

# Green Infrastructure Practice and a Sustainability Key Performance Indicators Framework for Neighbourhood-Level Construction of Sponge City Programme

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## Abstract

In recent years, the Sponge City program (SCP) of China, as a sustainable stormwater management approach, has been strengthened as a national strategic level program. The Green Infrastructure (GI), due to its multi-objective and multi-benefits, has been adopted as an important measure of this new nationwide initiative. However, there is a lack of a comprehensive quantitative evaluation system for neighbourhood scale SCP. Hence, in the process of GI plan optimization, selection of implementation methods to balance its multi-benefits has become one of the key obstacles in the practice of SCP. To support robust decision making on multi-objective GI planning and comprehensive assessment, the analytic hierarchy process (AHP) has been used as a structural and systematic technique. In addition, a set of sustainability key performance indicators (KPIs) including requisite dimensions is the foundation for neighbourhood scale sustainability. Hence, AHP-based evaluation system including selection, weighting and ranking of the KPIs, is defined as a key performance indicator framework (KPIF), which is still in need for further development. Taking the GI planning for the Liangnong, Siming Lake sponge node restoration as an example, this paper develops KPIF with a comprehensive evaluation system for high-quality “Sponge Node” transitional construction. This KPIF consists of three basic criteria: “Environmental Performance”, “Economic and Adaptability Performance”, and “Social-cultural Performance and Wellbeing Performance”. In addition, 15 weighted KPIs are

concluded and amongst them, the followings were relatively high: weight of the ATRCR, the promotion of biodiversity, the construction cost saving, the maintenance cost saving, and the level of recreational and wellbeing improvements for all people. In addition, the developed KPIF provides a reference for similar program's decision-making, not only for the Jiangnan area of China, but also for quantitatively comprehensive evaluations of SCP in other regions.

## Keywords

Sustainability, Sponge City, Ecosystem Services, Stormwater Management, Key Performance Indicators Framework, Green Infrastructure

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## 1. Introduction

### 1.1. Sponge City Background and Progress

It has been widely reported that the increase in the impermeable surface areas as a result of urbanization has produced significant global hydrological effects [1]-[7]. Furthermore, the alteration of natural hydrological systems by urbanization patterns is generally translated as various means of: increased runoff rate and volume, decreased groundwater recharge and base flow, and deterioration of water quality in streams, rivers, and shallow groundwater [8] [9]. Such changes result in water environment deterioration, as well as ecological damage that is recorded in various scholarly research [10] [11]. Now these urban water-related environmental problems are intensified with the combined effect from climate change impacts and inappropriate urban planning policies in many countries [12] [13]. Hence, worldwide sustainable stormwater management methods are applied to address these problems and some progress is made to embrace better practical results [14].

For developing countries like China, fast urbanization has led to increasingly prominent environmental and resource problems, particularly associated to water ecology crisis [15]. A context-specific solution is therefore essential that can learn from and adapt successful practices of stormwater management and to resolve the local environmental problems. Hence, the Sponge City Program (SCP) was launched in 2013 under such motivation [16] [17]. In November 2014, Sponge City Development Technical Guide (SCDTG) was issued. Later in October 2015, the General Office of the State Council issued "Guiding Opinions on Promoting Building of Sponge Cities", and allocated tasks to drive construction of sponge cities. Also in 2015 and 2016, 30 cities were selected as the first batch of pilot cities, including: Baicheng, Zhenjiang, Jiaying, Chizhou, Xiamen, Ningbo, etc. [13]. Currently, these 30 sponge city construction pilot cases are under development and actively progressing towards building a large number of sponge construction projects [18]. As a result, sponge city is listed as a national

strategic level, and an important topic both nationally and internationally [13] [18].

## 1.2. Define GI and Sponge as well as Its Relationship

Green Infrastructure (GI) has been adopted as an important measure in many popular strategies of stormwater management practices, such as Best Management Practices (BMPs) and Low Impact Development (LID) in the US [3] [11] [19] [20] [21], Sustainable Urban Drainage System (SUDS) in the UK [22], and Water Sensitive Urban Design (WSUD) in Australia [23]. These new solutions have been successfully implemented in many places, and the core concept of these strategies is centralized around the use of green infrastructure, such as, rain gardens, bio-retention cells, vegetative swale, wetlands, etc. [3] [24] [25] [26]. Many studies have shown that GI facilities can effectively control the quantity and quality of rainfall runoff [27] [28] [29] [30]. Consequently, and by learning from such global examples, China's Sponge City Programme (SCP) has a similar purpose. Therefore, GI is widely used and applied as an innovative stormwater management approach to cope with urban hydrology and water related issues [13] [18] [31] [32]. This is due to their multi-functional and multi-beneficial applicability, such as maximizing ecosystem services, watershed restoration, and biodiversity conservation [33] [34] [35]. These will ultimately promote resilience, biodiversity, human health, wellbeing and social cohesion, as a comprehensive method of restoration programs.

In reality, GI has broader definitions, typically refers to an interconnected network of multifunctional green-spaces that are strategically planned and managed to provide a range of ecological, social, and economic benefits at a macro scale, or a green space for infrastructure at site or neighbourhood scale [36] [37] [38] [39]. In addition, GI approaches have recently been defined as the methods of Nature-based Solutions (NBS), which have broad appeal [40] [41].

However, when we emphasize the application of GI in sustainable stormwater management projects, a more specific concept is defined as "Green Stormwater Infrastructure (GSI)" [42] [43] [44]. In addition, the US Environmental Protection Agency (EPA) describes GI as a cost-effective, resilient approach to managing stormwater that benefits the communities [45]. They provide the following GI measures of: Bio-Retention Cells (BC), Rain Gardens (RG), Bio-Swales (BS), Permeable Pavements (PP), Green Roofs (GR), Rainwater Harvesting, Planter Boxes, Green Streets and Alleys, Green Parking, Land Conservation, etc. [46]. Therefore, GSI is part of GI, and this study mainly focuses on the GI for sustainable stormwater management. This study particularly addresses GSI approaches of Nature-based Solutions (NBS) at the neighbourhood scale for SCP, which are widely used in China, such as BC, RG, BS, PP, and GR. In addition, the site land conservation and land use transition design with the natural landscape restoration were contained as integrated sustainability GI design pathways, together with the GSI measures, as the concerned scope in this research.

### 1.3. High-Quality Implemented GI for Multi-Beneficial Sponge Node Repairable Needs with China's "Quality Urbanization" Transition

After nearly 40 years of rapid economic development and rapid urbanization, China's demand for "quality urbanization" and quality of life is evolving [47] [48]. This is because urbanization has proved to be one of the most severe threats to the preservation of natural areas and biodiversity. Especially, during the last 20 years, the ecological pressure from urbanization has been steadily increasing, particularly in the metropolises in China's South-east coastal area. These ecological pressures are not only the water environment crisis, but are also related to larger problems of wetland reduction, habitat degradation and biodiversity reduction [48] [49]. However, in recent years, the growth of urbanization in these cities in China has begun to decelerate. Urban construction has begun to attach more importance to ecological environment protection and ecological restoration [50]. In addition, the high-quality urbanization transition is an all-around sustainable transition, which aims at a comprehensive sustainable development of economy, environment and society [51]. Hence, not only ecological sustainability is emphasized, but also human centred healthy city and high-quality built environment for human wellbeing improving are valued.

In this context, GI, due to its multi-functionality and multi-beneficially, has gained great attention in ongoing sponge related comprehensive restoration programs [52] [53]. However, there remains a lack of certainty amongst practitioners about how to deliver and evaluate a high-quality GI plan toward a high-quality construction, particularly under China's transition period. Hence, this paper addresses this particular matter.

### 1.4. Literature Review and Research Gap

Globally, GI literature and guidance recognize the need for more scholarly research to refine and enhance our understanding of the sustainability characteristics of: 1) high quality GI planning approach with sustainability dimensions, 2) the multi-benefits trade-off with the needs of different stakeholders [52] [54].

Bowen and Parry [54] except that a substantial body of evidence from GI research and practice the significant multi-benefits GI offers to environment, people and society [28] [55] [56] [57]. O'Neil and Gallagher [58] identify a "good quality green network" within urban planning research and practice in England and Scotland. In addition, government guidance is clear in its advocacy for GI as the preferred mechanism to deliver multiple benefits for people and environment through the planning and development system. Globally, many countries and cities have strategic policies and guidance towards development and quality assurance of GI. For example, in the UK, the Revised National Planning Policy Framework [59] [60], presents the GI guidance in national planning policy. Similarly, the European Union has developed a strategy for GI, primarily to enhance healthy environment, to stop the loss of biodiversity and enable eco-

systems to deliver their services to people and nature. Hence, many European cities have prioritized biodiversity and recreation outcomes in their policies [61] [62] [63].

The Chinese government and existing research work have already begun to explore the assessment of the overall benefits of the GI for SCP. Sponge City Development Technical Guide (SCDTG), together with other China local sponge city design guidance, also provide some design guidelines for GI design. SCDTG and “Sponge City Construction Performance Evaluation and Assessment Criterion (2015)” put forward the annual total runoff control rate (ATRCA) as a quantitative indicator for SCP assessment [64]. Moreover, the “Sponge City Construction Performance Evaluation and Assessment Criterion”, strengthened the specific indicators for water quality and water assessment requirements as well as ATRCA requirements [65]. In addition, this criterion puts forward some comprehensive construction requirements of water ecology, water culture, and water environment at the macro scale. It includes principles such as the improvement of the protection and ecological restoration of the urban natural waterfront areas, retaining and stabilizing the annual average groundwater table, and promotion of the utilization of rainwater resources. These are provided in the general guidance for the pilot city. However, there is no further detailed comprehensive KPIs for the GI delivery and evaluation pathways at the site level or the neighbourhood scale projects. Moreover, as SCP’s local character affects practice, the detailed GI delivery guidance and assessment standards, especially for neighbourhood scale, need to be explored in the local context.

In more recent scholarly work, Jerome *et al.* (2019) present a framework for the delivery of high-quality GI in the built environment of the UK [60]. The framework presented 23 principles for delivering GI, based on a review of both literature and interview. These principles related to health and wellbeing, water management and nature conservation. Pakzad, Osmond [66] suggested a set of potential indicators that facilitate the development of an inclusive model for the sustainability assessment of GI performance. These two studies highlighted the comprehensive evaluation for a high-quality GI delivery towards sustainability, but still mainly focus on the broader GI scope. Gordon, Quesnel [67] propose a framework used to standardize GI project evaluation, including a set of technical performance metrics. The technical dimension stands for the GI adaptability for local area, which is also significant for a high-quality GI assessment for SCP. Li, Wang [68] puts forward a more comprehensive evaluation system based on AHP with the Guangxi project case study, which is enlightening for the restoration of China’s domestic the neighbourhood scale. The study developed the comprehensive evaluation system for SCP, but it still needs to be further optimized in terms of its KPIF, such as the need for systematic research, comprised of the key sustainability dimensions, such as health and wellbeing for people. In addition, more in-depth research is essential for the KPIF of sustainability with multi-benefits trade-offs, which is of great significance to GI planning compre-

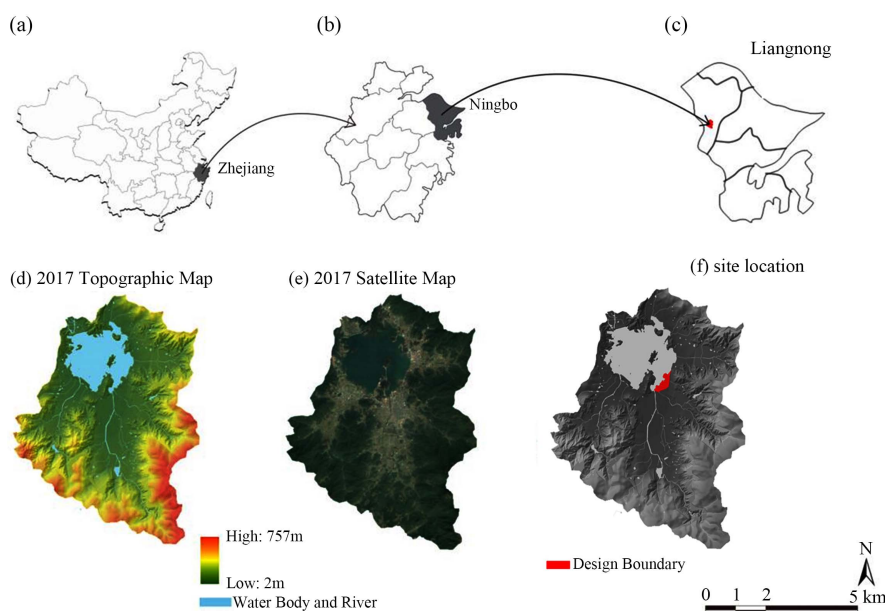
hensive assessment and robust decision making of project implementation, especially at the neighbourhood scale. Because that delivering high-quality GI at a “local community scale” is an implantation scale with starting small but thinking big. This is identified to be major research gap of sustainability in the field.

## 2. Key Points and Research Frame of This Study

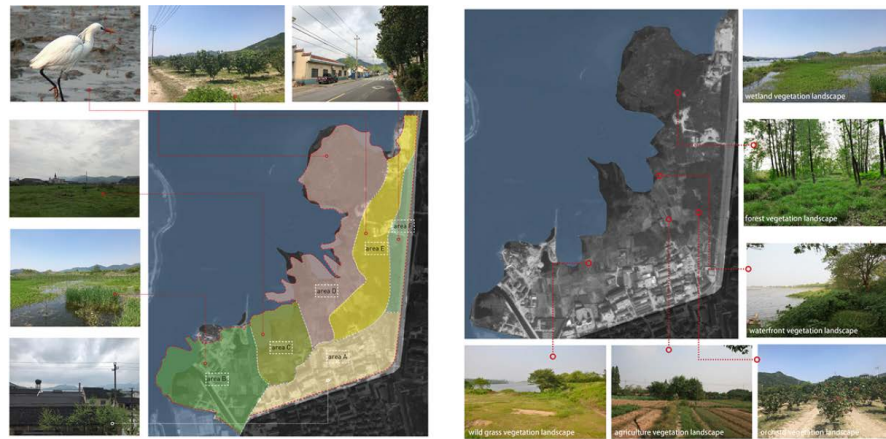
### 2.1. Key Points for Case Study

Due to varying characteristics and priorities for SCP across china, evaluating a local case study in the local context for urban high-quality GI planning assessment is important. This study selects Siming Lake area of Liangnong, a water source area of City of Ningbo, as a case study area (**Figure 1**). Ningbo is a large-scale city in the southeast coastal area in China, with a developed economy and prosperous culture. Ningbo is a famous “Jiangnan water town” in the Zhejiang Province and a well-known economic centre of the south Yangtze River Delta. Ningbo was selected as a sponge pilot city in 2015.

The study area is one of the water source areas of Ningbo. After rapid urbanization development, the traditional sponge landscape pattern of this area is drastically changed. The study area is severely intervened by human activities, and some parts of the natural waterfront landscapes are covered and replaced by different types of artificial landscape and build-up area. It can be divided into 6 landscape units (**Figure 2**). Area A is the build-up area with some small buildings. Area B is estuary wetland with artificial landscape due to the river cut. Area C is mainly wetland with cherry trees. Area D mainly includes natural forests and wetland. Area E mainly includes some artificial farmlands. Area F is mainly with trees next to a highway.



**Figure 1.** The location with topographic and the focus case study area of GI application.



**Figure 2.** Landscape unit with typical landscape and land cover of the case study area.

The main problem for the study area, located just next to the first-class water source protection area, is the pollution and the lake view block from the industrial buildings of area A (as shown in **Figure 2** and **Figure 3**). In addition, the Siming Lake waterfront area, as an important ecological sponge node and a beauty spot, not only faces water environment problems such as water quality degradation, but also faces serious ecological crisis such as wetland reduction, habitat degradation and the damage of the related ecological cultural and well-being services. This situation requires comprehensive ecological restoration. Currently, relevant land conservation and ecological restoration planning are in progress, and the government and relevant experts have formed a SCP project dialogue platform to help the delivery of the high-quality GI plan for sustainability. In the process of project promotion, it is found that balancing the multi-benefits was challenging. Hence, SCP is a government-led program, developing an evaluation system in a communicative way: working within local governance and partnering with experts from different backgrounds is required. In addition, promoting a high-quality GI planning still needs to trade off the multi-benefits based on structuration and systematization decision-making process.

## 2.2. Method Selection and Research Frame

GI planning for SCP is multi-objective and multi-beneficial approach. The active participation of all relevant governmental agencies, experts, and stakeholders in the process is required. In addition, multi-criteria decision-making techniques have been used to support decision making for the SCP and sustainable development, and the Analytic hierarchy process (AHP) is the most often used and well known among them [69] [70] [71] [72] [73]. The AHP approach was proposed by Saaty [74], which is a robust multi-criteria decision-making method that has been applied for analysing complex and unstructured problems in various decision-making situations. However, when it comes to high-quality implemented GI practices for multi-objective SCP projects, which naturally is a very



**Figure 3.** Land use and the buildings status quo of the landscape unit A.

complex issue, the method involves many indicators for ecological, economic, and social aspects. However, many of them lose meaning in the KPIs for achieving the goal. In order to make the problem clearer and easier to implement, only the KPIs need to be the focus of evaluation system. Hence in this study, development of a comprehensive evaluation system with sustainability KPIF of trade-offs for a high-quality multi-objective sponge node is proposed.

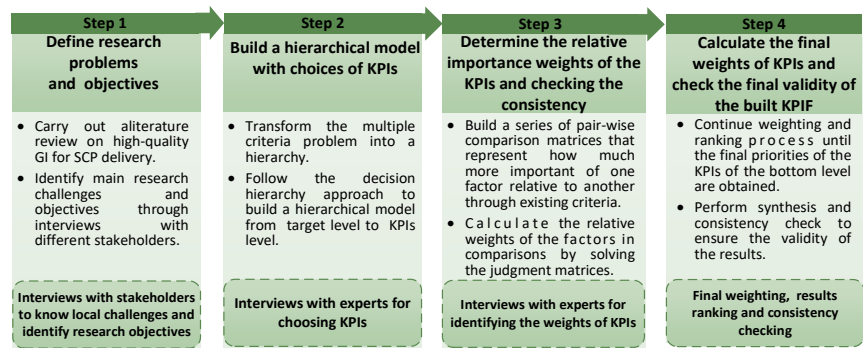
In addition, the KPIF should be proposed base on both the literature and experts' interviews. Interviews from different stakeholders and different levels of expert need to be completed in an organized process. Therefore, this paper explores a more structured multi-criteria evaluation process base on AHP method. The improving research process base on AHP method consists of four steps, which are summarized in **Figure 4**, and the detailed steps will be illustrated in the flowing methods section.

### 3. Methods for High-Quality Implemented GI Assessment Framework Case Study

#### 3.1. Study Area and the Identified Problems

The Liangnong Siming waterfront area, as an important ecological barrier of Siming Lake, plays an important role in the water ecology and water security for Ningbo city. As illustrated in Section 2.1, with the process of urbanization and industrialization, the Liangnong lakeside waterfront area has been seriously affected by human construction. In particular, the lakeside wetland area nearest to downtown Liangnong, where the research area is located, has been partially occupied by industrial buildings. More recently, the site has been scheduled to be restored and transitioned to a waterfront wetland park in multiple stages. These include GI ecological restoration of Wetland Park sponge node, and then the overall GI restoration of Liangnong Daxi watershed. In addition, this GI evaluation research is focused on the first stage. In this 5-year-long stage of the first





**Figure 4.** Research process of the improving AHP.

stage, the waterfront site area occupied by industrial buildings will be transformed into a landscape park, consisted of rainwater harvesting plants and ecological detention purification areas using GSI facilities, such as BC, RG, GS, PP, etc. In addition, site land conservation and land use transition design with the natural landscape restoration was also used as the integrated GI delivery tools for the neighbourhood GI plan. This study proposes a Sustainability KPIF for the final selection of optimal high-quality GI plan that will be implemented for the first stage within 5 years.

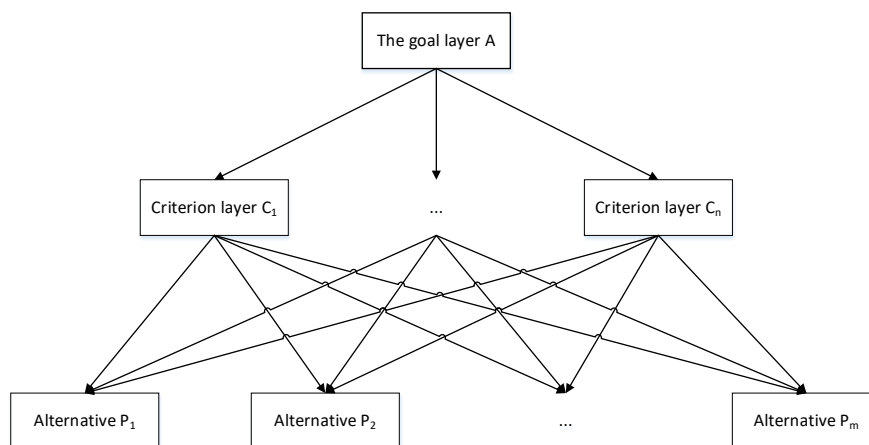
## 3.2. Analytic Hierarchy Process (AHP) Evaluation with KPIF

### 3.2.1. Overview of AHP

Analytic hierarchy process (AHP) is a structured method for organising and analysing complex decision criteria [74]. It is known for its rigorousness in analyzing the relative strengths of preferences, qualitative judgments, and contradictory opinions of decision makers [74] [75]. Hence it is considered the most appropriate technique to achieve a weighting system for prioritizing relevant indicators in an assessment framework [76]. The approach uses quantified weights of each alternative, and its strength lies in its ability to rank choices in the order of their relevance to meet complex and competing needs and interests. In addition, the AHP framework utilizes hierarchical structures, providing a systematic methodology to calibrate numeric values to measure qualitative performance [77]. It also facilitates analysis by decomposing complex evaluations into smaller manageable sub-evaluations [76].

### 3.2.2. Hierarchical Model Structure

This problem is explored at multiple levels, from the general to detailed, and is then expressed in a multileveled way using the hierarchical model. The hierarchical model typically consists of three basic levels: 1) The top level is the target level, which represents the overall goal to determine the ranking of importance. 2) The middle level is the criterion level, which contains the criteria and sub-criteria that influence the goal and includes the selected key indicators. In this study, these are termed the KPIs and are used for evaluating the alternatives. 3) The bottom level is the scheme level, which includes alternatives. The general hierarchical model is shown in **Figure 5** below.



**Figure 5.** The general hierarchical model.

### 3.2.3. Development of the KPIs of the Hierarchical Model

The AHP supports decision making by decomposing the complex problem into several levels and indicators based on the goal of decision making. The process emphasizes the necessary and important criteria that are chosen, including the KPIs. In this study, the KPIF was emphasized and further developed.

The KPIF of the AHP is organized in a hierarchical structure, descending from an overall goal to criteria, sub-criteria, and alternatives in successive levels, as mentioned above [74] [78]. In addition, KPIs from many performance indicators were selected based on review and interviews in the early stage. In this study, experts from four groups were interviewed: 1) experts from the Liang-nong government management and the Ningbo Sponge City Construction Leading Group Office; 2) experts from the Ningbo bureau of natural resources and planning and the Ningbo Housing and Urban-Rural Development Bureau; 3) experts from local design institute and construction; and 4) experts from universities, such as, Peking University, Beijing University Department of Civil Engineering and Architecture and Tongji University. Each group consisted of five people for a total of 20 people (15 local experts and 5 non-local). These experts were to assist in establishing the evaluation system.

### 3.3. The Improved Solution Process with KPI Development

Decision making is based on calculating the correlation degree and relationships of the evaluation indicators [79]. The solution steps of an improving process are as follows: 1) Define the problem with the main objective consultants; 2) Start building the hierarchical model by structuring the decision hierarchy from the top level to the lowest level, also including development of KPIs for the lowest level; 3) Build a set of pair-wise comparison matrices to indicate important factors in relation to another by considering the criteria. This approach helps to obtain relative weights of comparative elements by solving the judgment matrix. It also uses priorities obtained from the comparisons to weight the priorities in the level immediately below. In addition, a consistency check is required. 4) Continue this process of weighing and ranking until the final priorities of the al-

ternatives in the bottommost level are obtained. In addition, a synthesis and consistency check is performed to ensure the result will pass the consistency test.

The AHP hierarchical model structure with the KPIs can be generally summarized as shown in **Figure 6**. The top goal layer is goal A. The middle level containing  $n$  criteria B is denoted as B1, B2, B3, ..., and B $n$ ;  $q$  sub-criteria C, denoted as C1, C2, C3, ..., and C $q$ , as well as  $m$  KPIs D1, D2, D3, ..., and D $m$ ; and the bottom layer containing  $X$  alternatives. The detailed evaluation and calculation steps are as follows:

In step 1 of the AHP, the primary task is to examine main objectives and define the problem with both literature review and interviews. Related published literature and technical guidance of existing GI for SCP related assessment frameworks, criteria, and tools were reviewed to identify similar works, define the research problem and determine the scope of the problem solving from a context-specific approach. In addition, interviews with different stakeholders were carried out to find the main challenge and the main objectives for GI delivery. In Step 2 of the AHP, the aim is to transform the multiple criteria problem into a hierarchy. In addition, this is accomplished by building the KPIF by structuring the decision hierarchy from the top goal level to the KPIs level. In this study, these are a set of KPIs for different dimensions identified for the KPIF building in this step.

In step 3 of the AHP, the judgment matrixes are constructed and are used to determine the relative importance of each alternative in terms of each criterion. The value of each pair-wise comparison, on the basis of a 1–9 scale as shown in **Table 1**, is evaluated by the opinion of experts and governmental decision makers [80].

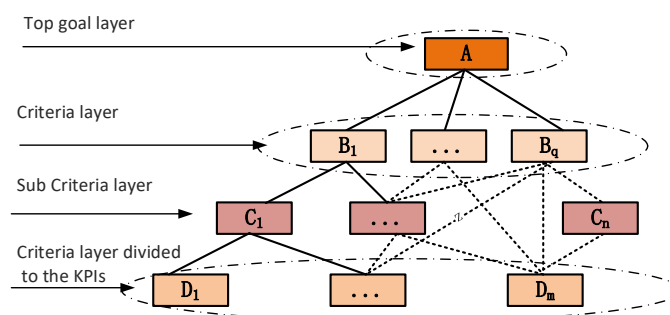
A matrix consistency check is required in this step. The purpose of a matrix consistency check is to check the consistency of the evaluation and to ensure each judgment is rational and to avoid conflicting results. Perfect consistency rarely occurs in practice. The judgment matrix is considered to be adequately consistent if the corresponding consistency ratio ( $CR$ ) is less than 0.1. First, a consistency index ( $CI$ ) can be calculated using Equation (1) based on the maximum eigenvalue  $\lambda_{\max}$ :

$$CI = \frac{\lambda_{\max} - n}{n - 1}, n = 1, 2, \dots, 9 \quad (1)$$

Then, the  $CR$  is obtained by dividing the  $CI$  by the random consistency index ( $RI$ ), as shown in **Table 2**:

$$CR = \frac{CI}{RI} \quad (2)$$

In step 4 of the AHP, final hierarchy priority ranking is used to calculate the ranking weights of the relative importance of all elements of each certain layer to the top layer. The final weighting priorities, denoted by  $W_{D1}$ ,  $W_{D2}$ , ...,  $W_{Dm}$ , of the alternatives in terms of all the criteria combined are determined according to Equation (3):



**Figure 6.** The general AHP model structure used in this investigation.

**Table 1.** Scale of relative importance.

| Intensity of relative importance | Definition   |
|----------------------------------|--|
| 1                                | Equal importance   |
| 3                                | Moderate importance  |
| 5                                | Strong importance  |
| 7                                | Demonstrated importance  |
| 9                                | Absolute importance  |
| 2, 4, 6, 8                       | Intermediate values between two adjacent judgment values   |
| The reciprocal value             | The judgment value of the importance of the element $i$ and $j$ is $r_{ij}$ , and the reciprocal value is $1/r_{ij}$ |

**Table 2.** The RI values.

| Elements  | 1 | 2 | 3    | 4    | 5    | 6    | 7    | 8    | 9... |
|-----------|---|---|------|------|------|------|------|------|------|
| <i>RI</i> | 0 | 0 | 0.58 | 0.90 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 |

$$W_{Di} = \sum_{j=1}^n W_{Cij} W_j, i = 1, 2, \dots, m \tag{3}$$

where  $W_j$  is the overall ranking weight of each element of the above layer  $c_j$ , and  $W_{Cij}$  is the ranking weight of the layer corresponding to  $c_j$ .

The consistency check of the final ranking weight is shown in Equation (4):

$$CI = \frac{\lambda_{\max} - n}{n - 1}, n = 1, 2, \dots, 9 \tag{4}$$

where  $CI(j)$  is the consistency index,  $CI$ , of the criterion  $j$ , and  $RI(j)$  is the average random consistency index,  $RI$ , of the criterion  $j$ .

## 4. Findings and Discussion

### 4.1. The Hierarchical Model with the KPIs

A hierarchical structure of the evaluation system with the KPIF was developed, as shown in **Table 3** and **Figure 7**. The hierarchy consisted of three main levels with the KPIF: the target level A, the middle level consisting of criterion level B, and the sub-criterion level C consisting of the KPIs, as well as a layer of KPIs that contained the key sustainability indicators. The target level is the high-quality

GI design scheme that is the best comprehensive benefit for SCP. Also, SCP is a sustainable water management idea, similar to LID, WSUD, SSUD, the three-pillar concept is widely known in the area of sustainable development. This three-pillar concept of environmental, economic, and social sustainability has commonly been linked to the so-called triple bottom line (TBL) of economic-social-environmental balance [79] [81] [82]. Moreover, as mentioned above, authoritative scholars have pointed out that GI is a global movement to improve multiple dimensions of urban sustainability, it is necessary to strengthen sustainability indicators of dimensions such as health and wellbeing for people, efficient adaptability with local characteristics etc. Therefore, according to the literature and expert interviews, the top level was further divided into three criteria: environmental performance, economic and adaptability performance, Social-cultural and wellbeing performance. The result of choosing the KPI as a further division of these four criteria is discussed below.

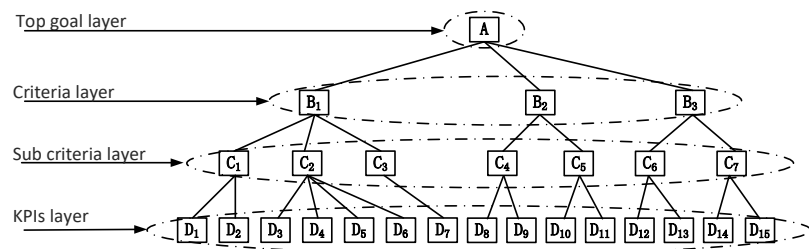


Figure 7. Structure of the KPIF for the case study.

Table 3. Structure of the KPIF with the basic description of the KPIs.

| Target Hierarchy (A)     | Criterion Hierarchy (B)                 | Indicator Hierarchy (C)                  | Symbol | Remarks   | References   |
|--------------------------|---|--|--------|---|--|
| Comprehensive Assessment | Water quantity regulating services (C1) | Annual total runoff control rate (ATRCR) | D1     | The percentage of the accumulated annual rainfall in the site that accounts for the total annual rainfall, which was calculated according to the analysis and calculation of 30 years rainfall statistics | MOHURD [64]; MOHURD [65]; Ningbo Municipal Housing and Urban-Rural Development Bureau [83] |
|                          |   | Peak reduction rate                      | D2     | The percentage of the peak reduction after construction calculated based on the simulation of the designed return period  | MOHURD [64]; MOHURD [65]; Ningbo Municipal Housing and Urban-Rural Development Bureau [83] |
|                          |   | SS reduction rate                        | D3     | Typical pollutants reduction rate for total suspended solids (SS)   | MOHURD [64]; MOHURD [65]   |
|                          | Water quality regulating services (C2)  | COD reduction rate                       | D4     | Typical pollutants reduction rate for chemical oxygen demand (COD)  | Ningbo Municipal Housing and Urban-Rural Development Bureau [83]                           |
|                          |   | TN reduction rate                        | D5     | Typical pollutants reduction rate for total nitrogen (TN)   | Ningbo Municipal Housing and Urban-Rural Development Bureau [83]                           |
|                          |   | TP reduction rate                        | D6     | Typical pollutants reduction rate for total phosphorus (TP)   | Ningbo Municipal Housing and Urban-Rural Development Bureau [83]                           |

## Continued

|  |  |  |  |   |  |
|--|--|--|--|---|--|
|  | Habitat supporting Services (C3)                             | Promotion of Biodiversity                              | D7                                     | The level of the enhance of biodiversity, measured by the richness of the species of each design.   | Sadler, Bates [84]; Yu [85]; Hunter, Christian [86]; Payne and Barker [87]; European Commission [88]; Pakzad and Osmond [89]; Jeanjean, Monks [90]; Frumkin, Bratman Gregory [91]; Sinnett, Calvert [63]; Revised National Planning Policy Framework [59]; Jerome, Sinnett [60]; Ministry of Housing Communities and Local Government [92]; Heymans, Breadsell [93]; Charoenkit and Piyathamrongchai [94]; Pauleit, Ambrose-Oji [52] |
|  | Economic and adaptability performance (B2)                   | Construction cost saving                               | D8                                     | The level of GI measures construction cost saving   | Dhakal and Chevalier [95]; Mei, Liu [96]; Luan, Yin [30]; Kim and Song [97]; Liang [98];   |
|  |  | Maintenance cost saving                                | D9                                     | The level of GI measures maintenance cost saving  | Mei, Liu [96]; Luan, Yin [30]; Pauleit, Ambrose-Oji [52]   |
|  | Efficient adaptability (C5)                                  | Facility adaptability                                  | D10                                    | The level of GI measures operation effect according to local soil, plants and horological conditions.   | Wu, Wang [99]; Gordon, Quesnel [67]; Cao, Lin [100]; Ye, Li [101]; Huang, Wu [102]   |
|  |  | Efficient land use                                     | D11                                    | The level of efficient land use measured by if the facility needs more land to reach the same water quality or quantity control goal  | Wu, Wang [99]; Kim and Song [97]; Mulligan, Bukachi [103];   |
|  | Social-cultural and wellbeing performance (B3)               | landscape cultural services (C6)                       | D12                                    | The level of providing attractive landscape features and views, as well as contributing to a high-quality built environment with strong feeling of belonging to a particular community or space | Yu [104]; Wang and Banzhaf [105]; Kim and Song [97]; Zhang and Muñoz Ramírez [106]; Jerome, Sinnett [60]   |
|  |  | Health and wellbeing supporting Services (C7)          | Promotion of educational opportunities | D13   | The level of providing scientific and aesthetic education activities   |
|  | Recreational and wellbeing improvements for all times a year |  | D14                                    | The level of providing recreational activities richness with assessable times of a year   | Pakzad and Osmond [107]; Ministry of Housing Communities and Local Government [92]   |
|  |  | Recreational and wellbeing improvements for all people | D15                                    | The level of providing recreational activities and space richness, with improvements of health and wellbeing for all people   | Pakzad and Osmond [107]; Ministry of Housing Communities and Local Government [92]; Ramyar, Saeedi [108]; Garau, Annunziata [109]; Jerome, Sinnett [60]; Kim and Miller [110]; Mulligan, Bukachi [103]   |

## 4.2. KPIs for Multi-Objective “Sponge Node” Construction

### 4.2.1. KPIs for Environmental Performance

Water quantity and water quality were selected as two key dimensions for stormwater regulating services performance, due to that sponge city is a sustainable water management measure. The governmental performance evaluation document, SCDTG, issued in 2014, clearly puts forward the proposed objectives of annual total runoff control (ATRCR) for different kinds of projects at various regions of those pilot cities. Moreover, the *Sponge City Construction Performance Evaluation and Assessment Criterion* (2015) [65] and the *Sponge City Construction Performance Evaluation and Assessment Criterion* (2019) [65], clearly state that water quantity and water quality are two important components that represent hydro-environmental benefits. Indicators including the ATRCR, Typical pollutants reduction rates for total suspended solids (SS) as a representative indicator. Other Indicators including chemical oxygen demand (COD), total nitrogen (TN), and total phosphorus (TP) are required by local urban planning and design guideline for Sponge City of Ningbo [83]. To more accurately and comprehensively evaluate the hydrological environmental effects of GI plans according to the requirements of the *Sponge City Development Technical Guide*, 30 years of continuous daily rainfall data in the local area are needed to calculate the ATRCR and related pollutant reduction. In addition, the percentage of the peak reduction after construction, calculated based on the simulation of the designed return period is also stated in these documents. Therefore, water quantity and water quality were two sub-criteria for the hydro-environmental criterion level. For water quality evaluation, the typical pollutants reduction rates for total suspended solids (TSS), chemical oxygen demand (COD), total nitrogen (TN), and total phosphorus (TP) were chosen as the KPIs [30] [69] [111]. In addition, the ATRCR, and annual peak reduction rate were selected as the KPIs for water quantity evaluation.

Moreover, apart from the stormwater quantity and quality performance, promotion of biodiversity is also selected as key dimension for supporting sustainability of the total environmental. Many European cities have prioritized biodiversity and recreation outcomes in their policies, as mentioned in section 2.1. In addition, considerable research, as shown in **Table 3**, has shown significant social and cultural benefits provided by GI that are primarily reflected in contributing to high-quality environment by protecting and enhancing biodiversity and enable ecosystems to deliver better services to people and nature.

### 4.2.2. KPIs for Economic and Adaptability Performance

In terms of economy and adaptability criterion, the inclusion of construction costs saving, maintenance costs saving, facility adaptability, and efficient land use as key indicators, should be selected for the KPIs in the evaluation system.

As some studies have pointed out, despite the multi-sector benefits of GI, the major barrier that has prevented the widespread adoption of these systems worldwide is adequate funding. Securing funding is often the primary challenge

in implementing a GI project [67] [75] [95] [112]. Moreover, although the environmental benefits of GI were significant in this case, the cost of compensation for building demolition is relatively high, especially for the owners of industrial and retail units. According to the interviews, if the government does not provide satisfactory compensation, those owners are not willing to restore green spaces. In addition, the impact of construction costs and maintenance costs is an important factor in GI implementation. However, a high-quality GI will bring economic benefits, such as, reviving the surrounding areas, helping to make it attractive by promoting recreational activities and other landscape cultural services [97]. Hence, GI aids economic growth in target neighbourhoods, as well as the overall improvement of communities' social, physical, and environmental conditions. This then impacts the increase in land value, therefore, can be compensated by the long-time sustainability benefit. Construction costs and maintenance costs saving needs to be evaluated in a long-time sustainability way.

Moreover, efficient adaptability is of great importance for economic performance, according to relevant literature and interviews. Indicators including facility adaptability and efficient land use are the four KPIs for the efficient adaptability sub-criterion [67] [97] [99] [103]. Facility adaptability is measured by the level of GI measures operation effect according to local soil, plants and horological conditions. In order to acquire the technical performance of the suitability of typical GI facilities for SCP, such as Bio-Retention, Rain Gardens, Grass swales, Permeable Pavements, Rainwater Harvesting and Green Roofs etc., an application evaluation study was carried out before this KPIF study [99]. The application of these various typical GI facilities in Ningbo was investigated by experts' questionnaire from different background. The findings suggested that, Grass swales, Rain Gardens, and Bio-Retention were ranking the first three among the facilities. Hence, they are also the GI facilities with the high technical suitability. A high-quality GI plan for SCP must fully consider the difference of geological environment conditions, as well as the easily optimization ability in order to adapt to the local condition in both design and implementation stage.

The efficient land use is a KPI in many projects, especially for many reconstruction projects where the available area for GI facilities is often limited. It is measured by if the facility needs more land to reach the same water quality or quantity control goal. If the space is limited, more efficient facility is needed to achieve the same water quality and water quantity control goals. In this case and similar cases of landscape restoration, a design that uses more of a facility land saving rate means a higher technical adaptability and smarter design for land-use because it has more external benefits. More succinctly, more space can be reserved for buildings and other landscape spaces that enhance aesthetics, health, biodiversity, and ecosystem services.

Moreover, in this case, the accumulation of local experience must be taken seriously. Ningbo is already selected as the pilot city for three years. Prior to the selection, there were eight years of GI project implementation with the purpose of sustainable water management, which was a famous project called "water sen-



sitive design for the new district of Cicheng,” located just within the city’s sponge pilot area. In addition, some other similar local projects provided practical experience for the GSI facilities, and implementation adaptability research was conducted prior to the Siming case study project. Therefore, this can be used as an important reference for new project planning. Although a certain GI facility, such as Bio-Retention may have a variable adaptability to different projects for different regions [99], it is still necessary to incorporate this important criterion of local adaptability into the KPIF of the evaluation system. Based on the literature review and expert interviews, facility adaptability and efficient land use are important KPIs that affects and restricts the implementation effect of GI facilities. Therefore, it affects the implementation outcome of the application of the overall GI plan.

#### **4.2.3. KPIs for Social-Cultural and Wellbeing Performance**

Promotion of landscape aesthetics and identity, promotion of educational opportunities, recreational and wellbeing improvements for all times a year, as well as recreational and wellbeing improvements for all people are the final selection of KPIs for social-cultural and wellbeing performance.

As the ecological cultural service function mainly refers to the landscape cultural benefits, such as promotion of landscape aesthetics and identity, educational opportunities, and recreational improvements to the built environment, etc. [113]. Recreational and wellbeing improvements for all times a year and recreational and wellbeing improvements for all people are selected as the KPIs for health and wellbeing improvements. While they are measured by the level of providing recreational activities and space richness, with assessable times of a year and with improvements of health and wellbeing for all people. Hence, the activities richness focus on two principles of the high-quality GI, which are: 1) all people are encouraged to use and enjoy the GI, especially young children, the old people and the disabled; 2) GI is designed to be assessable at all times of a year, especially the hot summer days and cold winter day, as well as the raining day, due to the case study area, Jiangnan water town area is a typical climate area with hot summer and cold winter also more than one third of days of a year are raining days [60] [103] [108] [109] [110].

In addition, to maximising the beneficial outcomes from GI, the level of providing recreational activities richness also linked to following three main kinds of wellbeing benefits: 1) improving physical wellbeing through physical outdoor activity; 2) improving social wellbeing through social interaction; and 3) improving mental wellbeing through reduced depression and anxiety, recovery from stress and positive emotions etc. [107].

### **4.3. Ranking and Weighting Results and Further Discussions of KPIF**

#### **4.3.1. Ranking and Weighting Results of KPIF**

Based on the total ranking and weighting analysis process, the final weighting result of the of KPIs are shown in **Table 4**. In addition, the final CR value for

consistency check is 0.0911, less than 0.1, indicating a good consistency of the weighting results. A consistency check of the overall ranking result was then implemented.

Also as demonstrated in **Table 4**, the followings are assessed: the weight of the ATRCR (D1), the promotion of biodiversity (D7), the construction cost saving (D8), and the level of recreational and wellbeing improvements for all people (D15). Those are relatively high among the 15 studied indicators.

#### 4.3.2. Further Discussions of the KPIF

The ATRCR (D1) is the KPI that both the guidance and experts' interviews attached great importance to; hence, its relatively high weight is reasonable. Economical KPIs (D8) and (D9) also received high weight in this case study, especially the experts with a governmental background have a higher weighing for those two indicators. In fact, as a major barrier affecting the implementation, economic aspect has also been stressed in many GI delivery case studies [67] [75] [95] [112].

**Table 4.** Weighting results of the key performance indicators (KPIs).

| Target Hierarchy (A)                           | Criterion Hierarchy (B)        | Sub-criterion Hierarchy (C)                   | KPI Hierarchy (D)  | Weight of KPIs layer             | Total weight   |        |
|--|--------------------------------|---|--|----------------------------------|--|--------|
| Goal layer                                     | Environmental performance (B1) | Water quantity regulating services (C1)       | Annual total runoff control rate (D1)                              | 0.7018                           | 0.1968   |        |
|  |                                |   | Peak reduction rate (D2)   | 0.2982                           | 0.0836   |        |
|  |                                |   | SS reduction rate (D3)   | 0.2427                           | 0.0435   |        |
|  |                                | Water quality regulating services (C2)        | COD reduction rate (D4)  | 0.2502                           | 0.0448   |        |
|  |                                |   | TN reduction rate (D5)   | 0.2526                           | 0.0453   |        |
|  |                                |   | TP reduction rate (D6)   | 0.2546                           | 0.0456   |        |
|  |                                |   | Habitat supporting Services (C3)                                   | Promotion of Biodiversity (D7)   | 1.0000   | 0.0981 |
|  |                                | Economic and adaptability performance (B2)    | Cost saving (C4)   | Construction cost saving (D8)    | 0.6368   | 0.1055 |
|  |                                |   |  | Maintenance cost saving (D9)     | 0.3632   | 0.0602 |
|  |                                |   | Efficient adaptability (C5)  | Facility adaptability (D10)      | 0.5042   | 0.0359 |
|  |                                |   |  | Efficient land use (D11)         | 0.4958   | 0.0354 |
|  |                                |   |  | landscape cultural services (C6) | Promotion of landscape aesthetics and identity (D12) | 0.3397 |
|  |                                | Promotion of educational opportunities (D13)  | 0.6603   |                                  | 0.0456   |        |
|  |                                | Health and wellbeing supporting Services (C7) | Recreational and wellbeing improvements for all times a year (D14) |                                  | 0.3548   | 0.0483 |
|  |                                |   | Recreational and wellbeing improvements for all people (D15)       | 0.6452                           | 0.0879   |        |
| Social-cultural and wellbeing performance (B3) |                                |   |  |                                  |  |        |

Promotion of biodiversity, KPI D7, is also received a relatively high weight, as key dimension for supporting sustainability of the environment in this neighbourhood scale case. In addition, biodiversity as KPI for habitats supporting function, linkage network, which means being part of a bigger scale ecological network, is critical to delivering high-quality GI for sustainability. Hence, biodiversity is important for this neighbourhood scale case [60] [109].

In addition, biodiversity and the linkage network are even more important for the bigger scale GI, which should be continued researched and discussed in the future study of bigger scale long-term GI planning for Liangnong case.

The level of recreational and wellbeing improvements for all people, KPI D15, emphasize the landscape ecosystem services that ultimately improve health and wellbeing for all people. In recent years, health and wellbeing for all people dimension have attracted increasing concerns from academia and different stakeholders [60] [63] [90] [91]. In terms of ease of access of GI for improving health and wellbeing, the need for providing assessable activities for more people, including children, old people and disabled, marked a higher relative importance with providing assessable activities for more times of a year.

Moreover, in this case study, by delivering the high-quality GI, the sponge node is transformed to a lakeside landscape park, where people and nature interact most acutely, and where ecosystems reside and provide valuable services to people. These ecosystem services not only include water management, but also social and cultural benefits, such as improvements of recreational, aesthetic, and natural education opportunities, as well as supporting the spiritual and psychological and mental health and wellbeing benefits. Considerable research has shown significant social and cultural benefits provided by GI that are primarily reflected in contributing to high-quality built environments by protecting and enhancing biodiversity and promoting landscape aesthetics, increasing leisure and mental benefits promoting educational opportunities, as well as, supporting health and wellbeing [60] [84] [86] [87] [90] [91]. In addition, these benefits are summarized as the ecological socio-cultural service functions and health and wellbeing supporting functions [59] [61] [62] [63] [85] [88].

Therefore, these KPIs stand for ecological socio-cultural service functions as well as health and wellbeing supporting these functions, such as recreational and wellbeing improvements for all people, as well as wellbeing improvements for all times a year, should be included in the comprehensive assessment system, serving as the experts' quantitative evaluation basis of GI alternatives.

While the KPIs for stormwater quantity and quality performance, including ATRCR, SS reduction rate, COD reduction rate, TN reduction rate, and TP reduction rate, can be calculated based on the simulations using SWMM or other typical hydrological software. KPIs for economic and adaptability performance can be assessed by experts with the related field base on, as well as the biodiversity KPI for environmental performance. The total assessing result of the KPIs serves as the quantitative evaluation basis of GI alternatives, which is a compre-

hensive sustainability quantitatively evaluation system of neighbourhood scale SCP.

## 5. Conclusions

A multi-benefit trade-off GI evaluation system is an important tool to promote the implementation of a high-quality GI plan for SCP, while assisting GI optimization for decision-making. In addition, a set of KPIs, including comprehensive dimensions, is the foundation and key step for a high-quality GI assessment and the overall KPIF development for the neighbourhood scale SCP implementation. This study utilised the Liangnong Siming Lake waterfront area as a case study and further developed a comprehensive evaluation system (KPIF) based on the AHP. By improved application of AHP, the KPIF building is carried out in a more systematic and structured way, which included the multi-participation process. In addition, this evaluation path led by experts and governmental bodies, enables a participation opportunity by other stakeholders, too.

After this improved AHP process, the KPIF was developed. It contains three criteria: “Environmental Performance”, “Economic and adaptability performance”, and “Social-cultural Performance and wellbeing Performance”. In addition, 15 KPIs were concluded to characterize these criteria, and among these KPIs, the weight of the ATRCR, the promotion of biodiversity, the construction cost saving, the maintenance cost saving, and the level of recreational and wellbeing improvements for all people were relatively high. The proposed KPIF of high-quality GI practices for multi-objective “sponge node” construction, can help not only to optimize design schemes in the Jiangnan area of China, which was represented by this case study area, but also for quantitatively comprehensive evaluations of similar or sponge-related projects in other regions.

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## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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