APPLICATION OF FUZZY-AHP METHOD IN RANKING CRITERIA FOR ENVIRONMENTAL IMPACT ASSESSMENT OF COASTAL CONSTRUCTION PROJECTS IN DA NANG CITY

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Abstract - Da Nang, a coastal city with a 60 km shoreline, has seen rapid coastal development. Environmental Impact Assessment (EIA) plays a vital role in early project planning, requiring clear prioritization of environmental criteria. This study employs the Fuzzy Analytic Hierarchy Process (Fuzzy-AHP), integrating triangular and trapezoidal fuzzy numbers, to rank EIA criteria for coastal construction projects in Da Nang. Expert judgments were analyzed through fuzzy pairwise comparisons at three α-cut levels (0, 0.5, 1) to reflect uncertainty. Results show that the project preparation stage has the highest importance (weights 0.535–0.573), followed by construction and operation stages. The proposed model quantifies expert opinions and provides a structured approach to prioritize EIA criteria, enhancing transparency and applicability of environmental assessments for coastal projects.

Key words - Environmental impact assessment; coastal construction projects; Fuzzy; AHP; Da Nang City

1. Introduction

Da Nang is a famous coastal city with many beautiful beaches such as Nam O, Man Quang, My Khe, Non Nuoc,... Among them, My Khe beach was once recognized by America's leading economic magazine, *Forbes* – voted one of the most attractive beaches on the planet. Because of that advantage, the need to develop resort tourism and restaurant - hotel services in the city is increasing, becoming an inevitable trend. The tourism real estate market in Da Nang in recent years has recorded sudden growth. According to the city's socio-economic development strategy to 2030, with a vision to 2050, Da Nang is oriented to become a major tourism center of the country, with a focus on developing the marine economy, especially coastal tourism. Master plans and zoning plans for coastal areas clearly indicate priority areas for tourism development, while requiring the relocation of residents and inappropriate activities out of the planning area [1].

Da Nang City, a grade I urban area directly under the Central Government and a key development center of the Central region of Vietnam, is making strong strides in expanding urban space as well as socio-economic growth. However, along with that development, the city is also facing increasingly serious impacts of climate change, including widespread flooding, increased saltwater intrusion and prolonged droughts. Although the city government has focused on urban planning and management, and conducted a number of studies to assess adaptive capacity and vulnerability to climate change, these contents are still general at the city-wide level and not specific enough to support the development of effective action solutions in responding to and improving resilience to climate change at the local level.

According to regulations in Article 29 and Article 35 of the Law on Environmental Protection 2020 [2], the environmental impact assessment report (EIA) must be prepared during the project preparation stage and carried out by the investor. The results of the EIA report appraisal are the basis for granting investment decisions or environmental licenses, depending on the nature of the project. Preliminary environmental impact assessment report required in the application for investment policy appraisal for projects falling under the investment policy approval authority of the National Assembly, the Prime Minister, or the People's Council or Provincial People's Committee. Strategic environmental assessment is a mandatory requirement in the planning process related to socio-economic development, industries, fields, and territories, and is assessed by a specialized environmental agency before the planning is approved [3-4].

Method Analytic Hierarchy Process (AHP), proposed by Saaty [5], is an effective multi-criteria decision-making (MCDM) tool in environments with complex multiple choices. This method builds a hierarchical structure and uses pairwise comparisons to determine priorities between elements. However, traditional AHP encounters some limitations due to not handling factors well uncertain and lack of precision which often occurs in converting the decision maker's qualitative perceptions into specific quantitative values. To overcome this limitation, Fuzzy AHP has been developed for integration logic mờ (fuzzy logic) into the evaluation process, allowing vague, unclear evaluations to be described through use fuzzy numbers [6]. One of the foundational works is AHP's Fuzzy model Buckley, was built to improve accuracy and better reflect human thinking in the decision-making process [7]. Up to now, there have been many studies expanding and applying the Fuzzy AHP method in different fields [8–15].

Although the Fuzzy AHP method has been widely applied, most models are currently mainly used triangular fuzzy number (Triangular Fuzzy Numbers) due to its simplicity in representation and manipulation. However, this method often comes with complex and demanding fuzzy operations large amount of calculation and High processing time. Meanwhile, recent studies show that the use trapezoidal fuzzy number (Trapezoidal Fuzzy Numbers) có thể Better handling of uncertainty, thanks to its ability to more flexibly characterize the levels of ambiguity in the decision maker's assessments [16].

To overcome the limitations associated with complex calculations in traditional Fuzzy AHP models, Pan proposed a new approach using a combination triangular fuzzy number and trapezoidal fuzzy number to simplify the calculation process while still ensuring reliability in assessment [16]. This model allows more flexibility in representing the uncertainty of expert assessments, while improving computational efficiency. In [16], the Fuzzy AHP model is applied to determine weight of criteria for environmental impact assessment (EIA) for the coastal construction project in Da Nang city.

Since Pan's study on selecting bridge construction methods via Fuzzy-AHP [16], the approach has been increasingly adapted to diverse construction-related decision-making contexts. Soltanzadeh et al. conducted a comprehensive assessment of occupational safety risks in a major construction project using Fuzzy-AHP, prioritizing hazards like falls and electric shocks [17]. Similarly, Wefki et al. introduced a Fuzzy-AHP model to select appropriate excavation support systems, effectively balancing safety and cost considerations [18]. Cheng, Hu & Wu developed a hybrid Fuzzy-AHP–TOPSIS framework to evaluate sustainable green building materials, notably ranking geopolymer concrete as the most eco-friendly option [19]. Meanwhile, Fuzzy-AHP, entropy weights, and genetic algorithms were combined to assess sustainability performance of green construction, integrating environmental, social, and technological criteria [20]. Contractor delay causes were analyzed using Fuzzy-AHP in 2024, revealing financial factors as top contributors. These studies collectively demonstrate how Fuzzy-AHP has evolved from Pan's original bridge method into a versatile tool across safety, material selection, quality management, and sustainability domains in modern construction.

2. Methodology

2.1. Research process

The research process of this topic is presented in Figure 1.

2.2. Build a hierarchical system

A typical Fuzzy AHP model includes four basic components: (1) set of decision options Mi (with i=1,2,...,m); (2) set of evaluation criteria Cj (with j=1,2,...,n); (3) the language judgment rij represents the relative priority between each pair of criteria; and (4) weight vector w=(w1,w2,...,wn). The first step in the Fuzzy AHP process is to identify all the important criteria and their relationships to the decision problem, thereby building a hierarchy hierarchy. This is the fundamental step, because the selection and organization of criteria can directly affect the final assessment results. This hierarchical structure includes: the top level is overall goal, followed by the intermediate level (including groups of criteria or assessment standards), and the lowest level is options to choose from specifically.

2.3. Evaluation of fuzzy pair comparisons

In the Fuzzy AHP method, all criteria that are at the same level in the hierarchy will be compared each pair to determine the relative priority between them. The comparison is done through qualitative linguistic terms, includes five levels of interpretation: "Very unimportant" (VU), "Less important" (LI), "Equally important" (NO), "More important" (MI), and "Very important" (VI).

These terms are then convert to fuzzy number between 0 and 10, to build fuzzy pair comparison matrix serve the calculation process. Specifically, as shown in Table 1, each language level is mapped to triangular or trapezoidal fuzzy numbers respectively. According to Figure 2, the two levels "Very unimportant" and "Very important" are represented by One-sided trapezoidal function, while the remaining three levels use symmetrical triangular function to reflect the relative level between criteria.

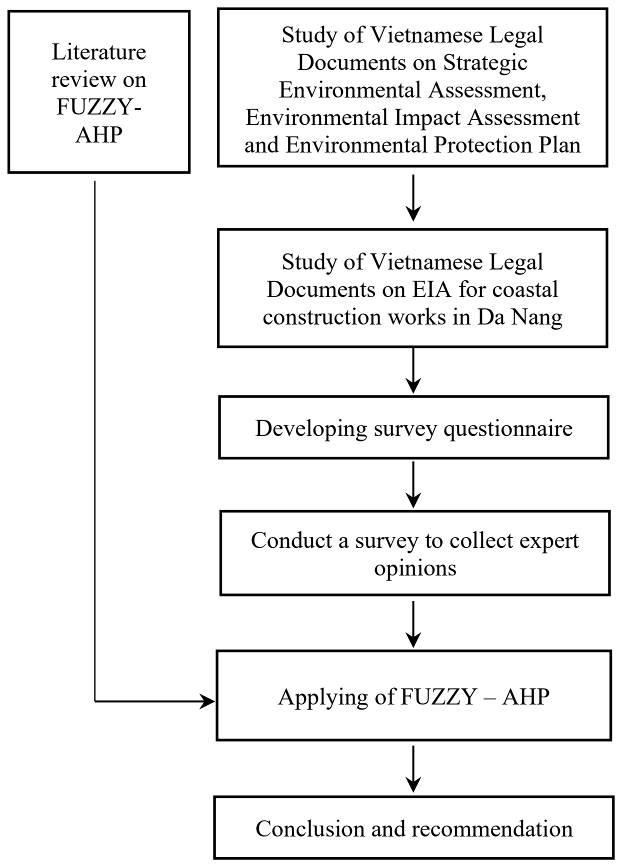

Figure 1. *Research process*

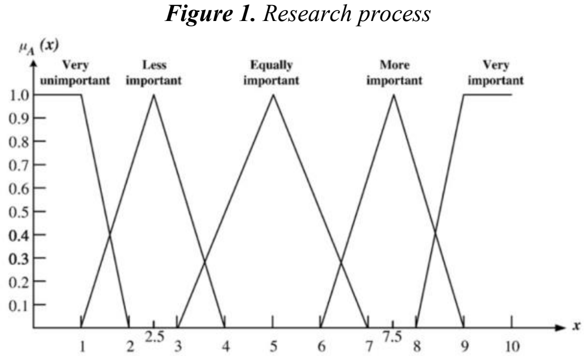

Figure 2. *Membership functions for linguistic values*

Table 1. *Fuzzy importance scale*

How to interpret	Explain	Fuzzy number
Very Unimportant (VU)	Very poor criterion than another criterion	(0, 0, 1, 2)
Less important (LI)	The criterion is slightly weaker than another	(1, 2.5, 4)
Equally important (EI)	The two criteria contribute equally to the object	(3, 5, 7)
More important (MI)	Judgment slightly favors one criterion over another	(6, 7.5, 9)
Very important (VI)	Judgment strongly favors one criterion over another	(8, 9, 10, 10)

The fuzzy comparison matrix, Ã, represents the fuzzy relative importance of each pair of elements given by:

$$\tilde{A}=\begin{bmatrix}1 & r_{12} & r_{13} & \cdots & r_{1n}\\ r_{21} & 1 & r_{23} & \cdots & r_{2n}\\ \vdots & \vdots & \vdots & \ddots & \vdots\\ r_{n1} & r_{n2} & r_{n3} & \cdots & 1\end{bmatrix} \quad (1)$$

In Buckley's method, the element of the negative judgment is considered to be the inverse of the fuzzy number of the corresponding positive judgment.

Compared with the "more important" criterion B expressed by fuzzy numbers (6, 7.5, 9), the negative judgment "less important" is described (1/9, 1/7.5, 1/6). Therefore, careful checking is required to avoid errors arising from such simple operations while constructing an inverse matrix. To overcome this difference, each negative inverse element is characterized by its own representative fuzzy number as defined in Table 1.

To redefine the specific level of uncertainty involved in the decision-making process, the α-cut confidence level concept is applied. This is another improvement of the proposed method for Buckley's model. The value of α is between 0 and 1. The values α = 0 and α = 1, represent the greatest and least degree of uncertainty, respectively. In practical applications, α = 0, α = 0.5, and α = 1 are used to indicate pessimistic, moderate, and optimistic decision-making conditions, respectively.

Figure 3 shows that a triangular fuzzy number related to a given value can be expressed as ($X_{\alpha,L}$, $X_{\alpha,M}$, $X_{\alpha,U}$). $X_{\alpha,M}$, $X_{\alpha,L}$ and $X_{\alpha,U}$ represent the most likely value, minimum value and maximum value of the fuzzy number respectively. The functions shown in Figure 3 can also be expressed mathematically through equations (2) - (6).

$$X(\alpha)_{very\ unimportant}=\begin{cases}X_{\alpha,L}=0\\ X_{\alpha,M}=\frac{0.5+(X_{\alpha,L}-1)\left[(X_{\alpha,L}-1)(0.33+0.17\alpha)+1\right]}{1+(0.5X_{\alpha,L}-0.5)(1+\alpha)}\\ X_{\alpha,U}=2-\alpha\end{cases} \quad (2)$$

$$X(\alpha)_{less\ unimportant}=\begin{cases}X_{\alpha,L}=1+1.5\alpha\\ X_{\alpha,M}=2.5\\ X_{\alpha,U}=4-1.5\alpha\end{cases} \quad (3)$$

$$X(\alpha)_{equally\ important}=\begin{cases}X_{\alpha,L}=3+2\alpha\\ X_{\alpha,M}=5\\ X_{\alpha,U}=7-2\alpha\end{cases} \quad (4)$$

$$X(\alpha)_{more\ important}=\begin{cases}X_{\alpha,L}=6+1.5\alpha\\ X_{\alpha,M}=7.5\\ X_{\alpha,U}=9-1.5\alpha\end{cases} \quad (5)$$

$$X(\alpha)_{very\ important}=\begin{cases}X_{\alpha,L}=8+\alpha\\ X_{\alpha,M}=8+\frac{1.5+(9-X_{\alpha,L})(0.67+0.17\alpha)+0.5}{1+(4.5-0.5X_{\alpha,L})(1+\alpha)}\\ X_{\alpha,U}=10\end{cases} \quad (6)$$

Accordingly, a comparison matrix m can be defined as follows:

$$\tilde{A}=\begin{bmatrix}1 & (X_{12,L},X_{12,M},X_{12,U}) & \cdots & (X_{1n,L},X_{1n,M},X_{1n,U})\\ (X_{21,L},X_{21,M},X_{21,U}) & 1 & \cdots & (X_{2n,L},X_{2n,M},X_{2n,U})\\ \vdots & \vdots & \ddots & \vdots\\ (X_{n1,L},X_{n1,M},X_{n1,U}) & \cdots & \cdots & 1\end{bmatrix} \quad (7)$$

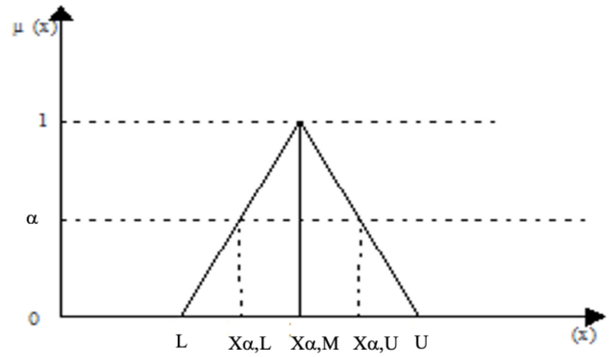

Figure 3. Triangular fuzzy interval according to α-cut confidence levels

For example, ($X_{12,L}$, $X_{12,M}$, $X_{12,U}$) in equation (7) shows the lower, middle, and upper bound values of the first element relative to the second element at the higher level, respectively. To facilitate the calculation of fuzzy weights, the matrix $\tilde{A}$ is further decomposed into three sharp matrices: the lower bound matrix (A_L), the most likely matrix, (A_M) and the upper bound matrix (A_U). Regarding (A_U), for example, (A_U) is defined by:

$$A_U=\begin{bmatrix}1 & X_{12,U} & \cdots & X_{1n,U}\\ X_{21,U} & 1 & \cdots & X_{2n,U}\\ \vdots & \vdots & \ddots & \vdots\\ X_{n1,U} & \cdots & \cdots & 1\end{bmatrix} \quad (8)$$

2.4. Evaluation of fuzzy pair comparisons

The geometric equation normalization method is used in Buckley's model, which is applied to calculate the local weights.

$$W_i=\frac{g_i}{\sum_{i=1}^{n} g_i} \quad (9)$$

$$g_i=\left(\prod_{j=1}^{n} r_{ij}\right)^{1/n} \quad (10)$$

In the above equations, g_i is the geometric mean of criterion i, r_{ij} is the comparison value of criterion i with criterion j, W_i is the first weight criterion, in which:

$W_i>0$ and $\sum_{i=1}^{n} W_i=1$, $1\le i\le n$

To evaluate a group, it is necessary to synthesize opinions from many evaluators into one. Aggregation of assessments by multiple experts includes a range of member values that must be blurred to resolve on a single representative value. The proposed adoption model uses center of gravity (COG) techniques because of their simplicity and effectiveness. The Fuzzy maximum operator is as follows:

$$\mu_A(X) = max\{min[\mu_1(X), \mu_2(X), \mu_3(X), \ldots, \mu_n(X)]\} \quad (11)$$

where $\mu_A(X)$ is the membership value of element X in the aggregate subset A; $\mu_1(X)$, $\mu_2(X)$, ..., $\mu_n(X)$ are the membership levels representing the first, second,…, and n^{th} evaluator's judgment, respectively.

The COG method is given by the following expression [35]

$$z^* = \frac{\int \mu(z).zdz}{\mu(z).dz} \quad (12)$$

Where $\mu(z)$ is the membership value; z^* is the average value of the weights. Accordingly, the overall weight of the 1^{st} sub-criterion, S_l, can be calculated by:

$$S_l = \sum_{l=1}^{L} W_k S_{lk} \quad (13)$$

Where W_k is the weight of the k^{th} main criterion; S_{lk} is the local weight of the lth sub-criterion with respect to the k^{th} main criterion. Similarly, the overall weight of the m^{th} alternative with respect to the l^{th} sub-criterion, R_m, is given by the equation (14).

$$R_m = \sum_{m=1}^{M} S_l R_{ml} \quad (14)$$

3. Results and discussion

3.1. Survey questionnaire

The set of environmental impact assessment (EIA) criteria used in this study was developed based on the guidance at Circular No. 02/2022/TT-BTNMT [3] and Decree No. 08/2022/ND-CP [4], combined with the Fuzzy–AHP method to determine the importance of evaluation criteria in coastal projects. The criteria system is divided into three phases of the project life cycle, including: Preparation stage, construction stage, operation/operation stage.

Criteria for evaluating and forecasting impacts during the project preparation stage include:

- Evaluate the suitability of the project location with the natural and socio-economic conditions of the project area (Symbol A1).

- Assess the impact of land appropriation, migration, and resettlement (especially for households losing residential land, farmland, and jobs) (Symbol B1).

- Assess the impact of site clearance activities (vegetation clearing, leveling and other activities) (Symbol C1).

Criteria for evaluating and forecasting impacts during the project construction stage include:

- Evaluate and forecast the impact of construction material exploitation activities serving the project (if within the project scope) (Symbol A2).

- Evaluate and forecast the impact of transportation of construction materials, machinery and equipment (Symbol B2).

Evaluate and forecast the impact of construction activities on project items or project implementation activities (Symbol C2).

Criteria for evaluating and forecasting impacts during the project's operational stage include:

- Evaluate and forecast the impact of waste generation sources (gas, liquid, solid) (Symbol A3).

- Assess and forecast the impact of sources unrelated to waste such as noise, traffic, and landscape (Symbol B3).

Figure 4 shows the hierarchical tree diagram of the above EIA criteria.

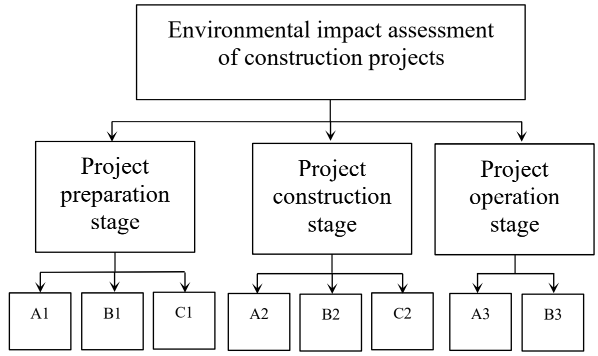

Figure 4. *Hierarchical tree of EIA criteria*

Accordingly, the survey questionnaire is arranged into 3 parts: Basis for survey questionnaire design; survey questionnaire structure; survey questionnaire questions. The study applied a 5-level rating scale as presented in Table 1 above: very less important (VU); less important (LI); have equal importance (EI); more important (MI); very important (VI). These rating levels are mapped to a range of values from 0 to 10 to build fuzzy pair comparison matrix. The corresponding linguistic variables are modeled using fuzzy number, as function belongs to a symmetrical triangle or Unilateral trapezoidal jaw, as illustrated in Figure 2. Specifically, the two levels "Very unimportant" and "Very important" are represented by trapezoidal function, while the remaining levels use symmetrical triangular function to reflect the relative priorities between factors. Specifically, the two levels "Very unimportant" and "Very important" are represented by trapezoidal function, while the remaining levels use symmetrical triangular function to reflect the relative priorities between factors.

3.2. Expert survey

The goal of the survey is to collect expert opinions to evaluate and rank the importance of criteria in environmental impact assessment (EIA). From the survey results, data is analyzed to serve the research process and calculate criteria weights. The selection of experts in the study is based on three criteria: (i) number of years of experience in the field of EIA, (ii) educational level, and (iii) role and authority in appraisal or project management with environmental factors. The study conducted a survey of the opinions of 7 experts, including: 02 PhDs in environmental science, each with at least 12 years of experience in evaluating and appraising EIA reports; 02 heads of natural resources and environment departments of coastal districts in Da Nang, with at least 09 years of experience in implementing or appraising EIA; 01 head of the urban construction department of the People's Council of Da Nang city, with 11 years of experience related to EIA; 02 PhDs in construction, each with at least 09 years of experience in the field of environmental impact assessment.

Table 2 and Table 3 respectively present the results of evaluating the main group of standards and component criteria provided by experts:

Table 2. *Matrix comparing pairs of criteria according to expert opinions*

Pair criteria	Result						
	Exp 1	Exp 2	Exp 3	Exp 4	Exp 5	Exp 6	Exp 7
A1 with B1	VI	VI	MI	EI	VI	VI	VI
A1 with B2	MI	VI	EI	VI	MI	VI	MI
B1 with C1	MI	EI	LI	EI	EI	EI	MI
A2 with B2	MI	EI	MI	EI	VI	EI	MI
A2 with C2	LI	EI	MI	LI	VI	EI	LI
B2 with C2	LI	LI	EI	LI	MI	LI	LI
A3 with B3	EI	VI	MI	MI	VI	VI	EI

Table 3. *Standard pair comparison matrix*

Pair criteria	Result						
	Exp 1	Exp 2	Exp 3	Exp 4	Exp 5	Exp 6	Exp 7
Stage 1 with Stage 2	VI	VI	VI	VI	VI	VI	VI
Stage 1 with Stage 3	MI	VI	MI	VI	MI	VI	MI
Stage 2 and Stage 3	VI	EI	VI	EI	VI	EI	VI

3.3. Typical calculation results correspond to an α-cut level

The fuzzy numbers introduced in the above section are applied to convert expert judgments into numbers. For example, Table 4 presents the results of converting to fuzzy numbers of the 1st expert corresponding to α=0 in comparing the importance of EIA between 3 stages.

Table 4. *Paired comparison matrix 3 between*

Stage 1					Stage 2				Stage 3		
	1	1	1	8	9	10	10	6	7.5	9	
0	0	1	2	1	1	1		8	9	10	10
	1	2.5	4	0	1	2		1	1	1	

Table 5. *Upper bound, probable, lower bound weight matrix*

$$\tilde{A}_U = \begin{bmatrix} 1 & 10 & 9 \\ 2 & 1 & 10 \\ 4 & 2 & 1 \end{bmatrix} \quad \tilde{A}_M = \begin{bmatrix} 1 & 9 & 7.5 \\ 1 & 1 & 9 \\ 2.5 & 1 & 1 \end{bmatrix} \quad \tilde{A}_L = \begin{bmatrix} 1 & 8 & 6 \\ 1 & 1 & 8 \\ 1 & 1 & 1 \end{bmatrix}$$

Table 6. *Upper bound, possible, lower bound weights for directors*

W_i	Upper bound	Possible	Lower near
Stage 1	0.487	0.542	0.548
Stage 2	0.295	0.277	0.301
Stage 3	0.217	0.181	0.151

Applying formulas (11) and (12), the average weight of the stages corresponding to the first expert's opinion is 0.526; 0.291; 0.183. Applying the same calculation method for experts also corresponds to the confidence levels α=0.5 and α=1 for the entire research criteria. The results are presented in section 3.4.

3.4. Results compiled by experts

Table 7. *Weight of importance level of 3 stages*

Stage	α=0	α=0.5	α=1
Prepare	0,535	0,565	0,573
Construction	0,256	0,262	0,236
Operate	0,199	0,173	0,190

Table 8*. Weighting of criteria in the preparation phase*

Criteria	α=0	α=0.5	α=1
A1	0,507	0,534	0,532
B1	0,240	0,235	0,226
C1	0,245	0,231	0,242

Table 9*. Weight of criteria during construction phase*

Criteria	α=0	α=0.5	α=1
A2	0,401	0,413	0,593
B2	0,238	0,242	0,240
C2	0,361	0,354	0,167

Table 10*. Weighting of criteria in the operational phase*

Criteria	α=0	α=0.5	α=1
A3	0,637	0,690	0,704
B3	0,363	0,310	0,296

4. Conclusion

This study applied the Fuzzy-AHP method developed in [16] to rank criteria for assessing coastal environmental impacts in Da Nang city. EIA criteria are issued in Circular No. 02/2022/TT-BTNMT and Decree No. 08/2022/ND-CP used in this study. The researcher conducted a survey to get the opinions of 07 experts in the field of EIA report appraisal of construction projects in Da Nang. Data collected after the survey is used to rank the criteria. The Fuzzy-AHP method in this study is analyzed with 3 α-cut tree beliefs (α= 0; α=0.5; α=1). Besides, the Center-Of-Gravity (COG) method is used to synthesize the opinions of experts. Accordingly, the research results show that the weight of the importance of EIA in the stages of project preparation, construction, and operation corresponding to the confidence levels (α= 0; α= 0.5; α= 1) is respectively at α= 0 (0.535; 0.256; 0.199); at α=0.5 (0.565; 0.262; 0.173); α= 1 (0.573, 0.236, 0.190). In addition, the criteria in each stage of preparation, construction, and operation corresponding to (α=0; α=0.5; α=1) are also calculated. At α=0, the weights of criteria A1, B1, C1 in the preparation phase are 0.507 respectively; 0.240; 0.245; The weight of criteria A2, B2, C2 during the construction phase is 0.401; 0.238; 0.361; The weights of criteria A3 and B3 in the operational phase are 0.637 and 0.363. At α=0.5; The weight of A1, B1, C1 in the preparation phase is 0.534; 0.235; 0.231; The weight of A2, B2, C2 in the construction phase is 0.413; 0.242; 0.354; of A3, B3 in the operating phase is 0.690; 0.310. At α=1, the preparation stage is (0.532; 0.226; 0.242); construction phase (0.593; 0.240; 0.167); operational phase is (0.704; 0.296).

The results of this study are useful for members of the appraisal council for EIA assessment because they have quantified by weight the importance of the set of criteria. In addition, this study takes into account the uncertainty factor, thereby giving three assessment viewpoints: pessimistic, average and optimistic. Thanks to that, the results of EIA appraisal of projects will be more accurate.

In future research, it is necessary to consider other specific criteria from previous research works on EIA for domestic and international coastal projects. Furthermore, the research also needs to expand the number of experts invited to survey from many other provinces and cities to increase reliability and expand the scope of research applicable throughout Vietnam.

In future research, it is necessary to enhance the reliability validation of the proposed Fuzzy-AHP model by incorporating additional verification steps. Specifically, sensitivity analysis should be conducted to assess the stability of the ranking results under variations in expert input. Moreover, comparing the model's outcomes with actual environmental impact assessment (EIA) reports from completed coastal construction projects in Da Nang would provide valuable evidence to support the practical applicability of the model. These additions will further strengthen the scientific validity and decision-making relevance of the model for environmental management in coastal urban areas.

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