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Fuzzy MCDM approach for selecting the best environment-watershed plan

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ABSTRACT

In the real word, the decision-making problems are very vague and uncertain in a number of ways. Most of the criteria have interdependent and interactive features, so they cannot be evaluated by conventional measure method. Such as the feasibility, thus, to approximate the human subjective evaluation process, it would be more suitable to apply a fuzzy method in the environment-watershed plan topic. This paper describes the design of a fuzzy decision support system in multi-criteria analysis approach for selecting the best plan alternatives or strategies in environment watershed. The fuzzy analytic hierarchy process (FAHP) method is used to determine the preference weightings of criteria for decision makers by subjective perception (natural language). A questionnaire was used to find out from three related groups comprising 15 experts, including 5 from the university of expert scholars (include Water Resources Engineering and Conservation, Landscape and Recreation, Urban Planning, Environment Engineering, Architectural Engineering, etc.), 5 from the government departments, and 5 from industry. Subjectivity and vagueness analysis is dealt with the criteria and alternatives for selection process and simulation results by using fuzzy numbers with linguistic terms. It incorporated the decision-makers' attitude towards the preference; overall performance value of each alternative can be obtained based on the concept of fuzzy multiple-criteria decision-making (FMCDM). This research also gives an example of evaluation consisting of five alternatives, solicited from an environment-watershed plan work in Taiwan, is illustrated to demonstrate the effectiveness and usefulness of the proposed approach. The result is useful for destination planning and the sustainability of watershed tourism resources as well.

1. Introduction

Ordinary selection and evaluation of the environment-watershed plan considering various criteria is a multiple-criteria decision-making (MCDM) process and then it is a popular approach to decision analysis in the watershed management, use and plan [1–4]. However, in the past, many precision-based methods of MCDM for evaluating/selecting alternatives have been developed. These methods have been widely used in various fields such as location selection, information project selection, material selection, management decisions, strategy selection, and problems relating to be decision-making [5–7]. In the last few years, numerous attempts to handle this uncertainty, imprecision and subjectiveness have been carried out basically by fuzzy set theory, and the applications of fuzzy set theory to multi-criteria evaluation methods under the framework of utility theory have proven to be an effective approach [8,7,9].

When in initiating the best environment-watershed plan project, most government departments must consider life, produce ecologic environment engineering services in order to develop the preliminary plans and the associated details. In a project life cycle, this best plan phase is most critical to project success. Yet, when a best plan alternative is selected, most environment-watershed plan of government department owners is to lack the ability of effec-

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tively evaluating the candidates. Substandard the best plan work is often a direct result of inadequate tender selection.

For the best plan or government authorities, plan engineering not only acquires nice planning and design but also good plan to achieve the three goals for planning management with high efficiency and high quality: Firstly, the evaluation criteria are generally multiple and often structured in multilevel hierarchies; secondly, the evaluation process usually involves subjective assessments by perception, resulting in the use of qualitative and fallacious data; thirdly, other related interest groups' input for the best plan alternative selection process should be considered.

The analytic hierarchy process (AHP) method is widely used for multiple-criteria decision-making (MCDM) and has successfully been applied to many practical decision-making problems [10]. In spite of its popularity, the method is often criticized for its inability to adequately handle the inherent uncertainty and imprecision associated with the mapping of a decision-maker's perception to crisp numbers. The empirical effectiveness and theoretical validity of the AHP have also been discussed by many authors [11,12], and this discussion has focused on four main areas: the axiomatic foundation, the correct meaning of priorities, the 1–9 measurement scale and the rank reversal problem. However, most of the problems in these areas have been partially resolved, at least for three-level hierarchic structures [13]. It is not our intention to contribute further to that discussion. Rather, the main objective of this paper is to propose a new approach to tackle uncertainty and imprecision within the prioritization process in the AHP, in particular, when the decision-maker's judgments are represented as fuzzy numbers or fuzzy sets. In the AHP, the decision problem is structured hierarchically at different levels, each level consisting of a finite number of elements.

However, in many cases the preference model of the human decision maker is uncertain and fuzzy and it is relatively difficult crisp numerical values of the comparison ratios to be provided by subjective perception. The decision maker may be subjective and uncertain about his level of preference due to incomplete information or knowledge, inherent complexity and uncertainty within the decision environment, lack of an appropriate measure or scale.

An effective evaluation procedure is essential in promoting decision quality for problem solving and a governmental agency must be able to respond to these problems and incorporate/solve them into the overall process. This study examines this group decision-making process and proposes a multi-criteria framework for the best plan alternative selection in the environment-watershed.

Fuzzy analytic hierarchy process (FAHP) and fuzzy multiple-criteria decision-making (FMCDM) analysis have been widely used to deal with decision-making problems involving multiple-criteria evaluation/selection of alternatives [14,15,12,16–23], have shown advantages in handling unquantifiable/qualitative criteria and obtained quite reliable results. Thus, this research applied fuzzy set theory to the managerial decision-making problems of alternative selection, with the intention of establishing a framework of incorporating FAHP and FMCDM, in order to help a government entity select the most appropriate plan candidate for environment-watershed improvement/investment.

This research uses the FAHP to determine the criteria weights from subjective judgments of decision-making domain experts. Since the evaluation criteria of the best plan have the diverse connotations and meanings, there is no logical reason to treat them, as if they are each of equal importance. Furthermore, the FMCDM was used to evaluate the synthetic performance for the best plan alternatives, in order to handle qualitative (such as natural language) criteria that are difficult to describe in crisp values, thus strengthen the comprehensiveness and reasonableness of the decision-making process.

The rest of this paper is organized as follows. Section 2 provides discussion on the establishment of a hierarchical structure for the best plan evaluation, and a brief introduction to FAHP and FMCDM methods. In Section 3, in order to demonstrate the applicability of the framework, we then examine an empirical case as an illustration to demonstrate the synthesis decision using integration of FAHP and FMCDM approach for environment-watershed plan. In Section 4 discussions are conducted. Finally concluding remarks are presented in Section 5.

2. The best plan environment-watershed measurements

The purpose of this section is to establish a hierarchical structure for tackling the evaluation problem of the best environment-watershed plan alternative. Multiple-criteria decision-making (MCDM) is an analytic method to evaluate the advantages and disadvantages of alternatives based on multiple criteria. MCDM problems can be broadly classified into two categories: multiple objective programming (MOP) and multiple-criteria evaluation (MCE) [24]. Since this study focuses mainly on the evaluation problem, the second category is emphasized. The typical multiple-criteria evaluation problem examines a set of feasible alternatives and considers more than one criterion to determine a priority ranking and improvement for alternative implementation. The contents include three subsections: building hierarchical structure of evaluation criteria, determining the evaluation criteria weights, and getting the performance value.

2.1. Building hierarchical structure of environment-watershed evaluation criteria

What is watershed? Component landform that commonly occurs in a watershed include steam channels, flood plains, stream terraces, alluvial valley bottoms, alluvial fans, mountain slopes, and ridge tops [17]. Environment-watershed plan measurements involve a number of complex factors, however, including engineering of management, ecological restoration, environmental construction, and environmental conservation issues. Once upon a time a plan dimension index could be based, simply, on the aggregate environment engineering of catastrophe rate for a period of time or landing cycles but this may be incomplete. Yeh and Lin [4] suggested that the merge of ecological engineering measures into the framework of watershed management becomes one of the most crucial research topics for our local authority institutions. At the moment, we need to consider many factors/criteria the environment-watershed plan index focused on catastrophe, human safety, comfortable, interest, ecological system and sustainable environment. Chen et al. [1] suggested the four dimensions and 26 criteria. While many studies provide useful methodology and models based on problem-solving procedures have been mainly applied to the field of environment-watershed plan management in Taiwan and the rest of the world for decades. A watershed plan, restoration and management have a specific hydrologic function and ecological potential. To inventory, evaluation and plan watershed restoration are based on geomorphic, hydrologic and ecological principles. That is nature approach to watershed plan that works with nature to restore degraded watershed [17]. The operation procedures of several key model components, participation of local community, utilization of geographical information systems, investigation and analysis of the ecosystem, habitat, and landscape, and allocation of ecological engineering measures, are illustrated in detail for better understanding on their values in the model [25,4]. In Austrian Danube case study, there are 12 alternatives and 33 criteria. The criteria include mainly three conflicting types of interest: economy, ecology and sociology. Apart

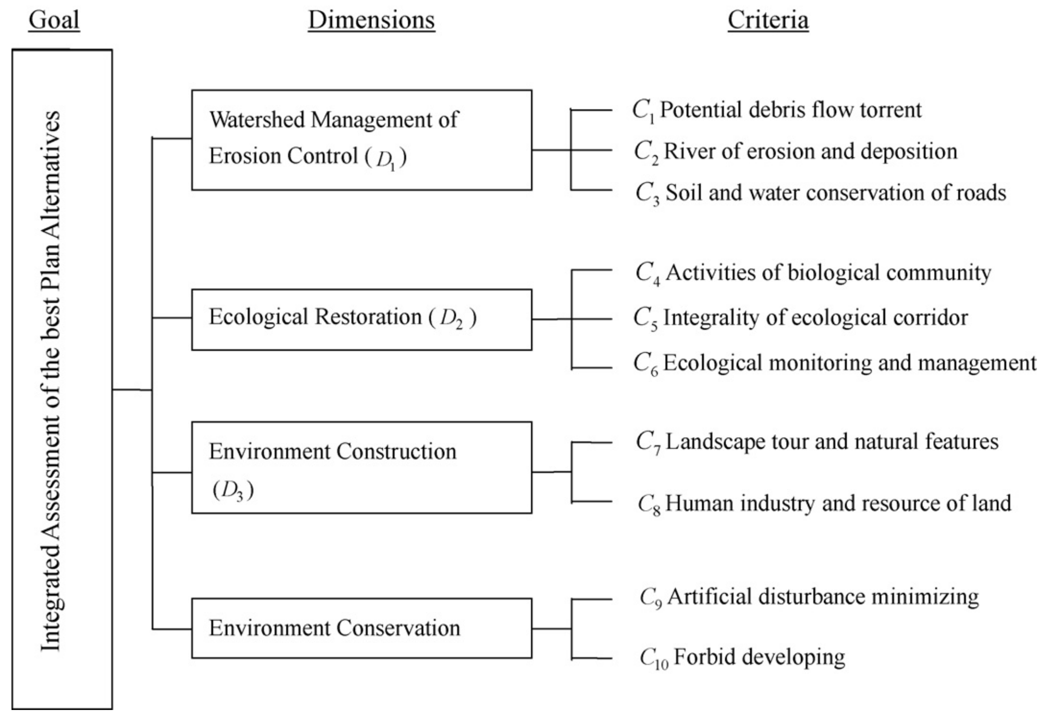

Fig. 1. The hierarchical structure for the best plan alternatives assessment.

from calamity, which still accounts for environment-watershed plan in nature catastrophe, engineering design error and incident data, maintenance, and operational deficiencies are typically cited as causes of plan failed. It has been suggested that "proactive" plan measures are instituted, especially during monitoring human-error-related engineering design error.

Environment-watershed problems in the world statistics describe from natural disasters and artificially jamming two levels, in the first the typhoon, torrential rain and earthquake cause the flood to overflow, violent perturbation of landslide, potential debris flow torrent and so on [2,3]. In addition the reason why space and water environmental demand increase in artificial disturbance because of population expansion, so that the changes of land pattern utilizing and terrain features, moreover carry out the transition of developing and also leading to the fact road water and soil conservation is destroyed, the environment falls in the destruction, biological habitat in destroyed, rivers and creeks of the quality had polluted, threatened fish species, loss of forest cover, erosion and urban growth, among other things. How can we do for solving environment-watershed problems? Firstly from the environment-watershed survey data found characteristic value to improve stabilize the river canal shape, increase the activities of biological community, habitat mold and regeneration, structure integrality of ecological corridor, and to create peripheral landscape and natural environment features, develop from tour facilities and resources of humane industry, repeat structure nature of beautiful

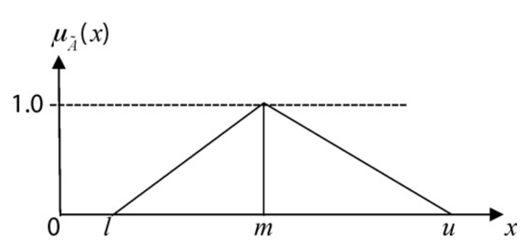

Fig. 2. The membership function of the triangular fuzzy number.

material, and in the environment-watershed of precipitous slope where the soil-stone flow outpost area and environment preserve against district are, it needs to minimize artificial disturbance or forbid development absolutely. In summarization, we need to consider intact factors/criteria, which have to enclose four dimensions and ten factors/criteria, i.e. including: (1) watershed management and erosion control, (2) ecological restoration, (3) environmental construction, and (4) environmental conservation. Based on these, 10 evaluation criteria for the hierarchical structure were to be used in our study.

The hierarchical structure adopted in this study to deal with the problems of plan assessment for environment-watershed as shown in Fig. 1.

2.2. Determining the evaluation criteria weights

Since the criteria of the best plan evaluation have diverse significance and meanings, we cannot assume that each evaluation criteria is of equal importance. There are many methods that can be employed to determine weights [24] such as the eigenvector method, weighted least square method, entropy method, AHP (analytic hierarchy process), and LINMAP (linear programming techniques for Multidimensional of Analysis Preference). The selection of method depends on the nature of problems. To evaluate the best plan is a complex and wide-ranging problem, so this problem requires the most inclusive and flexible method. Since the AHP was developed by Saaty [26,27], it is a very useful decision analysis tool in dealing with multiple-criteria decision problem, and has successfully been applied to many construction industry decision areas [11,28–30,12]. However, in operation process of applying AHP method, it is more easy and humanistic for evaluators to assess "criterion A is much more important than criterion B" than to consider "the importance of principle A and principle B is seven to one". Hence, Buckley [31] extended Saaty's AHP to the case where the evaluators are allowed to employ fuzzy ratios in place of exact ratios to handle the difficulty for people to assign exact ratios when comparing two criteria and derive the fuzzy weights

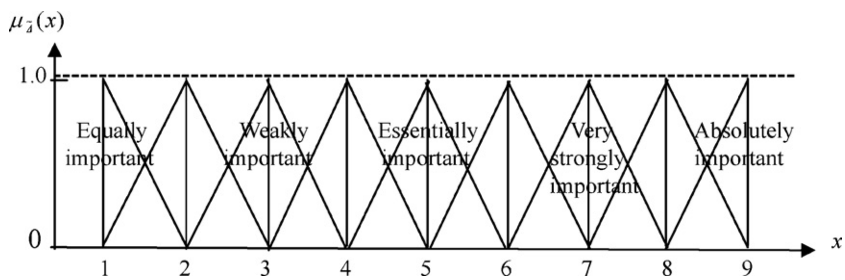

Fig. 3. Membership functions of linguistic variables for comparing two criteria (example).

of criteria by geometric mean method. Therefore, in this study, we employ Buckley's method, FAHP, to fuzzify hierarchical analysis by allowing fuzzy numbers for the pairwise comparisons and find the fuzzy weights. In this section, we briefly review concepts for fuzzy hierarchical evaluation.

2.2.1. Fuzzy number

Fuzzy numbers are a fuzzy subset of real numbers, representing the expansion of the idea of the confidence interval. According to the definition of Laarhoven and Pedrycz [32], a triangular fuzzy number (TFN) (Fig. 2) should possess the following basic features.

A fuzzy number $\tilde{A}$ on $\mathbb{R}$ to be a TFN if it is membership function $x \in \tilde{A}, \mu_{\tilde{A}}(x) : \mathbb{R} \to [0, 1]$ is equal to

$$\mu_{\tilde{A}}(x) = \begin{cases} (x-l)/(m-l), & l \le x \le m \\ (u-x)/(u-m), & m \le x \le u \\ 0, & \text{otherwise} \end{cases} \quad (1)$$

where l and u stand for the lower and upper bounds of the fuzzy number $\tilde{A}$, respectively, and m for the modal value (see Fig. 2). The TFN can be denoted by $\tilde{A} = (l, m, u)$ and the following is the operational laws of two TFNs $\tilde{A}_1 = (l_1, m_1, u_1)$ and $\tilde{A}_2 = (l_2, m_2, u_2)$.

- Addition of a fuzzy number $\oplus$:

$$\tilde{A}_1 \oplus \tilde{A}_2 = (l_1, m_1, u_1) \oplus (l_2, m_2, u_2) = (l_1 + l_2, m_1 + m_2, u_1 + u_2) \quad (2)$$

- Multiplication of a fuzzy number $\otimes$:

$$\tilde{A}_1 \otimes \tilde{A}_2 = (l_1, m_1, u_1) \otimes (l_2, m_2, u_2) = (l_1 l_2, m_1 m_2, u_1 u_2),$$
$$\text{for } l_1, l_2 > 0; \; m_1, m_2 > 0; \; u_1, u_2 > 0 \quad (3)$$

- Subtraction of a fuzzy number Θ:

$$\tilde{A}_1 \Theta \tilde{A}_2 = (l_1, m_1, u_1) \Theta (l_2, m_2, u_2) = (l_1 - u_2, m_1 - m_2, u_1 - l_2) \quad (4)$$

- Division of a fuzzy number $\varnothing$:

$$\tilde{A}_1 \varnothing \tilde{A}_2 = (l_1, m_1, u_1) \varnothing (l_2, m_2, u_2) = \left(\frac{l_1}{u_2}, \frac{m_1}{m_2}, \frac{u_1}{l_2}\right),$$
$$\text{for } l_1, l_2 > 0; \; m_1, m_2 > 0; \; u_1, u_2 > 0 \quad (5)$$

Table 1
Membership function of linguistic scales (example).

Fuzzy number	Linguistic scales	Scale of fuzzy number
$\tilde{1}$	Equally important (Eq)	(1,1,2)
$\tilde{3}$	Weakly important (Wq)	(2,3,4)
$\tilde{5}$	Essentially important (Es)	(4,5,6)
$\tilde{7}$	Very strongly important (Vs)	(6,7,8)
$\tilde{9}$	Absolutely important (Ab)	(8,9,9)

Note: This table is synthesized by the linguistic scales defined by Chiou and Tzeng [34] and fuzzy number scale used in Mon et al. [35].

- Reciprocal of a fuzzy number:

$$\tilde{A}^{-1} = (l_1, m_1, u_1)^{-1} = \left(\frac{1}{u_1}, \frac{1}{m_1}, \frac{1}{l_1}\right),$$
$$\text{for } l_1, l_2 > 0; \; m_1, m_2 > 0; \; u_1, u_2 > 0 \quad (6)$$

2.2.2. Linguistic variables

According to Zadeh [33], it is very difficult for conventional quantification to express reasonably those situations that are overtly complex or hard to define; so the notion of a linguistic variable is necessary in such situation. A linguistic variable is a variable whose values are words or sentences in a natural or artificial language. Here, we use this kind of expression to compare to build the best plan evaluation criteria by five basic linguistic terms, as "absolutely important," "very strongly important," "essentially important," "weakly important" and "equally important" with respect to a fuzzy five level scale (see Fig. 3) [34]. In this paper, the computational technique is based on the following fuzzy numbers defined by Mon et al. [35] in Table 1. Here each membership function (scale of fuzzy number) is defined by three parameters of the symmetric triangular fuzzy number, the left point, middle point, and right point of the range over which the function is defined. The use of linguistic variables is currently widespread and the linguistic effect values of the best plan alternatives found in this study are primarily used to assess the linguistic ratings given by the evaluators. Furthermore, linguistic variables are used as a way to measure the performance value of the best plan alternative for each criterion as "very good," "good," "fair," "poor" and "very poor". Triangular fuzzy numbers (TFN), as shown in Fig. 4 for an example, can indicate the membership functions of the expression values.

2.2.3. Fuzzy analytic hierarchy process

The procedure for determining the evaluation criteria weights by FAHP can be summarized as follows:

- **Step 1**: Construct pairwise comparison matrices among all the elements/criteria in the dimensions of the hierarchy system. Assign linguistic terms to the pairwise comparisons by asking

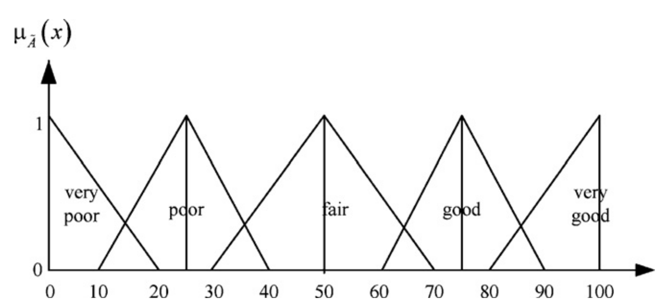

Fig. 4. Membership functions of linguistic variables for measuring the performance value of alternatives (example).

which is more important in each of the two elements/criteria, such as:

$$\tilde{A} = \begin{bmatrix} \tilde{1} & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ \tilde{a}_{21} & \tilde{1} & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \cdots & \tilde{1} \end{bmatrix} = \begin{bmatrix} \tilde{1} & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ 1/\tilde{a}_{21} & \tilde{1} & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/\tilde{a}_{n1} & 1/\tilde{a}_{n2} & \cdots & \tilde{1} \end{bmatrix} \quad (7)$$

where $\tilde{a}_{ij}$ measure denotes, let $\tilde{1}$ be (1,1,1), when i equal j (i.e. $i=j$); if $\tilde{1}, \tilde{2}, \tilde{3}, \tilde{4}, \tilde{5}, \tilde{6}, \tilde{7}, \tilde{8}, \tilde{9}$ measure that criterion i is relatively important to criterion j and then $\tilde{1}^{-1}, \tilde{2}^{-1}, \tilde{3}^{-1}, \tilde{4}^{-1}, \tilde{5}^{-1}, \tilde{6}^{-1}, \tilde{7}^{-1}, \tilde{8}^{-1}, \tilde{9}^{-1}$ measure that criterion j is relatively important to criterion i.

- **Step 2**: To use geometric mean technique to define the fuzzy geometric mean and fuzzy weights of each criterion by Buckley [31] as follows:

$$\tilde{r}_i = (\tilde{a}_{i1} \otimes \tilde{a}_{i2} \otimes \cdots \otimes \tilde{a}_{in})^{1/n},$$

$$\text{and then} \quad \tilde{w}_i = \tilde{r}_i \otimes (\tilde{r}_1 \otimes \cdots \otimes \tilde{r}_n)^{-1} \quad (8)$$

where $\tilde{a}_{in}$ is fuzzy comparison value of criterion i to criterion n, thus, $\tilde{r}_i$ is geometric mean of fuzzy comparison value of criterion i to each criterion, $\tilde{w}_i$ is the fuzzy weight of the ith criterion, can be indicated by a TFN, $\tilde{w}_i = (lw_i, mw_i, uw_i)$. Here lw_i, mw_i and uw_i stand for the lower, middle and upper values of the fuzzy weight of the ith criterion, respectively.

2.3. Fuzzy multiple-criteria decision-making

Bellman and Zadeh [36] were the first to probe into the decision-making problem under a fuzzy environment-watershed and they heralded the initiation of FMCDM. This analysis method has been widely used to deal with decision-making problems involving multiple-criteria evaluation/selection of alternatives. The practical applications reported in the literatures: weapon system evaluating [35], technology transfer strategy selection in biotechnology [37], optimization the design process of truck components [14], energy supply mix decisions [18], urban transportation investment alternatives selection [20], tourist risk evaluation [22], electronic marketing strategies evaluation in the information service industry [21], restaurant location selection [19], performance evaluation of distribution centers in logistics and bank prediction [8,38]. These studies show advantages in handling unquantifiable/qualitative criteria, and obtained quite reliable results. This study uses this method to evaluate the best plan alternatives performance and rank the priority for them accordingly. The following will be the method and procedures of the FMCDM theory.

2.3.1. Alternatives measurement

Using the measurement of linguistic variables to demonstrate the criteria performance/evaluation (effect-values) by expressions such as “very good,” “good,” “fair,” “poor,” “very poor,” the evaluators are asked for conduct their subjective judgments by natural language, and each linguistic variable can be indicated by a TFN within the scale range 0–100, as shown in Fig. 4. In addition, the evaluators can subjectively assign their personal range of the linguistic variable that can indicate the membership functions of the expression values of each evaluator. Take $\tilde{e}_{ij}^{k}$ to indicate the fuzzy performance/evaluation value of evaluator p towards alternative k under criterion i, and all of the evaluation criteria will be indicated by $\tilde{e}_{ki}^{p} = (le_{ki}^{p}, me_{ki}^{p}, ue_{ki}^{p})$. Since the perception of each evaluator varies according to the evaluator’s experience and knowledge, and the definitions of the linguistic variables vary as well, this study uses the notion of average value to integrate the fuzzy judgment values of q evaluators, that is,

$$\tilde{e}_{ki} = \left(\frac{1}{q}\right) \otimes (\tilde{e}_{ki}^{1} \oplus \cdots \oplus \tilde{e}_{ki}^{p} \oplus \cdots \oplus \tilde{e}_{ki}^{q}), \quad p = 1, 2, \ldots, q. \quad (9)$$

The sign $\otimes$ denotes fuzzy multiplication, the sign $\oplus$ denotes fuzzy addition, $\tilde{e}_{ki}$ shows the average fuzzy number of the judgment of the decision makers, which can be displayed by a triangular fuzzy number as $\tilde{e}_{ki} = (le_{ki}, me_{ki}, ue_{ki})$. The end-point values le_{ki}, me_{ki} and ue_{ki} can be solved by the method put forward by Buckley [31], that is,

$$le_{ki} = \frac{\sum_{p=1}^{q} le_{ki}^{p}}{q}; \qquad me_{ki} = \frac{\sum_{p=1}^{q} me_{ki}^{p}}{q}; \qquad ue_{ki} = \frac{\sum_{p=1}^{q} ue_{ki}^{p}}{q} \quad (10)$$

2.3.2. Fuzzy synthetic decision

The weights of the each criterion of building P&D evaluation as well as the fuzzy performance values must be integrated by the calculation of fuzzy numbers, so as to be located at the fuzzy performance value (effect-value) of the integral evaluation. According to the each criterion weight $\tilde{w}_i$ derived by FAHP, the criteria weight vector $\tilde{\boldsymbol{w}} = (\tilde{w}_1, \ldots, \tilde{w}_i, \ldots, \tilde{w}_n)^t$ can be obtained, whereas the fuzzy performance/evaluation matrix $\tilde{\boldsymbol{E}}$ of each of the alternatives can also be obtained from the fuzzy performance value of each alternative under n criteria, that is, $\tilde{\boldsymbol{E}} = (e_{ki})_{m \times n}$. From the criteria weight vector $\tilde{\boldsymbol{w}}$ and fuzzy performance matrix $\tilde{\boldsymbol{E}}$, the final fuzzy synthetic decision can be conducted, and the derived result will be the fuzzy synthetic decision vector $\tilde{\boldsymbol{e}} = (e_1, \ldots, e_k, \ldots, e_m)'$, that is,

$$\tilde{\boldsymbol{e}} = \tilde{\boldsymbol{E}} \otimes \tilde{\boldsymbol{w}} = \tilde{\boldsymbol{w}}' \otimes \tilde{\boldsymbol{E}}'. \quad (11)$$

The sign “$\otimes$” indicates the calculation of the fuzzy numbers, including fuzzy addition and fuzzy multiplication. Since the calculation of fuzzy multiplication is rather complex, it is usually denoted by the approximate multiplied result of the fuzzy multiplication and the approximate fuzzy number $\tilde{s}_i$, of the fuzzy synthetic decision of each alternative can be shown as $\tilde{e}_k = (le_k, me_k, ue_k)$, where ls_k, ms_k and us_k are the lower, middle and upper synthetic performance values of the alternative k respectively, that is:

$$le_k = \sum_{i=1}^{n} le_{ki} \times lw_i, \qquad me_k = \sum_{i=1}^{n} me_{ki} \times mw_i,$$
$$ue_k = \sum_{i=1}^{n} ue_{ki} \times uw_i. \quad (12)$$

2.3.3. Ranking the fuzzy number

The result of the fuzzy synthetic decision reached by each alternative is a fuzzy number. Therefore, it is necessary that a non-fuzzy ranking method for fuzzy numbers be employed for comparison of each of the best plan alternative. In other words, the procedure of defuzzification is to locate the Best Non-fuzzy Performance value (BNP) [16]. Methods of such defuzzified fuzzy ranking generally include mean of maximal (MOM), center of area (COA), and α-cut. To utilize the COA method to find out the BNP is a simple and practical method, and there is no need to bring in the preferences of any evaluators, so it is used in this study. The *BNP* value of the fuzzy number $\tilde{e}_k = (le_k, me_k, ue_k)$ can be found by the following equation:

$$BNP_k = le_k + \frac{(ue_k - le_k) + (me_k - le_k)}{3}, \quad \forall k. \quad (13)$$

According to the value of the derived *BNP* for each of the alternatives, the ranking of the best plan of each of the alternatives can then proceed.

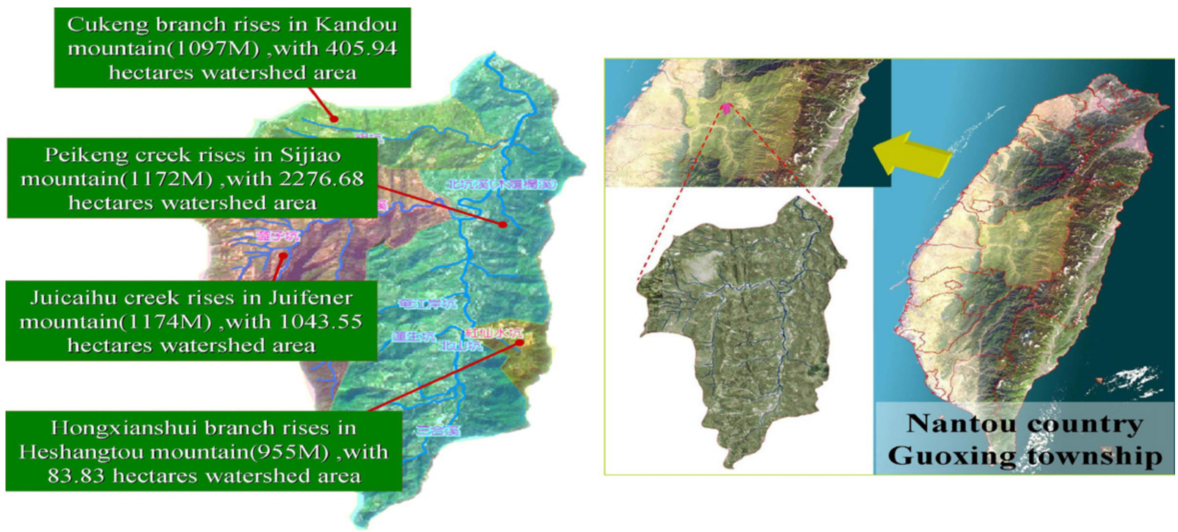

Fig. 5. Regional map of the Pei-Keng brook of catchments area.

3. An empirical case for selecting the best environment-watershed plan

When a government entity would like to construct a new environment watershed in Taiwan, it must follow sub-paragraph 9 of first paragraph, article 10 of the Government Procurement Law, to publicly and objectively select the best plan consultant company to provide professional services for follow-up to build environment watershed. Thus, this study used the previous case of the Pei-Keng Brook Environment-Watershed plan to exercise the process of engineering service tender selection.

The Pei-Keng brook catchments geography position is situated in the Guoxing town part of Nantou County, Taiwan (23°53′15″N–23°58′36″N, 120°49′15″E–120°53′01″E). With aids from geographical information system (GIS) and cover about 3810.21 ha, accounting for 46% of the total land area of the towns (Fig. 5). Within the boundaries mountain winds, presents the north and south long and narrow tendency, the brook flows from south to north, in the area the highest sierra is about approximately 1200 m, the lowest river valley elevation is about approximately 300 m, the average elevation is 686.96 m (Fig. 6). The entire district third-level slope reaches 56.83%, above the third-level slope accounts for

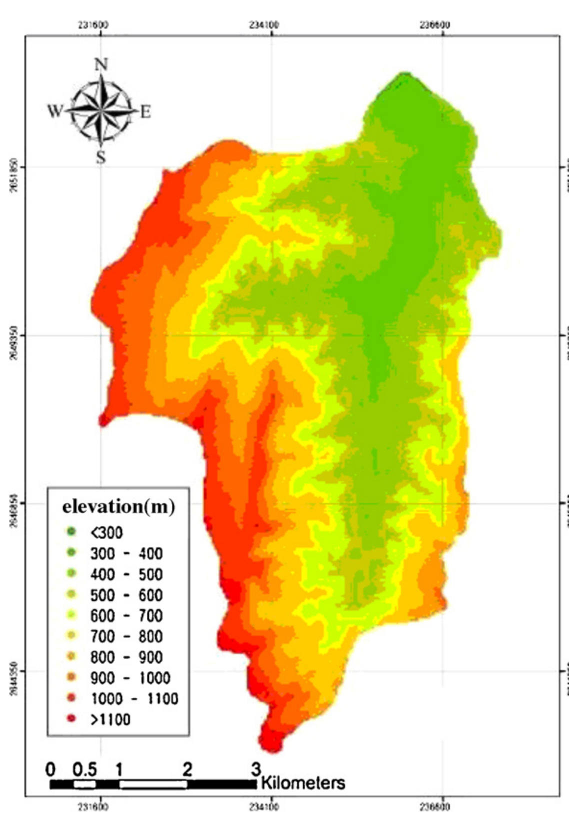

Fig. 6. High Cheng's distribution map of the Pei-Keng brook of catchment's area.

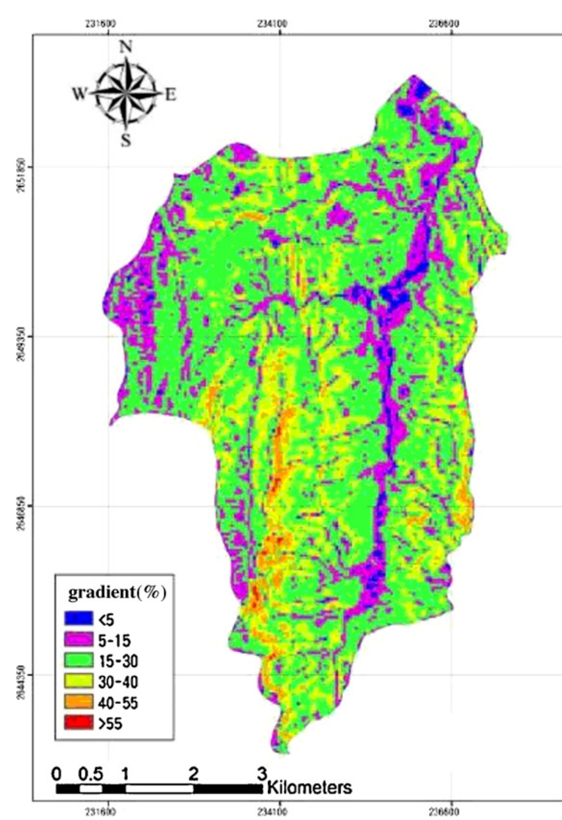

Fig. 7. Distribution map of the slope of the Pei-Keng brook of catchment's area.

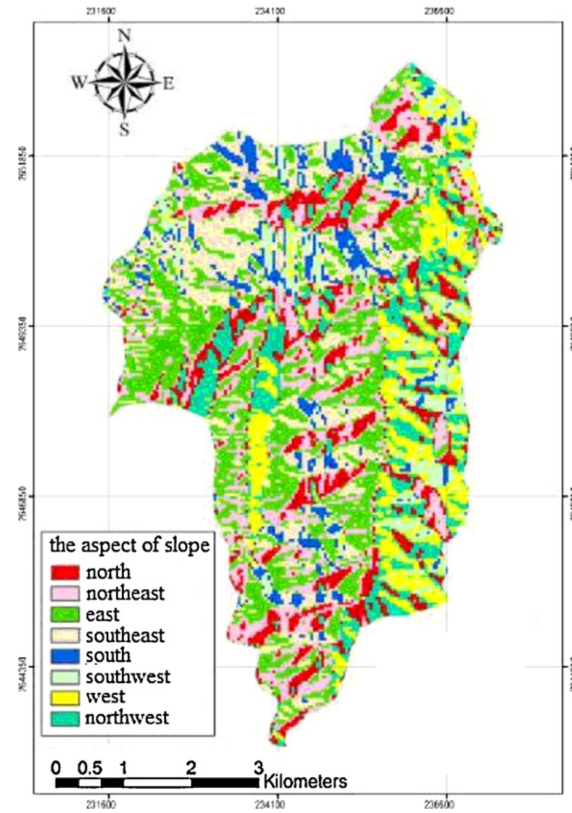

Fig. 8. The slope is to the distribution map of the Pei-Keng brook of catchment's area.

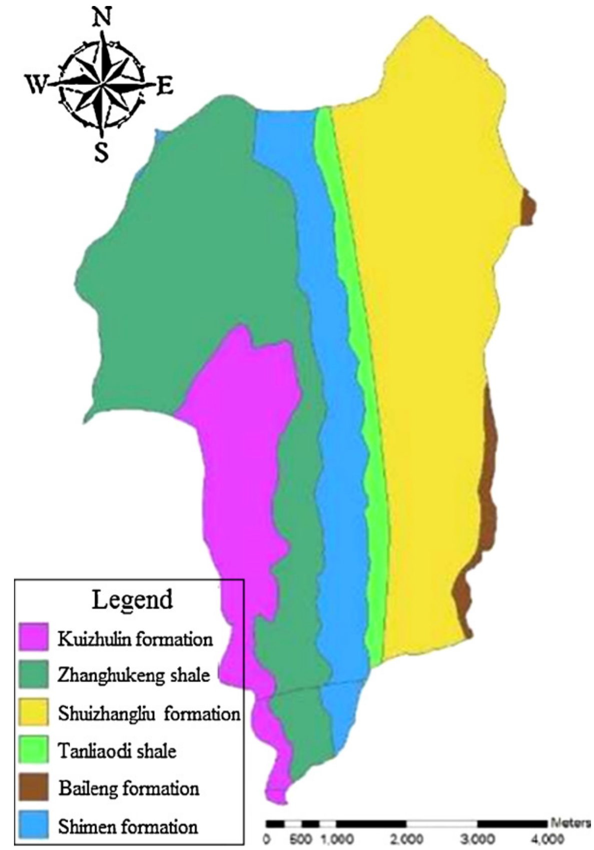

Fig. 9. Stratum distribution map of the Pei-Keng brook of catchment's area.

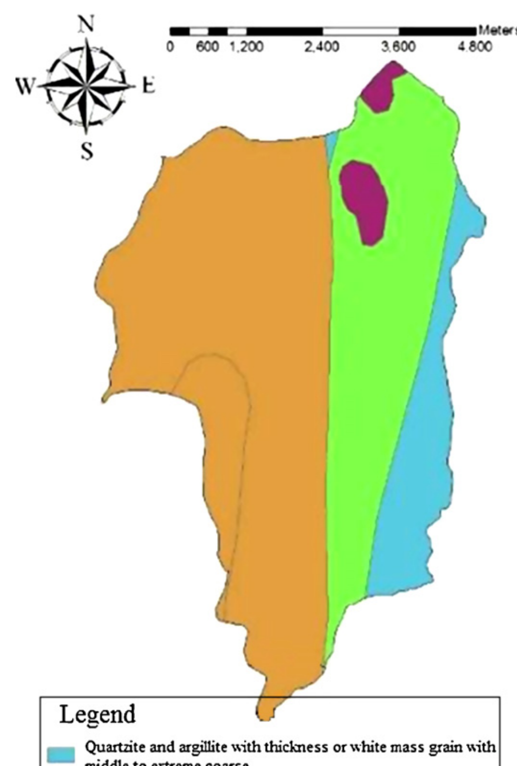

Fig. 10. Geological distribution map of the Pei-Keng brook of catchment's area.

77.95% (Fig. 7). The slope accounts are many of the easts for 22.14% (Fig. 8). Gather and fall and is located in gorges in the main countryside, surrounded by mountains on four sides. Collect the average width in water district about 4.5 km, length is about 9 km on average, and plan the major length in the area of about 11.2 km, it is about 1/11 that the average slope is lowered. With 'Kuizhulin formation' and 'Zhanghukeng shale' take heavy proportion most as 35.52% and 31.67%, respectively, stratum (Fig. 9). Geological structure Israel 'the Sandstone and Shale correlation, coal formation, include the coal seam' 57.49% (Fig. 10) in order to mainly take, have 'large cogon-grass Pu – a winter, fault of the hole in water' with the main fault. The soil makes up and relies mainly on the fact that 'Colluvial soils' accounts for 39.95% (Fig. 11).

In this case, five consultant companies submitted proposals for the new environment-watershed plan to the region authorities.

3.1. The weights calculation of the evaluation criteria

According to the formulated structure of the best plan alternatives evaluation, the weights of the dimension hierarchy and criterion hierarchy can be analyzed. The simulation process was followed by a series of interviews with three decision-making groups: domain experts (evaluators), including five from the university of expert scholars (include Water Resources Engineering and Conservation, Landscape and Recreation, Urban Planning, Environment Engineering, Architectural Engineering), five from the government departments, and five from industry. Weights were obtained by using the FAHP method; then the weights of each decision-making group and average weights were derived by geometric mean method suggested by Buckley [31]. The following example demonstrates the computational procedure of the weights of dimensions for domain experts:

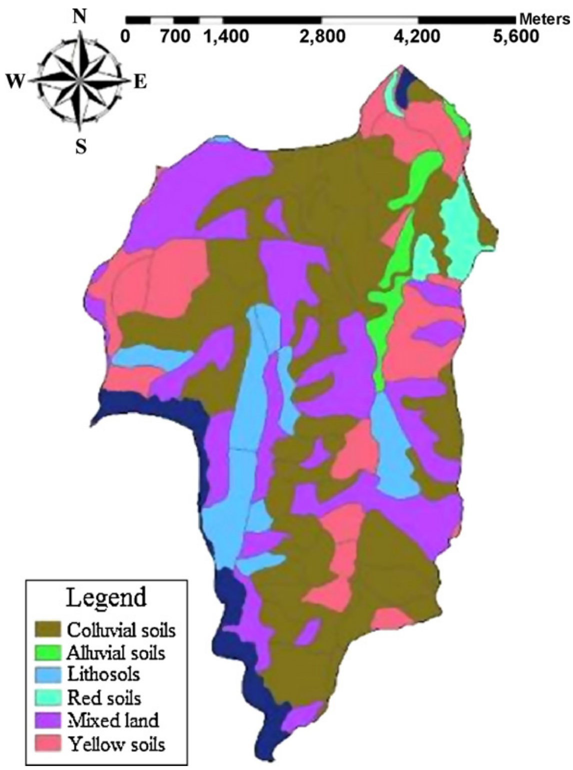

Fig. 11. Soil distribution map of the Pei-Keng brook of catchment's area.

(1) According to the interviews with domain experts about the importance of evaluation dimensions, then the pairwise comparison matrices of dimensions and computing the elements of synthetic pairwise comparison matrix by using the geometric mean method suggested by Buckley [31] that is: $\tilde{a}_{ij} = (\tilde{a}_{ij}^1 \otimes \tilde{a}_{ij}^2 \otimes \tilde{a}_{ij}^3 \otimes \tilde{a}_{ij}^4)^{1/4}$. It can be obtained the other matrix elements by the same computational procedure, therefore, the synthetic pairwise comparison matrices will be constructed and to use Eq. (8) the fuzzy weights of dimensions domain experts can be obtained as shown in Table 2.

(2) To employ the COA method to compute the *BNP* value of the fuzzy weights of each dimension: To take the *BNP* value of the weight of environment-watershed for domain experts.

Similarly, the weights for the remaining dimensions and criteria for domain experts can be found as shown in Table 3. However, we listed the final *BNP* value of them in Table 3.

Table 2
Weights of dimensions.

Dimensions	l	m	u
D_1: Watershed management of erosion control	0.144	0.352	0.559
D_2: Ecological restoration	0.190	0.454	0.718
D_3: Environment construction	0.059	0.103	0.147
D_4: Environment conservation	0.055	0.091	0.127

From the FAHP results, for the domain experts, we find the first two most important aspects are ecological restoration (0.454) and watershed management of erosion control (0.352); whereas the least important is environment conservation (0.091). These results indicate that the domain experts are worried about the ecological restoration in the environment-watershed, in addition, they also care about the watershed management of erosion control which will be considering the environment conservation.

3.2. Estimating the performance matrix

The evaluators can define their own individual range for the linguistic variables employed in this study according to their subjective judgments within a scale of 0–100 (Table 4) reveals a degree of variation in their definitions of the linguistic variables. It can be seen in the divergent understandings of the 3rd and 4th evaluator with respect to the same linguistic variable. For each evaluator with the same importance, this study employed the method of average value to integrate the fuzzy/vague judgment values of different evaluators regarding the same evaluation criteria. In other words, fuzzy addition and fuzzy multiplication are used to solve for the average fuzzy numbers of the performance values under each evaluation criterion shared by the evaluators for the five best plan alternatives.

For alternative A-1 as an example, the average fuzzy performance values of criterion-C01 (balance of site layout) from experts' judgment can be obtained as follows:

(1) The experts assigned their subjective judgments for A-1 under C01 by expressions "very good (VG)," "good (G)," "fair (F)," "poor (P)," "very poor (VP)" and corresponding to the linguistic variable of Table 4, it can obtain the fuzzy performance matrix $\tilde{e}_{ij}^k$, example e_{11}^k, $k = 1, 2, 3, 4, 5$:

$$\begin{bmatrix} \overset{e_{11}^1}{(10,30,50)} & \overset{e_{11}^2}{(60,70,80)} & \overset{e_{11}^3}{(23,36,65)} & \overset{e_{11}^4}{(80,100,100)} & \overset{e_{11}^5}{(75,80,90)} \end{bmatrix}$$

Table 3
Weights of dimensions and criteria for domain experts.

Dimensions and criteria	Local weights			Global weight			BNP (Normal)	
				l	m	u	Local	Global
Watershed management of erosion control	**0.144**	**0.352**	**0.559**				**0.352**	
Potential debris flow torrent	0.292	0.527	0.848	0.042	0.183	0.474	0.556	0.195
River of erosion and deposition	0.106	0.260	0.365	0.015	0.090	0.204	0.243	0.086
Soil and water conservation of roads	0.082	0.214	0.308	0.012	0.074	0.172	0.201	0.071
Ecological restoration	**0.190**	**0.454**	**0.718**				**0.454**	
Activities of biological community	0.197	0.405	0.751	0.037	0.182	0.540	0.451	0.205
Integrality of ecological corridor	0.197	0.481	0.583	0.037	0.216	0.419	0.420	0.191
Ecological monitoring and management	0.060	0.114	0.211	0.011	0.051	0.152	0.128	0.058
Environment construction	**0.059**	**0.103**	**0.147**				**0.103**	
Landscape tour and natural features	0.551	0.691	0.812	0.033	0.070	0.119	0.685	0.071
Human industry and resource of land	0.258	0.309	0.379	0.015	0.032	0.056	0.315	0.033
Environment conservation	**0.055**	**0.091**	**0.127**				**0.091**	
Artificial disturbance minimizing	0.401	0.634	0.798	0.024	0.065	0.101	0.611	0.055
Forbid developing	0.268	0.366	0.533	0.016	0.037	0.068	0.389	0.035

Table 4
Subjective cognition results of evaluators towards the five levels of linguistic variables.

Evaluator	Linguistic variable				
	Very poor	Poor	Fair	Good	Very good
1	(0,0,25)	(10,30,50)	(30,50,70)	(65,75,85)	(80,100,100)
2	(0,0,40)	(15,30,60)	(60,70,80)	(80,85,90)	(90,100,100)
3	(0,0,19)	(23,36,57)	(38,58,66)	(54,77,88)	(87,100,100)
4	(0,0,25)	(10,30,50)	(30,50,70)	(65,75,85)	(80,100,100)
5	(0,0,15)	(15,30,45)	(45,60,75)	(75,80,90)	(90,100,100)

(2) To employ Eqs. (9) and (10) to obtain the fuzzy performance value of A-1 under C01, that is:

$$e_{11} = \left(\frac{\sum_{p=1}^{5} le_{11}^{p}}{15}, \frac{\sum_{p=1}^{5} me_{11}^{p}}{15}, \frac{\sum_{p=1}^{5} uk_{11}^{p}}{15} \right)$$
$$= (49.6, 63.2, 75.4)$$

The remainder elements of fuzzy performance values of each criterion of experts for each alternative can be obtained by the same procedure, and it is shown in Table 5.

3.3. Ranking the alternatives

From the criteria weights of three decision-making groups of the obtained by FAHP (Table 3) and the average fuzzy performance values of each criterion of experts for each alternative (Table 5), the final fuzzy synthetic decision (e_k) can then be processed. After the fuzzy synthetic decision is processed, the non-fuzzy ranking method is then employed, and finally the fuzzy numbers are changed into non-fuzzy values. Though there are methods to rank these fuzzy numbers, this study has employed COA to determine the *BNP* value, which is used to rank the evaluation results of each of the best plan alternative. We use Eq. (11) to find out its *A-1* alternative value, details of the results are presented in Table 6.

Table 7
Performance value and ranking by various criteria weightings.

Alternatives	Performance		BNP_k	Ranking
	$\tilde{e} = \tilde{E} \otimes \tilde{w} = \tilde{w}' \otimes \tilde{E}'$	$\tilde{e} = \tilde{E} \otimes \tilde{w} = \tilde{w}' \otimes \tilde{E}'$		
A-1	(09.36,48.85,152.54)	(09.36,48.85,100.0)	52.74	5
A-2	(12.02,65.62,175.86)	(12.02,65.62,100.0)	59.72	1
A-3	(09.83,53.14,155.02)	(09.83,53.14,100.0)	54.32	4
A-4	(09.98,55.23,158.92)	(09.98,55.23,100.0)	55.07	3
A-5	(10.85,58.57,163.10)	(10.85,58.57,100.0)	56.48	2

Note: Compromised refer to the weights of average of three groups, which are computed by geometric mean.

To take the fuzzy synthetic decision value of alternative A-1 under weights of domain experts as an example, we can use Eq. (12) to obtain this value. Next, we use Eq. (13) to find out its *BNP* value, details of the results are presented in Table 7.

As we can be seen from Table 7 that when using traditional plan rate as a plan index, the plan levels of environment watershed are identical. Table 7 can be seen from the alternative evaluation results, alternative A-2 is the best alternative considering the weights. The results in Table 7 reflect the perception that changes in criteria weights may affect the evaluation outcome to a certain degree. It is clear that most alternatives maintain similar relative rankings under different criteria weights. In addition, obviously, the Alternative A-1 has poorest performance rating relative to other alternatives, which is the most common consensus among the decision-making domain experts.

4. Discussions

This research presented the selection plan in the environment-watershed of a fuzzy decision support system for the assessment of alternative strategies proposed. It is highly affected by environment conservation and environment construction. In terms of the results, the priority order of weights of criteria for decision-making domain

Table 5
Average fuzzy performance matrix ($\tilde{E}'$) of each criterion of domain experts for alternatives.

Criteria	A-1	A-2	A-3	A-4	A-5
Potential debris flow torrent	(49.6,63.2,75.4)	(61.8,77.4,85.6)	(55.6,69.2,79.4)	(44.6,58.2,74.4)	(61.8,77.4,85.6)
River of erosion and deposition	(48.6,55.2,69.4)	(30.6,47.6,62.2)	(36.6,45.2,60.4)	(51.6,63.2,77.4)	(57.8,68.4,78.6)
Soil and water conservation of roads	(38.6,48.2,65.4)	(71.4,84.0,90.0)	(45.6,56.2,69.4)	(53.6,66.2,77.4)	(42.8,53.4,66.6)
Activities of biological community	(34.6,50.6,67.2)	(52.6,64.6,74.2)	(41.6,55.6,67.2)	(46.6,60.6,73.2)	(41.6,55.6,67.2)
Integrality of ecological corridor	(48.6,35.2,57.4)	(41.6,56.6,69.2)	(25.6,37.2,55.4)	(28.6,41.6,53.2)	(28.6,41.6,57.2)
Ecological monitoring and management	(22.6,35.6,55.2)	(40.6,57.6,69.2)	(34.6,47.6,63.2)	(30.6,47.6,62.2)	(34.6,47.6,63.2)
Landscape tour and natural features	(21.6,49.2,69.4)	(47.8,64.4,78.6)	(41.6,56.2,72.4)	(40.6,54.2,69.4)	(47.8,64.4,78.6)
Human industry and resource of land	(34.6,58.6,72.2)	(57.4,71.0,82.0)	(43.6,58.6,71.2)	(52.6,67.6,77.2)	(53.4,67.0,78.0)
Artificial disturbance minimizing	(43.6,41.2,61.4)	(43.8,61.4,76.6)	(33.6,49.2,66.4)	(34.6,48.2,63.4)	(29.8,47.4,62.6)
Forbid developing	(43.6,41.2,61.4)	(50.8,66.4,79.6)	(40.6,54.2,69.4)	(34.6,48.2,63.4)	(46.8,62.4,75.6)

Table 6
A-1 alternative various synthetic performance value.

A-1 alternative (example)	$\tilde{e}_{1i}$	$\tilde{w}_i$	$\tilde{e}_{1i} \otimes \tilde{w}_i$
Potential debris flow torrent	(49.6,63.2,75.4)	(0.042,0.185,0.474)	(2.089,11.710,35.774)
River of erosion and deposition	(48.6,55.2,69.4)	(0.015,0.091,0.204)	(0.742,5.045,14.150)
Soil and water conservation of roads	(38.6,48.2,65.4)	(0.012,0.075,0.172)	(0.457,3.621,11.247)
Activities of biological community	(34.6,50.6,67.2)	(0.037,0.184,0.540)	(1.296,9.316,36.269)
Integrality of ecological corridor	(48.6,35.2,57.4)	(0.037,0.218,0.491)	(1.821,7.684,24.030)
Ecological monitoring and management	(22.6,35.6,55.2)	(0.011,0.052,0.152)	(0.259,1.843,8.376)
Landscape tour and natural features	(21.6,49.2,69.4)	(0.033,0.071,0.119)	(0.707,3.509,8.284)
Human industry and resource of land	(34.6,58.6,72.2)	(0.015,0.032,0.056)	(0.529,1.869,4.026)
Artificial disturbance minimizing	(43.6,41.2,61.4)	(0.024,0.065,0.101)	(1.037,2.696,6.225)
Forbid developing	(43.6,41.2,61.4)	(0.016,0.038,0.068)	(0.423,1.556,4.163)
$\sum_{i=1}^{10} \tilde{e}_{1i} \otimes \tilde{w}_i$	–	–	(9.36,48.85,152.54)
Linguistic value of alternatives $\max_i = 100$	–	–	(9.36,48.85,100.00)

experts in the complete evaluation criteria hierarchy, we can see the decision-making domain experts in the decision-making process.

In this study of the best environment-watershed plan alternative evaluation, the domain experts from the FAHP results, for the domain experts, by the compromise ranking method, the compromise solution is determined, which would be most acceptable to the decision makers. Via the priority decision-making we find the first most important dimensions are ecological restoration (0.454) and watershed management of erosion control (0.352); whereas the least important is environment conservation (0.091). On the other hand, the domain expert is more concerned about the planning of landscape tour and natural features, because they think that these criteria may identify the design ability of a designer (the first three important criteria are: Activities of biological community 0.205, Potential debris flow torrent 0.195 and Integrality of ecological corridor 0.191).

The results in Table 7 reflect the perception that changes in criteria weights may affect the evaluation outcome in a sense. It is clear that most alternatives maintain similar relative rankings under different criteria weights. In addition, obviously, the Alternative A-1 got the domain expert 52.74 that has the poorest performance rating relative to other alternatives. Alternative A-2 has got 59.72 it has the best alternative, which is the most common consensus among the decision-making domain experts. Thus, an effective evaluation procedure is essential to promote the decision quality. This work examines this group decision-making process and proposes a multi-criteria framework for the best plan selection. To deal with the qualitative attributes in subjective judgment, this work employs fuzzy analytic hierarchy process (FAHP) to determine the weights of decision criteria for domain experts, including five from the university of expert scholars (include Water Resources Engineering and Conservation, Landscape and Recreation, Urban Planning, Environment Engineering, Architectural Engineering), five from the government departments, and five from industry.

An empirical case study of nine proposed plan alternatives for a new plan project of the Pei-Keng Brook Environment Watershed is used to exemplify the approach. The underlying concepts applied were intelligible to the decision-making groups, and the computation required is straightforward and simple. It will also assist the government agencies in making critical decisions during the selection of the best environment-watershed plan alternatives.

5. Concluding remarks

Using the FMCDM can decide the relative weights of criteria. The FMCDM to construct a new plan model for environment-watershed effects, which may be worth doing further researches. This is an important finding in the study. The proposed model well suitable deal with any decision problem which constructs complicated and confused and whose criteria are dependent, so it can be applied to many fields, such as environment plan, psychology, consumer behavior, human resources management and so on. The study sets up causal model of the best environment-watershed plan effect and the relational structure model is verified through satisfactory statistical technique in order to confirm the model efficiency. In current methods of the best plan selection, government agencies rely only on a panel of experts to perform the evaluation, neglecting the fuzziness of subjective judgment and other relative perception in this process. Then the fuzzy multiple-criteria decision-making (FMCDM) approach is used to synthesize the group decision. This process enables decision makers to formalize and effectively solve the complicated, multi-criteria and fuzzy/vague perception problem of most appropriate and the best plan alternative selection. Over the past its poor watershed plan record has led to Taiwan's Soil and Water Conservation Bureau, Council of Agriculture, conducting annual plan evaluations of Pei-Keng brook of watershed. Traditionally, the plan is assessed on the number of storm water of catastrophes, and possibly "land and monitored" during audits. These statistics are not always helpful when catastrophes incident or land and monitored rates are very low and give little indication of possible future trends. Based on several aspects of the best environment-watershed plan systems we have used FAHP and FMCDM methods and approach that considers independent between a range of criteria and their weighting. An empirical testing of the approach using a Taiwanese case study illustrates its usefulness.

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