Reasonable utilization and study of rainwater in semiarid area

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Abstract. The important way to improve productivity and realize sustainable development in semi-arid area is to utilize rainwater, this paper takes Fengxi New Town as an example, comprehensively uses the Analytic Hierarchy Process (AHP) and fuzzy comprehensive evaluation method to comprehensively evaluate and analyze the utilization benefit of rainwater. The results show that the weight of rainwater utilization benefit is ecological benefit > economic benefit > Social benefits benefit; the strategy of efficient utilization of rainwater in semi-arid area is put forward.

1. Introduction
The problem of water shortage is the main challenge facing the semi-arid areas. Many countries and regions are constantly trying to explore how to better solve or to some extent alleviate the problem of water shortage in the arid areas. Rational utilization of rainwater resources can solve the problem of water shortage in semi-arid areas to a certain extent. Therefore, this paper, taking Fengxi New City as an example, combined with the analytic hierarchy process and fuzzy comprehensive evaluation method to evaluate the comprehensive benefits of rainwater utilization. On this basis, relevant strategies of rainwater utilization in Fengxi New City were put forward, in order to provide reference for rainwater utilization and sustainable development in semi-arid areas.

2. Research methods

2.1. Overview of the study area
Fengxi New City in the study area belongs to the temperate continental monsoon semi-arid and sub-humid climate zone and has the hydrogeological characteristics of less rainfall, lack of water resources, more sandy soil layer, and higher soil permeability coefficient. At present, in some areas of Fengxi New City, a 4-level rainwater comprehensive utilization system has been constructed, which is composed of landscape green space, municipal road, building community and ecological stormwater storage system.

2.2. Evaluation method

2.2.1. Analytic hierarchy process. Analytic Hierarchy Process (AHP) is to decompose a problem into different components and build a multi-level analysis model based on the relevance and affiliation of each factor [1]. In this study, the evaluation index of rainwater utilization efficiency in Fengxi New City was analyzed by AHP, and the weight of each evaluation index factor was calculated.
2.2.2. Fuzzy comprehensive evaluation method. Fuzzy comprehensive evaluation is a comprehensive evaluation based on the membership theory of fuzzy mathematics, considering various factors related to the evaluated thing [2]. According to the weight obtained by the analytic hierarchy process, it is evaluated by fuzzy comprehensive evaluation method.

2.2.3. The construction of evaluation index system. Through the investigation and analysis of rainwater utilization theory and experts' research experience [3], the latitude was divided according to the "Socio-Economic-Environment" in the thematic framework of the urban sustainability indicator set [4], the corresponding evaluation index system is constructed. As show in Fig. 1.

![Evaluation index system model of rainwater utilization benefit](image)

**Figure 1.** Evaluation index system model of rainwater utilization benefit

2.2.4. Determine the weight of evaluation index. In this paper, experts were first interviewed and questionnaires were issued to determine the importance of each evaluation index, and pairwise comparisons were made among the factors within the hierarchy to establish a first-level judgment matrix for the evaluation index of rainwater utilization, as shown in Table 1.

After calculation, the maximum eigenvalue is \( \lambda_{\text{max}} = 3.004 \); the eigenvector is \((1.744, 0.927, 0.329)\); the matrix weight vector is \((0.581, 0.309, 0.110)\); Consistency check: \( CI = (\lambda_{\text{max}} - n)/(n - 1) = 0.002 \), Query random consistency metrics: \( RI = 0.58 \); \( CR = CI/RI = 0.003 < 0.1 \) [4], the judgment matrix in this study meets the consistency test, and the weight calculated is consistent.

**Table 1.** First order judgment matrix

| Level indicators | Social benefits | Social benefits | Social benefits |
|------------------|----------------|----------------|----------------|
| Social benefits  | 1              | 2              | 5              |
| Social benefits  | \( 1/2 \)       | 1              | 3              |
| Social benefits  | \( 1/5 \)       | \( 1/3 \)      | 1              |
In the same way, it can be concluded that: the judgment matrix of the second-level evaluation index of economic benefit and social benefit, and the six third-level judgment matrix of improving the ecological environment, etc., and the CR value obtained through a series of calculations is all less than 0.1, which meets the consistency test. The statistical results of weight calculation of rainwater utilization benefit evaluation indexes are shown in Table 2.

Table 2. Evaluation index weight of rainwater utilization benefit

| target layer | Evaluate item layer | Evaluation index layer | Evaluate factor layer | Global weight |
|--------------|---------------------|------------------------|----------------------|---------------|
| B1 Ecological benefits (0.581) | C1 Improving the ecological environment (0.333) | Increasing biodiversity (0.118) | 0.023 |
| | | Purify air (0.201) | 0.039 |
| | | Microclimate regulation (0.681) | 0.132 |
| | C2 Water conservation (0.667) | Purifying water quality (0.750) | 0.291 |
| | | Replenish soil moisture (0.250) | 0.097 |
| B2 Economic benefits (0.309) | C3 Direct economic value (0.750) | Save water expenditure (0.141) | 0.033 |
| | | Save municipal investment (0.334) | 0.077 |
| | | Develop efficient agriculture (0.525) | 0.122 |
| | C4 Indirect economic value (0.250) | Promote industrial development (0.167) | 0.013 |
| | | Promote innovative industries (0.833) | 0.064 |
| B3 Social benefits (0.110) | C5 Promote urban development (0.800) | Alleviating water shortages (0.073) | 0.006 |
| | | Recharge ground water (0.494) | 0.043 |
| | | Reducing flood hazards (0.157) | 0.014 |
| | | Lower drainage pressure (0.276) | 0.024 |
| | C6 Improving people's lives (0.200) | Water conservation education (0.082) | 0.002 |
| | | public participation (0.603) | 0.013 |
| | | Improve quality of life (0.315) | 0.007 |

2.2.5. Fuzzy comprehensive evaluation and analysis. According to the classification of semantic scale, the evaluation results of rainwater utilization efficiency are divided into five grades [5]. For the convenience of statistics and calculation, the subjective evaluation of rainwater utilization benefit is respectively assigned with values of 5, 4, 3, 2 and 1 for quantification, as shown in Table 3.

Table 3. Evaluate the quantitative classification criteria

| value        | comments       | grading |
|--------------|----------------|---------|
| X > 4.5      | Very good      | I level |
| 3.5 < X ≤ 4.5| better         | II level|
| 2.5 < X ≤ 3.5| general        | III level|
| 1.5 < X ≤ 2.5| More bad       | IV level|
| X ≤ 1.5      | Very poor      | V level |

A total of 1000 questionnaires were sent out, a total of 986 valid interviews and questionnaires were collected after statistics. Calculate the evaluation results of each index factor, as shown in Table 4.
Table 4. Evaluation results and score statistics of rainwater utilization efficiency index

| Evaluation index                     | Very good | better | general | More bad | Very poor | score |
|--------------------------------------|-----------|--------|---------|----------|-----------|-------|
| Increasing biodiversity              | 0.2       | 0.3    | 0.3     | 0.1      | 0.1       | 3.4   |
| Purify air                           | 0.1       | 0.3    | 0.3     | 0.2      | 0.1       | 3.1   |
| Microclimate regulation              | 0.2       | 0.3    | 0.4     | 0.1      | 0.0       | 3.6   |
| Purifying water quality              | 0.3       | 0.2    | 0.2     | 0.3      | 0.0       | 3.5   |
| Replenish soil moisture              | 0.5       | 0.4    | 0.1     | 0.0      | 0.0       | 4.4   |
| Save water expenditure               | 0.1       | 0.2    | 0.2     | 0.3      | 0.2       | 2.7   |
| Save municipal investment            | 0.1       | 0.1    | 0.2     | 0.3      | 0.3       | 2.4   |
| Develop efficient agriculture        | 0.1       | 0.1    | 0.3     | 0.3      | 0.2       | 2.6   |
| Promote industrial development       | 0.1       | 0.2    | 0.4     | 0.2      | 0.1       | 3.0   |
| Promote innovative industries        | 0.2       | 0.3    | 0.3     | 0.1      | 0.1       | 3.4   |
| Alleviating water shortages           | 0.3       | 0.3    | 0.2     | 0.1      | 0.1       | 3.6   |
| Recharge ground water                | 0.4       | 0.2    | 0.3     | 0.1      | 0.0       | 3.9   |
| Reducing flood hazards                | 0.2       | 0.1    | 0.4     | 0.2      | 0.1       | 3.1   |
| Lower drainage pressure               | 0.2       | 0.2    | 0.2     | 0.2      | 0.1       | 3.2   |
| Water conservation education          | 0.3       | 0.4    | 0.2     | 0.1      | 0.0       | 3.9   |
| public participation                  | 0.2       | 0.2    | 0.5     | 0.1      | 0.0       | 3.5   |
| Improve quality of life               | 0.2       | 0.4    | 0.3     | 0.1      | 0.0       | 3.7   |

The weighted average operator is used in this study $M(\oplus)$ to study the [6]. The compound operation of $A1$ and $R1$ and the normalization of membership degree are performed. The first-level fuzzy comprehensive evaluation vector of improving ecological environment:

$$B_1 = A_1 \circ R_1 = (0.118, 0.201, 0.681)
\begin{pmatrix}
0.2 & 0.3 & 0.3 & 0.0 & 0.1 \\
0.1 & 0.3 & 0.3 & 0.2 & 0.1 \\
0.2 & 0.3 & 0.4 & 0.1 & 0
\end{pmatrix}
= (0.180, 0.300, 0.368, 0.120, 0.032)$$

Grade I fuzzy comprehensive evaluation score of ecological environment improvement:

$$V_1 = 0.180 \times 5 + 0.300 \times 4 + 0.368 \times 3 + 0.12 \times 2 + 0.032 \times 1 = 3.476$$

Similarly, it can be concluded that the first level fuzzy comprehensive evaluation vector and score of water conservation are respectively: $B_2 = (0.350, 0.250, 0.175, 0.225, 0), V_2=3.725$. The first level fuzzy comprehensive evaluation vectors and scores of the other four indicators were obtained by the same method.

Table 5. Evaluation and grading of rainwater benefit index

| target layer                      | C and grading                                      | D and grading                                      |
|-----------------------------------|----------------------------------------------------|----------------------------------------------------|
| B1 Ecological benefits (3.641II)  | C1 Improving the ecological environment (3.476III) | Increasing biodiversity (3.400III)                  |
|                                   | C2 Water conservation (3.725II)                   | Purify air (3.100III)                              |
| B2 Economic benefits (2.744III)   | C3 Direct economic value (2.548III)               | Microclimate regulation (3.600II)                  |
|                                   | C4 Indirect economic value (3.332III)             | Purifying water quality (3.500III)                 |
| B3 Social benefits (3.610II)      | C5 Promote urban development (3.559II)            | Replenish soil moisture (4.400II)                  |
| Evaluation of rainwater utilization benefit (3.361III) |                                   | Save water expenditure (2.700III)                |
|                                   | C 6 Improving people's lives (3.592II)            | Save municipal investment (2.400IV)                |
|                                   |                                                   | Develop efficient agriculture (2.600III)           |
|                                   |                                                   | Promote industrial development (3.000III)          |
|                                   |                                                   | Promote innovative industries (3.400III)           |
|                                   |                                                   | Alleviating water shortages (3.600II)              |
|                                   |                                                   | Recharge ground water (3.900II)                    |
|                                   |                                                   | Reducing flood hazards (3.100III)                  |
|                                   |                                                   | Lower drainage pressure (3.200III)                 |
|                                   |                                                   | Water conservation education (3.900II)             |
|                                   |                                                   | public participation (3.500III)                     |
|                                   |                                                   | Improve quality of life (3.700II)                   |
Similarly, it can be concluded that: the second-level fuzzy comprehensive evaluation vector and score of economic benefit and social benefit, and then the evaluation score of rainwater utilization can be obtained according to the second step. The evaluation score and grading of each index of rainwater utilization benefit are shown in Table 5.

3. Results analysis
Being western new city rainwater utilization comprehensive benefit evaluation score of 3.361 minutes, is III (generally) level. In layer B evaluation project, ecological (3.641) and social benefit is relatively high, the score of (3.610) (better) standard for II level; the score of economic efficiency (2.744). Relatively low, a category III (generally) standards.

4. Advice
According to the above analysis and research results, the following suggestions are put forward for the efficient utilization of rainwater in semi-arid areas:

4.1. Ecological strategies for rainwater utilization
By increasing urban green space area and improving its quality, it can better provide good ecological habitat environment for other organisms. It is of great significance for the utilization of rainwater resources, reducing carbon balance and reducing urban heat island effect to take natural ways such as increasing green space and vegetation as the ecological measures for rainwater collection and utilization.

4.2. Economic strategies for rainwater utilization
Through the rainwater pipe network to collect the rainwater, and then after unified treatment into the sewage treatment plant, classification treatment, after a simple primary treatment to meet the municipal water quality requirements, can be used for municipal construction water; After multi-level depth, to meet the requirements of water quality, can be used for People's Daily life water.

4.3. Social strategies for rainwater utilization
In urban landscape design, landscape pieces such as sculpture, characteristic water body and entertainment facilities are combined with the concept of rainwater collection and utilization, so that rainwater collection and utilization actually happen around people, so that people can "see, touch and learn", and urge people to "want to do it, actively do it and happily do it".

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