Environmental Science and Ecotechnology 12 (2022) 100188

Contents lists available at ScienceDirect

Environmental Science and Ecotechnology

journal homepage: www.journals.elsevier.com/environmental-science-and-ecotechnology/

Original Research

SCC-UEFAS, an urban-ecological-feature based assessment system for sponge city construction

Zi-Tong Zhao [a, 1], Hou-Ming Cheng [a, 1], Sheng Wang [a], Hai-Yan Liu [b], Zi-Ming Song [b], Jun-Hui Zhou [a], Ji-Wei Pang [c], Shun-Wen Bai [a], Shan-Shan Yang [a, *], Jie Ding [a, **], Nan-Qi Ren [a]

[a] *State Key Laboratory of Urban Water Resource and Environment, Harbin Institute of Technology, Harbin, 150000, China*
[b] *Central & Southern China Municipal Engineering Design and Research Institute Co., Ltd, Wuhan, 430010, China*
[c] *China Energy Conservation and Environmental Protection Group, Beijing, 100089, China*

ARTICLE INFO

Article history:
Received 20 January 2022
Received in revised form
19 May 2022
Accepted 19 May 2022

Keywords:
Sponge city evaluation system
Principal component analysis
Factor analysis
Variable weight theory

ABSTRACT

An effective sponge city construction evaluation system plays a crucial role in evaluating sponge city construction schemes. The construction of a sponge city evaluation system still faces challenges related to incomplete index selection and unscientific weight division. Limited studies have focused on the comprehensive assessment of sponge city construction in the early stages. This study constructed a scientific assessment indicator system and a quantitative indicator weight at all levels by literature review and statistical analysis methods from an objective perspective. To demonstrate how to utilize our evaluation methods, three construction schemes randomly generated by MATLAB were evaluated under evaluation states of constant weight and variable weight, respectively. Scheme 3 had the highest score of 0.638 under the constant weight assessment, but it cannot practically be the final construction scheme due to the imbalance between indicators. Compared to the constant weight assessment, a variable weight assessment can effectively balance the states of the evaluation index with changes in the decision variable. Among the three schemes, Scheme 2 is the best choice with a value of 0.0355 under variable weight evaluation due to punishment and incentives in the variable weight method. The concept of "punishing" a disadvantageous indicator and "motivating" an advantageous indicator increases the relative advantages of the indices, ultimately affecting the assessment results of schemes and leading to a more balanced state. This study provides reasonable analysis and decision-making mechanisms to support decision-making and guide the scientific selection of a construction scheme.

© 2022 Published by Elsevier B.V. on behalf of Chinese Society for Environmental Sciences, Harbin Institute of Technology, Chinese Research Academy of Environmental Sciences. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

1. Introduction

The construction of sponge cities is based on the premise of regional water cycle protection, which is achieved by cross-regional and cross-scale water and ecological landscape facilities [1–3]. It enables "natural permeability purification" [4], which allows cities to have more resilient responses to urban waterlogging, water blackening, and odors [5–9]. The construction of sponge cities aims to solve important water and ecological challenges such as urban waterlogging and storage, the urban heat island effect, water blackening, and odors, which together constitute a complex and interdisciplinary urban construction concern [10–14]. Performance assessment of sponge cities upon their completion must confirm whether there is any improvement in the water ecology, water resources, and water security of these cities [4,15]. Such a comprehensive assessment system of sponge city construction must be implemented in the early stages and should be scientific, reasonable, and credible to guide the assessment and construction of sponge cities [16,17].

The selection of assessment indicators and their weight division are at the core of a comprehensive sponge city assessment system [18]. The selection of assessment indicators for sponge cities mainly

---

* Corresponding author.
** Corresponding author.
E-mail addresses: shanshanyang@hit.edu.cn (S.-S. Yang), dingjie123@hit.edu.cn (J. Ding).
[1] These two authors made equal contribution to this work.

https://doi.org/10.1016/j.ese.2022.100188

2666-4984/© 2022 Published by Elsevier B.V. on behalf of Chinese Society for Environmental Sciences, Harbin Institute of Technology, Chinese Research Academy of Environmental Sciences. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

depends on the properties and functional orientation of the land [19]. During selection, scientific, operational, integral, hierarchical, and systematic principles of indicators must be comprehensively considered, and reasonable science-based screening methods must be adopted in order to achieve twice the result with half the effort [20]. In addition to the Ministry of Water Resources and the Ministry of Housing and Urban-Rural Development of China, which proposed assessment methods. Liang et al. developed a comprehensive framework for assessing sponge city construction schemes. This framework includes resilience and sustainability indicators that help designers optimize their design schemes. They selected ten indicators and calculated the weights of these indicators using the analytic hierarchy process (AHP) to analyze the performance of three sponge city construction schemes [21]. Li et al. developed an assessment system for quantifying the performance of low impact development (LID) practices [22]. Selected assessment indicators were based on environmental-economic and social benefits, of which the main factors are described in the literature. The weights of the comprehensive performance assessment indicators of LID practices are based on expert scoring and the analytical hierarchy process [23]. Zhang et al. established a water resource utilization assessment indicator system to assess the water resource utilization in ten pilot sponge cities in China [24]. And classified, summarized, and screened out four sub-system indicators. However, from previous studies, it can be seen that errors caused by subjective factors and the application of a single method for index selection and weight division greatly impact the evaluation of indicators [25–27]. Examples are the Delphi method and the expert method or the brainstorming method, which will affect the evaluation results. The current indicator selection and weight division are incomplete and unreasonable given previous assessment systems [28]. Limited studies have considered the integrity and scientific nature of selecting indicators and weight division of the sponge city assessment systems, and regional differences and specific functional differences have not been reflected [29,30].

Therefore, the correlation between the assessment systems should be explored from a more objective perspective, and a method should be established that is in line with the ecological environment and policies in China [31]. The literature review method and the data frequency statistics method can be used to screen the assessment indicators by considering both subjective and objective factors to reduce errors and solve the problem of subjective factors in selecting indicators [32]. This will reflect the correlation between system indicators and improve the integrity of the assessment system. Objective assessment methods will address the disadvantages of subjective factors in the assessment method. Here, the fuzzy method can be combined with different analysis methods, whereas the subjective method can be combined with the objective method [33]. In addition, the selection of indicators, weight division, and evaluation of the assessment system should be more scientific. Therefore, a combination of guidelines and standards for ecological protection and sponge city construction [34–37] should be integrated into the sponge city evaluation system in China using the concepts of the ecological red line [38], sustainable development [39], and ecological carrying capacity [40–42].

When the construction scheme is completed, it is necessary to assess different construction schemes and choose the optimal one [43]. Weighting is an important factor in the assessment of the construction scheme. The optimal construction scheme is determined by selecting the scheme with the best evaluation result. Construction schemes are different due to the different construction sites of sponge cities. Each construction scheme will have distinctive indicators due to different ecological characteristics, specific functions, and regional differences. The constant weight assessment method keeps the weight of each indicator constant during the assessment of the assessment object and cannot be used effectively in combination with the state of the assessment indicator if the decision-making variables change [44]. In any assessment system, attention should be paid to both the relative importance of indicators and the assessment of some special indicators in the scheme [45]. These special indicators have distinct “advantages” and “disadvantages” [46]. The local state variable weight method can increase the weights of “advantageous” indicators and reduce the weights of “disadvantageous” indicators in accordance with the characteristics of different construction schemes [6]. Therefore, the evaluation schemes reflected regional and functional differences in sponge city construction more objectively. Nevertheless, the current assessment system mainly focuses on post-construction performance assessment. Ecological characteristics, specific functions, and regional differences of sponge cities are not reflected, and not every indicator and specific weight is scientifically presented [47]. Limited studies focus on a comprehensive assessment system of sponge city construction in the early stages [48].

This study discusses the ideal process of sponge city construction by summarizing successful experiences and problems in sponge city construction, which considers the ecological red line, the ecological carrying capacity, and sustainable development. The detailed objectives were: (i) Literature review and the application of frequency statistics to establish an urban-ecological-feature based assessment system for sponge city construction (SCC-UEFAS) from an objective perspective; (ii) Principal component analysis (PCA) and factor analysis are used to reasonably establish the weight of indicators in order to optimize the construction scheme of sponge city and conduct a scientific evaluation of different plans; and (iii) The variable weight evaluation method is used to evaluate the construction scheme according to the characteristics of different schemes. This paper provides a reasonable analysis and decision-making procedure for guiding and standardizing subsequent comprehensive sponge city construction practices [49].

2. Method and theory

2.1. Theory

The concepts of ecological carrying capacity, ecological red line, and sustainable development during the sponge city construction can be explained as follows:

(1) *Ecological carrying capacity* includes urban ecological carrying capacity, environmental carrying capacity, and resource carrying capacity. The concept of urban ecological carrying capacity has a more diversified meaning than ecological and environmental carrying capacity. Under the same environmental pressure, urban ecological carrying capacity can self-regulate and self-repair to a greater extent than ecological and environmental carrying capacity, giving it stronger ecosystem resilience [50].

(2) The *ecological red line* limits the upper and lower spatial boundaries of the ecological environment, biodiversity, storage of water resources, and green coverage. The application of the ecological red line concept in the sponge city construction mainly includes the reduction of surface runoff and interception of rain pollutants, the reduction of flood disasters, and the promotion of water cycle and water resource purification. This can be done by adding ponds, streams, lakes, and wetlands, increasing the water area ratio, enhancing soil and water conservation functions, ensuring

flood discharge, conserving and purifying water, and reducing the occurrence of land desertification and flood disasters [51].

(3) The concept of *sustainable development* usually refers to the sustainable coordination of the economy and ecological environment. This concept has a richer and deeper meaning in the field of sponge city construction [15]. Achieving sustainable development is the goal of sponge city construction [52]. Sponge cities are important for future urban construction as they show outstanding advantages in rain storage, water purification, and the elimination of water blackening and odors. Sponge city construction increases the threshold of the ecological red line protection, improves the efficiency of resource utilization (especially water), and reduces the consumption of resources, which greatly contributes to sustainable economic development and environmental protection. Furthermore, improving the environment of human settlements is an important indicator of sponge city construction, which will ultimately encourage economic development, increase environmental carrying capacity, and provide a suitable living environment for human beings after realizing sustainable development [41,53].

2.2. Methods

2.2.1. Principal component analysis (PCA)

PCA is a widely used mathematical statistics method to transform a multi-variable factor system into several comprehensive indicators [54]. A new set of linear independent comprehensive indicators ($Y_1, Y_2 \ldots, Y_m$) is used simultaneously to replace several original variables with certain correlations ($X_1, X_2 \ldots, X_p$, $m \leq P$), as described in Equations S1 and S2. These new comprehensive indicators reflect the information represented by the original variables to the maximum extent, and there is no overlap of information between the new comprehensive indicators. The PCA procedure can be summarized in 11 steps, as described in the Supplementary information S2.1. The software used for PCA analysis in this study was SPSS-22.

2.2.2. Factor analysis (FA)

Factor analysis (FA) is a technique of data simplification. It explores the basic structure of the observed data by studying the internal dependent relationship between the variables to classify the observed variables. Variables with higher correlation are classified in the same group. When the correlation between different groups of variables is lower, each group of variables represents a basic structure or a common factor. The basic steps of FA can be summarized as follows. Data standardization and applicability tests are performed first, after which the variables are screened and removed based on the relationship between factors and variables. The factors are then explained and named by transforming the coordinate system (factor rotation). Finally, the factors' scores and samples' comprehensive scores are calculated. Supplementary information S2.2 introduces the mathematical model, statistical significance, and basic steps of FA in detail.

2.2.3. Variable weight theory

Compared to constant weight assessment, variable weight assessment has the characteristic that the weight value of the assessment index will change in accordance with the change in the state of the assessment object. It can effectively balance the states of the evaluation index with the change of the decision variable [55]. Variable weight assessment methods include incentive variable weight, punitive variable weight, and local variable weight. The punitive variable weight method and the incentive variable weight method either decrease the corresponding weight of a variable more than a certain standard or increase the variables lower than a certain standard by reducing its weight. The local variable weight method is a synthesis of the first two concepts. Simultaneous incentives and penalties can effectively and reasonably determine the relative importance of indicators with constant weights to assess the assessment object. The principles of punitive variable weight, incentive variable weight, and local variable weight are explained in detail in Supplementary information S2.3.

2.3. Construction and weighting of a comprehensive sponge city assessment system

2.3.1. Data sources

The measures issued by the Ministry of Housing and Urban-Rural Development in China and the acceptance reports of the first and second batches of sponge city pilot cities were taken as the literature basis for statistics of the frequency of indicators. The list of literature data can be seen in Table S1.

2.3.2. Construction of a comprehensive assessment indicator system

Based on the *Measures for Performance Evaluation and Assessment of Sponge City Construction (Trial)* issued by the Ministry of Housing and Urban-Rural Development, the analysis of the complex connotations of the ecological red line, the ecological carrying capacity, and the sustainable development of sponge cities, several “candidate indicators” were selected. These “candidate indicators” fully or partially harmonize with the urban construction model of sponge cities in China. The total frequency of these “candidate indicators” in the acceptance reports of the 27 pilot sponge cities was calculated by frequency statistics. The total frequency of the indicators greater than or equal to 3/4 of the literature data was used as a screening basis of the indicators to determine the sponge city assessment system. Statistics were used to determine the frequency of occurrence of each of the indicators in the literature, as shown in Table S2. Overall, the indicators were screened using literature review and frequency statistics.

2.3.3. Indicator screening

Based on the complex scientific connotations of the ecological carrying capacity, the ecological red line and sustainable development of sponge cities, frequency mining and statistical analysis of relevant literature and normative data were performed.

As shown in Table S2, the two main indicators named “Groundwater level increase” and “Water environment capacity” were selected from the indicator frequency list. Even though the two assessment indicators “Groundwater level increase” and “Water environment capacity” appeared very often in the indicator frequency list, the “Groundwater level increase” was not considered as relevant for sponge cities when urban rainfall was greater than 1000 mm. Approximately one-third of the pilot cities had rainfall greater than 1000 mm, and “Groundwater level increase” was not included in the assessment indicator system of sponge city construction. The indicator “Water environment capacity” is not included in the final performance assessment system due to the difficulties with measuring the water environment capacity in the pilot area. Finally, 30 secondary indicators were determined, of which 23 were quantitative indicators (X1–X23) and 7 qualitative indicators (X24–X30). Since seven qualitative indicators cannot be quantified, they were not included in this study.

Moreover, during the collection of indicator data, it was found that the indicators “elimination rate of black and smelly water (X9)”, “elimination rate of historical water points (X10)”, and “compliance rate of flood dikes (X19)” of all pilot cities were 100%, and the variance of the three indicators was 0. The PCA showed that X9, X10, and X19 do not influence on the comprehensive assessment system of sponge city construction, so these indicators are not considered in this study. Therefore, a total of 20 variables were determined for PCA, namely X1–X8, X11–X18, and X20–X23. Specific preliminary indicators included in the sponge city comprehensive assessment system are shown in Fig. 1.

However, the sponge city acceptance reports of Chizhou, Zhuhai, and the Xixian new area contain too little data on indicators. After removing the data from these three cases, the sample size (27 pilot cities) is still greater than the variable size (20 quantitative indicators). Therefore, three documentary sources were selected as the main source of data samples for the remaining 27 selected pilot cities, including the ‘sponge city acceptance report’, the ‘guideline of planning and design’, and the ‘special planning report’. Furthermore, the ‘urban and rural construction statistical yearbook’, the ‘water resource bulletin’, and the ‘urban landscaping design guideline of sponge city’, were used as secondary data sources to fill the gap of some missing data on indicator variables in the primary data source of the 27 pilot cities.

2.4. *Sponge city construction schemes generation by MATLAB*

MATLAB is a powerful tool and has been used across many fields. In this study, our evaluation system is applicable to most decision-making scenarios in sponge city planning and design as long as the evaluation indicators have been successfully generated. To demonstrate how our evaluation system works, three sponge city construction schemes with the same scales and characteristics as real sponge city construction schemes were generated by MATLAB. That is, a 3 × 20 matrix with two decimal places in the range [0, 100] was randomly generated by the random function 100*rand (3, 20) in MATLAB. The specific version of MATLAB used in this research was MATLAB® R2018a (MathWorks, Inc., USA).

Based on the above-mentioned analysis of the relevant theories and methods, the research framework of this paper can be viewed in Fig. S3 of the Supplemental information.

3. Results

3.1. *Sample matrix*

Based on the collected indicator data, each pilot city was regarded as a sample, and each indicator was regarded as a variable.

Then, a sample matrix $X = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1p} \\ x_{21} & x_{22} & \cdots & x_{2p} \\ \vdots & \vdots & & \vdots \\ x_{n1} & x_{n2} & \cdots & x_{np} \end{bmatrix} x_{ij}$ was established, where x_{ij} denotes the observed value of the jth indicator of the ith pilot city.

Different indicator data have different dimensions. In order to eliminate the influence of different dimensions on the observed values of the indicators, the sample matrix must first be standardized. The zero-center transformation (standardization transformation) was performed on the sample data matrix X to obtain the standardized matrix Z. Equation S(3) in Supplementary information S2.1.2 was used to obtain the correlation coefficient matrix R (Fig. 2) of the standardized matrix Z. Next, the characteristic equation $|R-\lambda I_p| = 0$ of the characteristic equation $R_{p\times p}$ of the correlation coefficient matrix was solved to obtain p eigenvalues λ_1, $\lambda_2, \cdots, \lambda_{p-1}, \lambda_p$ of the matrix R, and $\lambda_1 \geq \lambda_2 \geq \cdots \geq \lambda_{p-1} \geq \lambda_p$, where $\lambda_i = \text{var}(Y_i)$. Finally, the variance contribution rate and the cumulative variance contribution rate corresponding to each eigenvalue were calculated, while the number of principal components was determined based on the principle that the eigenvalue is greater than 1 and that the cumulative variance contribution rate is maximized. After these calculations were completed, the eigenvalues and the cumulative variance contribution rate of the correlation coefficient matrix were obtained (Table 1), while the scree plot is shown in Fig. 2.

From the scree plot, before the x-axis component 9, the scattering curve changes from high to low, first steep, then flat, and finally almost forming a straight line. Combined with Table 1, the correlation coefficient matrix contains eight eigenvalues greater than 1. The cumulative variance contribution rate of the first eight eigenvalues is 79.246%, accounting for 79.246% of the total information. All eigenvalues after the 8th principal component were less than 1, so their contribution to explaining the original variables is negligible. The eight principal components could now be extracted as a new comprehensive indicator. Table 1 shows that the eight principal components contain the most information of all the original indicators. Therefore, these eight principal components were extracted and named Y1, Y2, Y3, Y4, Y5, Y6, Y7, and Y8.

3.2. *Determination of comprehensive assessment system*

3.2.1. *Factor naming*

The eigenvalue criterion and the scree plot test criterion are common methods for determining the number of factors of any assessment system. The scree plot was used to extract eight common factors, named F1–F8.

Factors extracted by PCA often have little difference in the load of each variable, and it is difficult to reasonably explain and name them. To better name the extracted factors, factor rotation is therefore often required [56]. Factor rotation is a method of transforming the coordinate system to change the projected area of

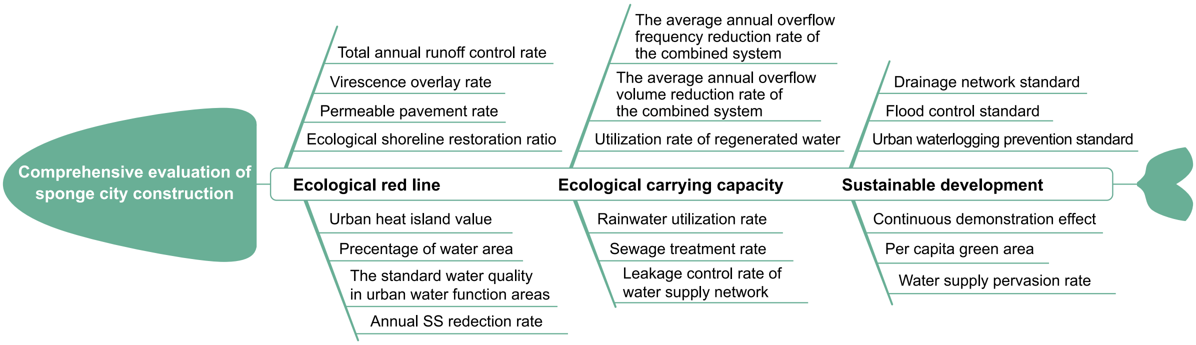

Fig. 1. Preliminary indicator system for comprehensive assessment system of sponge city.

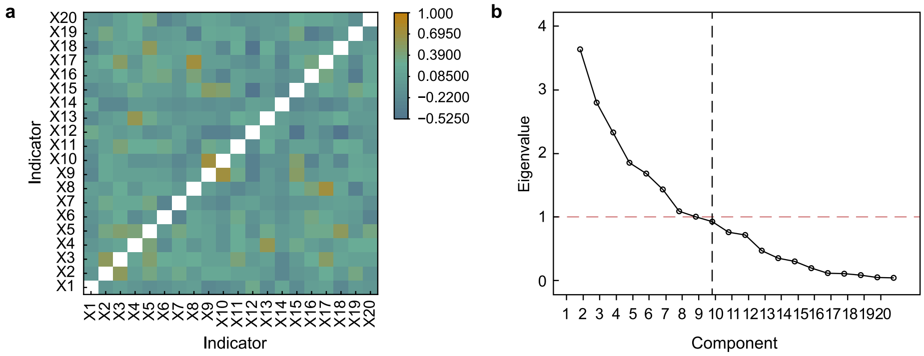

Fig. 2. a, Correlation coefficient matrix R. **b**, Lithotripsy diagram.

Table 1
The eigenvalue and variance contribution rate of the correlation coefficient matrix.

Component	Initial eigenvalue			Extract the sum of squares of the load			Rotating load sum of squares		
	Total	Contribution rate	Cumulative contribution rate %	Total	Contribution rate	Cumulative contribution rate %	Contribution rate	Total	Contribution rate
1	3.639	18.196	18.196	3.639	18.196	18.196	2.575	12.874	12.874
2	2.802	14.011	32.207	2.802	14.011	32.207	2.355	11.774	24.648
3	2.332	11.658	43.865	2.332	11.658	43.865	2.303	11.515	36.163
4	1.856	9.278	53.142	1.856	9.278	53.142	2.069	10.345	46.508
5	1.686	8.432	61.574	1.686	8.432	61.574	2.054	10.272	56.78
6	1.438	7.19	68.764	1.438	7.19	68.764	1.707	8.533	65.313
7	1.089	5.446	74.211	1.089	5.446	74.211	1.596	7.978	73.291
8	1.007	5.035	79.246	1.007	5.035	79.246	1.191	5.955	79.246
9	0.931	4.653	83.898						
10	0.764	3.818	87.716						
11	0.715	3.575	91.292						
12	0.475	2.375	93.667						
13	0.354	1.772	95.439						
14	0.302	1.509	96.948						
15	0.197	0.986	97.934						
16	0.12	0.6	98.534						
17	0.111	0.553	99.087						
18	0.086	0.432	99.519						
19	0.051	0.256	99.775						
20	0.045	0.225	100						

a common factor in the direction of the original variable and then adjusting the correlation coefficient between the common factor and the original variable to facilitate interpretation and naming. The transformation will change the eigenvalues of each common factor but not the commonality of each variable. Thus, the naming of extracted factors is not classified according to physical meaning but according to the calculated loading value. The eigenvalue and variance contribution rate after factor rotation is shown in Table 1.

Based on Tables 1 and 2, the information contained in the first common factor F1 after factor rotation is maximum (12.874%) and has a high load on three indicators, namely “X9: Overflow frequency reduction rate of the combined system”, “X10: Overflow volume reduction rate of the combined system”, and “X15: Drainage pipe network standard”. The absolute values of the correlation coefficients are 0.833, 0.887, and 0.609, respectively. These three indicators reflect the overflow control effect of the combined drainage system after the sponge city construction, so the common factor F1 is named the “Overflow control factor”. F2 contains the second-highest information (11.774%) and has a high load on the indicators “X8: SS total reduction rate”, “X16: Flood control standard”, and “X17: Urban waterlogging prevention standard”. The absolute values of the correlation coefficient are 0.892, 0.462, and 0.849, respectively. All three of these indicators focus on water security, so the common factor F2 was named the “Water security factor”. The information contained in F3 is 11.515% and has a high load on the two indicators “X2: Green coverage rate” and “X3: Permeable pavement rate”. The absolute values of its correlation coefficients are 0.875 and 0.782, respectively, and the common factor F3 is named the “Runoff control factor”. The information contained in F4 is 10.345% and has a high load on the indicators “X5: Urban heat island value”, “X12: Rainfall resource utilization rate”, and “X18: Continuous demonstration effect”. The absolute values of the correlation coefficients are 0.628, 0.707, and 0.868, respectively. As these three indicators focus on the overall impact of sponge city construction, common factor F4 is named the “Display factor”. The information contained in F5 is 10.272% and has a high load on the indicators “X4: Restoration ratio of ecological shoreline” and “X13: Sewage treatment rate”, with correlation coefficients of 0.895 and 0.879, respectively. This common factor is named the “Water ecological factor” because both indicators reflect water ecological issues. The information contained in F6 is 7.978% and has a high load on the indicators “X6: Water area rate”, “X7: Water quality compliance rate of urban water function zone”, and “X11: Sewage regeneration utilization rate”. The absolute values of the correlation coefficients are 0.874, 0.455, and 0.542, respectively. Since these three indicators embody the water environment, this common factor is named the “Water environmental factor”. The information contained in F7 is 10.272% and has a high load on the

Table 2
Factor loading of the first eight common factors.

ID	Indicator name	Common factor							
		F1	F2	F3	F4	F5	F6	F7	F8
X1	Total annual runoff control rate	−0.264	0.141	0.102	−0.297	−0.173	−0.014	0.128	0.694
X2	Virescence overlay rate	0.095	0.033	0.875	−0.095	−0.028	−0.007	0.129	−0.134
X3	Permeable pavement rate	0.093	0.288	0.782	0.108	0.125	0.235	−0.072	0.133
X4	Ecological shoreline restoration ratio	0.061	0.002	0.1	0.091	0.895	−0.168	0.192	0.157
X5	Urban heat island value	−0.001	0.134	0.46	0.628	0.376	−0.134	−0.273	0.117
X6	Percentage of water area	−0.009	0.208	0.04	0.029	−0.051	0.874	0.001	−0.059
X7	The standard water quality in urban water function areas	−0.383	0.007	0.494	0.195	0.052	−0.455	0.226	−0.143
X8	Annual SS reduction rate	−0.045	0.892	−0.015	0.054	−0.011	0.048	−0.099	−0.028
X9	The average annual overflow frequency reduction rate of the combined system	0.833	−0.004	0.124	0.11	0.04	0.092	0.081	−0.13
X10	The average annual overflow volume reduction rate of the combined system	0.887	−0.069	0.099	−0.15	−0.122	−0.01	0.079	−0.135
X11	Utilization rate of regenerated water	0.213	−0.3	0.337	0.338	0.282	0.542	0.036	0.049
X12	Rainwater utilization rate	−0.4	−0.148	0.176	−0.707	0.273	−0.093	−0.248	0.118
X13	Sewage treatment rate	−0.093	0.002	−0.015	0.031	0.879	0.155	−0.07	−0.23
X14	Leakage control rate of water supply network	−0.132	−0.318	−0.317	−0.046	0.062	0.001	−0.036	0.491
X15	Drainage network standard	0.609	0.37	−0.155	0.216	0.156	−0.081	0.527	0.017
X16	Flood control standard	−0.11	0.462	0.133	0.155	0.084	0.315	−0.473	0.205
X17	Urban waterlogging prevention standard	0.095	0.849	0.294	0.082	0.004	0.047	−0.107	−0.011
X18	Continuous demonstration effect	−0.137	0.073	0.036	0.868	0.138	0.058	−0.014	−0.183
X19	Per capita green area	0.171	−0.274	0.217	0.04	0.132	0.056	0.795	0.145
X20	Water supply pervasion rate	0.427	0.154	−0.024	0.18	0.214	−0.427	−0.399	0.41

indicator “X19: Per capita Park green area”. The absolute value of the correlation coefficient is 0.795, so this common factor is named the “Ecological greening factor”. The information contained in F8 is 5.955% and has a high load on the three indicators “X1: Annual runoff total control rate”, “X14: Water supply network leakage control rate”, and “X20: Water supply popularization rate”, with the absolute correlation coefficients values of 0.694, 0.491, and 0.41, respectively. These three indicators together explain water resources, so this common factor is named the “Water resource common factor”. Based on the results, a total of eight common factors were obtained, including the Overflow control factor, the Water security factor, the Runoff control factor, the Display factor, the Water ecological factor, the Water environmental factor, the Ecological greening factor, and the Water resource common factor.

Based on the factor analysis results and the preliminary indicator assessment system determined in Section 3, the SCC-UEFAS was obtained and shown in Fig. 3.

3.3. Determination of indicators’ weights

3.3.1. Weights of secondary indicators

Table 1 shows the corresponding eigenvalue of each common factor. The percentage of each common factor in the sum of the corresponding eigenvalue of the extracted common factor (variance contribution rate) was used as the weight of the secondary indicators. For example, the contribution rates of F1, F2, and F3 are 18.196%, 14.011%, and 11.658%, respectively. The equation is as follows:

$$\alpha_{\mathrm{i}} = \lambda_i \Big/ \sum\nolimits_{i=1}^{p} \lambda_i \tag{1}$$

where α_{i} denotes the weight of the common factor i, λ_i denotes the eigenvalue corresponding to the common factor, and p denotes the number of extracted common factors. The weight and percentage of each secondary indicator are shown in Table 3. Taking the “Overflow control factor” as an example, the eigenvalue of the total runoff control factor is 3.639 after the factor rotation (Table 1). According to the calculation principles, the number of extracted common factors is eight. Thus, the ratio of the eigenvalues of the total runoff control factor to the sum of the eigenvalues of the extracted eight common factors is as follows:

$3.639 / (3.639 + 2.802 + 2.332 + 1.856 + 1.686 + 1.438 + 1.089 + 1.007) = 0.2296$.

Therefore, the “Overflow control factor” has the greatest weight (23%) and the greatest impact on the Sponge City construction.

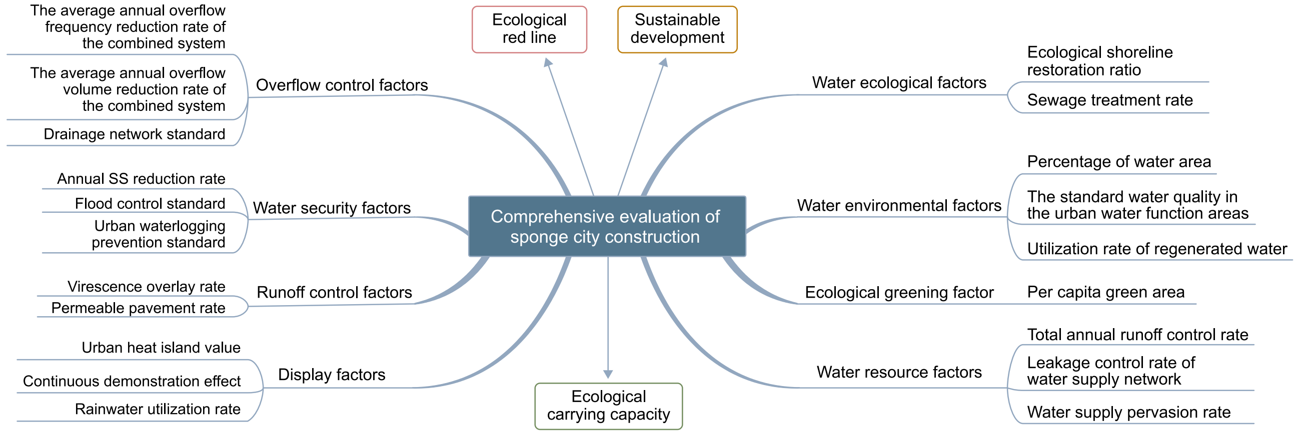

Fig. 3. The sponge city comprehensive assessment system.

Table 3
The weight and percentage of each secondary indicator.

Secondary indicator	Weight	Weight percentage (%)
F1 Overflow control factor	0.2296	23
F2 Water security factor	0.1768	18
F3 Runoff control factors	0.1471	15
F4 Display factor	0.1171	12
F5 Water ecological factor	0.1064	10
F6 Water environmental factor	0.0907	9
F7 Ecological greening factor	0.0687	7
F8 Water resource factor	0.0635	6

Following the same calculation principles, the weight of the "Water security factor", "Runoff control factor" and "Water resource factor" is 18%, 12%, and 6%, respectively.

3.3.2. Weights of tertiary indicators

Determining the weights of the tertiary indicators mainly depend on the strength of the correlation between the common factors and the tertiary indicators. The weights are calculated as follows.

(1) Obtaining the original data relationship between the common factors and the tertiary indicators under common factor indicators and performing PCA on the tertiary indicators under each common factor.
(2) Establishing the contribution matrix using the variance contribution rate corresponding to the first *m* principal components extracted after PCA, and denoted as A. At the same time, establishing a new contribution matrix using the load of all the tertiary indicators in the factor load matrix that correspond to *m* principal components, and denoted as B.
(3) The contribution matrix C of each tertiary indicator to the corresponding common factor is calculated by equation $C = A \times B$.
(4) Finally, the weight of each tertiary indicator can be obtained by standardizing the weight obtained by taking each common factor as a unit.

As shown in Fig. 4a, the annual average overflow frequency reduction rate of the combined system, the annual average overflow volume reduction rate of the combined system, and the urban waterlogging prevention standard account for a maximum of 8%, indicating that these three indicators play an important role in the sponge city construction. They are followed by the drainage pipe network standard, the flood control standard, the green coverage rate, the permeable pavement rate, and the per capita park green area (7%). The water supply popularization rate has a minimum value (1%).

3.3.3. Assessment indicator system and quantitative indicator weight of sponge city construction

The assessment indicator system and the quantitative indicator weight at all levels of sponge city construction were obtained by normalizing the contribution weight of each tertiary indicator to the secondary indicator (see Fig. 4b).

4. Discussion

4.1. Data simulation of construction scheme

4.1.1. Source of simulated data

The evaluation methods proposed in this study established a scientific index system and a data processing procedure. This evaluation system is applicable to the decision-making scenario where a "best option" is required from various feasible plans to guide sponge city planning and design. Three plans of sponge city construction were generated by a random generation method to demonstrate how to operate our evaluation methods. In this study, MATLAB is used to build a matrix (3×20) with the characteristics and scale. The data obtained after the simulation are shown in Table S3. To meet the need for subsequent statistical scoring results, the indicator values of the three schemes are normalized, and the normalized indicator values of each scheme are shown in Fig. 5.

4.2. Constant weight assessment and results

The comprehensive sponge city construction assessment system (as described in Supplementary information S4.2 and the constant weight assessment equation were used to score and calculate the secondary and tertiary quantitative assessment indicators for the three construction schemes. Among the three schemes, Scheme 3 had the highest score of 0.638, followed by Scheme 2 with 0.575 and Scheme 1 with 0.538. As can be seen in Fig. 5, the value of the

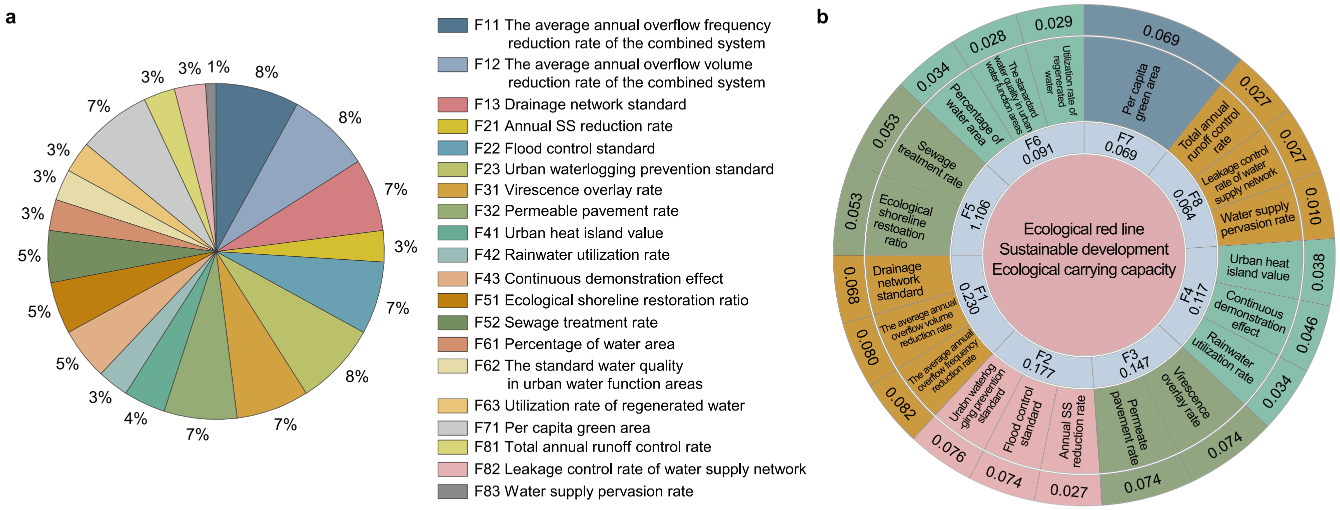

Fig. 4. **a**, The proportion of tertiary indicators' weight. **b**, Sponge city construction evaluation indicator system and summary of quantitative indicators' weights at all levels

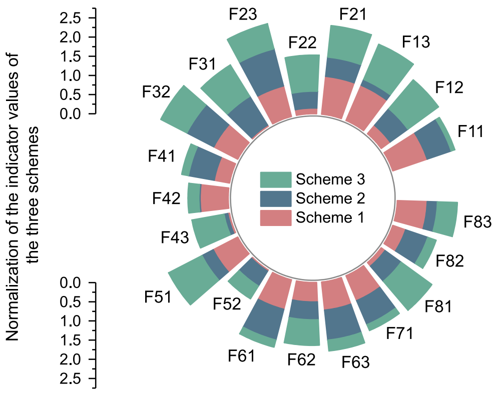

Fig. 5. Normalization of the indicator values of the three schemes.

tertiary indicator "The average annual overflow frequency reduction of the combined system" in Scheme 3 was 0.1005, which was much smaller than that in Scheme 1 (0.9466) and Scheme 2 (0.6591). However, the score of Scheme 3 in the corresponding secondary indicator "Overflow control factor" was higher than in Scheme 2 and slightly lower than in Scheme 1, while the comprehensive score of Scheme 3 was higher than in Schemes 1 and 2. The tertiary indicator "F11: The actual improvement rate of the average annual overflow frequency reduction rate of the combined system" in Scheme 3 was much smaller than in other schemes, meaning that this scheme had obvious shortcomings. No matter how high the scoring result of Scheme 3 is, it cannot be the final construction scheme. Research shows that the main reason for this phenomenon is that the weight of the "Overflow control factor" in Scheme 3 was too high to constrain the "Failure" indicators. Therefore, the introduction of a variable weight function was used to perform a variable weight assessment for the sponge city construction scheme.

4.3. Variable weight assessment results

4.3.1. Assessment results of tertiary indicators

Based on Section 2.2.3, the variable weight theory and the axiomatic definition of the state variable weight vector, a punitive state variable weight vector was constructed for indicators at all levels in the comprehensive sponge city construction assessment system.

Fig. 6a shows the assessment results after introducing the variable weight vectors into the tertiary assessment indicators in the sponge city construction assessment system. To evaluate the performance of each secondary index more intuitively in the three schemes, we performed data preprocessing and found that the preprocessed data had a normal distribution (Fig. S4). The *p*-value is 0.139 (Fig. S4) and greater than 0.05, indicating that the statistical analysis is reasonable. In addition, the mean value is 0.06, and the variance is 0.03. Therefore, according to the normal distribution, we can set a value greater than 0.09 (mean + variance) as an excellent level, less than 0.03 (mean − variance) as a denied level, and a value between 0.03 and 0.09 as a failure level. For Scheme 1, the assessment scores of "F5: Water ecological factor", "F7: Ecological greening factor" and "F8: Water resource factor" were lower than the denial level of 0.03. The assessment score of "F1: Overflow control factor" was at an excellent level with a value of 0.0932. Even though the scores of "F1: Overflow control factor" and "F2: Water security factor" reached 0.09 (the excellent level) in Scheme 2, the score of "F8: Water resource factor" was only 0.0286, which was at the denied level. For Scheme 3, the indicators "Overflow control factor", "Water security factor", and "Runoff control factor" were at an excellent level. However, the "Ecological greening factor" was at the denied level."

4.3.2. Assessment results of secondary indicators

To better balance the impact of the assessment score of the secondary indicators on the sponge city construction assessment system, the local variable weight vector was introduced. The local state variable weight vector is constructed based on the axiomatic definition of the local variable weight (described in detail in Supplementary information S4.2).

Fig. 6b shows that the weights of the "F1: Overflow control factor" and the "F2; Water security factor" in Scheme 1 are significantly lower than those with constant weight in the other two schemes. This is because these two indicators in this scheme perform poorly. Although the weights of the four indicators, the "F4: Display factor", the "F5: Water ecological factor", the "F7: Ecological greening factor", and the "F8: Water resource factor" in Scheme 1 were significantly higher than the constant weights when compared to Schemes 2 and 3, the advantages of these four indicators in Scheme 1 were not obvious. These two reasons led to the lowest final assessment score of Scheme 1.

In Scheme 2, the weights of the "F1: Overflow control factor", "F2: Water security factor", and "F3; Runoff control factor" were

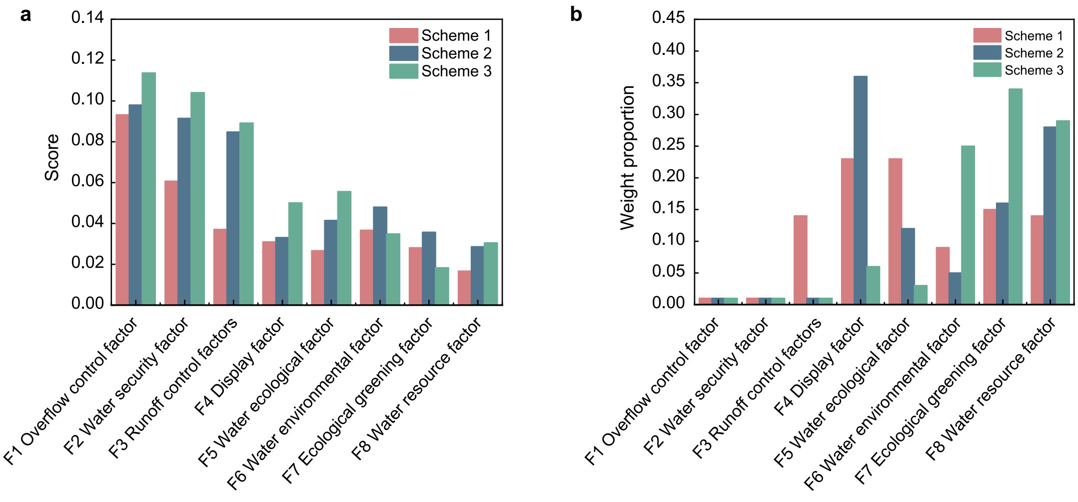

Fig. 6. **a**, The evaluation score of secondary indicators. **b**, The weight of each secondary indicator in three schemes

significantly lower than the constant weights in Scheme 2. However, they showed an absolute advantage in the “F4: Display factors” over the other two schemes and were only slightly worse than in Scheme 3 for the “F8: Water resource factor”. These two reasons mean that Scheme 2 ranked first among the schemes.

In Scheme 3, the weights of the “F1: Overflow control factor”, “F2: Water security factor”, and “F3: Runoff control factor” were significantly lower than the constant weights but had absolute advantages in the “F6: Water environmental factor” and the “F7: Ecological greening factor”. Due to that, Scheme 3 ranked second in the final ranking of all schemes.

Based on the above discussion, the variable weight assessment method can reasonably change the weight values of the indicators according to different assessment objects and then change the assessment results to perform a scientific and reasonable assessment. The disadvantages and advantages of each scheme can also be identified during the process of variable weight determination. By absorbing the advantages and removing the disadvantages of each scheme, a more reasonable and optimized construction scheme can be developed.

4.4. Analysis of constant weight assessment and variable weight assessment

The weights of the indicators in the three schemes have been scientifically and reasonably changed by the variable weight method, which accordingly changes the assessment scores and ranking of the three schemes. Under the constant weight assessment, Scheme 3 is in first place with 0.638, and Scheme 1 is in third place with 0.538. Under the variable weight assessment, Scheme 2 ranked first with 0.0355, and Scheme 1 ranked third with 0.0296. During variable weight assessment, the disadvantageous indicators are punished, and the advantageous indicators are motivated by changing the weights of the assessment indicators at all levels for the indicators at the denial level and the excellent level. This is done by increasing the relative advantages of some indicators to achieve incentives and the relative disadvantages of some indicators for achieving punishment. Since both punishment and incentives are used in the variable weight method, Scheme 2 overtakes Scheme 3 in the variable weight assessment and becomes the final winner after applying the variable weight method.

5. Conclusions

This study combined indicator data from the acceptance reports of 27 pilot sponge cities to develop the SCC-UEFAS using a systematic literature review combined with data frequency mining technology. Factor extraction, factor naming, and indicator weight determinations were also performed at all levels according to correlation coefficients. Constant weight and variable weight methods were used to evaluate the three randomly generated construction schemes. More reasonable evaluation results were obtained with the variable weight method as it can punish the disadvantageous indicators and motivate the advantageous indicators according to regional and functional differences of each sponge city construction. This study provides reasonable analysis and a decision-making mechanism to guide and standardize the practice of comprehensive construction of sponge cities in the future.

Author contributions

Zi-Tong Zhao: Methodology, Formal analysis, Investigation, Methodology, Writing-review & editing. Hou-Ming Cheng: Methodology, Formal analysis, Writing-review & editing. Sheng Wang: Methodology, Formal analysis, Methodology. Hai-Yan Liu: Methodology, Formal analysis, Methodology; Zi-Ming Song: Methodology, Formal analysis, Methodology; Jun-Hui Zhou: Methodology, Formal analysis, Investigation, Methodology. Shan-Shan Yang: Conceptualization, Methodology, Supervision, Validation, Writing-original draft, Review & editing, Funding acquisition. Ji-Wei Pang: Conceptualization, Methodology, Supervision, Validation, Writing-review & editing; Shun-Wen Bai: Conceptualization, Methodology, Supervision, Validation, Writing-review & editing; Jie Ding: Conceptualization-experimental design, Funding acquisition. Nan-Qi Ren: Conceptualization-experimental design. All authors contributed to manuscript reviewing & editing.

Declaration of competing interest

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

Acknowledgements

The authors gratefully acknowledge financial support from the National Key Research and Development Program of China (Grant No. 2019YFD1100204); The National Natural Science Foundation of China (52170073); The State Key Laboratory of Urban Water Resource and Environment, Harbin Institute of Technology (No. 2021TS03). We gratefully thank the contribution of the algorithm model and tool support by the artificial intelligence department of CECEP Talroad Technology Co., Ltd. We gratefully acknowledge the support from the Heilongjiang Province Touyan Team.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ese.2022.100188.

References

[1] Y. Sun, L. Deng, S.-Y. Pan, P.-C. Chiang, S.S. Sable, K.J. Shah, Integration of green and gray infrastructures for sponge city: water and energy nexus, Water-Energy Nexus 3 (2020) 29–40.

[2] J. Wang, J. Liu, H. Wang, W. Shao, C. Mei, X. Ding, Matching analysis of investment structure and urban inundation control function of sponge cities in China, J. Clean. Prod. 266 (2020), 121850.

[3] C. Wang, J. Hou, D. Miller, I. Brown, Y. Jiang, Flood risk management in sponge cities: the role of integrated simulation and 3D visualization, Int. J. Disaster Risk Reduc. 39 (2019), 101139.

[4] E. Palazzo, From water sensitive to floodable: defining adaptive urban design for water resilient cities, J. Urban Des. 24 (1) (2019) 137–157.

[5] J. Xia, Y. Zhang, L. Xiong, S. He, L. Wang, Z. Yu, Opportunities and challenges of the Sponge City construction related to urban water issues in China, Sci. China Earth Sci. 60 (4) (2017) 652–658.

[6] X.-J. Qiao, K.-H. Liao, T.B. Randrup, Sustainable stormwater management: a qualitative case study of the Sponge Cities initiative in China, Sustain. Cities Soc. 53 (2020), 101963.

[7] H. Liu, Y. Jia, C. Niu, Sponge city” concept helps solve China's urban water problems, Environ. Earth Sci. 76 (14) (2017) 473.

[8] S. Shadman, P. Ahanaf Khalid, M.M. Hanafiah, A.K. Koyande, M.A. Islam, S.A. Bhuiyan, S.W. Kok, P.-L. Show, The carbon sequestration potential of urban public parks of densely populated cities to improve environmental sustainability, Sust. Energy Technol. 52 (2022), 102064.

[9] M.M.A. Allouzi, D.Y.Y. Tang, K.W. Chew, J. Rinklebe, N. Bolan, S.M.A. Allouzi, P.L. Show, Micro (nano) plastic pollution: the ecological influence on soil-plant system and human health, Sci. Total Environ. 788 (2021) 147815.

[10] Y. Jiang, C. Zevenbergen, D. Fu, Understanding the challenges for the governance of China's “sponge cities” initiative to sustainably manage urban stormwater and flooding, Nat. Hazards 89 (1) (2017) 521–529.

[11] S. Feng, T. Yamamoto, Preliminary research on sponge city concept for urban flood reduction: a case study on ten sponge city pilot projects in Shanghai, China, Disaster Prev. Manag. 29 (6) (2020) 961–985.

[12] S. Hawken, S.M.E. Sepasgozar, V. Prodanovic, J. Jing, A. Bakelmun, B. Avazpour, S. Che, K. Zhang, What makes a successful Sponge City project? Expert perceptions of critical factors in integrated urban water management in the Asia-Pacific, Sustain. Cities Soc. 75 (2021), 103317.

[13] D. La Rosa, V. Pappalardo, Planning for spatial equity - a performance based approach for sustainable urban drainage systems, Sustain. Cities Soc. 53 (2020), 101885.

[14] A. Aslam, M. Ibrahim, A. Mahmood, M. Mubashir, H.F.K. Sipra, I. Shahid, S. Ramzan, M.T. Latif, M.Y. Tahir, P.L. Show, Mitigation of particulate matters and integrated approach for carbon monoxide remediation in an urban environment, J. Environ. Chem. Eng. 9 (4) (2021), 105546.

[15] C. Hepburn, Y. Qi, N. Stern, B. Ward, C. Xie, D. Zenghelis, Towards carbon neutrality and China's 14th Five-Year Plan: clean energy transition, sustainable urban development, and investment priorities, Environ. Sci. Ecotechnol. 8 (2021), 100130.

[16] L. Leng, X. Mao, H. Jia, T. Xu, A.S. Chen, D. Yin, G. Fu, Performance assessment of coupled green-grey-blue systems for Sponge City construction, Sci. Total Environ. 728 (2020), 138608.

[17] F. Jabeen, M. Adrees, M. Ibrahim, A. Mahmood, S. Khalid, H.F.K. Sipra, A. Bokhari, M. Mubashir, K.S. Khoo, P.L. Show, Trash to energy: a measure for the energy potential of combustible content of domestic solid waste generated from an industrialized city of Pakistan, J. Taiwan Inst Chem. E (2022), 104223.

[18] M. Heckert, C.D. Rosan, Developing a green infrastructure equity index to promote equity planning, Urban For Urban Gree 19 (2016) 263–270.

[19] L. She, M. Wei, X.-y. You, Multi-objective layout optimization for sponge city by annealing algorithm and its environmental benefits analysis, Sustain. Cities Soc. 66 (2021), 102706.

[20] Y. Wang, Z. Liu, G. Wang, W. Xue, Cellular automata based framework for evaluating mitigation strategies of sponge city, Sci. Total Environ. 796 (2021), 148991.

[21] C. Liang, X. Zhang, J. Xu, G. Pan, Y. Wang, An integrated framework to select resilient and sustainable sponge city design schemes for robust decision making, Ecol. Indicat. 119 (2020), 106810.

[22] Y. Bai, Y. Li, R. Zhang, N. Zhao, X. Zeng, Comprehensive performance evaluation system based on environmental and economic benefits for optimal allocation of LID facilities, Water Ski. 11 (2) (2019).

[23] C. Song, Application of nature-based measures in China's sponge city initiative: current trends and perspectives, Nat. Based Solut. 2 (2022), 100010.

[24] T. Cowton, D. Slater, A. Sole, D. Goldberg, P. Nienow, Modeling the impact of glacial runoff on fjord circulation and submarine melt rate using a new subgrid-scale parameterization for glacial plumes, J. Geophys. Res. Oceans 120 (2) (2015) 796–812.

[25] S.-S. Yang, J.-W. Pang, W.-Q. Guo, X.-Y. Yang, Z.-Y. Wu, N.-Q. Ren, Z.-Q. Zhao, Biological phosphorus removal in an extended ASM2 model: roles of extracellular polymeric substances and kinetic modeling, Bioresour. Technol. 232 (2017) 412–416.

[26] Y.-H. Tsai, Y.-H. Huang, S.-Y. Lin, B. Wang, 2288 - intercity transportation's role in affecting distal area's urbanization/green coverage – a high-speed rail's case in urban land teleconnections, J. Transport Health 9 (2018) S7–S8.

[27] R.J. Winston, A.M. Al-Rubaei, G.T. Blecken, M. Viklander, W.F. Hunt, Maintenance measures for preservation and recovery of permeable pavement surface infiltration rate – the effects of street sweeping, vacuum cleaning, high pressure washing, and milling, J. Environ. Manag. 169 (2016) 132–144.

[28] B. Luan, R. Yin, P. Xu, X. Wang, X. Yang, L. Zhang, X. Tang, Evaluating Green Stormwater Infrastructure strategies efficiencies in a rapidly urbanizing catchment using SWMM-based TOPSIS, J. Clean. Prod. 223 (2019) 680–691.

[29] L. Zhang, H. Fukuda, Z. Liu, The value of cool roof as a strategy to mitigate urban heat island effect: a contingent valuation approach, J. Clean. Prod. 228 (2019) 770–777.

[30] T. Meakhail, I. Teaima, Experimental and numerical studies of the effect of area ratio and driving pressure on the performance of water and slurry jet pumps, Proc. IME C J. Mech. Eng. Sci. 226 (9) (2011) 2250–2266.

[31] Z. Xie, China's historical evolution of environmental protection along with the forty years' reform and opening-up, Environ. Sci. Ecotechnol. 1 (2020), 100001.

[32] G. Ma, F. Peng, W. Yang, G. Yan, S. Gao, X. Zhou, J. Qi, D. Cao, Y. Zhao, W. Pan, H. Jiang, H. Jing, G. Dong, M. Gao, J. Zhou, F. Yu, J. Wang, The valuation of China's environmental degradation from 2004 to 2017, Environ. Sci. Ecotechnol. 1 (2020), 100016.

[33] Q. Liu, Z. Gui, S. Xiong, M. Zhan, A principal component analysis dominance mechanism based many-objective scheduling optimization, Appl. Soft Comput. 113 (2021), 107931.

[34] C. Xu, X. Shi, M. Jia, Y. Han, R. Zhang, S. Ahmad, H. Jia, China Sponge City database development and urban runoff source control facility configuration comparison between China and the US, J. Environ. Manag. 304 (2022) 114241.

[35] S. Wang, E. Palazzo, Sponge City and social equity: impact assessment of urban stormwater management in Baicheng City, China, Urban Clim. 37 (2021), 100829.

[36] D. Yin, Y. Chen, H. Jia, Q. Wang, Z. Chen, C. Xu, Q. Li, W. Wang, Y. Yang, G. Fu, A.S. Chen, Sponge city practice in China: a review of construction, assessment, operational and maintenance, J. Clean. Prod. 280 (2021), 124963.

[37] Y. Wang, J. Cai, J. Zuo, K. Bartsch, M. Huang, Conflict or consensus? Stakeholders' willingness to participate in China's Sponge City program, Sci. Total Environ. 769 (2021), 145250.

[38] J.R. Wolch, J. Byrne, J.P. Newell, Urban green space, public health, and environmental justice: the challenge of making cities 'just green enough, Landsc. Urban Plann. 125 (2014) 234–244.

[39] T.H.F. Wong, B.C. Rogers, R.R. Brown, Transforming cities through water-sensitive principles and practices, One Earth 3 (4) (2020) 436–447.

[40] T. Hu, J. Peng, Y. Liu, J. Wu, W. Li, B. Zhou, Evidence of green space sparing to ecosystem service improvement in urban regions: a case study of China's Ecological Red Line policy, J. Clean. Prod. 251 (2020), 119678.

[41] W. Wang, C. Feng, F. Liu, J. Li, Biodiversity conservation in China: a review of recent studies and practices, Environ. Sci. Ecotechnol. 2 (2020), 100025.

[42] C.J. Herringshaw, J.R. Thompson, T.W. Stewart, Learning about restoration of urban ecosystems: a case study integrating public participation, stormwater management, and ecological research, Urban Ecosyst. 13 (4) (2010) 535–562.

[43] Y. Wang, X. Liu, M. Huang, J. Zuo, R. Rameezdeen, Received vs. given: willingness to pay for sponge city program from a perceived value perspective, J. Clean. Prod. 256 (2020), 120479.

[44] F. Yang, B. Sheng, Z. Wang, Y. Xue, J. Liu, T. Ma, R. Bush, H. Kušić, Y. Zhou, Performance of UV/acetylacetone process for saline dye wastewater treatment: kinetics and mechanism, J. Hazard Mater. 406 (2021), 124774.

[45] N. Zafra-Calvo, U. Pascual, D. Brockington, B. Coolsaet, J.A. Cortes-Vazquez, N. Gross-Camp, I. Palomo, N.D. Burgess, Towards an indicator system to assess equitable management in protected areas, Biol. Conserv. 211 (2017) 134–141.

[46] Z. Zhu, J. Ren, X. Liu, Green infrastructure provision for environmental justice: application of the equity index in Guangzhou, China, Urban For Urban Gree 46 (2019), 126443.

[47] J. Liu, X. Gong, L. Li, F. Chen, J. Zhang, Innovative design and construction of the sponge city facilities in the chaotou park, talent island, Jiangmen, China, Sustain. Cities Soc. 70 (2021), 102906.

[48] Y. Wang, M. Sun, B. Song, Public perceptions of and willingness to pay for sponge city initiatives in China, Resour. Conserv. Recycl. 122 (2017) 11–20.

[49] Y. Li, H.X. Li, J. Huang, C. Liu, An approximation method for evaluating flash flooding mitigation of sponge city strategies – a case study of Central Geelong, J. Clean. Prod. 257 (2020), 120525.

[50] C. Jiang, J. Li, Y. Hu, Y. Yao, H. Li, Construction of water-soil-plant system for rainfall vertical connection in the concept of sponge city: a review, J. Hydrol. 605 (2022), 127327.

[51] T. Cheng, B. Huang, Z. Yang, J. Qiu, B. Zhao, Z. Xu, On the effects of flood reduction for green and grey sponge city measures and their synergistic relationship—case study in Jinan sponge city pilot area, Urban Clim. 42 (2022), 101058.

[52] F.K.S. Chan, J.A. Griffiths, D. Higgitt, S. Xu, F. Zhu, Y.-T. Tang, Y. Xu, C.R. Thorne, Sponge City" in China—a breakthrough of planning and flood risk management in the urban context, Land Use Pol. 76 (2018) 772–778.

[53] T.T. Nguyen, H.H. Ngo, W. Guo, X.C. Wang, A new model framework for sponge city implementation: emerging challenges and future developments, J. Environ. Manag. 253 (2020) 109689.

[54] F. Wu, Z. Zhuang, H.-L. Liu, Y.-C. Shiau, Evaluation of water resources carrying capacity using principal component analysis: an empirical study in Huai'an, Jiangsu, China, Water Ski. 13 (18) (2021).

[55] S. Liu, W. Li, Indicators sensitivity analysis for environmental engineering geological patterns caused by underground coal mining with integrating variable weight theory and improved matter-element extension model, Sci. Total Environ. 686 (2019) 606–618.

[56] X. Wang, L. McCarty Perry, J. Liu, N.-Q. Ren, D.-J. Lee, H.-Q. Yu, Y. Qian, J. Qu, Probabilistic evaluation of integrating resource recovery into wastewater treatment to improve environmental sustainability, P Natl. A Sci. India B 112 (5) (2015) 1630–1635.