoff and lessening the burden of urban drainage systems. Although many SPC parks still rely on sewer systems for discharge, more than half of the sites are capable of storing runoff in artificial ponds.

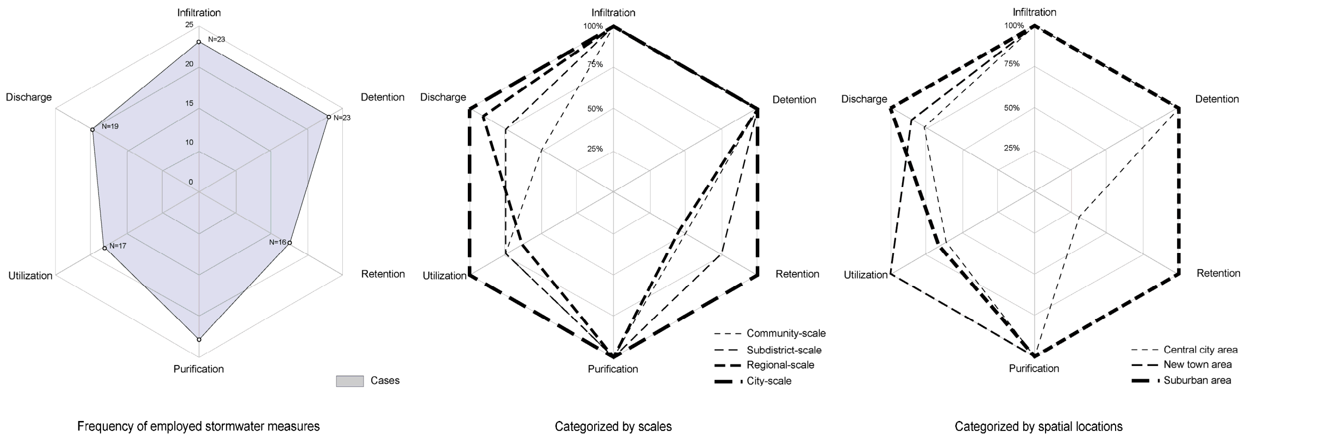

Figure 3. The implementation of stormwater measures.

Figure 3 also presents the employed stormwater measures categorized by park size and spatial location. The selected SPC parks at community and sub-district scales prominently employed infiltration, detention, and purification measures. Meanwhile, larger-size parks at the city scale utilized all types of stormwater measures. When categorized by their spatial locations, most of the SPC parks in the central city and suburban areas prioritized infiltration, detention, and purification measures over retention and utilization measures. In new town areas, the selected SPC parks employed all types of stormwater measures, indicating their capacity to maximize the sponge effects.

3.2. Park Services in the Selected Sites

3.2.1. Employment of Park Facilities

In terms of park services, Figure 4 shows that the most frequently observed park facilities were pathways (n = 23), paved open spaces (n = 23), lawn areas (n = 23), water areas (n = 23), other natural areas (n = 21), and buildings and other areas (n = 20). These park facilities provide the backbone of everyday park activities as well as accommodating park services for a wider range of visitors. Comparatively, sports areas (n = 13) and playgrounds (n = 9) were the least frequently observed park facilities in SPC parks. Other than running tracks, most sports areas, such as athletic courts, tend to cost more to construct and require a large amount of land. Although playgrounds may require less space, this type of park facility has stricter safety and management burden while only serving a limited range of park users, primarily children and their parents. This may explain their limited presence.

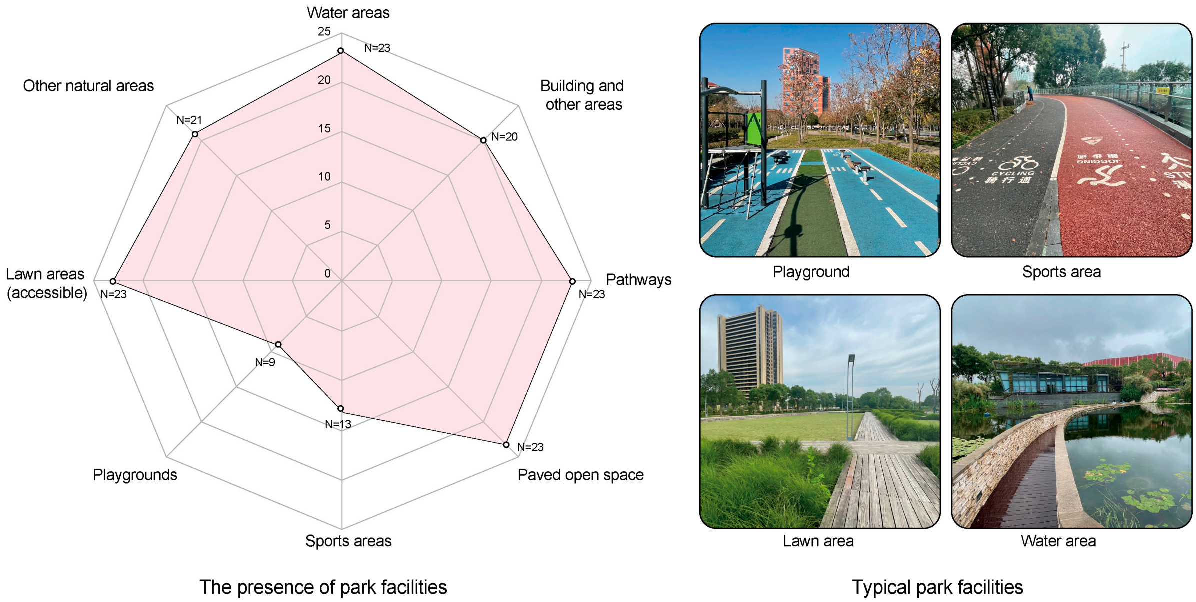

Figure 4. The configurations of park facilities.

3.2.2. Implementation of Park Activities

As shown in Figure 5, social (n = 23) and economic (n = 18) activities were the most common park activities, while educational (n = 11) and historical (n = 11) activities were the least common. According to the observational results, pathways, paved open space, and buildings and other areas were used for basic park services, which provide access to a variety of social and economic activities. Paved open space, lawn areas, and water areas help to form a pleasant and sociable place for numerous types of park activities, such as boating, fishing, markets, art exhibitions, dining, etc. Comparatively, most educational activities, such as wildlife viewing, require access to nature, so they are less applicable in the selected sites located in dense urban areas. Additionally, cultural activities, such as flower beds available for viewing, may require a large open space area and may only operate for a limited time. Educational and cultural activities may be less common in parks that have limited space for these reasons.

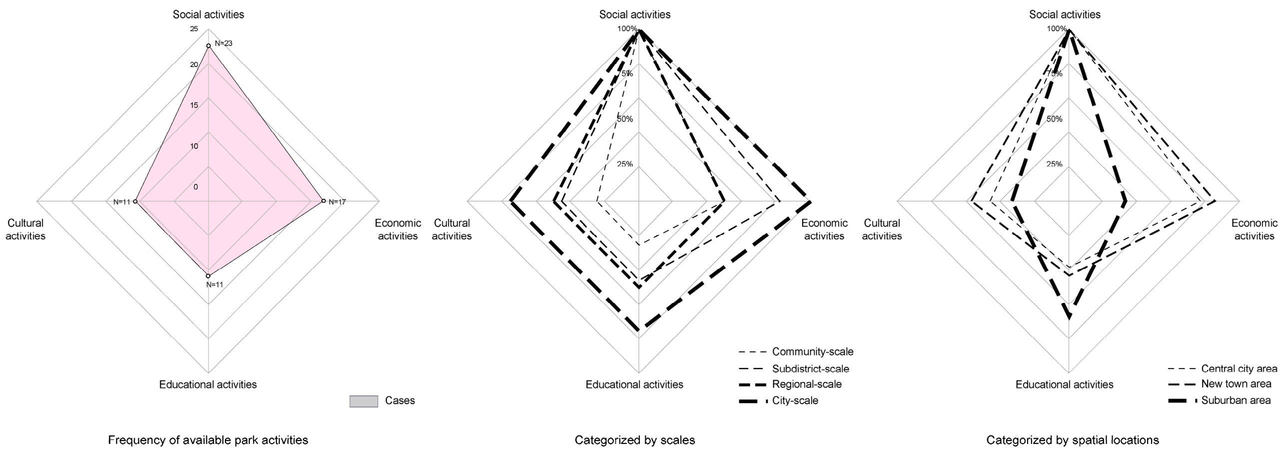

Figure 5. The implementation of park activities.

When categorizing the park facilities by locations vis-à-vis the scales and locations of the selected sites, we found that most SPC parks at community and sub-district scales prioritized social activities. In comparison, larger-scale sites provided a broader range of social, economic, and cultural activities. When categorized by location, the selected sites in the central city or new town areas concentrated on providing access to social and economic activities. Comparatively, the majority of the SPC parks in suburban areas provided access to social and educational activities.

3.3. The Combination of Stormwater Management and Park Services

After examining the park facilities that simultaneously incorporate stormwater management techniques (Figure 6), we found that pathways with permeable pavement (n = 23), and paved open spaces with permeable pavement (n = 23), followed by water areas (n = 16) were the most common. Buildings and other areas (n = 6) and playgrounds (n = 7) were the least frequently observed park facilities that employed stormwater techniques. Furthermore, less than half of the selected sites (n = 11) had playgrounds. It is important to mention that permeable surface was frequently constructed in playgrounds, but many of them were elevated, which kept surface water away from the site.

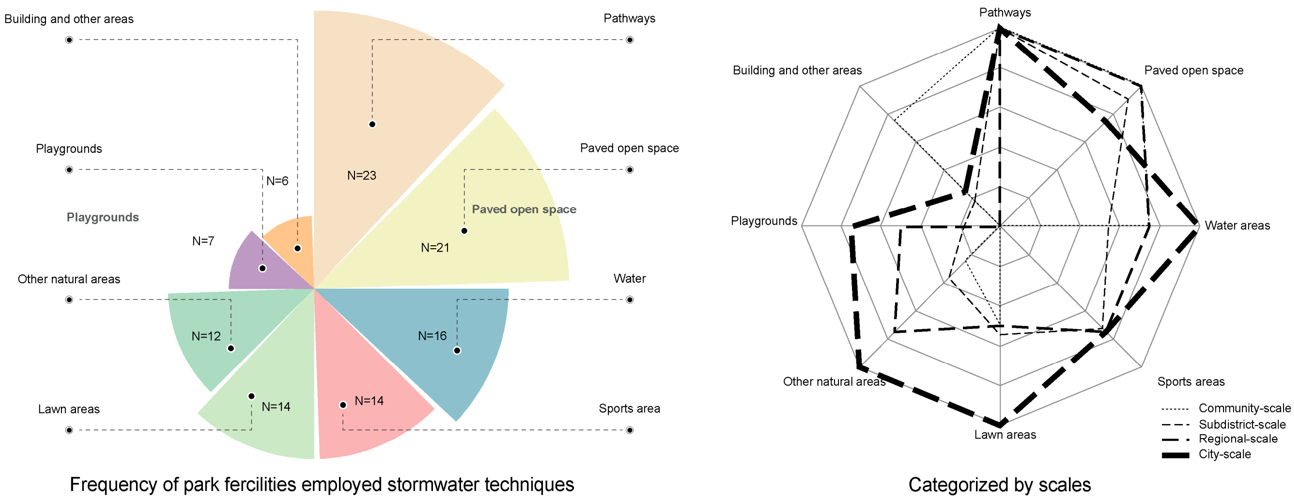

Figure 6. The combinations of park facilities and stormwater techniques.

Additionally, when categorized by scale, larger sites predominantly combined stormwater techniques in the park facilities of water areas, lawn areas, playgrounds, and other natural areas. Comparatively, smaller sites at the community scale combined the park facility of the buildings and other areas with stormwater techniques to create additional park space, such as the utilization of rooftops and space under elevated roads. Still, the least commonly applied park facility was buildings and other areas that integrated stormwater techniques. These findings show that in larger SPC parks stormwater techniques have been integrated into a wider range of park facilities, suggesting that these sites are capable of treating a larger amount of runoff on-site as well as serving a wider range of park activities. Relatively, smaller parks struggle to balance the use of stormwater management techniques and park facilities due to space and technological constraints.

4. Discussion

Building on the results presented above, this research helps fill the gaps in knowledge on the contemporary practices of combining stormwater management and park services. This section will discuss the employment of LID techniques in SPC parks, the combination of stormwater techniques and park facilities, and implications for SPC development in China. In addition, the limitations of this study will be highlighted.

4.1. Implementation of LID Techniques in the Selected Sites

Integrating stormwater techniques with park space provides an important approach for implementing sustainable urban development. The observational results showed that the most commonly used stormwater technique was permeable pavement. Originally, permeable pavement was designed to filter runoff with a relatively low cost of construction and has become widely used [49]. However, while permeable pavement is a frequently used tool that can simultaneously meet the combined goals of improving stormwater management and creating recreational park space, it is limited by its relatively weak capacity for managing stormwater.

Another frequently used stormwater technique was bio-swales. They are designed to convey and concentrate stormwater runoff, thereby slowing down the flow, reducing runoff volumes, and removing pollutants and debris through filtration by vegetation and soils. However, its primary sponge effects are infiltration and detention rather than retention, most of which are located along the buildings or pathways and are not usable for park activities. The frequent implementation of permeable pavement and bio-swales indicated that infiltration, detention, and purification were the primary measures employed by the majority of sites.

Compared to permeable pavement and bio-swales, the use of artificial ponds allows for treating more significant volumes of stormwater runoff on-site [50]. When implemented in the SPC parks, it creates aesthetic focal points and added park space for economic activities, such as fishing and boating. Because land constraints impact many sites, the use of artificial ponds is less common in smaller parks [38]. Thus, more innovative techniques are needed to support the retention of stormwater runoff and create water space for daily activities in small sites.

Lastly, the least commonly used stormwater technique was green roofs, which are designed to provide overlapping economic and ecological benefits in urban areas. They can significantly reduce the amount of stormwater released into the sewer systems by using plantings and contribute to the natural beauty of the city where there is a concentration of buildings [49]. Despite its success in retaining precipitation and providing ecological benefits, green roofs were the least common among techniques used in the selected parks even though most parks had buildings or structures with rooves. As it is partially or completely covered with plants with limited park space, the rooftops can provide limited accessible space for outdoor activities. In addition, the high initial investment on the construction of green roofs and additional requirements on the rooftop's loading capacity often act as a barrier to their widespread adoption [51].

4.2. Combining Stormwater Management and Park Services in the Selected Sites

With a relatively low cost of construction and maintenance, fewer requirements on existing infrastructure, and less need for space, pathways and paved open space are frequently combined with stormwater techniques such as bio-swales and permeable pavement [49]. For instance, the Xuhui Runway Park, a sub-district park in the central city area, was created from an abandoned airport with the primary goal of combining bio-swales and permeable pavement with athletic fields, such as running tracks and fitness courts. The park is parallel to a major roadway with a narrow and long form, which highlights its detention, purification, and infiltration measures; it also utilizes the linear form for running tracks and exercise spaces. The combination of permeable pathways and paved open space with bioswales appears commonly applicable combinations of park facilities and stormwater management across the selected sites at multiple scales.

Similarly, water areas are frequently combined with artificial ponds or artificial wetlands in approximately two-thirds of the selected sites. Since Shanghai is rich in river resources, most of the selected sites are adjacent or directly attached to waterways [40]. However, the construction of small-scale wetlands or ponds requires a relatively large amount of land and higher construction cost [49]. Except where it is convenient to leverage the river resources to provide visitors with water-related activities, the combination of stormwater management and park services in water areas is less commonly employed than with pathways and paved open spaces.

While permeable pathways and paved areas, as well as water areas, are frequently combined with stormwater techniques, lawns or grassy open spaces areas are only combined with stormwater techniques in 40% of sites. Although lawn areas are inherently permeable surfaces and occupy a large proportion of a park, most of these spaces were sloped and did not allow for infiltration. Consequently, the majority of the runoff appears to be drained from the park by sewer systems, which do not fully utilize the potential infiltration function of the permeable surface. However, sunken green beds could be used to accumulate and filter stormwater runoff while becoming accessible for park entertainment when it becomes dry instead [28]. Because there are fewer limitations to integrating lawn areas with stormwater management regardless of context, it could be a cost-effective way to increase the capacity to manage stormwater and improve park services.

This research also finds that 13 of the 15 SPC parks that had sports facilities combined with permeable pavement and/or bio-swales. But, considering that these can successfully be combined, only 15 of the 23 selected sites had this type of park facility. Sports facilities tend to be in high demand in urban areas and it is the small SPC parks where they are missing. The lack of sports facilities in a third of the parks indicates limitations or tensions that small sites may encounter when balancing the park services and stormwater management.

Due to the higher cost of construction and potential challenges posed to existing buildings or infrastructure, buildings and other areas were the least frequently observed park facilities combined with stormwater techniques. While there are various limitations in dense urban areas, the green roof is a good tool that can create additional green space while engendering innovative ways of managing precipitation [49]. Our emphasis should shift to the connections between the construction of SPC parks and the existing infrastructure to create additional accessible park space, especially for the sites in dense urban areas. Playgrounds were another park facility that was commonly combined with stormwater management. However, while many playgrounds use permeable pavements, most of the playgrounds in the SPC parks are elevated to prevent the concentration of stormwater runoff allowing only limited sponge effects. Understandably, designers prioritize safety requirements to reduce children's interactions with concentrated runoff (containing pollutants) [52]. However, new designs should be developed that can fully utilize the sponge effects of the permeable pavements and achieve the multiple objectives of absorbing stormwater while creating park space for additional benefits.

As discussed above, we found that combinations of stormwater management and park services are highly influenced by the size of the selected sites. Specifically, larger parks employ a wider range of stormwater techniques and park facilities, thereby treating a larger amount of stormwater runoff on-site and creating more and more varied park services. There are simply fewer space tradeoffs needed when combining stormwater and park services in large sites. In small sites, there are inherent tensions between fitting in more robust stormwater techniques (compared to simply constructing permeable pavement or bio-swales), versus creating park space. This calls for the development of new stormwater techniques to relieve these tensions and integrate smaller parks with more stormwater management techniques.

4.3. Implications for SPC Development in China

The selected SPC parks demonstrate a variety of ways to combine stormwater techniques and park facilities. One key finding is that there remains a need for more innovations in design and techniques to surmount the tensions and constraints in combining the goals, particularly in small sites. First, SPC parks need more techniques to maximize the sponge effects of treating stormwater runoff while creating park space for outdoor activities [28]. Shanghai has seen a rapid increase in urbanization and population growth. This enormous development in scope and intensity has decreased the permeable area for the catchment and reduced the urban green space, thereby resulting in increased stormwater issues across the city [40]. Therefore, more innovative designs or techniques for combining the two goals are required to better guide the park design considering its hydrological characteristic and complementing the existing drainage systems in Shanghai.

Second, the SPC parks need more techniques that can manage flooding in ways that can also double as park space. Flooding can cause a significant change in water quantity and quality, which interfere with park activities in the process of stormwater utilization. In addition, as described in previous studies, integrating stormwater techniques with landscape design helps to prevent mosquito and insect breeding grounds [53].

Third, the dynamic use of stormwater infrastructure should be encouraged to increase the efficient use of park space. With the dual goals of treating stormwater and increasing park services, alternative designs are encouraged that can use the park infrastructure dynamically, corresponding to different hydrological conditions [52]. For instance, a sunken lawn area or a rain garden can be designed for temporarily storing stormwater and become an accessible green space for recreational activities after rain. This would extend the park's ability to meet both goals, particularly on smaller sites.

Last, it is important to consider the stormwater measures employed by SPC parks that may lead to changes in the hydrological condition of the entire basin. Some have even claimed it may result in severe runoff attenuation and destroy the sustainability of river systems [54]. Thus, the hydrological performance of the system of SPC parks should be simulated at the city scale to understand the role that SPC development plays in the process of managing stormwater.

4.4. Limitations

Despite this study's insights into practices that combine stormwater and park services, there are some limitations. First, this preliminary research only focused on projects in China and, within China, only on SPC parks in Shanghai. It did not consider parks in rural areas or cities with less urbanization. The next stage for the SPC program is its gradual adoption nationwide in China, which will allow for additional investigation. Second, on-site observations permitted the examination of the techniques used in the process of combining stormwater management and park services, but their performance should be further quantified and validated to gain deeper insights into their effectiveness. Third, the connections between the SPC parks and the existing urban infrastructure, such as sewer systems or waterways, were not deeply investigated. Understanding their function within a network of parks and drainage systems would further deepen our understanding of their effectiveness.

5. Conclusions and Next Steps

Climate change has induced a profound increase in uncertainties related to frequent and severe urban flooding, which poses challenges to existing infrastructure. This has exposed urban populations to considerable economic and environmental safety risks. Rapid urbanization has also left many of the world's inhabitants with insufficient park space for outdoor recreational activities. This paper investigates the combination of stormwater management and park services to concurrently tackle both these problems through the investigation of SPC parks in Shanghai. Our results show that combining stormwater management and park services in Shanghai's SPC parks has made significant strides in tackling these contemporary challenges. However, we found that the implementation of stormwater techniques and park facilities is still a work in progress as well as highly impacted by the size of the selected sites. The combination of stormwater management and park services requires additional innovation to improve their effectiveness and overcome key limitations, particularly those of smaller sites.

Looking forward, there are three key next steps that can help better understand the full potential for combining stormwater management and park services in China and globally. First, more comprehensive measures of effectiveness need to be developed to understand the quality of park facilities provided by parks that combine stormwater management and park services. This assessment should include both an analysis of the park facilities and, more importantly, of their level of integration with stormwater techniques. Evaluation of park services can help facilitate the management of urban green spaces regarding the local environment and encourage innovative design or techniques to overcome potential constraints and tensions.

Second, the performance of stormwater management should be quantified in relation to the provision of park services. Specifically, quantifying the performance of stormwater management, such as the relationship between the size of a park facility zone and the capacity for retaining stormwater runoff for the site as a whole, could facilitate our understanding of the tradeoffs when balancing the two goals, thereby complementing guidelines park design in Shanghai and other cities.

Lastly, previous studies on stormwater management in parks have not shed light on the potentially distinctive forms and spatial relationships created within the parks or their interactions with the surrounding urban environment. Identifying the morphological features and relationship to the city as a whole can facilitate a deeper understanding of parks that combine stormwater and park services and how they can be better integrated with the urban form.

It is hoped that the knowledge and insights gained from the combination of the two priorities will sustainably pave the way for the transformation of urban ecosystems to adapt to future uncertainties and deliver additional benefits to human well-being.

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