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Multiple criteria data envelopment analysis for full ranking units associated to environment impact assessment

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Abstract

The importance of the environmental impact assessment (EIA) of large development projects is increasingly underlined. Usually, EIA involves a lot of qualitative and quantitative criteria. Data Envelopment Analysis (DEA), an effective method which is used to rank and select the best alternative from a set of alternatives, is not tailored to address qualitative criteria, thus rendering the application to multiple criteria problems not amenable. This paper presents a new methodology of Multiple Criteria Data Envelopment Analysis (MCDEA) which can address both qualitative and quantitative criteria. MCDEA is divided into two-stage for fully ranking units and each unit has multiple inputs and outputs. In the first stage, a qualitative method is applied to compare the qualitative performance of alternatives. Then MCDEA is used to rank the alternatives by considering the relative membership degree of qualitative factors as one of the quantitative data. A case study on the selection of dam location illustrates the effectiveness of the proposed methodology.

Keywords: multiple criteria data envelopment analysis; qualitative method; environment impact assessment

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1. Introduction

The importance of the environmental impact assessment of large development projects is increasingly underlined. Proper evaluation of the ecological, environmental, as well as socio-economic impacts resulting from the construction process is very important. Nilsson and Dalkmann (2001) outlined some theoretical perspectives to decision-making and suggested that each model would have its particular implications for decision support and for environmental assessments. Dalkmann et al. (2004) presented the analytical strategic environmental assessment approach to allow an evaluation of how far environmental considerations have been integrated into the decision-making process under assessment. Brismar (2004) presented the results of the analysis of six EIAs prepared for large dam projects, in order to analyze how and to what extent potential impact pathways involved in the generation of dam-related cumulative impacts has been addressed in the analyzed material. However, little attention was given to the assessment of options based on qualitative criteria. Ramanathan (2001) used the analytic hierarchy process (AHP) for conducting socio-economic impact assessment with qualitative and quantitative elements. Yedla and Shrestha (2003) ranked the alternative environmentally sustainable transportation system options by applying AHP with weighted arithmetic mean method with respect to six important quantitative and qualitative criteria. In the evaluation of environmental impacts, the method used in weight assignment of criteria is quite significant. In order to minimize bias and subjectivity in the evaluation of various parameters which depend on human judgment or expert opinion, Goyal and Deshpande (2001) compared three different methods, namely, Battelle environmental evaluation system, importance scale matrix (ISM), and a combination of them. It was found that a better result was obtained by the ISM approach. Therefore, more efforts can be performed to rank the alternative solutions with qualitative and quantitative data in environmental impact assessment for multicriteria and semi-structural decision-making.

In this paper, the multiple criteria data envelopment analysis (MCDEA) is employed as a decision aid for the evaluation of alternatives with multiple criteria information. It is generally recognized that DEA is an effective method which is used to rank and select the best alternative from a set of alternatives, since the pioneer work of Charnes et al. (1978) and its subsequent evolutionary developments. DEA has two inter-related drawbacks, which are unrealistic weight distribution and weak discriminating power. The original DEA does not perform full ranking, but merely provides classification into two dichotomic groups: efficient and inefficient. The problem of unrealistic weights has been tackled mainly by the techniques of weight restriction. Charns et al. (1990) proposed a “cone-ratio” DEA model attempting to restrict weight flexibility directly in the weight space. Wong and Beasley (1990) provided a weight restriction method by setting bounds on the proportions of individual inputs (or outputs) to total input (or output). In order to improve DEA's discriminating power, Sinuany-Stern et al. (1994) utilized the linear discriminant analysis for ranking units, based on the predefined DEA dichotomic classification. Oral et al. (1991) used the cross efficiency matrix in order to select projects. Sinuany-Stern and Friedman (1998) used the cross efficiency matrix to rank units. Rapid development in DEA has attracted attention from researchers in the field of Multiple Criteria Decision Making (MCDM). DEA originates from situations where the aim is to determine the productive efficiency of a system by comparing how well these units convert inputs into outputs, while MCDM models have arisen from problems of ranking and selecting from a set of alternatives that have conflicting criteria. One of the earliest attempts to integrate MCDM procedures and DEA techniques was made by Golany (1988), who suggests an interactive multiple objective linear programming procedure for estimating a target set of output levels given the available input levels of a decision making unit (DMU). Troutt (1995) recommended that DEA should be considered a methodology with MCDM. Li and Reeves (1999) suggested utilizing multiple objectives, such as minimax and minsum efficiency in addition to the standard DEA objective function in order to increase discrimination between DMUs. Sinuany-Stern et al. (2000) outlined an AHP/DEA ranking model based on a two-stage process. In calculating the efficiency, all input and output data had to be known exactly. Some subjective data, though limited to part of the units, cannot be known directly. No methods are able to provide an ultimately good model for fully ranking units in the DEA context. Even though a variety of parameters and factors of environmental impact assessment for planning project can be included in a DEA analysis, it is still difficult to integrate qualitative factors. Thus, how to address the qualitative performance data is the key to use DEA for environmental impact assessment problems.

This paper proposes the new methodology, which combines the qualitative method and multiple criteria data envelopment analysis (MCDEA) to solve the problem on the comparison of alternatives. The qualitative method is applied to convert qualitative information into a quantitative factor. Then MCDEA is used to compare the alternatives by considering the relative membership degree of qualitative factors as one of the quantitative data. The proposed methodology avoids the human judgment, improves the problem of measuring the relative efficiency of decision-making units and increases the decision's scientific and objectivity. The case study illustrates its efficiency and effectiveness for the environmental impact assessment problem with quantitative and qualitative factors.

This paper is organized as follows. The details of the proposed methodology are presented in Section 2. It is followed by the application of the methodology in Section3. Conclusions are then given in Section 4.

2. The methodology

2.1 Multiple criteria problems

There exist various optimization techniques for quantitative techniques. However, the problem on the evaluation of environmental impact for different dam location presents a case where there is a need to use a combination of qualitative and quantitative criteria for ranking of the alternatives. The qualitative method used in this paper is an effective tool to evaluate the qualitative criteria of alternatives. The proposed methodology is based on the qualitative method and a multiple criteria data envelopment analysis (MCDEA) model is used to solve the problem on the comparison of alternatives with qualitative and quantitative criteria.

It solves the current problem following a two-stage procedure. At the first stage, it computes the relative membership degree of all qualitative factors. Then, in the second stage, the MCDEA model is used to rank the alternatives by considering the relative membership degree of qualitative factors as one of the quantitative data. The new hybrid model is described as follows.

2.2 The qualitative criteria

The method to quantify these qualitative factors is the key to the use of the MCDEA to solve this multi-criteria decision-making problem. The flow chart of the model for the evaluation of the qualitative data is illustrated in Fig.1.

This qualitative method is similar to AHP (Saaty, 1980 and Chen, 1994). It solves the decision problem with qualitative factors using three basic principles: decomposition, comparative judgment, and synthesis of priorities. It then breaks down the problem into multi-levels and compares each pair, one by one. The pairwise comparison matrix is constructed in two steps: a qualitative sorting scale matrix is constructed to obtain the ranking of the qualitative factors, then, the pairwise comparison matrix is constructed based on the ranking. In this way, the pairwise comparison matrix is easy to satisfy the consistency conditions. During the consistency check, it is assumed that the upper rows of the matrix are more reliable than the lower rows and the system will re-set the values of the lower rows if inconsistencies are found.

Relative comparison is essential when one creates scales to judge alternatives. Thus, different experts with different backgrounds were asked to fill in the comparison matrices in order to reduce bias in the evaluation.

It is assumed that the pairwise comparison matrix is as follows:

$$ {}_iA = \begin{bmatrix} {}_ia_{11} & {}_ia_{12} & \cdots & {}_ia_{1n} \\ {}_ia_{21} & {}_ia_{22} & \cdots & {}_ia_{2n} \\ & \cdots & \cdots & \\ {}_ia_{n1} & {}_ia_{n2} & \cdots & {}_ia_{n\ n} \end{bmatrix} = ({}_ia_{kl}) \tag{1} $$

which is subject to
$$ \begin{cases} 0 \le {}_ia_{jk} \le 1 \\ {}_ia_{jk} + {}_ia_{kj} = 1 \\ {}_ia_{jk} = 0.5 \quad j = k \end{cases} \tag{2} $$

where matrix ${}_ia$ is a pairwise comparison ordered matrix of alternative set D regarding qualitative factor i, ${}_ia_{jk}$ is the quantitative scale on excellence of alternative d_j to d_k when d_j is compared with d_k regarding qualitative factor i; conversely, ${}_ia_{kj}$ is the quantitative scale on excellence of alternative d_k to d_j, j and k being subscripts representing the ranking according to qualitative sorting scale matrix.

The priority matrices of pair-wise comparison among the elements with respect to decision criteria C_i are confirmed. Summing up the values of indicators on each row, the elements are then rearranged in a descending order with respect to decision criteria C_i.

Based on the priority order, the corresponding relations between semantic operators and priority scores are constructed.. The formulation of the semantic operator is shown in Table.1.

These semantic scores, ${}_ia_{1j}$, are mapped into a priority score, ${}_ir_j$, by applying the fuzzy set theory through the following equation:

$$ {}_ir_j = \frac{1 - {}_ia_{1j}}{{}_ia_{1j}} \qquad 0.5 \le {}_ir_j \le 1 \tag{3} $$

where *i=1,2,…,m₁; j=1,2,…,n.*

Let $r^a_{ij} = {}_ir_j$, then we have the relative membership degree matrix of m_1 qualitative factors as follows:

$$ R^a_{m_1 \times n} = \begin{bmatrix} r^a_{11} & r^a_{12} & \cdots & r^a_{1n} \\ r^a_{21} & r^a_{22} & \cdots & r^a_{2n} \\ & \cdots & \cdots & \\ r^a_{m_1 1} & r^a_{m_1 2} & \cdots & r^a_{m_1 n} \end{bmatrix} = (r^a_{ij}) \tag{4} $$

where superscript *a* represents qualitative factor, m_1 is the total number of qualitative factors, $i=1,2,\ldots,m_1$; $j=1,2,\ldots,n$.

After obtaining the priority order of decision criteria and elements, it is necessary to measure the magnitude of the pair-wise comparison by assigning weightings to these decision criteria and elements. The set of weightings is developed from normalization of the semantic scores. Then,

$$w_i = \frac{w_{(i)}}{\sum_{i=1}^{m1} w_{(i)}} \tag{5}$$

$w = (w_1, w_2, ..., w_{m_1})$ are the weightings of decision criteria.

Then we use the fuzzy optimum selection model (Chen, 1994) to obtain the relative membership degree as follows:

$$u_j = \frac{1}{1 + \left\{ \frac{\sum_{i=1}^{m} w_i (r_{ij} - 1)}{\sum_{i=1}^{m} w_i r_{ij}} \right\}^2} \tag{6}$$

where u_j is the relative membership degree (RMD) on excellence of the jth alternative, r_{ij} is the RMD of the jth alternative regarding factor a_i and w_i is the weight of factor a_i ~~s~~. Hence the RMD of the alternatives qualitative factors can be obtained.

2.3 The integrated qualitative and quantitative criteria

Data Envelopment Analysis (DEA) is known as a nonparametric mathematical programming technique, which is based upon an application of linear programming. The inputs and outputs of DMUs are the required information for DEA modeling. Using the RMD of the alternatives qualitative factors as an output or input, with the other quantitative inputs and outputs, the final ranking making result can be obtained.

The DEA model for evaluation of the efficiency of a DMU, originally established by Charnes et al. (1978), is denoted by DMU_0 as follows:

$$\begin{aligned} \max \quad & h_0 = \sum_{r=1}^{s} u_r y_{rj0} \\ s.t. \quad & \sum_{i=1}^{m} v_i x_{ij0} = 1 \\ & \sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \le 0 \; j = 1, \cdots, n, \\ & u_r, v_i \ge 0, r = 1, \cdots s, i = 1, \cdots m, \end{aligned} \tag{7}$$

where j is the DMU index, $j=1,\ldots,n$; r is the output index, $r=1,\ldots,s$; x_{ij} *is* the ith input for the jth DMU, $i=1,2,\ldots,m$ and $j=1,2,\ldots,n$; y_{rj} is the rth output for the jth DMU, $r=1,2,\ldots,s$ and $j=1,2,\ldots,n$; v_i is the weight for the ith input; u_r is the weight given to the rth output; and h_0 is the relative efficiency of DMU_0. DMU_0 is evaluated as efficient if and only if h_0=1. It is assumed that there are n DMUs to be evaluated and that each

DMU consumes varying amount of *m* different inputs and produce *s* different outputs.

This basic DEA model does not always provide good discriminatory characteristics among alternatives; especially in situations where a number of alternatives may have scores equal to 1 (i.e. are efficient). A number of techniques have been proposed for better discrimination among alternative scores. The MCDEA can be used to improve discriminating power of classical DEA method. Its solution is not to find an optimal solution but, instead, to find non dominated solutions and to help select the most preferred one. The form of MCDEA model depends upon the efficiency criteria used. In this paper, the model suggested by Li and Reeves (1999) as follows is used.

$$\begin{aligned}
&\min d_0 \\
&\min M \\
&\min \sum_{j=1}^{n} d_j \\
&s.t. \sum_{i=1}^{m} v_i x_{ij0} = 1 \\
&\quad \sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} + d_j = 0 \\
&\quad M - d_j \geq 0 \; j = 1, \cdots, n \\
&\quad u_r, v_i, d_j \geq 0
\end{aligned} \tag{8}$$

It has three criteria, namely, minimizing d_0, minimizing the maximum deviation M, and minimizing the sum of the deviations $\sum_{j=1}^{n} d_j$. u_r, v_i are the variable weights, d_0 is the deviation variable for DMU_0, the variable *M* in the second objective represents the maximum quantity among all deviation variables d_j $(j=1,\ldots, n)$. The third objective function is a straightforward representation of the deviation sum. In the above three definitions, no matter if DMU_0 is efficient or not, its DEA efficiency score is $1\text{-}d_0$ (but the values of d_0 can vary under different criteria).

Using the RMD of the alternatives qualitative factors as an output of MCDEA with the other m_2 quantitative factors, the ranking of all alternatives can be obtained.

3. Case study

This methodology is applied to the environmental impact assessment of the design of a dam project. The environmental impact assessment criteria were considered for the selection of dam location. This is a multicriteria problem with qualitative and quantitative criteria. The choice of these qualitative and quantitative criteria is motivated by the practical background of the dam project and its benefits. A description of the criteria for the dam project is presented in Fig.2. There are ten qualitative criteria and seven quantitative criteria for the environmental impact assessment. The qualitative criteria includes 4 subsystems as shown below: 1) water quality unit, consisting of factors C_1 through C_2; 2) geologic unit, consisting of factors C_3 to C_6; 3) hydrographic unit, consisting of factors C_7 through C_8; 4) biology unit, consisting of factors C_9 through C_{10}. The factors from C_{11} to C_{17} are quantitative criteria, namely submerged valuable land, resettlement, water supply, electricity generation, irrigation, breed aquatics, and economical benefits.

Through pairwise comparison on excellence between 8 alternatives regarding qualitative factor C_i, $i=1,\ldots,10$, the sorting consistency scale matrix are obtained as Tables 2 to 11.

Then the RMDM of 10 qualitative factors of 8 alternatives can be obtained as follows:

$$R = \begin{bmatrix} 1 & 0.176 & 1 & 1 & 1 & 0.176 & 1 & 0 \\ 0.176 & 0.176 & 0.429 & 0.429 & 0.176 & 1 & 1 & 1 \\ 0.111 & 0.111 & 0.111 & 1 & 0.111 & 0.111 & 1 & 1 \\ 1 & 0.053 & 0.053 & 0.818 & 0.818 & 0.818 & 0.053 & 0.053 \\ 1 & 1 & 1 & 0.333 & 0.333 & 1 & 0.026 & 0.026 \\ 1 & 1 & 0.111 & 0.111 & 0.111 & 1 & 1 & 1 \\ 0.111 & 0.111 & 0.111 & 0.111 & 1 & 1 & 0.111 & 0.111 \\ 1 & 1 & 1 & 0 & .\ 1 & 0\ 1 & 2\ 1 & 6\ 1 \\ 0.25 & 0.25 & 0.25 & 0.026 & 0.026 & 1 & 1 & 1 \\ 0.111 & 0.111 & 1 & 1 & 1 & 0.111 & 1 & 1 \end{bmatrix} \tag{9}$$

The set of weightings is developed from normalization of the semantic scores.

$$E = \begin{bmatrix} 0.5 & 0.5 & 1 & 1 & 1 & 1 & 0.5 & 0.5 & 0 & 0 \\ 0.5 & 0.5 & 1 & 1 & 1 & 1 & 0.5 & 0.5 & 0 & 0 \\ 0 & 0 & 0.5 & 0.5 & 0.5 & 0.5 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0.5 & 0.5 & 0.5 & 0.5 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0.5 & 0.5 & 0.5 & 0.5 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0.5 & 0.5 & 0.5 & 0.5 & 0 & 0 & 0 & 0 \\ 0.5 & 0.5 & 1 & 1 & 1 & 1 & 0.5 & 0.5 & 0 & 0 \\ 0.5 & 0.5 & 1 & 1 & 1 & 1 & 0.5 & 0.5 & 0 & 0 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 0 & 0 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 0 & 0 \end{bmatrix} \begin{matrix} 6 \\ 6 \\ 2 \\ 2 \\ 2 \\ 2 \\ 6 \\ 6 \\ 9 \\ 9 \end{matrix} \tag{10}$$

$$w' = (0.429, 0.429, 0.053, 0.053, 0.053, 0.053, 0.429, 0.429, 1, 1) \tag{11}$$

The normalized weights of decision criteria are as follows:

$$w = (0.11, 0.11, 0.013, 0.013, 0.013, 0.013, 0.109, 0.109, 0.255, 0.255) \tag{12}$$

After having known the weightings of each decision criteria and elements, the fuzzy optimum selection model can be used to obtain the qualitative RMD.

$$u_j = (0.278, 0.131, 0.717, 0.426, 0.739, 0.803, 0.981, 0.916)$$

Using the RMD of the alternatives qualitative factors as a qualitative factor, with the other 7 quantitative factors, the quantitative and qualitative values of alternatives can be obtained as shown in Table 12. The identification of a minimizing or maximizing criterion determines whether the criterion will be considered an input or output in the DEA model. A DMU will be considered an alternative from the alternative set. The outputs are values for maximizing criteria and the inputs are values associated with minimizing criteria. So the criteria submerged valuable land (C_{11}) and resettlement (C_{12}) are the inputs and the water supply (C_{13}), electricity generation (C_{14}), irrigation (C_{15}), breed aquatics (C_{16}) and economical benefits (C_{17}) are the outputs of the MCDEA model. Since the qualitative factor is a maximizing criterion, it is an input of the MCDEA model.

The results are shown in Table 13. The solution that optimizes the first objective of MCDEA is identical to the optimal solution of objective of model (1). Five alternatives are relative efficient according to the first criterion. Efficiencies defined under minimax and minsum criteria are more restrictive than that defined in classical DEA.

It can be noted that both alternatives 4 and 5 are satisfactory and DMU_5 is the remaining one that is efficient under these three criteria. Since this dam project is a multiple function project, it includes flood prevention, water supply, electricity generation, and irrigation. On the basis of the synthesis of judgments on the quantitative data and subjective judgments on the qualitative data, alternative 5 is determined to be the preferable alternative.

4. Conclusions

The environmental impact assessment is a multi-criteria decision making problem that involves subjective value judgments. This study is an attempt to use a new methodology to solve this complex multicriteria and semi-structural decision-making problem with qualitative and quantitative factors. A number of multiple criteria decision models may be used for evaluation of the environmental impact of the project only with quantitative factors. The proposed methodology simultaneously considered both the quantitative and qualitative factors. The qualitative method is effective to compare the qualitative criteria of alternatives, where the MCDEA model can be used to improve discriminating power of classical DEA method and also effectively yield more reasonable input and output weights without a priori information about the weights. The MCDEA involves broader definitions of relative efficiency than the classical DEA. The MCDEA approach will extend the single criterion-based conventional DEA approach to multiple criteria-oriented one and get a more balanced distribution of optimal weights. The case study illustrates the effectiveness of the proposed methodology. This paper proposes a simple but important way to better assess the impacts of the project. In the specific event of undertaking an EIA for large dam project, this method could be used as complements to other EIA tools.

It should be noted that this study has examined only major factors of environmental impact for the project design. The cumulative impacts of the project are not considered, but only focused on describing the expected end-states of various environmental parameters. Clearly there is more work to be done on the development of environmental impact assessment of the dam project design with qualitative and quantitative criteria. This may be a challenging work.

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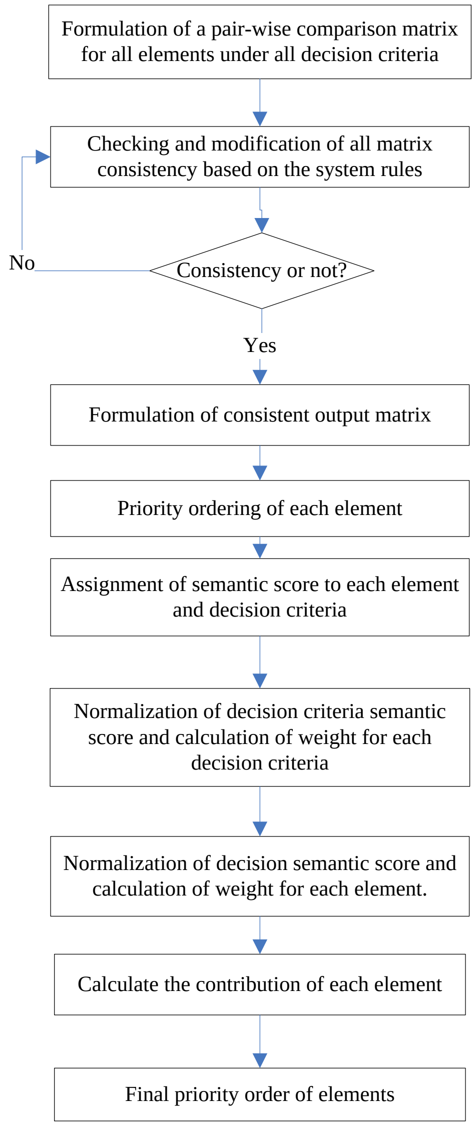

Fig.1. Flowchart of the qualitative method.

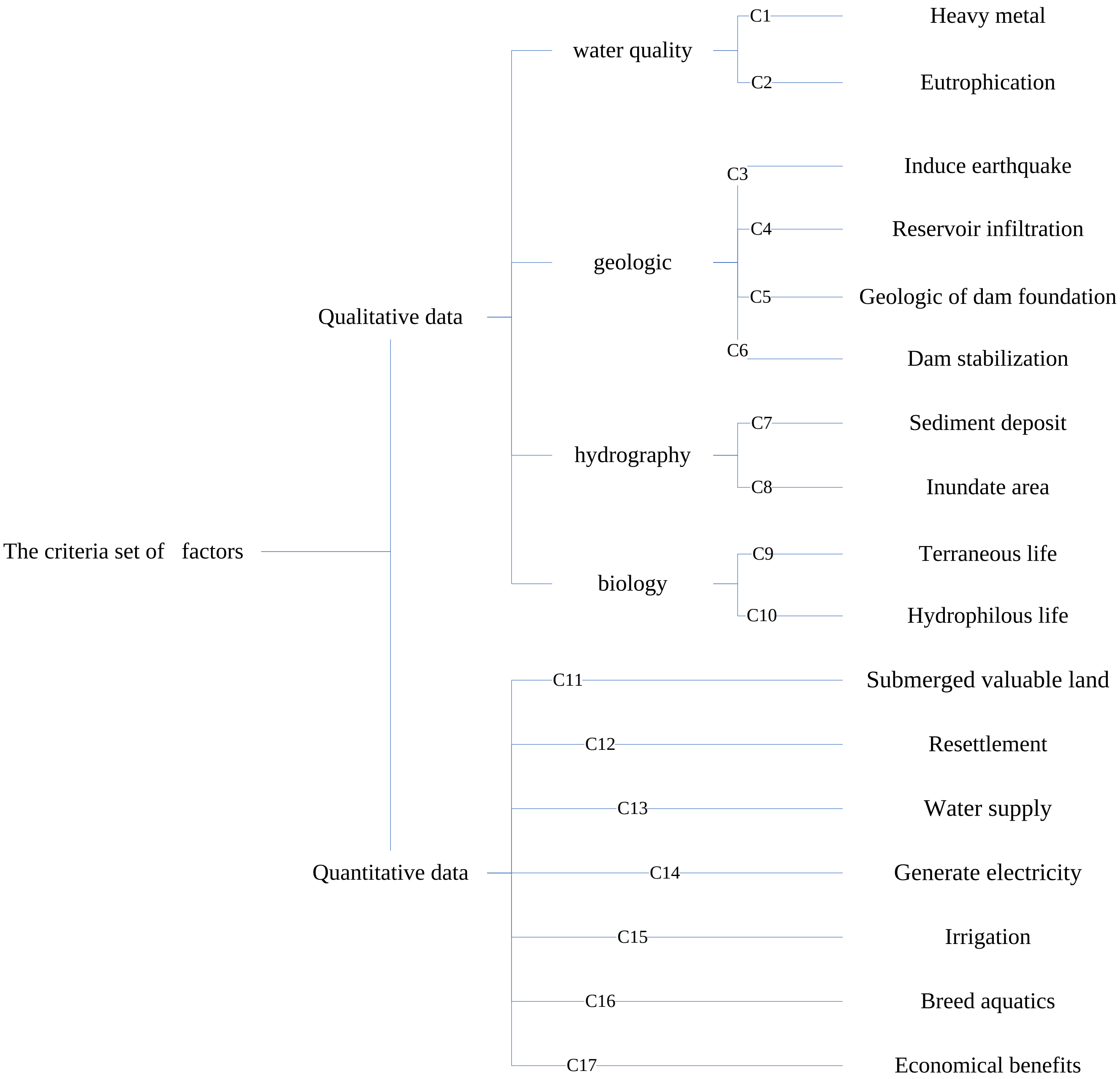

Fig.2. Criteria for alternatives evaluation

Table.1. Semantic operators, scores and transformed priority scores

Semantic operators	${}_{i}a_{1j}$	${}_{i}r_{j}$
Same	0.5	1
In-between	0.525	0.905
Marginally different	0.55	0.818
In-between	0.575	0.739
Slightly different	0.6	0.667
In-between	0.625	0.6
Quite different	0.65	0.538
In-between	0.675	0.481
Markedly different	0.7	0.429
In-between	0.725	0.379
Obviously different	0.75	0.333
In-between	0.775	0.29
Very different	0.8	0.25
In-between	0.825	0.212
Significantly different	0.85	0.176
In-between	0.875	0.143
Very significantly different	0.9	0.111
In-between	0.925	0.081
Extremely different	0.95	0.053
In-between	0.975	0.026
Absolutely Incomparable	1	0

Table.2. Evaluation matrix For C_1

Element	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*sum*	*ranking*	*score*
1	0.5	1	0.5	0.5	0.5	1	0.5	1	5.5	1	1
2	0	0.5	0	0	0	0.5	0	1	2	6	0.176
3	0.5	1	0.5	0.5	0.5	1	0.5	1	5.5	1	1
4	0.5	1	0.5	0.5	0.5	1	0.5	1	5.5	1	1
5	0.5	1	0.5	0.5	0.5	1	0.5	1	5.5	1	1
6	0	0.5	0	0	0	0.5	0	1	2	6	0.176
7	0.5	1	0.5	0.5	0.5	1	0.5	1	5.5	1	1
8	0	0	0	0	0	0	0	0.5	0.5	8	0

Table.3. Evaluation matrix For C_2

Element	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*sum*	*ranking*	*score*
1	0.5	0.5	0	0	0.5	0	0	0	1.5	6	0.176
2	0.5	0.5	0	0	0.5	0	0	0	1.5	6	0.176
3	1	1	0.5	0.5	1	0	0	0	4	4	0.429
4	1	1	0.5	0.5	1	0	0	0	4	4	0.429
5	0.5	0.5	0	0	0.5	0	0	0	1.5	6	0.176
6	1	1	1	1	1	0.5	0.5	0.5	6.5	1	1
7	1	1	1	1	1	0.5	0.5	0.5	6.5	1	1
8	1	1	1	1	1	0.5	0.5	0.5	6.5	1	1

Table.4. Evaluation matrix For C_3

Element	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*sum*	*ranking*	*score*
1	0.5	0.5	0.5	0	0.5	0.5	0	0	2.5	4	0.111
2	0.5	0.5	0.5	0	0.5	0.5	0	0	2.5	4	0.111
3	0.5	0.5	0.5	0	0.5	0.5	0	0	2.5	4	0.111
4	1	1	1	0.5	1	1	0.5	0.5	6.5	1	1
5	0.5	0.5	0.5	0	0.5	0.5	0	0	2.5	4	0.111
6	0.5	0.5	0.5	0	0.5	0.5	0	0	2.5	4	0.111
7	1	1	1	0.5	1	1	0.5	0.5	6.5	1	1
8	1	1	1	0.5	1	1	0.5	0.5	6.5	1	1

Table.5. Evaluation matrix For C_4

Element	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*sum*	*ranking*	*score*
1	0.5	1	1	0.5	0.5	0.5	1	1	6.5	1	1
2	0	0.5	0.5	0	0	0	0.5	0.5	2	5	0.053
3	0	0.5	0.5	0	0	0	0.5	0.5	2	5	0.053
4	0.5	1	1	0.5	0.5	0.5	1	1	6	2	0.818
5	0.5	1	1	0.5	0.5	0.5	1	1	6	2	0.818
6	0.5	1	1	0.5	0.5	0.5	1	1	6	2	0.818
7	0	0.5	0.5	0	0	0	0.5	0.5	2	5	0.053
8	0	0.5	0.5	0	0	0	0.5	0.5	2	5	0.053

Table.6. Evaluation matrix For C_5

Element	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*sum*	*ranking*	*score*
1	0.5	0.5	0.5	1	1	0.5	1	1	6	1	1
2	0.5	0.5	0.5	1	1	0.5	1	1	6	1	1
3	0.5	0.5	0.5	1	1	0.5	1	1	6	1	1
4	0	0	0	0.5	0.5	0	1	1	3	5	0.333
5	0	0	0	0.5	0.5	0	1	1	3	5	0.333
6	0.5	0.5	0.5	1	1	0.5	1	1	6	1	1
7	0	0	0	0	0	0	0.5	0.5	1	7	0.026
8	0	0	0	0	0	0	0.5	0.5	1	7	0.026

Table.7. Evaluation matrix For C_6

Element	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*sum*	*ranking*	*score*
1	0.5	0.5	1	1	1	0.5	0.5	0.5	5.5	1	1
2	0.5	0.5	1	1	1	0.5	0.5	0.5	5.5	1	1
3	0	0	0.5	0.5	0.5	0	0	0	1.5	6	0.111
4	0	0	0.5	0.5	0.5	0	0	0	1.5	6	0.111
5	0	0	0.5	0.5	0.5	0	0	0	1.5	6	0.111
6	0.5	0.5	1	1	1	0.5	0.5	0.5	5.5	1	1
7	0.5	0.5	1	1	1	0.5	0.5	0.5	5.5	1	1
8	0.5	0.5	1	1	1	0.5	0.5	0.5	5.5	1	1

Table.8. Evaluation matrix For C_7

Element	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*sum*	*ranking*	*score*
1	0.5	0.5	0.5	0.5	0	0	0.5	0.5	3	3	0.111
2	0.5	0.5	0.5	0.5	0	0	0.5	0.5	3	3	0.111
3	0.5	0.5	0.5	0.5	0	0	0.5	0.5	3	3	0.111
4	0.5	0.5	0.5	0.5	0	0	0.5	0.5	3	3	0.111
5	1	1	1	1	0.5	0.5	1	1	7	1	1
6	1	1	1	1	0.5	0.5	1	1	7	1	1
7	0.5	0.5	0.5	0.5	0	0	0.5	0.5	3	3	0.111
8	0.5	0.5	0.5	0.5	0	0	0.5	0.5	3	3	0.111

Table.9. Evaluation matrix For C_8

Element	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*sum*	*ranking*	*score*
1	0.5	0.5	0.5	1	0.5	0.5	0.5	0.5	4.5	1	1
2	0.5	0.5	0.5	1	0.5	0.5	0.5	0.5	4.5	1	1
3	0.5	0.5	0.5	1	0.5	0.5	0.5	0.5	4.5	1	1
4	0	0	0	0.5	0	0	0	0	0.5	8	0.026
5	0.5	0.5	0.5	1	0.5	0.5	0.5	0.5	4.5	1	1
6	0.5	0.5	0.5	1	0.5	0.5	0.5	0.5	4.5	1	1
7	0.5	0.5	0.5	1	0.5	0.5	0.5	0.5	4.5	1	1
8	0.5	0.5	0.5	1	0.5	0.5	0.5	0.5	4.5	1	1

Table.10.Evaluation matrix For C_9

Element	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*sum*	*ranking*	*score*
1	0.5	0.5	0.5	1	1	0	0	0	3.5	4	0.25
2	0.5	0.5	0.5	1	1	0	0	0	3.5	4	0.25
3	0.5	0.5	0.5	1	1	0	0	0	3.5	4	0.25
4	0	0	0	0.5	0.5	0	0	0	1	7	0.026
5	0	0	0	0.5	0.5	0	0	0	1	7	0.026
6	1	1	1	1	1	0.5	0.5	0.5	6.5	1	1
7	1	1	1	1	1	0.5	0.5	0.5	6.5	1	1
8	1	1	1	1	1	0.5	0.5	0.5	6.5	1	1

Table.11. Evaluation matrix For C_{10}

Element	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*sum*	*ranking*	*score*
1	0.5	0.5	0.5	0	0	0.5	0	0	2	6	0.111
2	0.5	0.5	0.5	0	0	0.5	0	0	2	6	0.111
3	0.5	0.5	0.5	0	0	0.5	0	0	6	1	1
4	1	1	1	0.5	0.5	1	0.5	0.5	6	1	1
5	1	1	1	0.5	0.5	1	0.5	0.5	6	1	1
6	0.5	0.5	0.5	0	0	0.5	0	0	2	6	0.111
7	1	1	1	0.5	0.5	1	0.5	0.5	6	1	1
8	1	1	1	0.5	0.5	1	0.5	0.5	6	1	1

Table.12. Quantitative and qualitative data of alternatives

	Element	Ⅰ	Ⅱ	Ⅲ	Ⅳ	Ⅴ	Ⅵ	Ⅶ	Ⅷ
Input	Submerged valuable land (km^2)	4667	4900	5220	5120	4800	5093	5473	5406
Input	Resettlement (10^4person)	5.00	5.20	5.38	5.26	5.18	5.15	5.80	5.63
Output	Water supply(10^8m^3)	1.03	1.04	1.03	1.12	1.08	1.00	1.15	1.16
Output	Electricity generation (10^4kw/h)	301	358	424	465	502	566	558	539
Output	Irrigation (10^8m^3)	0.758	0.829	0.938	1.015	1.289	1.697	1.573	0.892
Output	Breed aquatics (10^4yuan)	23	25	26	24	26	28	27	25
Output	Economical Benefits (10^8yuan)	6.27	7.70	6.89	6.76	6.86	6.68	6.98	7.21
Output	Qualitative RMD	0.278	0.131	0.717	0.426	0.739	0.803	0.981	0.916

Table.13. MCDEA results of example

DMUs		Efficiency	v_1	v_2	u_1	u_2	u_3	u_4	u_5	u_6
DMU_1	min d_1	0.985	0.0001	0.1153	0.9563	0.0000	0.0000	0.0000	0.0000	0.0000
	min M	0.937	0.0000	0.2000	0.4589	0.0000	0.0000	0.0153	0.0158	0.0462
	$\min\sum_{j=1}^{n} d_j$	0.968	0.0000	0.2000	0.6468	0.0000	0.0000	0.0000	0.0474	0.0164
DMU_2	min d_2	0.875	0.0000	0.1903	0.0432	0.0002	0.0195	0.0037	0.1016	0.0070
	min M	0.95	0.0000	0.1923	0.4413	0.0000	0.0000	0.0147	0.0152	0.0445
	$\min\sum_{j=1}^{n} d_j$	1	0.0000	0.1923	0.6219	0.0000	0.0000	0.0000	0.0456	0.0158
DMU_3	min d_3	0.963	0.0000	0.1859	0.0000	0.0000	0.0000	0.0028	0.1140	0.1468
	min M	0.941	0.0000	0.1859	0.4265	0.0000	0.0000	0.0142	0.0147	0.0430
	$\min\sum_{j=1}^{n} d_j$	0.934	0.0000	0.1859	0.6011	0.0000	0.0000	0.0000	0.0441	0.0152
DMU_4	min d_4	1	0.0000	0.1743	0.7843	0.0001	0.0060	0.0008	0.0048	0.0054
	min M	0.958	0.0000	0.1901	0.4362	0.0000	0.0000	0.0145	0.0150	0.0440
	$\min\sum_{j=1}^{n} d_j$	1	0.0000	0.1901	0.6148	0.0000	0.0000	0.0000	0.0451	0.0156
DMU_5	min d_5	1	0.0002	0.0206	0.3448	0.0004	0.0497	0.0055	0.0189	0.0991
	min M	1	0.0000	0.1931	0.4430	0.0000	0.0000	0.0148	0.0153	0.0446
	$\min\sum_{j=1}^{n} d_j$	1	0.0000	0.1931	0.6243	0.0000	0.0000	0.0000	0.0458	0.0158
DMU_6	min d_6	1	0.0000	0.1911	0.1111	0.0006	0.1029	0.0070	0.0172	0.0981
	min M	0.938	0.0000	0.1942	0.4455	0.0000	0.0000	0.0149	0.0153	0.0449
	$\min\sum_{j=1}^{n} d_j$	0.948	0.0000	0.1942	0.6280	0.0000	0.0000	0.0000	0.0460	0.0159
DMU_7	min d_7	1	0.0002	0.0224	0.1227	0.0002	0.0193	0.0035	0.0128	0.5500
	min M	0.953	0.0000	0.1724	0.3956	0.0000	0.0000	0.0132	0.0136	0.0399
	$\min\sum_{j=1}^{n} d_j$	0.941	0.0000	0.1724	0.5576	0.0000	0.0000	0.0000	0.0409	0.0141
DMU_8	min d_8	1	0.0001	0.1214	0.3038	0.0002	0.0012	0.0022	0.0251	0.3551
	min M	0.944	0.0000	0.1776	0.4076	0.0000	0.0000	0.0136	0.0140	0.0411
	$\min\sum_{j=1}^{n} d_j$	0.983	0.0000	0.1776	0.5744	0.0000	0.0000	0.0000	0.0421	0.0146