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# Optimal Site for Aquaculture Farming: An Elimination Decision Approach

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**Abstract:** One of the most important factors in determining sites of aquaculture farming is water quality. The appropriate site with the best water quality must be identified in order to grow the finest quality of fish. However, choosing the best site for aquaculture farming cannot be done only based on one single parameter of water quality. Instead, a number of water quality parameters, such as pH and dissolved oxygen levels, should be considered during the selection process. Thus, this study employed the Elimination and Choice Translating Reality (ELECTRE) method to rank four potential sites for aquaculture farming with five parameters or criteria of water quality. Three decision-makers who are professionals in aquaculture farming are invited to evaluate the rationality of the sites based on the considered criteria of water quality using real numbered linguistic terms. The eight computational steps of the ELECTRE method are applied in searching the optimal site. The findings show that site $A_4$ dominates the other three sites, proving that the Marang River is the best site for aquaculture farming. The results of this study could be used by local department of fisheries in suggesting new sites for aquaculture farming.

**Keywords:** aquaculture farming, decision-making, elimination method, water quality, optimal solution

## 1. Introduction

Selection for an optimal site for aquaculture farming is increasingly important in the aquaculture industry. There are many factors that need to be considered in the selection. Many studies have been carried out in determining the suitable site and criteria for aquaculture farming. One of the major components to be considered in aquaculture farming site selection is the quality of water (Ghobadi et al., 2021; Hadipour et al., 2015). Poor water quality may affect the growth, development, and health of aquatic organisms. Thus, water quality supply should be in sufficient quantity and adequate quality with appropriate pH value, temperature, dissolved oxygen, and other factors (Oladokun et al., 2013). It seems that these multiple independent criteria are contributed to water quality. Obviously, there are several factors to consider while choosing the best site for an aquaculture system. In other words, the selection of an optimal site for aquaculture farming can be seen as a multi-criteria decision-making (MCDM) problem where multiple factors and more than one site are concurrently considered in deciding the optimal site (Mamat et al., 2014; Vafaie et al., 2015). Therefore, the evaluation and selection of an optimal site for aquaculture farming are too complex and challenging as it has multiple criteria and alternatives to be considered (Mahalakshmi et al., 2012).

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Inspired by this motivation, this work proposes the optimal site for aquaculture farming using the Elimination and Choice Translating Reality (ELECTRE) method. The ELECTRE is one of the MCDM methods and was first developed by Benayoun et al. (1966). The ELECTRE is generally labeled as ELECTRE I due to several different versions of ELECTRE methods. The other versions of ELECTRE methods are ELECTRE II, ELECTRE III, ELECTRE IV, ELECTRE IS (one esse), and ELECTRE TRI (Tree), just to name a few (Figueira et al., 2005). The majority of ELECTRE variants have been extensively employed in decision-making situations where a group of alternatives must be ordered according to the weight of a number of criteria. The final decision is believed to be able to reflect the decision-makers' preferences based on the series of computational steps of ELECTRE. The underpinning theory of ELECTRE is based upon the pseudo-criteria where the vagueness and uncertainty that can affect the evaluation are taken into account. Additionally, ELECTRE's benefit comes from its ability to employ pure ordinal scales without transforming them into abstract variables. It is also founded on the superior relationships between alternatives in which concordance and discordance indexes are used to determine the domination of an alternative.

Some authors have applied various versions of ELECTRE methods in many different fields of selection such as selection of the best financial investment projects (Hashemi et al., 2016), energy investment projects (Peng et al., 2019), green supplier selection (Qu et al., 2020), stock portfolio selection (Emamat et al., 2022), and prioritizing MCDM problems (Yu et al., 2018). In the field of education, Ougiaroglou and Kazanidis (2011) used

ELECTRE to indicate students' interests in courses in secondary education and also rank special interests in the higher education categories list. The ELECTRE III-based decision-making method was created by Chen et al. (2021) for the evaluation of bids while choosing a building contractor. The effectiveness of the bidders was assessed using generalized comparative linguistic phrases. In environmental science research, Cardoso et al. (2022) used a variety of sample preparation techniques to conduct screening tests on 3000 pharmaceuticals and metabolites in hospital wastewater samples. The ELECTRE multi-criteria decision analysis method was used to prioritize analytes according to their environmental risk. In water supply management research, Haider et al. (2014) conducted research regarding the choice of performance metrics for small- and medium-sized water utilities. The authors applied the outranking method ELECTRE in searching the most suitable performance indicator under each category for medium-sized water utilities. The findings showed that the ELECTRE approach is appropriate when preferences between options based on minute variations in assessments cannot be established. The ELECTRE also offers network maps that are based on outranking outcomes and shows which performance indicator is most appropriate. Still, in water management study, Noori et al. (2021) used an extension fuzzy-based ELECTRE to solve optimization problem of water supply choice. In business-related studies, Xidonas et al. (2010) introduced the use of ELECTRE Tri method to solve the selection of stocks. Three categories of equities – acceptable stocks, stocks that should be further investigated, and unsatisfactory stocks – were identified using the procedure. The outcomes demonstrate how well the ELECTRE Tri technique, which was used to classify the stocks, matched the characteristics of the portfolio choice. These vast applications of ELECTRE in solving selection problems provide evidence on the advantages of its algorithm and absolutely can be extended to solving aquaculture farming site selection.

This paper is structured as follows. Section 2 provides literature reviews of criteria or parameters of water quality. In Section 3, the research framework including the algorithm of the ELECTRE method is briefly described. The proposed method is then applied to a case study of selecting the best site for aquaculture farming. The detailed descriptions of this case study are presented in Section 4. A comparative analysis is provided in Section 5. Eventually, Section 6 is the concluding remarks.

## 2. Related Research

This section provides a brief review on factors or criteria that normally considered in deciding the aquaculture farming sites or site. This review also includes the computational methods or analyses used in the respective research. These reviews are limited to research works that retrieved from Scopus database. The key words of "aquaculture farming," "factors," and "land suitability" are used to facilitate the search. Summary of the review is given in Table 1.

The above review highlights the multiple factors or criteria that can be considered in managing aquaculture farming. Some research focuses on the importance of non-scientific criteria such as socio-economic and infrastructure. However, there are limits to how far the factor of water quality can be taken. This study limits the number of factors or criteria by focusing on the parameters related to water quality. Details of these parameters are discussed in the next paragraph.

This section also provides reviews on the criteria of water quality and its parameters that are normally considered in deciding the aquaculture farming sites or locations. As aforementioned above, there are three many factors that contributed to the success of aquaculture farming. For example, Ezekiel et al. (2018) considered twelve factors in their research. They also adamantly included water quality as the main factor. The characteristics they take into consideration include distance to water sources, water temperature, water pH, and distance to pollution sources.

**Table 1**
**Reviews of computational methods and analyses in aquaculture farming**

| Sources/Authors | Research Focus | Computational Method used | Factors/Criteria |
|---|---|---|---|
| Truong et al. (2021) | Create a model of medium-scale land use change to better understand how farmers choose to use their land. | Satellite image processing | 1. land suitability<br>2. land use situation of neighbors<br>3. land convertibility<br>4. profitability of land use patterns |
| Jayanthi et al. (2020) | Select the most appropriate aquaculture zones to ensure sustainability and evaluate the ecosystem's capacity to support shrimp farming. | Spatial analysis and analytical hierarchy process | 1. Land type<br>2. soil characteristics<br>3. source water quality<br>4. infrastructure availability |
| de Freitas et al. (2019) | Determine the best locations for marine shrimp cultivation. | Remote sensing and geospatial analysis | 1. infrastructure and logistics<br>2. socio-economic factors<br>3. climate<br>4. soil<br>5. water availability<br>6. topography |
| Ezekiel et al. (2018) | Describe the elements that influence whether a location is suitable for gigantic freshwater prawns. | Pearson correlation and multiple regression | 1. water pH<br>2. water temperature<br>3. distance to sources of water<br>4. distance to source of pollution |
| Hossain et al. (2007) | Determine the best locations in Sitakunda Upazila to establish Nile tilapia (Oreochromis niloticus) farming. | Geographic Information Systems | 1. Topography<br>2. water and soil quality,<br>3. socio-economic<br>4. infrastructure |

The importance of water quality in aquaculture farming is further emphasized by many researchers. For example, Su et al. (2020) come with a firm statement on the importance of water quality. According to their assertion, maintaining water quality is a crucial component of fisheries management in order to ensure the expansion of aquaculture farming. Additionally, in aquaculture farming, Mahalakshmi et al. (2014), Ezekiel et al. (2018) and Ghobadi et al. (2021) have offered the information on the criteria of water quality. Their study started by evaluating five main criteria, and one of the criteria was water quality. In light of the vital role of water quality in aquaculture farming, this research focuses our attention to the water quality. The five criteria of this research have been chosen from the list of parameters that affected the health of fish. The following criteria are used in the selection of aquaculture farming.

## 2.1. pH value

The health of fish is greatly influenced by the acidity of the water. The pH range that is normally acceptable for fish culture is between 6.5 and 9.0. When the pH value of water is higher than pH 9.0, the water will become very alkaline, and ammonia in the water is transformed to toxic, which can kill the fish. On the other hand, if the water is very acidic, which means the pH value is less than 5.0, the water can leech the metals from sediments and rocks. These metals will affect the metabolism rate of fish. Therefore, the pH value is selected as one of the criteria, to evaluate the most ideal environment for aquaculture farming.

## 2.2. Dissolve oxygen (DO)

DO is the oxygen required for oxidation and other metals within aquatic resources. It is important to sustain the concentration of dissolved oxygen in the river. It is recommended that DO concentration must be more than 5.0 mg/L. Otherwise, it can create a condition that kills the fish. Therefore, the concentration of DO is chosen as the second criterion in this research.

## 2.3. Biochemical oxygen demand (BOD)

The amount of oxygen that must be used by bacteria during the decomposition of organic material is measured by BOD. The higher the BOD measured, the higher the level of organic pollutants in the water. Therefore, the amount of DO need to break down these organic materials is higher. When BOD is present in the water, it will persist until sufficient dissolved oxygen is satisfied.

## 2.4. Temperature

Water temperature is a controlling factor for aquatic life in which the temperature controls the reproductive activities, metabolism, and life cycle of fishes. Temperature affects the level of DO in which oxygen is more easily dissolved in cold water. As the temperature has strongly affected the health of fishes and it has strong relationships with DO in water, it is taken as other criteria of this research.

## 2.5. Ammonia

One of the most important pollutants in the water is ammonia. It is highly toxic which can affect the health of fishes. Ammonia concentration and pH value of water have a complex relationship. This is because the higher the level of ammonia in water, the higher the alkalinity of the water, and as a result, this would increase the pH value of water which is eventually harmful to the fishes. Fishes in high concentrations of ammonia can be fatal as well. Therefore, ammonia is taken as the criteria for this multi-criteria decision research.

Some literature suggests more than five parameters of water quality that are necessary for successful aquaculture management. However, the five parameters chosen in this research are among the most important parameters as these parameters provide vital information about the effect of water quality on fish health. The third section is concerned with the methodology used for this study.

# 3. Research Methodology

This section describes the selection of alternatives using the ELECTRE method. In particular, the ELECTRE method is used to identify the possible site of aquaculture farming with respect to several criteria. This research investigates the possible farming sites in the state of Terengganu, Malaysia. The sites that have been selected as the alternatives in this study are Tasik Kenyir, Setiu Wetland, Besut River, and Marang River. Figure 1 shows the networks of the criteria and sites that are considered in this study.

## 3.1. Data collection

Linguistic data were collected from three aquaculture industry decision-makers. Nonetheless, in this research, the source of data is based on secondary data. The decision-makers were interviewed to evaluate sites based on the given criteria. Table 2 shows the scales and linguistic terms used in the evaluation.

The evaluation data are gathered and summarized in Table 3.

**Figure 1**
**Criteria of water quality and sites**

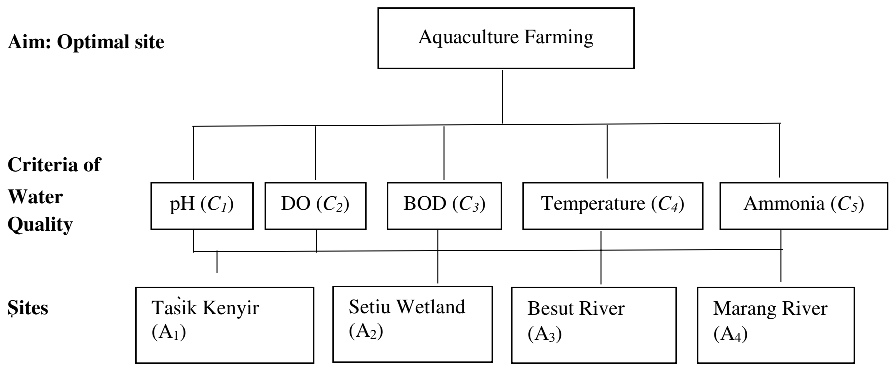

**Table 2**
**Representative number for water classes**

| Classes of water | Crisp number (Scale) | Linguistic terms |
|---|---|---|
| Class I | 5 | Very Good |
| Class II | 4 | Good |
| Class III | 3 | Moderate |
| Class IV | 2 | Poor |
| Class V | 1 | Very Poor |

**Table 3**
**The suitability of sites on each criterion based on classes of water**

| | pH | DO | BOD | Temperature | Ammonia |
|---|---|---|---|---|---|
| $A_1$ | 5 | 4 | 4 | 2 | 4 |
| $A_2$ | 5 | 3 | 4 | 3 | 4 |
| $A_3$ | 3 | 5 | 4 | 4 | 5 |
| $A_4$ | 4 | 4 | 5 | 5 | 4 |

The following information is needed to provide data input to the algorithm of ELECTRE. The input enables the algorithm to process the information and produce the output (the optimal alternative). The detailed algorithm of ELECTRE is presented in Section 3.2.

## 3.2. Algorithm of ELECTRE

The ELECTRE approach is frequently employed when ranking options in accordance with a set of factors that reflect the preferences of the decision-makers. Its theory is based upon the pseudo-criteria in which vagueness and uncertainty that can influence how the performance is assessed are counted into the computational model. The ELECTRE also has an ability to use the pure ordinal scales without transforming the original scales into abstract variables. It is also based on the outranking relations between alternatives by obtaining the concordance and discordance indexes to determine the domination of an alternative so that the best decision is obtained. The algorithm of steps in the procedure of ELECTRE method is presented as follows.

Let us assume that an MCDM problem has $m$ alternatives $(A_1, A_2, \ldots, A_m)$ and $n$ criteria $(C_1, C_2, \ldots, C_n)$. Each alternative is evaluated with respect to the $n$criteria. The evaluation value of alternatives in relation to each criterion is represented by a scale. These evaluation values form a decision matrix denoted by $X = (x_{ij})_{mxn}$. Let us assume $W = (w_1, w_2, \ldots, w_n)$ is the relative weight vector of criteria of which the summation of $w$ satisfies $\sum_{j=1}^{n} w_j = 1$. The algorithm of ELECTRE method can be summarized in the following steps (Haider et al., 2014).

**Step 1.** Normalize the decision matrix $X = (x_{ij})_{mxn}$ by calculating $r_{ij}$, which represents the normalized criteria,

$$r_{ij} = \frac{\frac{1}{x_{ij}}}{\sqrt{\sum_{i=1}^{m} \frac{1}{x_{ij}^2}}} \text{ for the minimization objective, where } i = 1, 2, \ldots, m \text{ and } j = 1, 2, \ldots, n. \tag{1}$$

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \text{ for the maximization objective, where } i = 1, 2, \ldots, m \text{ and } j = 1, 2, \ldots, n. \tag{2}$$

According to Marbini et al. (2012), normalization is a process applied in ELECTRE method for MCDM in order to deal with different scales. Calculate $r_{ij}$, the normalized criterion, and use it to normalize the decision matrix $X = (X_{ij})_{mxn}$.

**Step 2.** The weighted normalized decision matrix is calculated such that,

$$V = (v_{ij})_{mxn}, V_{ij} = r_{ij} x w_j \tag{3}$$

where $i = 1, 2, \ldots, m$ and $j = 1, 2, \ldots, n$ where $w_j$ is the relative weight of the $j-$th criteria, and $\sum_{j=1}^{n} w_j = 1$.

The scale used in evaluating criteria can be used to build a pairwise comparison matrix, which will reveal the weights of the criterion. The relative normalized weight $w_j$ of each criterion $j$ is calculated using equation below:

$$\text{Geometrical Mean, } GM_i = \left(\prod_{i=1}^{n} a_{ij}\right)^{\frac{1}{n}} \tag{4}$$

where $a_{ij}$ is the degree of importance of criteria $i$ over $j$.

$$W_j = \frac{GM_i}{\sum_{i=1}^{n} GM_i} \tag{5}$$

**Step 3.** Establish the sets of concordance and discordance. The concordance set is organized and formatted as follows:

$$C(p, q) = \{j | V_{pj} \geq V_{qj}\} \tag{6}$$

where $V_{pj}$ and $V_{qj}$ are the weighted normalized evaluation of alternatives with respect to criterion.

The discordance set is written as

$$D(p, q) = \{j | V_{pj} < V_{qj}\} \tag{7}$$

**Step 4.** Determine the indexes of concordance and discordance. The criteria concordance index is defined as follows:

$$C_{pq} = \sum_{j*} w_j \tag{8}$$

where $j^*$ are criteria in the concordance set.

The degree of disagreement is represented by the discordance index, which is defined as:

$$D_{pq} = \frac{\sum_{j+} | v_{pj+} - v_{qj+} |}{\sum_{j} | v_{pj} - v_{qj} |} \tag{9}$$

where the discordance set's attributes $j^+$ are located.

**Step 5.** Form the matrix of concordance denomination using Average Index of Concordance, $\overline{C}$ and matrix of discordance denomination using Average Index of discordance, $\overline{D}$ such that:

$$\overline{C} = \sum_{p=1}^{m} \sum_{q=1}^{m} \frac{C_{pq}}{m(m-1)} \tag{10}$$

$$\overline{D} = \sum_{p=1}^{m}\sum_{q=1}^{m}\frac{D_{pq}}{m(m-1)} \quad (11)$$

After that the aggregated denomination matrix is formed by multiplying the both matrixes for outranking relationship. The method defines that $A_p$ outranks $A_q$ when $\underline{C}_{pq} \geq \underline{C}$, and $\underline{D}_{pq} \leq \underline{D}$, where $\underline{C}$ and $\underline{D}$ are the of $\underline{C}_{pq}$ and $\underline{D}_{pq}$, respectively.

**Step 6.** Create the $F$ and $G$ Boolean matrices. A minimum concordance level, $\overline{C}$ determines the Boolean matrix $F$, where

$$f_{pq} = \begin{cases} 1, \text{ if } \tilde{C}_{pq} \geq \overline{C} \\ 0, \text{ if } \tilde{C}_{pq} < \overline{C} \end{cases} \quad (12)$$

Likewise, the Boolean matrix $G$ is calculated using the minimum discordance level, $\overline{D}$ where

$$g_{pq} = \begin{cases} 1, \text{ if } d_{pq} \geq \overline{D} \\ 0, \text{ if } d_{pq} < \overline{D} \end{cases} \quad (13)$$

The entries in matrices $F$ and $G$ with a value of 1 show which possibilities are more dominant.

**Step 7.** Build the Global matrix by multiplying the matrices $F$ and $G$, the general matrix $H$ is constructed, $H = F$ x $G$.

**Step 8.** Build a decision graph and then rank the options. Based on the global matrix, a decision graph is built to establish the ranking order of the options. The ELECTRE is the method that specifically deal with outranking relation. This outranking relation is generally indicated with $A_p \rightarrow A_q$ which means that, $A_p$ dominate $A_q$; thus, $A_p$ is better than $A_q$.

These computational steps are applied to the case of selecting aquaculture farming site.

## 4. Computational Implementation and Results

In this section, we discuss how the ELECTRE method is implemented to this study. There are five criteria that are taken into consideration in the water quality evaluation. The parameters or criteria are pH, dissolved oxygen, BOD, ammonia, and water temperature (see Table 3). Computations is implemented in this section where the information of water quality and the sites are become the input data to the ELECTRE method.

**Step 1.** Normalize the decision matrix $X = \left(x_{ij}\right)_{mxn}$. Thus, the Equations (1) and (2) are used in calculation for $X$.

For example, $r_{11} = \frac{5}{\sqrt{75}} = 0.577350$. The rest of the normalized decision matrix is presented in Table 4.

**Table 4**
**Normalized decision matrix**

| | $C_1$ | $C_2$ | $C_3$ | $C_4$ | $C_5$ |
|---|---|---|---|---|---|
| $A_1$ | 0.577350 | 0.492366 | 0.468165 | 0.272166 | 0.568165 |
| $A_2$ | 0.577350 | 0.369274 | 0.468165 | 0.408248 | 0.468165 |
| $A_3$ | 0.346410 | 0.615457 | 0.468165 | 0.544331 | 0.585206 |
| $A_4$ | 0.468165 | 0.492366 | 0.585206 | 0.680414 | 0.468165 |

**Table 5**
**Pairwise matrix (Expert 1)**

| | $C_1$ | $C_2$ | $C_3$ | $C_4$ | $C_5$ | $W_j$ |
|---|---|---|---|---|---|---|
| $C_1$ | – | 4 | 1/5 | 4 | 4 | 0.236789 |
| $C_2$ | ¼ | – | 1/5 | 3 | 3 | 0.121221 |
| $C_3$ | 5 | 5 | – | 5 | 5 | 0.515362 |
| $C_4$ | ¼ | 1/3 | 1/5 | – | ½ | 0.054588 |
| $C_5$ | ¼ | 1/3 | 1/5 | 2 | – | 0.072030 |

**Table 6**
**The average weights of criteria**

| Criteria | Weights |
|---|---|
| $C_1$ | 0.181875 |
| $C_2$ | 0.236204 |
| $C_3$ | 0.252601 |
| $C_4$ | 0.208179 |
| $C_5$ | 0.121139 |
| Sum of weights | 1.000000 |

**Step 2.** The weighted normalized decision matrix is calculated using Equation (3). Table 5 presents the pairwise matrix obtained using the degrees of importance of criteria that have been evaluated by Expert 1.

The similar pairwise matrices are also constructed based on the judgments made by other experts. Equations (4) and (5) are used to determine the relative normalized weight $w_j$ of each criterion $j$. The relative weights are presented in Table 6.

Equation (3) is used to multiply relative weight and normalized decision matrix. The weighted normalized matrix is given in Table 7.

**Step 3.** Determine the concordance and discordance sets.

Equations (6) and (7) are used to find concordance sets and discordance sets, respectively. Table 8 represents the concordance and discordance sets.

**Step 4.** Calculate the concordance and discordance indexes using Equations (8) and (9). Tables 9 and 10 show the matrix of concordance and discordance respectively.

**Step 5.** Use Equations (10) and (11) to construct the matrix of concordance and the matrix of discordance. Then, the aggregated denomination matrix is constructed by multiplying both matrixes for outranking relationship. The calculations of concordance and discordance are shown as below.

**Table 7**
**The weighted normalized decision matrix**

| | $C_1$ | $C_2$ | $C_3$ | $C_4$ | $C_5$ |
|---|---|---|---|---|---|
| $A_1$ | 0.105006 | 0.116299 | 0.118259 | 0.056659 | 0.056713 |
| $A_2$ | 0.105006 | 0.087224 | 0.118259 | 0.084989 | 0.056713 |
| $A_3$ | 0.063003 | 0.145373 | 0.118259 | 0.113318 | 0.070891 |
| $A_4$ | 0.085148 | 0.116299 | 0.147824 | 0.141648 | 0.056713 |

**Table 8**
**Sets of concordance and discordance**

| Concordance sets (C) | Discordance sets (D) |
|---|---|
| $C_{12} = \{1,2,3,5\}$ | $D_{12} = \{4\}$ |
| $C_{13} = \{1,3\}$ | $D_{13} = \{2,4,5\}$ |
| $C_{14} = \{1,2,5\}$ | $D_{14} = \{3,4\}$ |
| $C_{21} = \{1,3,4,5\}$ | $D_{21} = \{2\}$ |
| $C_{23} = \{1,3\}$ | $D_{23} = \{2,4,5\}$ |
| $C_{24} = \{1,5\}$ | $D_{24} = \{2,3,4\}$ |
| $C_{31} = \{2,3,4,5\}$ | $D_{31} = \{1\}$ |
| $C_{32} = \{2,3,4,5\}$ | $D_{32} = \{1\}$ |
| $C_{34} = \{2, 5\}$ | $D_{34} = \{1,3,4\}$ |
| $C_{41} = \{2,3,4,5\}$ | $D_{41} = \{1\}$ |
| $C_{42} = \{2,3,4,5\}$ | $D_{42} = \{1\}$ |
| $C_{43} = \{1,3,4\}$ | $D_{43} = \{2,5\}$ |

**Table 9**
**Matrix of concordance**

| | $A_1$ | $A_2$ | $A_3$ | $A_4$ |
|---|---|---|---|---|
| $A_1$ | – | 0.791819 | 0.434476 | 0.539218 |
| $A_2$ | 0.763794 | – | 0.434476 | 0.303014 |
| $A_3$ | 0.818123 | 0.818123 | – | 0.357343 |
| $A_4$ | 0.0818123 | 0.818123 | 0.642655 | – |

**Table 10**
**Matrix of discordance**

| | $A_1$ | $A_2$ | $A_3$ | $A_4$ |
|---|---|---|---|---|
| $A_1$ | – | 0 | 1 | 0 |
| $A_2$ | 0 | – | 1 | 0 |
| $A_3$ | 2.962548 | 2.962548 | – | 1.998166 |
| $A_4$ | 0 | 0 | 1 | – |

For concordance denomination matrix,

$$\overline{C} = \frac{\begin{array}{c}0.791819 + 0.434476 + 0.539218 + 0.763794 + 0.434476 + 0.303014+ \\ 0.818123 + 0.818123 + 0.357343 + 0.818123 + 0.818123 + 0.642655\end{array}}{4(4-1)}$$
$$= 0.628274$$

For discordance denomination matrix,

$$\overline{D} = \frac{1 + 1 + 2.962548 + 2.962548 + 1.998166 + 1}{4(4-1)} = 0.910272$$

**Step 6.** Create the Boolean matrices $F$ and $G$. The Boolean matrix $F$ takes the value as 1, if the element is greater than or equal to $\overline{C}$. Otherwise, it is 0 by computing Equations (12) and (13).

$$F = \begin{bmatrix} 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 \\ 1 & 1 & 1 & 0 \end{bmatrix} G = \begin{bmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 1 & 0 \\ 1 & 1 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{bmatrix}$$

**Step 7.** Construct the Global matrix by multiplying the matrices $F$ and $G$, and the general matrix $H$ is constructed, $H = F$ x $G$.

**Figure 2**
**The decision graph for four alternatives**

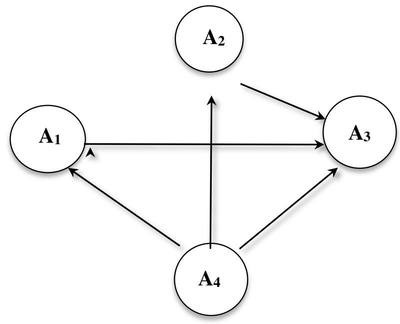


**Table 11**
**The ranking results**

| Alternative | Domination | Ranking |
|---|---|---|
| $A_1 \rightarrow A_3$ | $A_1$ dominates $A_3$ | – |
| $A_2 \rightarrow A_3$ | $A_2$ dominates $A_3$ | – |
| $A_3$ | Not dominant | 4 |
| $A_4 \rightarrow A_1$, $A_2$, $A_3$ | $A_4$ dominates $A_1$, $A_{2,}$ and $A_3$ | 1 |

$$f_{pq} \cdot g_{pq} = \begin{bmatrix} 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 \\ 1 & 1 & 1 & 0 \end{bmatrix} \times \begin{bmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 1 & 0 \\ 1 & 1 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{bmatrix} = \begin{bmatrix} A_1 & 0 & 1 & 0 \\ 0 & A_2 & 1 & 0 \\ 0 & 0 & A_3 & 0 \\ 1 & 1 & 2 & A_4 \end{bmatrix}$$

**Step 8.** Make a decision graph and assign a ranking to the alternatives.

By referring the obtained aggregated domination matrix, the decision graph is drawn in Figure 2. Based on the decision graph, domination and ranking can be inferred.

The decision graph tells the direction of domination among alternatives. For example, $A_1$ has a unidirectional relation with $A_{3;}$ therefore, $A_1$ dominates $A_3$. Table 11 summarizes the domination and ranking of alternatives.

Based on Table 11, the results show that the optimal site for aquaculture farming is $A_4$, Marang River. It can be seen that $A_4$ dominates the other three alternatives $A_1$, $A_{2,}$ and $A_3$. Therefore, Marang river ($A_4$) is the optimal solution in the site selection of aquaculture farming. The ranking result also shows that Besut River ($A_3$) is ranked as the fourth choice due to its failure to highlight dominant property. The site Tasik Kenyir ($A_1$) and Setiu Wetlands ($A_2$) are not able to show domination property as they dominate over the same alternative.

## 5. Comparative Analysis

For the purpose of comparing the final results, information of this case study is used as the input data to the computational model of fuzzy ELECTRE method. This method is a combination of ELECTRE method and fuzzy sets where linguistic variable is used in evaluation. The method has been popularized by many researchers including Babak and Turan (2012) and recently Tham and Le (2021). In contrast to ELECTRE, the fuzzy ELECTRE depends on decision-makers to provide evaluation of criteria and alternatives using a linguistic variable "importance." In this case study, triangular fuzzy numbers are utilized to define the importance of criteria and alternatives (Jiang et al., 2007). The

**Table 12**
**Comparative results of ELECTRE and Fuzzy ELECTRE methods**

| Alternatives | ELECTRE method | | Fuzzy ELECTRE method | |
|---|---|---|---|---|
| | Domination | Ranking | Domination | Ranking |
| $A_1$ | Dominates $A_3$ | – | Dominates $A_2$ and $A_3$ | 2 |
| $A_2$ | Dominates $A_3$ | – | Not dominant | – |
| $A_3$ | Not dominant | 4 | Not dominant | – |
| $A_4$ | Dominates $A_1$, $A_2$ and $A_3$ | 1 | Dominates $A_1$, $A_2$ and $A_3$ | 1 |

decision-makers were assigned to evaluate the importance of criteria and alternatives which are subsequently computed using the algorithm adopted from Esra et al. (2011). The final output shows that the optimal site for aquaculture farming development in Terengganu, Malaysia is $A_4$, Marang River of which surprisingly consistent with the output of ELECTRE method. However, dominations of alternatives are slightly different between these two methods. The comparative results of ELECTRE and fuzzy ELECTRE methods for this case study are summarized in Table 12.

The final result highlights the optimal alternative is $A_4$ regardless the method used. The site Marang River ($A_4$) is ranked as the optimal site among the four sites. The site ($A_1$) and ($A_2$) are not able to compare because they have the same ranking. In conclusion, the two methods provide evidence on the most ideal site for aquaculture farming.

## 6. Conclusion

MCDM method is a technique that provides an effective framework for evaluating alternatives from multiple and conflict criteria. Using the ELECTRE method, this research successfully determined the optimal site for aquaculture farming in Terengganu, Malaysia. Five criteria of water quality were taken into consideration which are the pH values, dissolved oxygen, BOD, ammonia, and temperature of water. Four strategic sites in Terengganu, Malaysia, were chosen as alternatives which are the Tasik Kenyir ($A_1$), Setiu Wetland ($A_2$), Besut River ($A_3$), and Marang River ($A_4$). The ELECTRE method suggests the outranking relations between alternatives by obtaining the concordance and discordance matrices. Finally, the aggregated domination matrix and the decision graph were obtained using which the best solution can be inferred subsequently. The ranking results reveal that Marang River ($A_4$) has the finest water quality and is the best site for aquaculture farming. It is apparent that the ELECTRE method successfully determined the optimal site for aquaculture farming. The findings of this study will have a positive impact on local farmers who want to succeed in aquaculture farming. Choosing the right farming site with good water quality is an important indicator for the growth of freshwater fishes. Other farming sites could improve their water quality by addressing the factors that contribute to low water quality. For example, Tasik Kenyir ($A_1$) is a popular tourist destination, which may contribute to increased water pollution. As a result, authorities should strengthen the policy in order to improve the water quality. However, the findings in this paper are subject to at least two limitations. First, the method fails to obtain a set of full ranking of alternatives due to incomparable ranking between two alternatives. Second, due to practical constraints, this paper cannot provide a comprehensive list of factors or criteria other than water quality. Notwithstanding these limitations, the study therefore suggests more criteria or factors should be considered in future research so that the problem of incomparable could be resolved and a more comprehensive ranking result could be obtained. Moreover, the distance measures in the concordance and discordance index could be extended to other types of distance measures.

## Conflicts of Interest

The authors declare that they have no conflicts of interest to this work.

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