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Research Article

A New Multicriteria Decision-Making Method for the Selection of Sponge City Schemes with Shapley–Choquet Aggregation Operators

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The construction of sponge cities is of great strategic significance to solving the urban water resource problem in the future. According to the policy guidance of sponge city construction, the evaluation index system of sponge city construction projects is constructed. In order to overcome the interference caused by the interaction between indexes, a nonadditive measure and Shapley function are combined to determine the weights of attribute indexes, and the generalized Shapley interval-valued intuitionistic uncertain linguistic Choquet averaging (GS-IVIULCA) operator is used to calculate the comprehensive evaluation value of the schemes. On this basis, a new evaluation method of sponge city construction project selection under an uncertain information environment is presented and empirically evaluated. The results show that the index weight of rainwater collection and utilization is the largest, indicating that decision makers pay more attention to the ecological and environmental benefits of this item in the sponge city construction process.

1. Introduction

At present, China is facing increasingly serious water resource problems. The destruction of the habitat of aquatic organisms, water shortages, and pollution coexist, among which the urban water resource problem is particularly prominent. First, urban water resources are being depleted, and second, the urban water logging problem is very serious. From 2018 to 2019, urban water logging occurred in 62 percent of Chinese cities, with 137 cities suffering more than three floods [1]. In the face of such a severe water resource situation, it is urgent that a scientific and reasonable solution to the urban water resource problem using the technology route be found. In February 2018, the urban construction department of the Ministry of Housing and Urban-Rural Development emphasized the following: they "urge all localities to accelerate the diversion of rain and sewage, improve the level of urban drainage and water logging prevention, vigorously promote the development and construction mode with low impact, and accelerate the research on policies and measures for the construction of sponge cities" [2]. In November of the same year, a technical guide for sponge city construction was issued [3]. From the end of 2018 to the beginning of 2019, the pilot construction of sponge cities was fully implemented, and the first batch of 16 pilot cities was approved [4]. These "sponge city" construction projects have become an important technical path to solve the urban water resource problem in China.

The concept of a "sponge city" comes from the characteristic of a "sponge city" used in industry and academia to describe a city's adsorption function. For example, Budge, an Australian demographer, used a sponge to describe the adsorption of cities regarding their population [5]. In recent years, more scholars have used sponges to describe the water storage and flood discharge capacity of cities or land. At present, most of the research on "sponge cities" proposes corresponding planning and design plans from the perspective of urban planning [6–8]. In contrast, research on the corresponding construction project plan decisions is still lacking. It is well known that a sponge city construction project is a typical multiattribute decision-making problem since it needs to take into account many topographical, architectural, and other factors such as hardening green areas [9–12]. In addition, with the development of society and the economy, many decision-making problems have become increasingly more complicated. It is no longer possible to ensure the optimality of the decisions made using an individual's knowledge structure and ability alone. One of the most effective ways to overcome this problem is to form a research team and involve many experts in the decision-making process. To address this situation, the fuzzy measure was proposed by Sugeno [13]. At present, many scholars have conducted in-depth research on the theory and method of multiattribute group decision making based on fuzzy measures [14–16]. This research provides a solid theoretical basis for the decision making of a multiattribute scheme based on interaction [15, 17–19]. Therefore, the adoption of the multiattribute group decision-making method in the decision-making process of sponge city construction projects will undoubtedly make the decision-making process more scientific and convincing.

At present, the traditional multiattribute decision-making method that has been developed is restricted due to the assumption of mutual independence regarding the importance of the evaluation indexes, which corresponds to an additive measure in essence [20–22]. However, the additive measure only gives the weights of the evaluation indexes without considering the importance of combinations of them [23–27]. However, in real life, the assumption that the importance of evaluation indicators is independent is not always valid. Due to the interaction between indicators, the same indicator combined with different indicators will have different effects [28–36]. Therefore, a new method considering the interaction between different indexes must be found to solve the decision problem. In order to cope with the disadvantages of traditional multiattribute group decision making, the expert scoring or fuzzy evaluation method is often used to evaluate indicators, but both cause considerable information loss [37–41]. The traditional multigeneric group method is based on the independence of the indexes and weights [42–45]. This paper adopts a new multiattribute group decision-making theory and method. In order to reduce the lack of information and reflect people's hesitation in making decisions, interval uncertain language is used for the evaluation. By using the theory and method of multiattribute group decision making, an expert gives a qualitative judgment of a scheme attribute's value by using interval uncertain language. Considering the interaction between attribute indexes, a nonadditive measure and the GS-IVIULCA operator are used to calculate the comprehensive evaluation value of the scheme. The weights of attribute indexes are determined by the information entropy and Shapley function, which overcome the interference of the interaction between indexes in traditional multiattribute group decision making. When the weights of experts and attributes are uncertain, the optimal fuzzy measure model of the expert set and attribute set is constructed. Based on this, a new evaluation method of sponge city construction project selection under an uncertain information environment is presented.

There are three innovative contributions of this research. First, a fuzzy measure and Shapley function are introduced to calculate the combined weights of the indexes to solve the problem that the interaction between indexes disturbs the weights. Second, the IG-IVIULCA operator is used to obtain the comprehensive attribute value of the scheme, which can reflect the interaction between the attribute weights and the indexes. Third, based on the information entropy and multiattribute group decision theory, the optimal weights are obtained when only part of the attribute weight information and expert information is known by establishing the optimization model on the fuzzy measure.

The remainder of this paper is organized as follows. Section 2 introduces some basic concepts and presents the improved method. In Section 3, according to the technical guide of sponge city construction in China, the decision-making index system (attribute set) of the sponge city construction project scheme is established. Section 4 gives the empirical evaluation process and the results of the robustness test. Section 5 presents the analysis and discussion. Section 6 presents the conclusions.

2. Methodology

2.1. Interval-Valued Intuitionistic Uncertain Linguistic Set. The linguistic method is a technique for approximating qualitative preferences with linguistic variables. $S = \{si \mid i = 1, 2, \ldots, t\}$ is a language item set with an odd number of items. An example of S can be expressed as follows: $S = \{$s1: very bad, s2: bad, s3: relatively bad, s4: average, s5: relatively good, s6: good, s7: very good$\}$.

Any s_i represents a possible language variable, which should satisfy the following properties:

(1) Order: if $i > j$, then si > sj.

(2) Taking large operator: if si ≥ sj, then max(si, sj) = si.

(3) Taking the small operator: if si ≤ sj, then min(si, sj) = si.

In order to maintain the continuity of the given language information, Xu extended the discrete language item set S to the continuous language item set $\overline{S} = \{s_a | s_1 \leq s_a \leq s_t, a \in [1, t]\}$ [46]. The elements in $\overline{S}$ also satisfy the above properties.

Definition 1. (see [47]). If $\tilde{s} = [s_a, s_b]$, $s_a, s_b \in \overline{S}$, and $a \leq b$, where s_a and s_b are the upper and lower limits of $\tilde{s}$, respectively, then, $\tilde{s}$ is called an uncertain language variable.

Definition 2. (see [48]). Let X not be an empty set. Then, an interval intuitionistic fuzzy set (IVIFS) A is represented on X as

$$A = \{ < x, [u_l(x), u_u(x)], [v_l(x), v_u(x)] > | x \in X\}, \quad (1)$$

where $[u_l(x), u_u(x)] \subseteq [0, 1]$ and $[v_l(x), v_u(x)] \subseteq [0, 1]$ are interval subordination and nonsubordination, respectively, full of subitem $u_u(x) + v_u(x) \leq 1$.

Definition 3. (see [49]). Let $X = \{x_1, x_2, \ldots, x_n\}$. Then, A is expressed on X as

$$A = \left\{ < x_i \middle| \left(\left[s_{\theta(x_i)}, s_{\tau(x_i)} \right], [u_l(x_i), u_u(x_i)], [v_l(x_i), v_u(x_i)] \right) \middle| x_i \in X \right\}, \tag{2}$$

where $s_{\theta(x_i)}, s_{\tau(x_i)} \in \overline{S}$, and the interval numbers $[u_l(x_i), u_u(x_i)]$ and $[v_l(x_i), v_u(x_i)]$, respectively, represent the degree to which x is subject to or not subject to the uncertain language evaluation value $[s_{\theta(x_i)}, s_{\tau(x_i)}]$. We call A an interval-valued intuitionistic uncertain linguistic set (IVIULS).

Definition 4. (see [50]). The interval intuitionistic uncertain fuzzy number (IVIULN) $\tilde{\alpha}$ is defined as

$$\tilde{\alpha} = \left(\left[s_{\theta(\alpha_i)}, s_{\tau(\alpha_i)} \right], [u_l(\alpha_i), u_u(\alpha_i)], [v_l(\alpha_i), v_u(\alpha_i)] \right), \tag{3}$$

which satisfies $[u_l(\alpha_i), u_u(\alpha_i)] \subseteq [0,1]$, $[v_l(\alpha_i), v_u(\alpha_i)] \subseteq [0,1]$, and $u_u(\alpha_i) + v_u(\alpha_i) \leq 1$. The interval numbers $[u_l(\alpha_i), u_u(\alpha_i)]$ and $[v_l(\alpha_i), v_u(\alpha_i)]$ represent the degree of subjection and nonsubjection to the uncertain language evaluation value $[s_{\theta(\alpha_i)}, s_{\tau(\alpha_i)}]$, respectively.

$\tilde{\alpha}$ and $\tilde{\beta}$ have the following algorithm:

(1) $\tilde{\alpha} \oplus \tilde{\beta} = ([s_{\theta(\alpha)+\theta(\beta)}, s_{\tau(\alpha)+\tau(\beta)}]), [1-(1-u_l(\alpha))(1-u_l(\beta)), 1-(1-u_u(\alpha))(1-u_u(\beta))], [v_l(\alpha)v_l(\beta), v_u(\alpha)v_u(\beta)]$

(2) $\tilde{\alpha} \otimes \tilde{\beta} = \left([s_{\theta(\alpha)\theta(\beta)}, s_{\tau(\alpha)\tau(\beta)}] \quad [u_l(\alpha)u_l(\beta), u_u(\alpha)u_u(\beta)], \begin{bmatrix} 1-(1-v_l(\alpha))(1-v_l(\beta)), \\ 1-(1-v_u(\alpha))(1-v_u(\beta)) \end{bmatrix} \right)$

(3) $\lambda\tilde{\alpha} = ([s_{\lambda\theta(\alpha)}, s_{\lambda\tau(\alpha)}], [1-(1-u_l(\alpha))^{\lambda}, 1-(1-u_u(\alpha))^{\lambda}], [v_l(\alpha)^{\lambda}, v_u(\alpha)^{\lambda}]), \ \lambda \in [0,1]$

(4) $\tilde{\alpha}^{\lambda} = ([s_{\theta(\alpha)^{\lambda}}, s_{\tau(\alpha)^{\lambda}}], [u_l(\alpha)^{\lambda}, u_u(\alpha)^{\lambda}], [1-(1-v_l(\alpha))^{\lambda}, 1-(1-v_u(\alpha))^{\lambda}]), \lambda \in [0,1]$.

For any IVIULN $\tilde{\alpha} = ([s_{\theta(\alpha_i)}, s_{\tau(\alpha_i)}], [u_l(\alpha_i), u_u(\alpha_i)], [v_l(\alpha_i), v_u(\alpha_i)])$, Liu defined the expected function of $\tilde{\alpha}$ as $E(\tilde{\alpha}) = (s(\theta(\alpha)+\tau(\alpha))(u_l(\alpha)+u_u(\alpha)+2-v_l(\alpha)-v_u(\alpha)))/8$ and the precise function of $\tilde{\alpha}$ as $H(\tilde{\alpha}) = (s(\theta(\alpha)+\tau(\alpha))(u_l(\alpha)+u_u(\alpha)+v_l(\alpha)+v_u(\alpha)))/4$ [50].

Definition 5. (see [38]). A fuzzy measure $\mu{:}p(N), \longrightarrow [0,1]$ on finite set N satisfies

(1) $\mu(\varnothing) = 0$, $\mu(\mathrm{N}) = 1$.

(2) If A, B∈P(N) and $A \subseteq B$, then $\mu(\mathrm{A}) \leq \mu(\mathrm{B})$.

Here, $p(N)$is a power set of N.

Definition 6. (see [51]). Let $X = \{x_1, x_2, \ldots, x_n\}$, f be a nonnegative real valued function defined on X, and μ be a fuzzy measure on N. The Choquet integral of function f with respect to μ is defined as

$$C_{\mu}\left(f\left(x_{(1)}\right), f\left(x_{(2)}, \ldots, f\left(x_{(n)}\right)\right)\right) = \sum_{i=1}^{n} f\left(x_{(i)}\right)\left(\mu\left(A_{(i)}\right) - \mu\left(A_{(i+1)}\right)\right), \tag{4}$$

where (.) represents a permutation of the subscript of the element in N, satisfying

$$A_{(n+1)} = \varnothing. \tag{5}$$

To consider the interaction between attributes, the Shapley function is used to establish a mathematical model on the attribute set. Therefore, the optimal fuzzy measure is obtained.

Murofushi first proposed applying the Shapley value to multiattribute decision making [52]. It is used to indicate the importance coefficient of experts. Combined with Definition 4, the generalized Shapley interval intuitive uncertainty linguistic Choquet average operator (GS-IVIULCA) is defined as follows [23, 53–55]:

$$\int \tilde{\alpha} d\Phi = \mathrm{GS-IVIULCA}_{\Phi}(\tilde{\alpha}, t\tilde{\alpha}n, q \ldots h, \tilde{\alpha}_n) = \oplus_{i=1}^{n}\left(\Phi_{A_{(i)}}(\mu, A)\right)\tilde{\alpha}_{(i)}, \tag{6}$$

where (.) represents the subscript of the element in A, satisfying $\tilde{\alpha}_{(1)} \leq \tilde{\alpha}_{(2)} \leq \cdots \leq \tilde{\alpha}_{(n)}$, $A(i) = \left\{\tilde{\alpha}_{(i)}, \ldots, \tilde{\alpha}_{(n)}\right\}$ and $A_{(n+1)} = \varnothing$.

2.2. Shapley–Choquet Aggregation Operators. A new multiattribute group decision-making method is proposed in this section, which not only considers the importance of each attribute but also gives the weight of each attribute combination. When the attribute weights are fully known, a cumulative operator can be used to obtain the comprehensive evaluation value of the scheme. However, for a variety of reasons, more often than not, there is only partial weight information about schema attributes. To consider the interaction between attributes, the Shapley function is used to establish a mathematical model of the attribute set. Therefore, the optimal fuzzy measure is obtained:

$$\Phi_s(\mu, N) = \sum_{T \subseteq (N/S)} \frac{(n-t-s)!t!}{(n-s+1)!}(\mu(S \cup T) - \mu(T)), \quad \forall S \subseteq N, \tag{7}$$

where μ is a fuzzy measure of N and n, t, and s represent the potential indices of N, T, and S, respectively.

When the attribute weights are known, the GS-IVIULCA operator can be directly used to calculate model (10). Otherwise, you need to determine the weights of the attributes first.

Consider a multiattribute group decision problem where $A = \{e_1, e_2, \ldots, e_n\}$ is the scheme set, $C = \{c_1, c_2, \ldots, c_n\}$ is the attribute set, and $E = \{e_1, e_2, \ldots, e_n\}$ is the expert set.

Assume that expert e_k determines the IVIULN judgment matrix $A^k = (\tilde{a}_{ij}^k)_{m \times n}$, and $\tilde{a}_{ij}^k = ([s_{\theta(a_{ij}^k)}, s_{\tau(a_{ij}^k)}]$, $[u_{l(a_{ij}^k)},$

$u_{u(a_{ij}^k)}]$, $[v_{l(a_{ij}^k)}, v_{u(a_{ij}^k)}])$ is an IVIULN of attribute $c_j \in C$ of scheme $a_i \in A$ [56].

In real life, the decision-making problems faced by people are characterized by complexity and uncertainty, as well as people's hesitation in making decisions. It is very difficult to obtain accurate weight information, and only partial weight information is usually obtained. Entropy, as an important tool to determine information measures in uncertain environments, has received considerable attention from experts and scholars since it was proposed. The following is the definition of the IVIULNs information entropy measure.

A real value function $E\colon \mathrm{IVIULN}(X) \longrightarrow [0,\ 1]$ is an entropy measure of IVIULN(X), which should satisfy the following conditions:

(1) $E(A) = 0$,when $s_{\theta(x_i)} = 0$, $s_{\tau(x_i)} = t$ and $[u\overline{A}(x_i), u_A^+ (x_i)] = [0,0]$, $[v\overline{A}(x_i), v_A^+(x_i)] = [1,1]$ or $[u\overline{A}(x_i), u_A^+(x_i)] = [1,1]$, $[v\overline{A}(x_i), v_A^+(x_i)] = [0,0]$, $for any${x_{{i}}}∈X.

(2) $E(A) = 1$, only if $s_{\theta(x_i)} = s_{\tau(x_i)}and[u\overline{A}(x),\ u_A^+(x)] = [v\overline{A}(x), v_A^+(x)]$, for any $x_i \in X$.

(3) $E(A) = E(A^c)$, where $A^c = \left\{ < x_i|([s_{t-\tau(x_i)}, s_{t-\theta(x_i)}], [v_l(x_i), v_u(x_i)], [u_l(x_i), u_u(x_i)]) > |x_i \in X > \right\}$.

(4) $E(A) \le E(B)$, when $A \subseteq B$and $u_l'(x_i) \le v_l'(x_i)$, $u_u'(x_i) \le v_u'(x_i)$, for any $x_i \in X$or $A \subseteq B$, and $u_l'(x_i) \le v_l'(x_i)$, $u_u'(x_i) \le v_u'(x_i)$for any $x_i \in X$.

Definition 7. The entropy measure EM formula of IVIULSs is given as follows:

$$E_M(A) = \frac{1}{n}\sum_{i=1}^{n}\frac{3 - |\theta(x_i) - (\tau(x_i)|/t) - |u_l(x_i) - v_l(x_i)| - |u_u(x_i) - v_u(x_i)| + \pi_l(x_i) + \pi_u(x_i)}{3 + |\theta(x_i) - (\tau(x_i)|/t) - |u_l(x_i) - v_l(x_i)| - |u_u(x_i) - v_u(x_i)| + \pi_l(x_i) + \pi_u(x_i)}, \tag{8}$$

for any IVIULS $A = \left\{ < x_i|([s_{\theta(x_i)}, s_{\tau(x_i)}],\ [u_l(x_i),\ u_u(x_i)], [v_l(x_i), v_u(x_i)]) > |x_i \in X \right\}$.

According to entropy value theory, the more useful the information provided by experts to decision makers is, the smaller the deviation of the entropy value given by experts to the scheme [19, 57, 58].

If only part of the weight information of experts is known, an optimization model is established to obtain the optimal fuzzy measure of expert set E on attribute C.

$$\min\sum_{k=1}^{q}\sum_{i=1}^{m}E\left(\tilde{a}_{ij}^k\right)\varphi_{ek}\left(\mu^j, E\right),$$
$$\text{s.t.}\quad \begin{cases} \mu^j(e_k) \in H_{e_k}^j,\ k = 1, 2, \ldots, q \\ \mu^j(\varnothing) = 0,\ \mu^j(E) = 1 \\ \mu^j(S) \le \mu^j(T)\ \forall\ S,\ T \subseteq E,\ S \subseteq T, \end{cases} \tag{9}$$

where $\varphi_{ek}(\mu^j, E)$ is the Shapley value of expert $e_k\,(k = 1, 2, \ldots, q)$ and H_{ek}^j represents the range of e_k for attribute c_j.

Similarly, if only part of the weight information of the attribute is known, an optimization model is established to obtain the optimal fuzzy measure on attribute set C.

$$\min\sum_{j=1}^{n}\sum_{i=1}^{m}E\left(\tilde{a}_{ij}\right)\varphi_{cj}(\mu, c),$$
$$\text{s.t.}\quad \begin{cases} \mu(c_k) \in H_{cj},\ j = 1, 2, \ldots, n \\ \mu(\varnothing) = 0,\ \mu(C) = 1 \\ \mu(S) \le \mu(T)\ \forall S,\ T \subseteq C,\ S \subseteq T, \end{cases} \tag{10}$$

where $\varphi_{cj}(\mu, c)$ is the Shapley value of attribute $c_j\,(j = 1, 2, \ldots, n)$ and H_{cj} is the value range of attribute c_j.

2.3. A New Multiattribute Group Decision-Making Method. Based on the GS-IVIULCA operator and optimization model given above, a multiattribute group decision-making method in the context of interval uncertainty is presented.

Step 1: the value of scheme a_i for attribute c_j is an IVIULN given by expert $e_k\,(k = 1, 2, \ldots, n)$, which can be expressed as

$$\tilde{a}_{ij}^k = \left(\left[s_{\theta\left(a_{ij}^k\right)}, s_{\tau\left(a_{ij}^k\right)}\right], \left[u_{l\left(a_{ij}^k\right)}, u_{l\left(a_{ij}^k\right)}\right], \left[v_{l\left(a_{ij}^k\right)}, v_{u\left(a_{ij}^k\right)}\right]\right), \quad (i = 1, 2, \ldots, m;\ j - 1, 2, \ldots n). \tag{11}$$

The evaluation matrix of the IVIULN can be obtained from $A^k = (\tilde{a}_{ij}^k)m \times n$.

Step 2: the optimal fuzzy measure μ_j of expert set E on attribute set $c_j\,(j = 1, 2, \ldots, n)$ is obtained from model (6).

Step 3: the value $\widetilde{a}_{ij} = ([s_{\theta(a_{ij})}, s_{\tau(a_{ij})}], [u_{l(a_{ij})}, u_{u(a_{ij})}], [v_{l(a_{ij})}, v_{u(a_{ij})}])$ of the IVIULN and the comprehensive value $A = (\widetilde{a}_{ij})m \times n$ matrix of the IVIULN are obtained by the GS-IVIULCA aggregation operator.

Step 4: according to the evaluation matrix A of the IVIULN obtained above, the optimal fuzzy measure μ of attribute set C can be obtained by model (7).

Step 5: obtain the IVIULN synthesis value $\widetilde{a}_i = ([s_{\theta(a_i)}, s_{\tau(a_i)}], [u_{l(a_i)}, u_{u(a_i)}], [v_{l(a_i)}, v_{u(a_i)}])$ of schemes via the GS-IVIULCA aggregation operators.

Step 6: the expected value $E(\widetilde{\alpha})$ and the exact function $H(\widetilde{\alpha})$ of schemes can be calculated.

Step 7: sort the schemes by ranking $E(\widetilde{\alpha})$ and $H(\widetilde{\alpha})$ to obtain the optimal scheme.

Step 8: end the process.

3. Index System Construction and Analysis

In November 2018, the Ministry of Housing and Urban-Rural Development issued the technical guide for sponge city construction—"construction of a rainwater system for low-impact development." The guidelines specified the content, requirements, and methods of constructing a rainwater system for low-impact development in sponge city planning, engineering design, construction, maintenance, and management [6, 9, 59]. During the construction of a sponge city, the system of natural precipitation, surface water, and ground water should be coordinated; the water supply, drainage, and other water recycling links should be coordinated, and its complexity and long-term impacts should be considered [9, 60, 61]. Based on the important indexes that need to be considered in the construction of a project, namely, costs, deadlines, and later operating and maintenance expenses, this paper proposes the decision-making index system of a sponge city construction project. The system includes four primary indexes: the engineering index, the flood control and drainage index, the ecological environment index, and the rainwater collection and utilization index (the groundwater supplement index). It is obvious that there are interactions among these indicators, such as between flood control and drainage and ecological environmental protection and between rainwater collection and utilization and ecological environmental protection. After further analysis of the four primary indicators, 13 secondary indicators are proposed to constitute a complete evaluation index system, as shown in Figure 1.

It is certain that there are interactions among these indicators, such as between flood control and drainage and ecological environment protection and between rainwater collection and utilization and ecological environment protection [7]. According to the analysis of the literature, the decision makers in sponge city selection should consider the comprehensive benefits of the project, which should be formed by the project's economic, social, and ecological attributes [7, 9, 18, 60]. The better the comprehensive benefits are, the better the scheme will be. Therefore, there are three evaluation attributes and one target attribute for the multiattribute evaluation of the sponge city scheme selected by decision makers. The three evaluation attributes are the economic benefits, social benefits, and ecological benefits of the project.

The interaction model is built according to the three evaluation attributes and one target attribute, as shown in Figure 2. The relationship between variables is marked with arrows, and the correlation is marked with signs of "+" and "−," where "+" indicates a positive correlation and "-" indicates a negative correlation.

Among the attributes, the better the social benefits, ecological benefits, and social benefits are, the better the comprehensive benefits are. The economic benefits are negatively correlated with the ecological environmental benefits, and higher economic benefits are usually at the expense of ecological environmental benefits. When the ecological environmental benefits are the main factor, the economic benefits are usually not high. Ecological environmental benefits and social benefits are complementary. The better the ecological benefits are, the better the social benefits are. Social benefits also promote ecological benefits. The three evaluation attributes corresponding to the four first-level indicators and 13 second-level indicators established in Figure 1 and their interaction relationships are shown in Figure 2.

4. Empirical Analysis

4.1. Background Information. An example is given to illustrate the calculation process of this method. The Xinglong area of Daming Lake in Jinan, Shandong Province, will be used as the pilot area and the Jixi wetland area of the Yufu River will be used as the promotion area to establish a sponge city. The location is shown in Figure 3.

There are three technology companies bidding: *A*: Shanghai Jingzhou Rainwater Technology Co., LTD., *B*: Shanghai Yuzhen Industrial Co., LTD., and *C*: Renchuang Technology Group. The three companies provide their respective construction plans, sponge city planning plans, and environmentally permeable materials. Each scheme and related technical contents are shown in Table 1.

4.2. Evaluation Process and Results. According to the decision indicator system and scheme proposed in this paper, three experts (e_1, e_2, e_3) are invited to evaluate each indicator of the three schemes via weight interval values and interval intuitive language $S = \{s_1, s_2, s_3, s_4, s_5, s_6, s_7\}$, as shown in Tables 2–4. The evaluation interval values of different experts and attributes are given by decision makers, as shown in Tables 5 and 6 .

Step 1: take the calculation of attribute C_{11} as an example and obtain the best fuzzy measure of expert set E on attribute C_{11} according to model (9). Obtain the expert evaluation LVIULN matrix for attribute C_{11}:

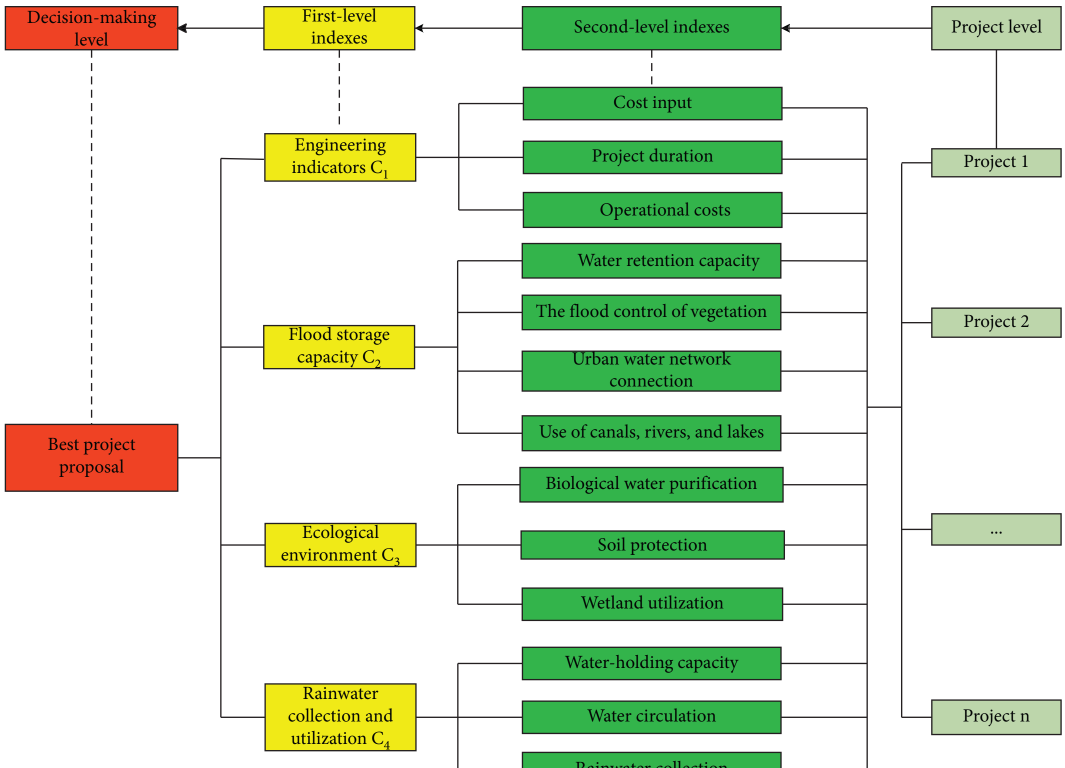

FIGURE 1: Decision-making index system of the sponge city construction project scheme.

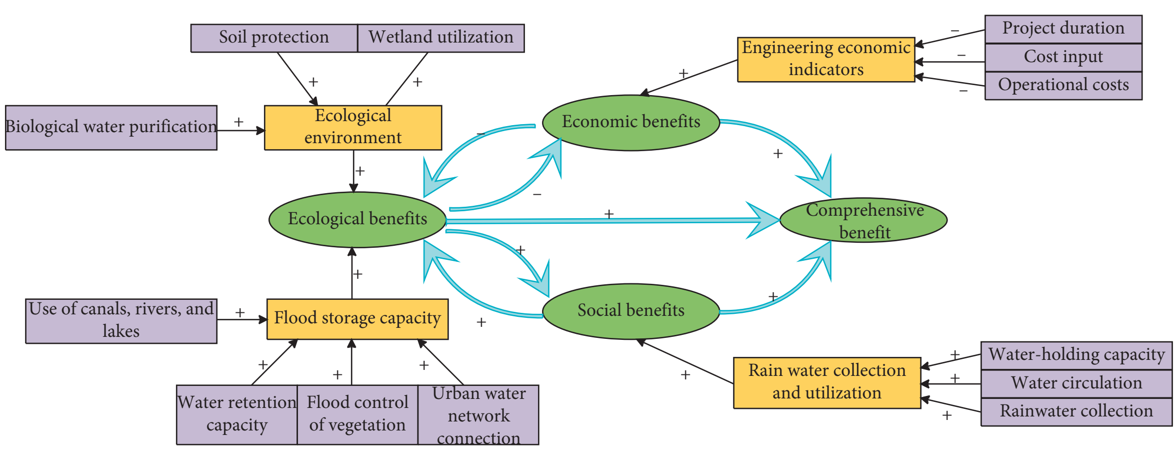

FIGURE 2: Interaction between attribute indexes.

$$A = \begin{pmatrix} ([s_5, s_6], [0.6, 0.7], [0.2, 0.3]) & ([s_4, s_6], [0.6, 0.8], [0.1, 0.2]) & ([s_6, s_7], [0.5, 0.6], [0.3, 0.4]) \\ ([s_4, s_7], [0.7, 0.8], [0.1, 0.2]) & ([s_6, s_7], [0.8, 0.9], [0, 0.1]) & ([s_5, s_7], [0.5, 0.8], [0.1, 0.2]) \\ ([s_3, s_4], [0.5, 0.7], [0.1, 0.3]) & ([s_4, s_5], [0.6, 0.7], [0.1, 0.3]) & ([s_3, s_5], [0.5, 0.6], [0.2, 0.4]) \end{pmatrix}. \tag{12}$$

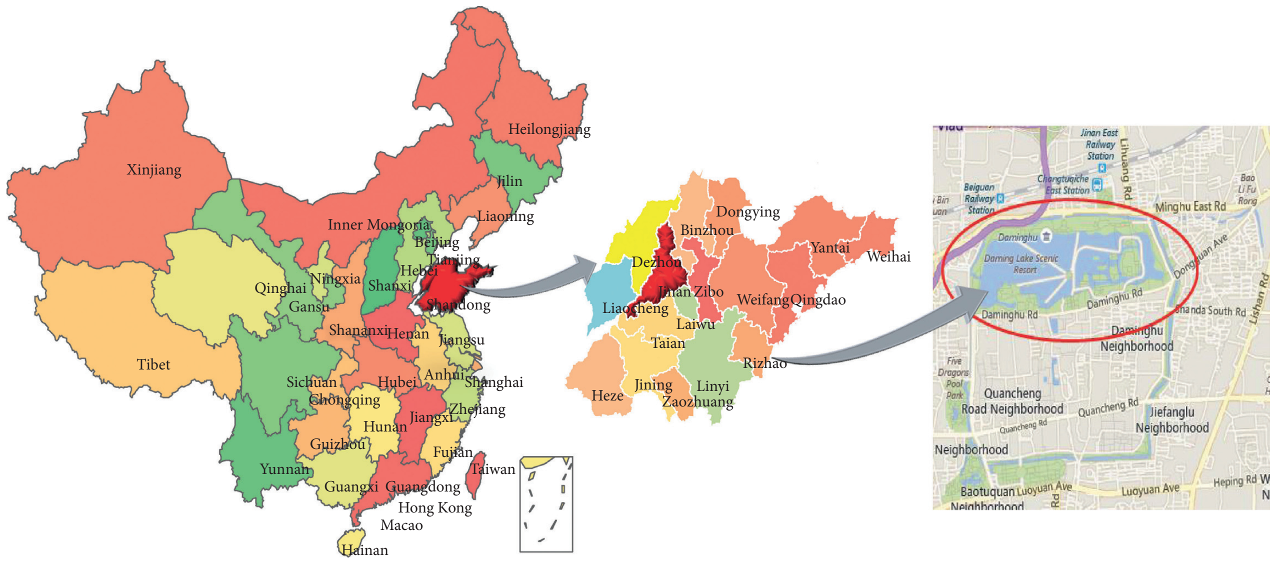

Figure 3: Geographical location of Jinan sponge city project.

Table 1: Each scheme and related technical contents.

Technical index	Scheme A	Scheme B	Scheme C
Sponge city project construction scheme	Sand base penetrates gully cover Sand foundation through gutter kerb stone Sand base permeable brick Ecological rain garden Silica sand self-absorbent rod Honeycomb structure well body Permeable impervious brick Permeable and sand proof Osmotic filtration wellbore Miniature sprinkler irrigation system Constructed wetland sewage treatment technology Use of road flushing Waste water flushing toilet	The flood control of vegetation Ceramic permeable brick Colored asphalt pavement Porous pavement Rain water abandoning device Rainwater filter Water storage module Waterproof membrane Elevator pump Rainwater purification all-in-one machine Miniature sprinkler irrigation system Spool shaft seat	Ecologically permeable concrete Permeable square Green roof Ecological parking lot Grass furrow Retention pond Underground reservoir Constructed wetlands Rainwater recycling Constructed wetland sewage treatment technology Circulating water car washing system
Cost input (ten thousand yuan)	1986.2	1563.6	2155.4
Project duration (month	7.2	5.6	4.6
Operation and maintenance cost (ten thousand yuan/year)	34.75	17.46	27.93

According to model (10), we can obtain

$$\min 0.0255\left(\mu^{11}(e_1)-\mu^{11}(e_2,e_3)\right)+0.008\left(\mu^{11}(e_1,e_3)-\mu^{11}(e_1,e_2)\right)+0.411$$
$$s.t.\quad \begin{cases} \mu^{11}(e_1,e_2,e_3)=1, \\ \mu^{11}(S)\le\mu^{11}(T)\forall S,\ T\subseteq\{e_1,e_2,e_3\}, S\subseteq T, \\ \mu^{11}(e_1)\in[0.2,0.5],\ \mu^{11}(e_2)\in[0.4,0.6],\ \mu^{11}(e_3)\in[0.2,0.3]. \end{cases} \tag{13}$$

Table 2: Evaluation value of the indexes by expert e_1.

Decision-making level	First-level indexes	Second-level indexes	Scheme A	Scheme B	Scheme C
Best project scheme	Engineering indicators C_1	Cost input C_{11}	$([s_4, s_7], [0.6, 0.7], [0.2, 0.3])$	$([s_6, s_6], [0.6, 0.7], [0.3, 0.3])$	$([s_4, s_6], [0.5, 0.7], [0.2, 0.3])$
		Project duration C_{12}	$([s_4, s_6], [0.6, 0.8], [0, 0.2])$	$([s_6, s_6], [0.7, 0.7], [0.2, 0.3])$	$([s_7, s_7], [0.5.0.6], [0.3, 0.4])$
		Operational costs C_{13}	$([s_4, s_5], [0.5, 0.7], [0.2, 0.3])$	$([s_6, s_7], [0.8, 0.8], [0.1, 0.2])$	$([s_6, s_6], [0.8, 0.9], [0, 0.1])$
	Flood storage capacity C_2	Water retention capacity C_{21}	$([s_4, s_7], [0.6, 0.8], [0.1, 0.2])$	$([s_4, s_6], [0.7, 0.8], [0.1, 0.2])$	$([s_6, s_6], [0.8, 0.9], [0.1, 0.1])$
		Flood control of vegetation C_{22}	$([s_3, s_6], [0.7, 0.7], [0.2, 0.3])$	$([s_4, s_4], [0.7, 0.9], [0, 0.1])$	$([s_6, s_7], [0.8, 0.9], [0.1, 0.1])$
		Urban water network connection C_{23}	$([s_4, s_6], [0.7, 0.9], [0.1, 0.1])$	$([s_4, s_{6,}\ ][0.7, 0.9,\ ] [0, 0.1])$	$([s_4, s_5], [0.7, 0.8], [0.1, 0.2])$
		Use of canals, rivers, and lakes C_{24}	$([s_3, s_4], [0.5, 0.7], [0.2, 0.3])$	$([s_4, s_5], [0.7, 0.8], [0.1, 0.2])$	$([s_5, s_5], [0.7, 0.7], [0.1, 0.3])$
	Ecological environmentC_3	Biological water purification C_{31}	$([s_3, s_5], [0.6, 0.7], [0.2, 0.3])$	$([s_3, s_5], [0.7, 0.9], [0, 0.1])$	$([s_5, s_6], [0.6, 0.7], [0.1, 0.3])$
		Soil protection C_{32}	$([s_4, s_5], [0.6, 0.7], [0.2, 0.3])$	$([s_4, s_4], [0.7, 0.8], [0.1, 0.2])$	$([s_6, s_6], [0.7, 0.8], [0.1, 0.1])$
		Wetland utilization C_{33}	$([s_5, s_6], [0.5, 0.6], [0.3, 0.4])$	$([s_5, s_7], [0.7, 0.8], [0.1, 0.2])$	$([s_3, s_4], [0.6, 0.6], [0.2, 0.4])$
	Rainwater collection and utilization C_4	Water-holding capacity C_{41}	$([s_6, s_7], [0.8, 0.8], [0.2, 0.2])$	$([s_6, s_6], [0.6, 0.8], [0.1, 0.2])$	$([s_6, s_6], [0.5, 0.7], [0.1, 0.3])$
		Water circulation C_{42}	$([s_6, s_7], [0.7, 0.9], [0, 0.1])$	$([s_4, s_6], [0.8, 0.9], [0.1, 0.1])$	$([s_5, s_5], [0.7, 0.9], [0.1, 0.1])$
		Rainwater collection C_{43}	$([s_4, s_4], [0.7, 0.7], [0.2, 0.3])$	$([s_5, s_5], [0.7, 0.8], [0.1, 0.2])$	$([s_6, s_7], [0.7, 0.9], [0, 0.1])$

Table 3: Interval-valued intuitionistic uncertain linguistic evaluation value of the index by expert e_2.

Decision-making level	First-level indexes	Second-level indexes	Scheme A	Scheme B	Scheme C
Best project scheme	Engineering indicators C_1	Cost input C_{11}	$([s_5, s_5], [0.7, 0.9], [0.1, 0.1])$	$([s_5, s_7], [0.7, 0.7], [0.1, 0.3])$	$([s_5, s_5], [0.6, 0.9], [0, 0.1])$
		Project duration C_{12}	$([s_3, s_4], [0.8, 0.9], [0.1, 0.1])$	$([s_4, s_5], [0.6, 0.7], [0.1, 0.3])$	$([s_7, s_7], [0.8.0.8], [0.1, 0.2])$
		Operational costs C_{13}	$([s_3, s_6], [0.7, 0.7], [0.1, 0.3])$	$([s_6, s_7], [0.8, 0.8], [0.1, 0.2])$	$([s_6, s_6], [0.6, 0.8], [0, 0.2])$
	Flood storage capacity C_2	Water retention capacity C_{21}	$([s_3, s_5], [0.5, 0.8], [0.1, 0.2])$	$([s_5, s_7], [0.7, 0.9], [0.1, 0.1])$	$([s_6, s_7], [0.7, 0.7], [0.1, 0.2])$
		Flood control of vegetation C_{22}	$([s_5, s_6], [0.7, 0.7], [0.2, 0.3])$	$([s_4, s_4], [0.7, 0.9], [0, 0.1])$	$([s_6, s_7], [0.8, 0.9], [0.1, 0.1])$
		Urban water network connection C_{23}	$([s_4, s_6], [0.6, 0.8], [0.1, 0.2])$	$([s_6, s_{6,}\ ][0.7, 0.8] [0, 0.2])$	$([s_5, s_5], [0.6, 0.8], [0.2, 0.2])$
		Use of canals, rivers, and lakes C_{24}	$([s_4, s_6], [0.7, 0.7], [0.1, 0.3])$	$([s_5, s_5], [0.8, 0.8], [0.1, 0.2])$	$([s_5, s_7], [0.7, 0.8], [0.1, 0.2])$
	Ecological environmentC_3	Biological water purification C_{31}	$([s_5, s_5], [0.7, 0.8], [0.1, 0.2])$	$([s_4, s_5], [0.7, 0.7], [0.1, 0.2])$	$([s_6, s_6], [0.8, 0.9], [0.1, 0.1])$
		Soil protection C_{32}	$([s_3, s_6], [0.7, 0.8], [0.1, 0.2])$	$([s_4, s_5], [0.8, 0.9], [0, 0.1])$	$([s_5, s_5], [0.8, 0.8], [0.1, 0.2])$
		Wetland utilization C_{33}	$([s_4, s_5], [0.6, 0.6], [0.2, 0.4])$	$([s_4, s_5], [0.7, 0.8], [0.1, 0.1])$	$([s_5, s_5], [0.7, 0.8], [0.1, 0.2])$
	Rainwater collection and utilization C_4	Water-holding capacity C_{41}	$([s_6, s_6], [0.6, 0.8], [0.1, 0.2])$	$([s_4, s_7], [0.7, 0.8], [0.1, 0.2])$	$([s_5, s_7], [0.8, 0.9], [0.1, 0.1])$
		Water circulation C_{42}	$([s_4, s_6], [0.7, 0.7], [0.1, 0.3])$	$([s_6, s_6], [0.8, 0.8], [0.1, 0.2])$	$([s_5, s_6], [0.7, 0.8], [0.1, 0.2])$
		Rainwater collection C_{43}	$([s_4, s_6], [0.6, 0.8], [0.2, 0.2])$	$([s_5, s_5], [0.8, 0.8], [0.1, 0.1])$	$([s_6, s_6], [0.7, 0.7], [0, 0.2])$

Table 4: Interval-valued intuitionistic uncertain linguistic evaluation value of the index by expert e_3.

Decision-making level	First-level indexes	Second-level indexes	Scheme A	Scheme B	Scheme C
Best project scheme	Engineering indicators C_1	Cost input C_{11}	$([s_6, s_6], [0.8, 0.8], [0.2, 0.2])$	$([s_6, s_7], [0.8, 0.9], [0.1, 0.1])$	$([s_4, s_5], [0.7, 0.9], [0, 0.1])$
		Project duration C_{12}	$([s_3, s_4], [0.8, 0.9], [0.1, 0.1])$	$([s_5, s_6], [0.7, 0.8], [0.1, 0.2])$	$([s_5, s_7], [0.7.0.7], [0.2, 0.2])$
		Operational costs C_{13}	$([s_4, s_5], [0.7, 0.8], [0.1, 0.2])$	$([s_7, s_7], [0.5, 0.8], [0.1, 0.2])$	$([s_6, s_6], [0.6, 0.8], [0, 0.2])$
	Flood storage capacity C_2	Water retention capacity C_{21}	$([s_4, s_6], [0.8, 0.9], [0, 0.1])$	$([s_6, s_6], [0.7, 0.9], [0.1, 0.1])$	$([s_5, s_7], [0.5, 0.8], [0.2, 0.2])$
		Flood control of vegetation C_{22}	$([s_5, s_5], [0.4, 0.7], [0.1, 0.3])$	$([s_4, s_6], [0.7, 0.8], [01, 0.2])$	$([s_7, s_7], [0.7, 0.9], [0.1, 0.1])$
		Urban water network connection C_{23}	$([s_3, s_5], [0.7, 0.7], [0.2, 0.3])$	$([s_6, s_6,][0.7, 0.7] [0.2, 0.2])$	$([s_6, s_6], [0.7, 0.8], [0.1, 0.1])$
		Use of canals, rivers, and lakes C_{24}	$([s_4, s_4], [0.7, 0.8], [0.2, 0.2])$	$([s_4, s_4], [0.7, 0.9], [0.1, 0.1])$	$([s_5, s_5], [0.7, 0.7], [0.1, 0.3])$
	Ecological environmentC_3	Biological water purification C_{31}	$([s_5, s_6], [0.7, 0.7], [0.2, 0.3])$	$([s_4, s_4], [0.8, 0.8], [0.1, 0.1])$	$([s_6, s_6], [0.7, 0.8], [0.1, 0.2])$
		Soil protection C_{32}	$([s_3, s_5], [0.7, 0.7], [0.2, 0.2])$	$([s_5, s_6], [0.7, 0.7], [0.3, 0.3])$	$([s_4, s_7], [0.8, 0.9], [0.1, 0.1])$
		Wetland utilization C_{33}	$([s_6, s_6], [0.7, 0.8], [0.1, 0.2])$	$([s_6, s_7], [0.6, 0.8], [0.2, 0.2])$	$([s_5, s_6], [0.8, 0.8], [0.2, 0.2])$
	Rainwater collection and utilization C_4	Water-holding capacity C_{41}	$([s_3, s_4], [0.7, 0.7], [0.3, 0.3])$	$([s_4, s_5], [0.7, 0.9], [0.1, 0.1])$	$([s_5, s_7], [0.7, 0.7], [0.2, 0.3])$
		Water circulation C_{42}	$([s_4, s_4], [0.8, 0.8], [0, 0.2])$	$([s_6, s_6], [0.6, 0.7], [0.1, 0.2])$	$([s_6, s_6], [0.7, 0.8], [0.2, 0.2])$
		Rainwater collection C_{43}	$([s_5, s_7], [0.8, 0.9], [0.1, 0.1])$	$([s_3, s_6], [0.8, 0.8], [0.1, 0.2])$	$([s_6, s_6], [0.7, 0.8], [0, 0.1])$

Table 5: Expert weight interval value.

Decision-making level	First-level indexes	Second-level indexes	Expert weight e_1	e_2	e_3
Best project scheme	Engineering indicators C_1	Cost input C_{11}	[0.2, 0.5]	[0.4, 0.6]	[0.2, 0.3]
		Project duration C_{12}	[0.1, 0.4]	[0.3, 0.5]	[0.1, 0.4]
		Operational costs C_{13}	[0.3, 0.5]	[0.2, 0.3]	[0.2, 0.4]
	Flood storage capacity C_2	Water retention capacity C_{21}	[0.2, 0.4]	[0.1, 0.3]	[0.3, 0.5]
		Flood control of vegetation C_{22}	[0.3, 0.5]	[0.2, 0.3]	[0.1, 0.3]
		Urban water network connection C_{23}	[0.2, 0.3]	[0.4, 0.5]	[0.2, 0.4]
		Use of canals, rivers, and lakes C_{24}	[0.3, 0.6]	[0.2, 0.4]	[0.5, 0.6]
	Ecological environmentC_3	Biological water purification C_{31}	[0.2, 0.5]	[0.4, 0.5]	[0.5, 0.6]
		Soil protection C_{32}	[0.2, 0.5]	[0.4, 0.5]	[0.4, 0.5]
		Wetland utilization C_{33}	[0.3, 0.5]	[0.4, 0.6]	[0.2, 0.4]
	Rainwater collection and utilization C_4	Water-holding capacity C_{41}	[0.1, 0.4]	[0.2, 0.4]	[0.2, 0.5]
		Water circulation C_{42}	[0.3, 0.5]	[0.2, 0.4]	[0.1, 0.5]
		Rainwater collection C_{43}	[0.4, 0.5]	[0.3, 0.5]	[0.2, 0.4]

MATLAB 9.0 was used to solve formula (7) to obtain the optimal fuzzy measure:

$$\begin{aligned} &\mu^{11}(e_1) = 0.2\mu^{11}(e_2) = 0.4,\\ &\mu^{11}(e_3) = 0.3,\\ &\mu^{11}(e_1, e_2) = 0.4,\\ &\mu^{11}(e_1, e_3) = \mu^{11}(e_2, e_3) = \mu^{11}(e_1, e_2, e_3) = 1. \end{aligned} \tag{14}$$

According to formula (6), the weight of the Shapley value of experts can be obtained:

$$\begin{aligned} \Phi_s^{11}(e_1) &= 0.19,\\ \Phi_s^{11}(e_2) &= 0.28,\\ \Phi_s^{11}(e_3) &= 0.53,\\ \Phi_s^{11}(e_1, e_2) &= 0.55,\\ \Phi_s^{11}(e_1, e_3) &= 0.8,\\ \Phi_s^{11}(e_2, e_3) &= 0.9,\\ \Phi_s^{11}(e_1, e_2, e_3) &= 1. \end{aligned} \tag{15}$$

Table 6: Attribute weight interval value.

Decision-making level	First-level indexes	Interval weight value	Second-level indexes	Interval weight value
Best project scheme	Engineering indicators C_1	[0.1, 0.3]	Cost input C_{11}	[0.2, 0.5]
			Project duration C_{12}	[0.4, 0.6]
			Operational costs C_{13}	[0.3, 0.5]
	Flood storage capacity C_2	[0.3, 0.4]	Water retention capacity C_{21}	[0.2, 0.4]
			Flood control of vegetation C_{22}	[0.3, 0.5]
			Urban water network connection C_{23}	[0.2, 0.4]
			Use of canals, rivers, and lakes C_{24}	[0.3, 0.4]
	Ecological environment C_3	[0.2, 0.3]	Biological water purification C_{31}	[0.3, 0.5]
			Soil protection C_{32}	[0.4, 0.6]
			Wetland utilization C_{33}	[0.3, 0.5]
	Rainwater collection and utilization C_4	[0.3, 0.4]	Water-holding capacity C_{41}	[0.4, 0.5]
			Water circulation C_{42}	[0.2, 0.5]
			Rainwater collection C_{43}	[0.3, 0.4]

Step 2: use the GS-IVIULCA aggregation operator to calculate the synthesis value of attribute C_{11} of scheme A as follows:

$$\tilde{a}_{11}^{A} = \mathrm{IG}-\mathrm{IVIULCA}_{\mu^{11}}\left(\tilde{a}_{11}^{1},\tilde{a}_{11}^{2},\tilde{a}_{11}^{3}\right) = \left(\begin{array}{c} \left[s_{6\times 0.53+5\times(0.9-0.53)+4\times(1-0.9)}, s_{5\times 0.53+5\times(0.9-0.53)+4\times(1-0.9)}\right], \\ \left[\begin{array}{l} 1-\left((1-0.8)^{0.53}\times(1-0.7)^{(0.9-0.53)}\times(1-0.7)^{(1-0.9)}\right), \\ 1-\left((1-0.8)^{0.53}\times(1-0.9)^{(0.9-0.53)}\times(1-0.8)^{(1-0.9)}\right) \end{array}\right], \\ \left[0.2^{0.53}\times 0.1^{(0.9-0.53)}\times 0.1^{(1-0.9)}, 0.2^{0.53}\times 0.1^{(0.9-0.53)}\times 0.2^{(1-0.9)}\right] \end{array}\right) \tag{16}$$

$$= \left[s_{5.1}, s_{5.5}\right], [0.76, 0.8], [0.14, 0.2].$$

Similarly, the comprehensive values of other secondary indicators of attribute C_1 can be obtained as shown in Table 7.

Repeat steps 1 and 2 to obtain the comprehensive IVIULCAN value of other secondary indicators of each scheme.

Step 3: obtain the IVIULN matrix of attribute C_1 according to Table 7:

$$B = \begin{pmatrix} \left[s_{5.4}, s_{5.6}\right], [0.76, 0.84], [0.15, 0.16] & \left[s_{3.1}, s_{4.6}\right], [0.69, 0.88], [0.08, 0.12] & \left[s_{4.3}, s_{5.4}\right], [0.7, 0.7], [0.1, 0.3] \\ \left[s_{5.6}, s_{6.9}\right], [0.75, 0.83], [0.11, 0.17] & \left[s_{4.6}, s_{5.5}\right][0.66, 0.76][0.1, 0.24] & \left[s_{6.1}, s_{7}\right], [0.79, 0.8], [0.1, 0.2] \\ \left[s_{4.3}, s_{4.9}\right], [0.69, 0.9], [0, 0.1] & \left[s_{5.9}, s_{7}\right], [0.75, 0.75], [0.15, 0.2] & \left[s_{6}, s_{6}\right], [0.74, 0.87], [0, 0.13] \end{pmatrix}. \tag{17}$$

According to model (7), we can get

$$\begin{array}{ll} \min & \begin{array}{l} -0.01\left(\mu\left(C_{11}\right)-\mu\left(C_{12}, C_{13}\right)\right)-0.001\left(\mu\left(C_{12}\right)-\mu\left(C_{11}, C_{13}\right)\right) \\ +0.008\left(\mu\left(C_{13}\right)-\mu\left(C_{11}, C_{13}\right)\right)+0.387, \end{array} \\ s.t. & \left\{\begin{array}{l} \mu\left(C_{11}, C_{12}, C_{13}, C_{14}\right)=1, \\ \mu(S) \leq \mu(T) \forall S,\ T \subseteq\left\{C_{11}, C_{12}, C_{13}\right\},\ S \subseteq T, \\ \mu\left(C_{11}\right) \in [0.2, 0.5],\ \mu\left(C_{12}\right) \in [0.4, 0.6],\ \mu\left(C_{13}\right)[0.3, 0.5]. \end{array}\right. \end{array} \tag{18}$$

Table 7: Comprehensive evaluation of second-level indicators for C_1 of each scheme attribute.

Scheme	Attribute		
	C_{11}	C_{12}	C_{13}
Scheme A	$[s_{5.4}, s_{5.6}]$, [0.76, 0.84], [0.15, 0.16]	$[s_{3.1}, s_{4.6}]$, [0.69, 0.88], [0.08, 0.12]	$[s_{4.3}, s_{5.4}]$, [0.7, 0.7], [0.1, 0.3]
Scheme B	$[s_{5.6}, s_{6.9}]$, [0.75, 0.83], [0.11, 0.17]	$[s_{4.6}, s_{5.5}]$[0.66, 0.76][0.1, 0.24]	$[s_{6.1}, s_7]$, [0.79, 0.8], [0.1, 0.2]
Scheme C	$[s_{4.3}, s_{4.9}]$, [0.69, 0.9], [0, 0.1]	$[s_{5.9}, s_7]$, [0.75, 0.75], [0.15, 0.2]	$[s_6, s_6]$, [0.74, 0.87], [0, 0.13]

Table 8: The Shapley value of the secondary index for attribute C_1.

$\Phi_{C_{11}}$	$\Phi_{C_{12}}$	$\Phi_{C_{13}}$	$\Phi_{\{C_{11},C_{12}\}}$	$\Phi_{\{C_{11},C_{13}\}}$	$\Phi_{\{C_{12},C_{13}\}}$	$\Phi_{\{C_{11},C_{12},C_{13}\}}$
0.5	0.4	0.1	0.85	0.55	0.45	1

Table 9: First-level attribute values of each scheme.

Scheme	Attribute			
	C_1	C_2	C_3	C_4
Scheme A	$[s_{4.3}, s_{4.9}]$, [0.77, 0.87], [0.12, 0.13]	$[s_{4.4}, s_{5.8}]$, [0.72, 0.8], [0, 0.14]	$[s_{3.6}, s_{5.5}]$, [0.68, 0.75], [0.14, 0.21]	$[s_{5.1}, s_{6.2}]$, [0.71, 0.84], [0, 0.16]
Scheme B	$[s_{5.2}, s_{6.3}]$, [0.72, 0.8], [0.1, 0.12]	$[s_{4.8}, s_{5.2}]$, [0.7, 0.89], [0, 0.1]	$[s_{4.4}, s_{5.4}]$, [0.73, 0.82], [0, 0.17]	$[s_{4.4}, s_{6.1}]$, [0.77, 0.85], [0.12, 0.15]
Scheme C	$[s_{5.7}, s_{5.8}]$, [0.72, 0.85], [0, 0.13]	$[s_{5.5}, s_{6.6}]$, [0.71, 0.85], [0.13, 0.14]	$[s_{4.8}, s_{5.8}]$, [0.78, 0.82], [0.11, 0.17]	$[s_{5.3}, s_{5.9}]$, [0.71, 0.86], [0, 0.13]

Table 10: Shapley value weight of the first-level index.

S	Φ_{C_s}	S	Φ_{C_s}	S	Φ_{C_s}	S	Φ_{C_s}	S	Φ_{C_s}
{1}	0.08	{4}	0.62	{1, 4}	0.76	{3, 4}	0.71	{1, 3, 4}	0.8
{2}	0.22	{1, 2}	0.326	{2, 3}	0.27	{1, 2, 3}	0.45	{2, 3, 4}	0.95
{3}	0.08	{1, 3}	0.149	{2, 4}	0.88	{1, 2, 4}	0.9	{1, 2, 3, 4}	1

MATLAB was used to solve (13) to obtain the optimal fuzzy measure:

$$\begin{aligned}&\mu(C_{11}) = \mu(C_{11}, C_{13}) = 0.5\mu(C_{12}) = \mu(C_{12}, C_{13}) = 0.4,\\&\mu(C_{13}) = 0.3,\\&\mu(C_{11}, C_{12}) = \mu(C_{11}, C_{12}, C_{13}) = 1.\end{aligned} \tag{19}$$

The Shapley weight value of attribute C_1 can be obtained from formula (6), as shown in Table 8.

Step 4: calculate the synthesis value of attribute C_1 of each scheme via the GS-IVIULCA aggregation operator. Repeat steps 3 and 4 to obtain the comprehensive value of all first-level indicators of each scheme, as shown in Table 9.

According to Table 9, the weight value of the first-level index can be obtained from model (7), as shown in Table 10.

Step 5: calculate the comprehensive IVIULN value of each scheme via the GS-IVIULCA aggregation operator:

$$\begin{aligned}F_A &= ([s_{4.7}, s_6], [0.71, 0.82], [0, 0.16,]),\\F_B &= ([s_{4.4}, s_{5.9}], [0.75, 0.85], [0, 0.14,]),\\F_C &= ([s_{5.3}, s_6], [0.72, 0.85], [0, 0.14,]).\end{aligned} \tag{20}$$

The expected functions of each scheme are calculated as follows:

$$\begin{aligned}E(F_A) &= 5.014,\\E(F_B) &= 4.403,\\E(F_C) &= 5.891.\end{aligned} \tag{21}$$

Step 6: sort the scheme synthesis values from high to low as follows:

$$F_C > F_A > F_B. \tag{22}$$

4.3. Robustness Test. In order to verify the rationality and superiority of this method, several other methods are used to perform a comparative analysis with the method in this paper.

Table 11: The ranking result.

Methods	Ranking result
OWA operator	$E(F_A) = 3.742 > E(F_C) = 3.431 > E(F_B) = 3.332$
Utility function	$E(F_C) = 4.146 > E(F_A) = 4.042 > E(F_B) = 3.921$
Choquet integral method	$E(F_C) = 3.23 > E(F_A) = 3.129 > E(F_B) = 2.932$
The new multiattribute group decision-making method	$E(F_C) = 5.891 > E(F_A) = 5.014 > E(F_B) = 4.403$

The OWA operator, as the most important cumulative operator, is essentially based on the fact that the increasing arrangement and weight of elements are only related to position. Since it was proposed by Professor Yager in 1988, the OWA operator has been extensively studied. Its definition is as follows [62]:

$$\mathrm{OWA}_w (a_1, a_2, \ldots, a_n) = \sum_{j}^{n} w_j b_j. \tag{23}$$

Dewancker obtained the utility value of the dimensionless evaluation index by using the utility function and then used the synthesis model for weighted synthesis to obtain the total evaluation value [63]. Büyüközkan applied the Choquet integral to project bid risk assessment. The attribute weights and attribute evaluation values were all calculated by experts using the Choquet integral after the fuzzy language was given [64].

Next, the OWA operator, utility function, and Choquet integral method were used to conduct the comprehensive evaluation of the scheme and compare it with the evaluation results of the article (see Table 11 for the ranking results).

It can be seen from Table 11 and Figure 4 that the sorting result based on the additive measure OWA operator is different from that of our method. There are two main reasons for this: one reason is that the additive measure does not consider the interaction between attributes, and the other reason is that the two methods are different in how they determine the attribute weights. The influence mechanism of the interaction between indexes is as follows. The interaction between indexes will directly affect the weight difference of indexes. If there is a strong interaction between the indicators, then the weight of each indicator will be roughly the same, and the key influencing factors cannot be identified. As a result, the evaluation value of each program is not differentiated enough, and the evaluation results cannot give decision makers more persuasive power.

The utility function is too small for scheme differentiation. The determination of the Choquet integral attribute weight is quite arbitrary and subject to the influence of experts. In this paper, the generalized Shapley function is used to determine the weights of the attributes, and the interaction between the attributes is fully considered. By comparing the evaluation results of the improved method with those of the traditional OWA operator method, utility function method, and Choquet integral method, it can be seen that the degree of the difference of evaluation results obtained by the improved method in this paper is significantly higher than that of the traditional method. It can be seen from Figure 4 that the scheme's discrimination is also very obvious.

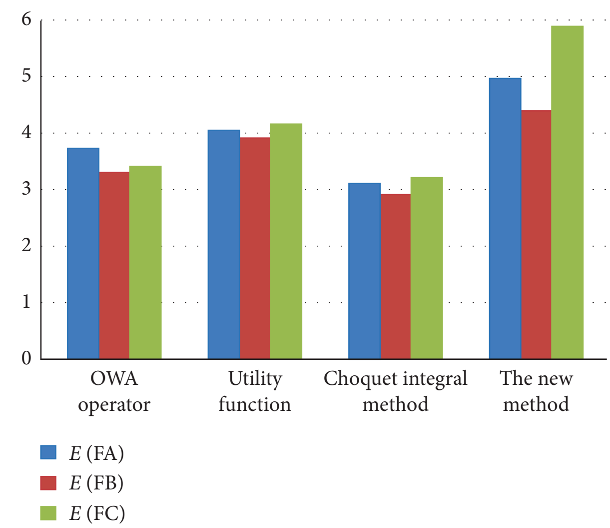

Figure 4: Bar chart comparison results.

Compared with the traditional fuzzy comprehensive evaluation methods (the AHP method and OWA operator), the proposed method not only considers the interaction between indicators but also considers the interaction between indicator weights, which is a generalization and application of traditional multiattribute group decision making. Although only three experts are listed in the example section of this paper, the new decision-making method proposed in this paper is also applicable to the situation where multiple experts make decisions, and the calculation steps are similar to the example in this paper.

5. Discussion

According to the results shown in Step 6, $E(F_C) = 5.891 > E(F_A) = 5.014 > E(F_B) = 4.403$; therefore, scheme C is the best choice, namely, the engineering construction scheme of the Renchuang Technology Group is the best solution. One reason is that the company's program has higher evaluations for the indexes of C_2 (flood storage capacity) and C_4 (rainwater collection and utilization) than other programs. It can be seen from Table 9 that the comprehensive evaluation values of Scheme C in the first-level indicators C_2 ([$s_{5.5}$, $s_{6.6}$],[0.71, 0.85],[0.13, 0.14]) and C_4 ([$s_{5.3}$, $s_{5.9}$],[0.71, 0.86],[0, 0.13]) are higher than the comprehensive evaluation values of schemes A and C on indicators C_2 and C_4, respectively.

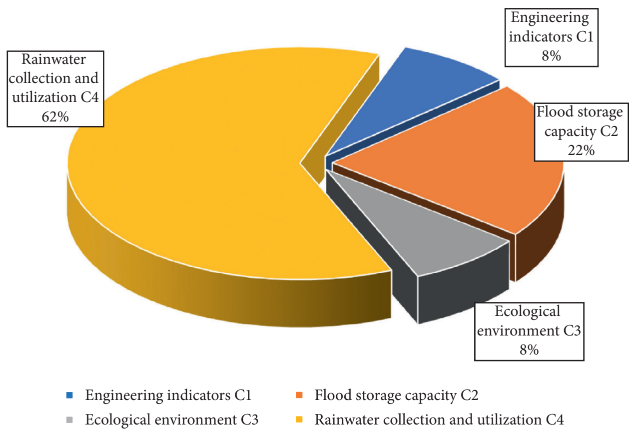

Figure 5: Shapley weight pie chart of the first-level indexes.

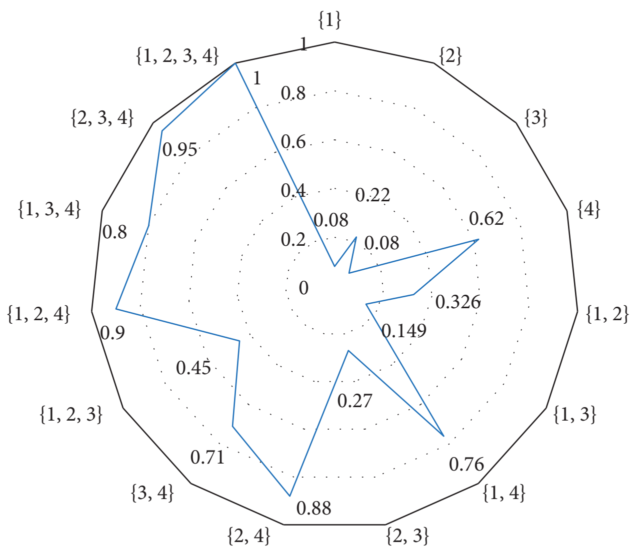

Figure 6: Combined weight radar chart.

Meanwhile, the Shapley weight values of the first-level indicators in Table 10 are represented by the pie chart in Figure 5. Another reason that can be obtained from Figure 5 is that the Shapley weight values of indicators C_2 and C_4 are $\Phi_{c_2} = 0.22$ and $\Phi_{c_4} = 0.62$, respectively, which are much larger than C_1 ($\Phi_{c_1} = 0.08$) and C_3 ($\Phi_{c_3} = 0.08$). The results show that the weight of index C_4 (rainwater collection and utilization) is the largest, which indicates that decision makers pay more attention to ecological and environmental benefits in the sponge city construction process.

Note: the combined weight is Φ_{C_S}, where S represents the index weight combination scheme.

In addition, the Shapley weight value of the first-level indicators and their combined weights in Table 10 are represented as a radar chart in Figure 6, and it can be observed that the single indicators $\Phi_{C_{\{2\}}} = 0.22$ and $\Phi_{C_{\{4\}}} = 0.62$ are much larger than $\Phi_{C_{\{1\}}}$ and $\Phi_{C_{\{3\}}}$. The combined weight $\Phi_{C_{\{2,4\}}}$ is much higher than the combined weight of the other two indexes. The combined weights of the three indexes include $\Phi_{C_{\{1,2,4\}}} = 0.9$ and $\Phi_{C_{\{2,3,4\}}} = 0.95$, which are also relatively high. The combination of the weights of indexes C_2 and C_4 is also the largest. This also proves that ecological benefits and social benefits have a strong mutual promotion effect, as shown in Figure 2. The results of this paper indicate that more consideration should be given to the influence of indexes C_2 (flood storage capacity) and C_4 (rainwater collection and utilization) in the selection of sponge city schemes. Therefore, these results are consistent with the characteristics that sponge cities should pay attention to flood control and rainwater collection and utilization in rainstorm weather [65, 66].

After the above discussion, one of the most important design features of a sponge city is that it must be able to store and use rainwater similar to a sponge. It must have good "elasticity" in adapting to environmental changes and responding to natural disasters. When it rains, a sponge absorbs water, stores water, percolates water, and purifies water and then it releases and uses the stored water when necessary. Sponge city construction should follow the principle of ecological priority, combine natural approaches with artificial measures, and maximize the accumulation, infiltration, and purification of rainwater in urban areas. This occurs under the premise of ensuring the safety of urban drainage and waterlogging prevention so as to promote the utilization of rainwater resources and the protection of the ecological environment. In the sponge city construction process, it is necessary to coordinate the systems of natural precipitation, surface water, and groundwater; coordinate the water recycling and utilization links such as water supply and drainage; and consider the sponge city's complexity and long-term nature.

6. Conclusion and Future Work

The sponge city construction scheme is a typical multi-attribute group decision-making problem. The research shows that the application of the GS-IVIULCA operator and Shapley function can provide objective and scientific rational guidance in the implementation scheme decision making of large-scale engineering projects. The index system established in this paper and the multiattribute group decision-making method can be applied to most large engineering project decision-making problems, especially when it involves fuzzy attribute indexes that are difficult to accurately quantify.

-The new multiattribute group decision-making method is verified by the empirical analysis in this research. The use of interval uncertainty language for evaluation avoids the lack of information and reflects people's hesitation in making decisions. Using information entropy and Shapley function to determine the weight of index attributes overcomes the interference of the interaction between indexes in traditional multiattribute group decision making. The nonadditive measure and GS-IVIULCA operator are used to calculate the comprehensive evaluation value of the scheme, and the interaction between the index attributes is considered to make the evaluation result more objective and persuasive. Finally, through the comparative analysis of the calculation results of different decision comparison methods, it can be seen that the decision results of this method have obvious differences. The weight of each indicator has a higher degree of differentiation, and the calculation results are more convincing, which can guide decision makers to form more scientific decision-making ideas.

Through the analysis of the empirical research results, the weight of the ecological environment index is higher than that of engineering projects. The results show that the weight of the rainwater collection and utilization index is the largest, which indicates that decision makers pay more attention to ecological and environmental benefits in the sponge city construction process.

In future research, as an effective decision-making method, multiattribute decision making will be developed and researched in more application fields. In particular, the method proposed in this paper will help decision makers to make decisions more scientifically and rationally under circumstances with uncertain information, high ambiguity, and a lack of data. It is worth further exploring whether the current research on fuzzy sets has reached the stage of being combined with language. Some scholars have proposed new evaluation methods, such as interval uncertain language sets and interval intuitive uncertain language sets. It is believed that fuzzy sets will make greater contributions to the evaluation of future schemes.

Data Availability

The data are from expert questionnaires. The standardized data can be found in Appendix.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

Guoqing Bai was responsible for conceptualization, methodology, software, validation, investigation, data curation, original draft preparation, and review and editing. Hua Dong reviewed and edited the manuscript. Yuanying Chi was responsible for formal analysis and supervision.

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