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AN APPLICATION OF COASTAL EROSION DECISION PROBLEM USING INTERVAL TYPE-2 FUZZY DEMATEL METHOD

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Abstract: In the coastal zone, there is an increasing of socioeconomic development which related to coastal erosion problem and causes some damages to the geography of the coastal zone. Besides, the environmental effects also play its role that may affect the coastal area such as shoreline changes, wave condition, relative sea level rise and climate change. In order to cope with the problem, this paper aims to illustrate the relationship of risk factors for coastal erosion decision problem using Interval Type-2 Fuzzy Decision-making Trial and Evaluation Laboratory (IT2FDEMATEL) method which is the evaluation of the factors is modelled by fuzzy approach. The study identified the four main risk factors and fourteen critical criteria as a factor that contributes to the coastal erosion. Determining the associated element towards the problems regards a wary action in order to demonstrate a critical point of decision problems in a real application which involve uncertainty during decision process. The preference scale provided by the decision makers is calculated using trapezoidal type-2 fuzzy number instead of crisp numbers. In this paper, the finding indicates that the shoreline changes/evolution is the most important risk factors to lead the coastal erosion problems followed by climate change, relative sea level rise and wave condition. Thus, it is hoped that the findings could be beneficial to policy makers to underline the need to be undertaken in dealing with coastal erosion.

Keywords: DEMATEL method, interval type-2 fuzzy set, coastal erosion, decision making.

Introduction

In Malaysia, 70% of the Malaysian population live in the coastal zone and practically become the center of urban and rural economic activities such as human working and trading activities (EPU, 1993). The growth of population density and development activities nowadays were unhealthy and unsanitary conditions (Mokhtar & Ghani, 2003). As a result, the coastal zone has some difficulties in environmental degradation by having a negative impact on the economic and social value of the coastal zone (Tang *et al*., 2005). According to National Coastal Erosion Study from November 1984 to January 1986, it is about 29% or 1,380 km was facing coastal erosion in Malaysia coastline (Ministry of Natural Resources and Environment, 2009). The risk assessment and research development have been implemented by the government to overcome the coastal zone problem such as the Coastal Engineering Centre in the Department of Irrigation and Drainage (DID) in 1987 to program a coastal erosion control. Coastal erosion occurs when the imbalance of the supply and export material from a coastal profile upon the state of the sea and is assessed by averaging over a period which is long enough to cut down the impacts of weather, storm events and local sediment supply. Normally, there are two main classified coastal erosions: structural erosion and acute erosion (Luo *et al*., 2013). The continuing process of erosion in consequence of changes conditions on coastal erosion is structural erosion. Acute erosion is caused by storm events, nevertheless, during calm periods, watching over the stormy period, the sediment coastal is often restructured and the coast will be rebuilt parts (Lou *et al*., 2013).

Nowadays the coastal zone becomes the center of social-economic activities which have increased the interest in erosion problem. The high value of coastal land use for the social-economy have changed the coastal profile, including the physical environment and nature of the coastline. These changes unconsciously result in causing the damages and destructions of coastal profile. For a most known circumstance, it can be stated that the most influential factors related to coastal erosion are both natural effects and human-interference factors. The natural effects such as wind, waves, continuous wave height with water depth leads to the unstable waves and driven near the shore through increasingly shallow water. The sea level rise and the climate change may also cause the coastal erosion by water flooding. In facts, every small level rise in the water can increase wave energy along the shoreline by causing more dangerous storms and reaches the shoreline with serious effect of drainage systems along the coastline areas (Ministry of Natural Resources and Environment, 2009). Climate change also gives an impact on wave climate which may occur the stormy and prevailing the wave direction (Masselink & Russell, 2013). Zhu *et al*. (2016) mentioned that the shoreline evolves in more complex variation of changes needed to recognize that the shoreline system in order to prevent the subsequences to the ecology of the coastal zone. Furthermore, the human-interference factors and coastal developments also tend to expose the coastline to the erosion from construction of navigation channels, dredging, reclamation, water extraction, artificial islands/artificial lagoon and also ports and harbours. All of these developments tend to cause sediments moving along to the shoreline and interrupt the accretion along the shoreline and cause wave shadow area and causing erosion on the down-drift coastline (Ministry of Natural Resources and Environment, 2009). The increasing number of ships exploiting the Straits of Malacca and the Port of Tanjung Pelepas by economic trading may result in large wave and threaten the coastline such as Tanjung Piai in Johor Bahru (Asmawi & Ibrahim, 2013).

An abundant development of focusing on coastal erosion may be one of the most important awareness to solve this environmental issue. Picking out the right methods along with the concrete factors may lead to effectiveness of the solution requires. To this point, there are dozens of dissimilar techniques conducted by researchers to overcome the erosion problems such as Brown *et al*. (2006) suggested the model linkages and technical issues involved while assessment and communication of the future risk from coastal erosion, by linking climate change with predictive simulation model and visualization system of Geographic Informatics System (GIS) model. Landry (2011) described coastal erosion resource management problem and applied economic dynamic optimization models for analyzing coastal replenishment. Baoteng (2012) provided a large-scale assessment of coastal geomorphology and GIS techniques to explain the various factors responsible for coastal erosion. Through the observation, erosion hotspots and various coastal developments were identified as at risk. Baoteng concluded that coastal erosion is due to major industries, urban settlements, recreational facilities and heritage and conservation sites are located few meters from the coast of Ghana. Lou *et al*. (2013) introduced an integrated methodology using Delphi method, the analytic hierarchy process and the fuzzy set theory to access and map the coastal erosion risk by integrating hazard, exposure, risk priority and coping capacity to guide coastal erosion risk management. To date, Lee and Park (2014) investigated the main problems related to coastal erosion in Cheju Island and showed that the main cause of erosion is the differential weathering of alternating layers of either sandstone with shale or basalt with weak sedimentary beds.

The demand regarding this massive environmental issue, it is necessary to identify and determine the factors related to coastal erosion before implementing coastal risk management planning. The importance of risk management planning is to provide a set of policy recommendation in order to improve the assessment procedures, coastal erosion planning and protection and local information for decision making system. Unfortunately, the knowledge base for decision making on coastal risk management is weak and remain unseen by public authorities as a platform to reduce the erosion. Besides, previous studies only focus on the general coastal erosion problem without capability on demonstrated the relationships between factors that may contribute to coastal erosion. This study intends to modelling the relationship of influential risk factor related to the coastal erosion problem using Interval Type-2 Fuzzy Decision Making Trial and Evaluation Laboratory (IT2-DEMATEL). DEMATEL method is known as for its characteristic to visualize a structural causal relationship between the criteria and indicate the degree of factor influence to each other (Liou *et al*., 2007) while the flexibility of IT2FS managed to represent the uncertainties involve during the decision process (Mendel, 2001; 2007). DEMATEL method have been widely used in many decision-making analyses. Hosseini & Tarokh (2013) evaluate the perceptual computing for knowledge management criteria of decision making using fuzzy DEMATEL and extended to the type-2 fuzzy set. Besides, the fuzzy DEMATEL method also have been combined with several MCDM methods such as fuzzy ANP and fuzzy VIKOR for selecting the city logistic concept (Tadic *et al*., 2014). Recently, Olfat &Pishdar (2015) investigated the environmental good governance component evaluation using IT2FDEMATEL method. The uniqueness of both DEMATEL method and IT2FS theory had motivate us to overlook the potential of these concepts in decision making process especially involving multiplicity of choices.

Methodology

Interval Type-2 Fuzzy Sets

This section describes the mathematical definitions of Interval Type-2 Fuzzy Sets (IT2 FS) as a basic concept used in this paper explained by Mendel *et al*. (2006), Wu & Mendel (2007) and Mendel & Wu (2010).

Definition 2.1

A type -2 fuzzy set $\tilde{\tilde{A}}$ in the universe of discourse X can be represented by a type-2 membership function $m_{\tilde{\tilde{A}}}$ shown as follows;

$$\tilde{\tilde{A}} = \{(x,u),u_{\tilde{\tilde{A}}}(x,u)|\forall x\in X, \forall u\in J_x\subseteq[0,1]\} \quad (1)$$

Such that $0\leq u_{\tilde{\tilde{A}}}(x,u)\leq 1$. The type-2 fuzzy set also can be represented as follows:

$$\tilde{\tilde{A}} = \int_{x\in X}\int_{u\in J_x} u_{\tilde{\tilde{A}}}(x,u)|/(x,u) \quad (2)$$

Such that $J_x\subseteq[0,1]$ and ∬ denotes the union over all admissible x and u.

Definition 2.2

Let $\tilde{\tilde{A}}$ be a type-2 fuzzy set in the universe of discourse X represented by the type-2 membership function $u_{\tilde{\tilde{A}}}$. If all $u_{\tilde{\tilde{A}}}(x,u)$, then $\tilde{\tilde{A}}$ is called IT2FS. An IT2FS $\tilde{\tilde{A}}$ can be regarded as a special case of type-2 fuzzy set, shown as follows:

$$\tilde{\tilde{A}} = \int_{x\in X}\int_{u\in J_x} 1/(x,u), \quad (3)$$

where x and u are primary and secondary variable respectively. Wu and Mendel (2007) describes that uncertainty of $\tilde{\tilde{A}}(FOU(\tilde{\tilde{A}}))$ called the footprint of uncertainty by the union of all the primary memberships of $\tilde{\tilde{A}}$.

$$FOU(\tilde{\tilde{A}}) = \bigcup_{x\in X} J_x\{(x,y):y\in J_x = [\tilde{A}^L(x), \tilde{A}^U(x)]\subseteq[0,1] \quad (4)$$

An IT2 FS is shown in Figure 1. The FOU is shown as the shaded region. The membership function is bounded by upper membership function (UMF), $\tilde{\tilde{A}}(x) \equiv \tilde{A}^U$ and the lower membership function (LMF) and $\tilde{\tilde{A}}(x) \equiv \tilde{A}^L$ which the membership grade of an IT2FS is an interval $\tilde{\tilde{A}}(x) \equiv [\tilde{A}^U, \tilde{A}^L]$. Besides, several studies also use $\underline{u}_{\tilde{\tilde{A}}}(x)$ and $\bar{u}_{\tilde{\tilde{A}}}(x)$ for the UMF and LMF for IT2 FS concept (Mendel & Wu, 2010).

$$FOU(\tilde{\tilde{A}}) = \bigcup_{\forall x\in X}[\underline{u}_{\tilde{\tilde{A}}}(x)\ ,\ \bar{u}_{\tilde{\tilde{A}}}(x)] \quad (5)$$

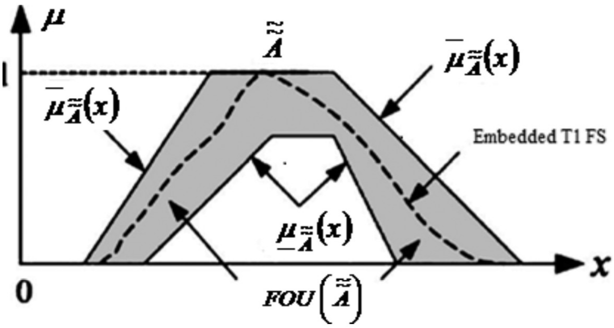

Figure 1: An interval type-2 fuzzy set

The UMF and LMF of $\tilde{\tilde{A}}$ are two membership functions that bound the FOU. The $UMF(\tilde{\tilde{A}})$ is associated with the upper bound of $FOU(\tilde{\tilde{A}})$ and is denoted by $\bar{u}_{\tilde{\tilde{A}}}(x)$, $\forall x \subseteq X$; and $LMF(\tilde{\tilde{A}})$ is associated with the lower bound of $FOU(\tilde{\tilde{A}})$ and is denoted as $\underline{u}_{\tilde{\tilde{A}}}(x)$, $\forall x \subseteq X$, which

$$UMF\left(\tilde{\tilde{A}}\right) \equiv \bar{\mu}_{\tilde{\tilde{A}}}(x) = \overline{FOU\left(\tilde{\tilde{A}}\right)} \quad \forall x \in X \quad (6)$$

$$LMF\left(\tilde{\tilde{A}}\right) \equiv \underline{\mu}_{\tilde{\tilde{A}}}(x) = \underline{FOU\left(\tilde{\tilde{A}}\right)} \quad \forall x \in X \quad (7)$$

Interval Type-2 Fuzzy DEMATEL Method

The DEMATEL-based technique originally successful in handling the evaluation of the criteria interdependence ability toward the restriction of a relation in systemic and development trend (Lu *et al*., 2013). In this study, the combination of interval type-2 fuzzy sets concept and DEMATEL is applied by using the trapezoidal interval type-2 fuzz sets numbers instead of crisp value. The sequence of the IT2-FDEMATEL method can be summarized as follows:

Step 1: Identify the decision-making problem goals along with its dimension of the problem, critical criteria and group of the decision makers (DMs).

Step 2: Scaling the relative of linguistic variables and constructing the pair-wise comparison of IT2FS matrices.

In decision problems, responses from DMs are mainly focused on judgement preference of the dimension and identified critical criteria for the problems. The preference scale of IT2-FDEMATEL is used to measure the DMs judgements scaling. The linguistic preference of trapezoidal interval type-2 fuzzy number is shown in Table 1.

Step 3: Construct the average decision comparison matrix, $\tilde{\tilde{A}}$.

The construction of the average matrix, $\tilde{\tilde{A}}$ is computed by Equation (8). Suppose the decision maker, H and n factors are considered for the decision problems. The n x n average matrix, $\tilde{\tilde{A}}$ for all decision maker opinions can be computed by averaging score of the H decision makers as follows:

Table 1: The preference scale of trapezoidal IT2FN

Linguistic Preference	**Linguistic Number**	**Trapezoidal IT2FN**
No influence	0	((0,0,0,0;1,1), (0,0,0,0 ;0.9,0.9))
Low influence	1	((0,0.1,0.1,0.1;1,1), (0,0.1,0.1,0.05;0.9,0.9))
Medium influence	2	((0.1,0.2,0.2,0.3;1,1), (0.15,0.2,0.2,0.25;0.9,0.9))
High influence	3	((0.2,0.3,0.3,0.4;1,1), (0.25,0.3,0.3,0.35;0.9,0.9))
Very high influence	4	((0.3,0.4,0.4,0.5;1,1), (0.35,0.4,0.4,0.45;0.9,0.9))

$$A_{ij} = \frac{1}{H}\sum_{p=1}^{H} \tilde{\tilde{A}}_{ij}(x)_{ij}^{p} \quad (8)$$

Hence, the total average matrix of trapezoidal interval type-2 fuzzy number can be defined as:

$$\tilde{\tilde{A}}_{ij} = \begin{bmatrix} (\tilde{A}^U, \tilde{A}^L)_{11} & \cdots & (\tilde{A}^U, \tilde{A}^L)_{1j} & \cdots & (\tilde{A}^U, \tilde{A}^L)_{1n} \\ \vdots & & \vdots & & \vdots \\ (\tilde{A}^U, \tilde{A}^L)_{i1} & \cdots & (\tilde{A}^U, \tilde{A}^L)_{ij} & \cdots & (\tilde{A}^U, \tilde{A}^L)_{in} \\ \vdots & & \vdots & & \vdots \\ (\tilde{A}^U, \tilde{A}^L)_{n1} & \cdots & (\tilde{A}^U, \tilde{A}^L)_{nj} & \cdots & (\tilde{A}^U, \tilde{A}^L)_{nn} \end{bmatrix} \quad (9)$$

Step 4: Computation the aggregated matrix for dimensions and critical criteria, $\tilde{\tilde{A}}_C$.

The aggregated matrix comparison of each dimension and its critical criteria is constructed using Equation (10).

$$\tilde{\tilde{A}}_c = \tilde{\tilde{f}}_c^{\,p} = \begin{bmatrix} \tilde{\tilde{f}}_{11}^{p} & \tilde{\tilde{f}}_{12}^{p} & \cdots & \tilde{\tilde{f}}_{1n}^{p} \\ \tilde{\tilde{f}}_{21}^{p} & \tilde{\tilde{f}}_{22}^{p} & \cdots & \tilde{\tilde{f}}_{2n}^{p} \\ \vdots & \vdots & \vdots & \vdots \\ \tilde{\tilde{f}}_{m1}^{p} & \tilde{\tilde{f}}_{m2}^{p} & \cdots & \tilde{\tilde{f}}_{mn}^{p} \end{bmatrix} \quad (10)$$

where $\tilde{\tilde{f}}_{ij} = \left(\dfrac{\tilde{\tilde{f}}_{ij}^{1} \oplus \tilde{\tilde{f}}_{ij}^{2} \oplus \cdots \oplus \tilde{\tilde{f}}_{ij}^{p}}{k}\right)$ (Chen & Lee, 2010), $\tilde{\tilde{f}}_{ij}$ is an IT2FS, $1 \le i \le m$, $1 \le j \le n$ and k denotes the number of factors.

Step 5: Calculate the initial direct influence matrix, $\tilde{\tilde{D}}$.

The initial direct-relation matrix $\tilde{\tilde{D}}$ is obtained by normalizing the aggregated matrix $\tilde{\tilde{A}}_c$ by Equation (11).

$$\tilde{\tilde{D}} = \frac{\tilde{\tilde{A}}_{c_{ij}}}{\max\left(\max\limits_{1\le i\le n}\sum_{j=1}^{n}\tilde{\tilde{A}}_{c_{ij}},\ \max\limits_{1\le i\le n}\sum_{i=1}^{n}\tilde{\tilde{A}}_{c_{ij}},\right)} \quad (11)$$

where $\max\left(\max\limits_{1\le i\le n}\sum_{j=1}^{n}\tilde{\tilde{A}}_{c_{ij}},\ \max\limits_{1\le i\le n}\sum_{i=1}^{n}\tilde{\tilde{A}}_{c_{ij}},\right)$ is equal to the bigger of two extreme sums, $\max\limits_{1\le i\le n}\sum_{j=1}^{n}\tilde{\tilde{A}}_{c_{ij}}$ represents the row j factor of the highest direct influence on the other factors and the sum of each column i of the matrix A represents the direct effects by a factor i, $\max\limits_{1\le i\le n}\sum_{i=1}^{n}\tilde{\tilde{A}}_{c_{ij}}$ represents the factor which is the most influenced factor by the other factors.

Step 6: Compute the total relation matrix, $\tilde{\tilde{T}}$.

The total relation matrix $\tilde{\tilde{T}}$ can be calculated by Equation (12) to obtain the sum $(\tilde{\tilde{r}}_i + \tilde{\tilde{c}}_j)$ shows the total effects given and received by factor i. The $(\tilde{\tilde{r}}_i + \tilde{\tilde{c}}_j)$ indicates the degree of importance for factor i in the entire system. In contrast, the difference $(\tilde{\tilde{r}}_i - \tilde{\tilde{c}}_j)$ represents the net effect that factor i contributes to the system. Specifically, if $(\tilde{\tilde{r}}_i - \tilde{\tilde{c}}_j)$ is positive, factor i is a net cause, while factor i is a net receiver or result if $(\tilde{\tilde{r}}_i - \tilde{\tilde{c}}_j)$ is negative.

$$\tilde{\tilde{T}} = \tilde{\tilde{D}}(I - \tilde{\tilde{D}})^{-1} \quad (12)$$

where I is the identity matrix.

Step 7: Normalization of the degree of importance, $(\tilde{\tilde{r}}_i + \tilde{\tilde{c}}_j)$ and net effect, $(\tilde{\tilde{r}}_i - \tilde{\tilde{c}}_j)$.

The normalized the degree of importance, $(\tilde{\tilde{r}}_i + \tilde{\tilde{c}}_j)$ and net effect, $(\tilde{\tilde{r}}_i - \tilde{\tilde{c}}_j)$ of IT2FS are calculated by Equation (13).

$$\tilde{\tilde{N}}_{r+c} = \frac{(\tilde{\tilde{r}}_i + \tilde{\tilde{c}}_j)^U + (\tilde{\tilde{r}}_i + \tilde{\tilde{c}}_j)^L}{2}$$

$$\tilde{\tilde{N}}_{r-c} = \frac{(\tilde{\tilde{r}}_i - \tilde{\tilde{c}}_j)^U + (\tilde{\tilde{r}}_i - \tilde{\tilde{c}}_j)^L}{2} \quad (13)$$

Step 8: Construction of causal relationship diagram.

The causal diagram can be acquired by mapping the dataset of $(\tilde{\tilde{N}}_{i\,\tilde{\tilde{r}}i + \tilde{\tilde{c}}j}, \tilde{\tilde{N}}_{\tilde{\tilde{r}}i - \tilde{\tilde{c}}j})$.

Coastal Erosion Decision Problem Using IT2-FDEMATEL

In this study, there are four identical dimensions and fourteen critical criteria to be investigated for contributing to coastal erosion problems.

For the selection purpose, a set of dimensions and its critical criteria are pointed from related researches and a discussion with the decision makers from the related field in this case study. The procedure of the IT2-FDEMATEL method can be demonstrated as follows:

Step 1: Identify the decision-making problem goals along with its dimension of the factors, critical criteria and group of the decision makers (DMs). The aim of the study is to investigate the causal relationship of the factors related to coastal erosion decision problems, thus Table 2 describes the dimensions and its critical criteria the recognized the most contribute to erosion.

Step 2: Scaling the relative of linguistic variables and constructing the pair-wise comparison of IT2FS matrices for the decision makers (*DM*1, *DM*2, *DM*3). The designed questions item was based on these four dimensions and fourteen critical criteria that involving three decision makers from the related field in this case study. The demographic variables of three experts are shown in Table 3.

The linguistic preference of trapezoidal interval type-2 fuzzy number for dimension preference scale is shown in Table 4, Table 5 and Table 6.

Table 2: The dimensions and critical criteria

Dimension	Critical Criteria
Shoreline changes/evolution, D_1	Population density, C_1 Hydrodynamic pattern, C_2 Long-shore sediment transport, C_3
Relative sea level rise, D_2	High intensity of current long-shore, C_4 Tidal range, C_5 Sea area class, C_6
Wave condition, D_3	High significant wave, C_7 Maximum wave height, C_8 Wave acceleration/gusts, C_9 Wave pattern, C_{10}
Climate change, D_4	Wave climate, C_{11} Seasonal climate (e.g.: Heavy rain), C_{12} Storm surge, C_{13} Wind speed, C_{14}

Table 3: Demographic variables of the decision makers

Demographic Variables	Total	Percentage
Gender		
Male	2	66.67%
Female	1	33.33%
Educational		
Bachelor	1	33.33%
Master	1	33.33%
Doctoral	1	33.33%
Experience in coastal erosion assessment		
< 5 years	2	66.67%
5–10 years	1	33.33%

Table 4: The interval type-2 fuzzy judgement matrix of dimensions for DM1

D_n	D_1	D_2	D_3	D_4
D_1	((0,0,0,0;1,1), (0,0,0,0;0.9,0.9))	((0.3,0.4,0.4,0.5;1,1), (0.35,0.4,0.4,0.45;0.9,0.9))	((0.1,0.2,0.2,0.3;1,1), (0.15,0.2,0.2,0.25;0.9,0.9))	((0,0.1,0.1,0.1;1,1), (0,0.1,0.1,0.05;0.9,0.9))
D_2	((0,0,0,0;1,1), (0,0,0,0;0.9,0.9))	((0,0,0,0;1,1), (0,0,0,0;0.9,0.9))	((0.2,0.3,0.3,0.4;1,1), (0.25,0.3,0.3,0.35;0.9,0.9))	((0.2,0.3,0.3,0.4;1,1), (0.25,0.3,0.3,0.35;0.9,0.9))
D_3	((0,0,0,0;1,1), (0,0,0,0;0.9,0.9))	((0,0.1,0.1,0.1;1,1), (0,0.1,0.1,0.05;0.9,0.9))	((0,0,0,0;1,1), (0,0,0,0;0.9,0.9))	((0.3,0.4,0.4,0.5;1,1), (0.35,0.4,0.4,0.45;0.9,0.9))
D_4	((0,0,0,0;1,1), (0,0,0,0;0.9,0.9))	((0,0,0,0;1,1), (0,0,0,0;0.9,0.9))	((0,0,0,0;1,1), (0,0,0,0;0.9,0.9))	((0,0,0,0;1,1), (0,0,0,0;0.9,0.9))

Table 5: The interval type-2 fuzzy judgement matrix of dimensions for DM2

D_n	D_1	D_2	D_3	D_4
D_1	((0,0,0,0;1,1), (0,0,0,0;0.9,0.9))	((0.3,0.4,0.4,0.5;1,1), (0.35,0.4,0.4,0.45;0.9,0.9))	((0.1,0.2,0.2,0.3;1,1), (0.15,0.2,0.2,0.25;0.9,0.9))	((0,0.1,0.1,0.1;1,1), (0,0.1,0.1,0.05;0.9,0.9))
D_2	((0,0.1,0.1,0.1;1,1), (0,0.1,0.1,0.05;0.9,0.9))	((0,0,0,0;1,1), (0,0,0,0;0.9,0.9))	((0.2,0.3,0.3,0.4;1,1), (0.25,0.3,0.3,0.35;0.9,0.9))	((0.2,0.3,0.3,0.4;1,1), (0.25,0.3,0.3,0.35;0.9,0.9))
D_3	((0.3,0.4,0.4,0.5;1,1), (0.35,0.4,0.4,0.45;0.9,0.9))	((0,0.1,0.1,0.1;1,1), (0,0.1,0.1,0.05;0.9,0.9))	((0,0,0,0;1,1), (0,0,0,0;0.9,0.9))	((0.3,0.4,0.4,0.5;1,1), (0.35,0.4,0.4,0.45;0.9,0.9))
D_4	((0.3,0.4,0.4,0.5;1,1), (0.35,0.4,0.4,0.45;0.9,0.9))	((0,0.1,0.1,0.1;1,1), (0,0.1,0.1,0.05;0.9,0.9))	((0,0.1,0.1,0.1;1,1), (0,0.1,0.1,0.05;0.9,0.9))	((0,0,0,0;1,1), (0,0,0,0;0.9,0.9))

Table 6: The interval type-2 fuzzy judgement matrix of dimensions for DM3

D_n	D_1	D_2	D_3	D_4
D_1	((0,0,0,0;1,1), (0,0,0,0;0.9,0.9))	((0,0.1,0.1,0.1;1,1), (0,0.1,0.1,0.05;0.9,0.9))	((0.2,0.3,0.3,0.4;1,1), (0.25,0.3,0.3,0.35;0.9,0.9))	((0.3,0.4,0.4,0.5;1,1), (0.35,0.4,0.4,0.45;0.9,0.9))
D_2	((0.3,0.4,0.4,0.5;1,1), (0.35,0.4,0.4,0.45;0.9,0.9))	((0,0,0,0;1,1), (0,0,0,0;0.9,0.9))	((0,0.1,0.1,0.1;1,1), (0,0.1,0.1,0.05;0.9,0.9))	((0,0.1,0.1,0.1;1,1), (0,0.1,0.1,0.05;0.9,0.9))
D_3	((0.1,0.2,0.2,0.3;1,1), (0.15,0.2,0.2,0.25;0.9,0.9))	((0.2,0.3,0.3,0.4;1,1), (0.25,0.3,0.3,0.35;0.9,0.9))	((0,0,0,0;1,1), (0,0,0,0;0.9,0.9))	((0.3,0.4,0.4,0.5;1,1), (0.35,0.4,0.4,0.45;0.9,0.9))
D_4	((0,0.1,0.1,0.1;1,1), (0,0.1,0.1,0.05;0.9,0.9))	((0.2,0.3,0.3,0.4;1,1), (0.25,0.3,0.3,0.35;0.9,0.9))	((0.3,0.4,0.4,0.5;1,1), (0.35,0.4,0.4,0.45;0.9,0.9))	((0,0,0,0;1,1), (0,0,0,0;0.9,0.9))

Step 3: Construct the average decision comparison matrix, $\tilde{\tilde{A}}$.

The construction of the average matrix, $\tilde{\tilde{A}}$ is computed by Equation (8). Table 7 shows the average decision comparison for decision makers.

With similar calculation, the calculation of average matrix for decision makers for critical criteria is computed by Equation (8).

Step 4: Computation the aggregated matrix for dimensions and critical criteria, $\tilde{\tilde{A}}_C$.

The aggregated matrix comparison of each dimension and its critical criteria is constructed using Equation (10). Table 8 shows the aggregated matrix comparison of decision makers for dimension.

With similar calculation, the calculation of aggregated matrix comparison for critical criteria is computed by Equation (10).

Step 5: Calculate the initial direct influence matrix, $\tilde{\tilde{D}}$.

In this step, the trapezoidal IT2 FS of $\tilde{\tilde{A}}_C$ is divided by upper and lower trapezoidal IT2 FS to obtain direct influence matrix, $\tilde{\tilde{D}}$.

Table 7: The average decision comparison matrix, $\tilde{\tilde{A}}$ of dimensions for decision makers

D_n	D_1	D_2	D_3	D_4
D_1	((0,0,0,0;1,1), (0,0,0,0;0.9,0.9))	((0.2,0.3,0.3,0.37;1,1), (0.23,0.3,0.3,0.32;0.9,0.9))	((0.13,0.23,0.23,0.33;1,1), (0.12,0.23,0.23,0.28;0.9,0.9))	((0.1,0.2,0.2,0.23;1,1), (0.12,0.2,0.2,0.18;0.9,0.9))
D_2	((0.1,0.17,0.17,0.2,0;1,1), (0.12,0.17,0.17,0.17;0.9,0.9))	((0,0,0,0;1,1), (0,0,0,0;0.9,0.9))	((0.13,0.23,0.23,0.3;1,1), (0.17,0.23,0.23,0.25;0.9,0.11))	((0.13,0.23,0.23,0.3;1,1), (0.17,0.23,0.23,0.25;0.9,0.9))
D_3	((0.13,0.2,0.2,0.27,0;1,1), (0.13,0.2,0.2,0.23;0.9,0.9))	((0.1,0.17,0.17,0.2;1,1), (0.1,0.17,0.17,0.15;0.9,0.9))	((0,0,0,0;1,1), (0,0,0,0;0.9,0.9))	((0.3,0.4,0.4,0.5;1,1), (0.35,0.4,0.4,0.45;0.9,0.9))
D_4	((0.1,0.17,0.17,0.2,0;1,1), (0.12,0.17,0.17,0.17;0.9,0.9))	((0.1,0.13,0.13,0.17;1,1), (0.1,0.13,0.13,0.13;0.9,0.9))	((0.1,0.17,0.17,0.2;1,1), (0.12,0.17,0.17,0.17;0.9,0.9))	((0,0,0,0;1,1), (0,0,0,0;0.9,0.9))

Table 8: The aggregated matrix comparison of decision makers for dimension

D_n	$\tilde{\tilde{A}}_C$
D_1	((0.1,0.18,0.18,0.23,0;1,1), (0.12,0.18,0.18,0.2;0.9,0.9))
D_2	((0.1,0.16,0.16,0.2,0;1,1), (0.12,0.16,0.16,0.17;0.9,0.10))
D_3	((0.13,0.19,0.19,0.24,0;1,1), (0.15,0.19,0.19,0.21;0.9,0.11))
D_4	((0.1,0.12,0.12,0.14,0;1,1), (0.1,0.12,0.12,0.12;0.9,0.12))

For example, the upper and lower trapezoidal IT2 FS of dimension, $\tilde{\tilde{A}}_{C_D}$ is

$$\tilde{\tilde{A}}c_D = \begin{bmatrix} 0.1 & 0.18 & 0.18 & 0.23 \\ 0.1 & 0.16 & 0.16 & 0.2 \\ 0.13 & 0.19 & 0.19 & 0.24 \\ 0.1 & 0.12 & 0.12 & 0.14 \end{bmatrix}^U, \tilde{\tilde{A}}c_{D1} = \begin{bmatrix} 0.12 & 0.18 & 0.18 & 0.2 \\ 0.12 & 0.16 & 0.16 & 0.17 \\ 0.15 & 0.19 & 0.19 & 0.21 \\ 0.1 & 0.12 & 0.12 & 0.12 \end{bmatrix}^L$$

The initial direct-relation matrix $\tilde{\tilde{D}}$ is obtained by normalizing the aggregated matrix $\tilde{\tilde{A}}_C$ by Equation (11). Then, we get the following direct influence matrix of dimension for both upper and lower trapezoidal IT2 FS.

$$\tilde{\tilde{D}}_D = \begin{bmatrix} 0.1235 & 0.2222 & 0.2222 & 0.2840 \\ 0.1235 & 0.1975 & 0.1975 & 0.2469 \\ 0.1605 & 0.2346 & 0.2346 & 0.2963 \\ 0.1235 & 0.1481 & 0.1481 & 0.1728 \end{bmatrix}^U, \tilde{\tilde{D}}_D = \begin{bmatrix} 0.1622 & 0.2432 & 0.2432 & 0.2703 \\ 0.1622 & 0.2162 & 0.2162 & 0.2297 \\ 0.2027 & 0.2568 & 0.2568 & 0.2838 \\ 0.1351 & 0.1622 & 0.1622 & 0.1622 \end{bmatrix}^L$$

With similar calculation, the calculation of direct influence matrix, $\tilde{\tilde{D}}$ for critical criteria is computed by Equation (11).

Step 6: Compute the total relation matrix, $\tilde{\tilde{T}}$.

The total relation matrix $\tilde{\tilde{T}}$ can be calculated by Equation (12) to obtain the degree of importance, $(\tilde{\tilde{r}}_i + \tilde{\tilde{c}}_j)$ and net effect, $(\tilde{\tilde{r}}_i - \tilde{\tilde{c}}_j)$. The total relation matrix, $\tilde{\tilde{T}}$ of dimension for both upper and lower trapezoidal IT2 FS is shown in Table 9 and Table 10.

Step 7: Normalization of the degree of importance, $(\tilde{\tilde{r}}_i + \tilde{\tilde{c}}_j)$ and net effect, $(\tilde{\tilde{r}}_i - \tilde{\tilde{c}}_j)$.

The normalized degree of importance, $(\tilde{\tilde{r}}_i + \tilde{\tilde{c}}_j)$ and net effect, $(\tilde{\tilde{r}}_i - \tilde{\tilde{c}}_j)$ of IT2FS are calculated by Equation (13). The normalization of degree of importance and net effect for dimension is shown in Table 11.

Table 9: Total relation matrix of dimensions for upper trapezoidal IT2 FS

Dimensions	D_1	D_2	D_3	D_4	r_i	c_j	$(\tilde{\tilde{r}}_i + \tilde{\tilde{c}}_j)^U$	$(\tilde{\tilde{r}}_i - \tilde{\tilde{c}}_j)^U$
D_1	0.609	0.933	0.934	1.166	3.6420	2.3250	**5.9670**	**1.3170**
D_2	0.561	0.839	0.840	1.042	3.2820	3.4330	**6.7150**	**-0.1510**
D_3	0.690	1.011	1.012	1.260	3.9730	3.4370	**7.4100**	**0.5360**
D_4	0.465	0.650	0.651	0.795	2.5610	4.2630	**6.8240**	**-1.7020**

Table 10: Total relation matrix of dimensions for lower trapezoidal IT2 FS

Dimensions	D_1	D_2	D_3	D_4	r_i	c_j	$(\tilde{\tilde{r}}_i + \tilde{\tilde{c}}_j)^U$	$(\tilde{\tilde{r}}_i - \tilde{\tilde{c}}_j)^U$
D_1	1.061	1.424	1.424	1.538	5.4470	3.9680	**9.4150**	**1.4790**
D_2	0.973	1.281	1.281	1.373	4.9080	5.2210	**10.1290**	**-0.3130**
D_3	1.184	1.546	1.546	1.669	5.9450	5.2210	**11.1660**	**0.7240**
D_4	0.750	0.970	0.970	1.030	3.7200	5.6100	**9.3300**	**-1.8900**

Table 11: The normalize degree of importance and net effect for dimension

Dimensions	$\tilde{\tilde{N}}_{r+c}$	$\tilde{\tilde{N}}_{r-c}$
Shoreline changes/ evolution, D_1	7.691	1.398
Relative sea level rise, D_2	8.422	-0.232
Wave condition, D_3	**9.288**	0.630
Climate changes, D_4	8.077	-1.796

Step 8: Causal relationship diagram is constructed.

The digraph can be acquired by mapping the dataset of $(\tilde{\tilde{N}}_{r+c}, \tilde{\tilde{N}}_{r-c})$. Figure 2 illustrates the causal relationship diagram of dimensions.

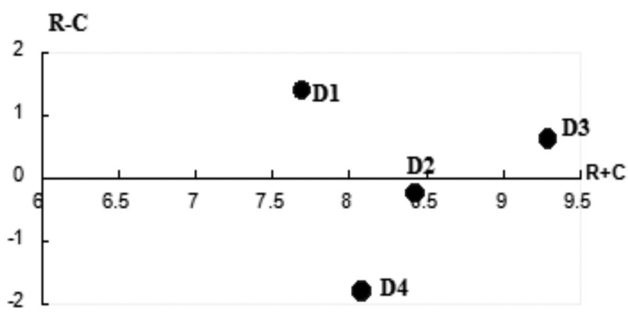

Figure 2: The causal relationship diagram of dimensions

From Table 11, the highest value of $\tilde{\tilde{N}}_{r+c}$ indicates the degree importance of the dimension that contributes to the coastal erosion problem. The table gives that the importance dimension is wave condition, D_3 which has the highest value of $(\tilde{\tilde{r}}_i + \tilde{\tilde{c}}_j)$ followed by relative sea level rise, D_2, climate change, D_3 and shoreline changes/ evolution, D_1. The value of $\tilde{\tilde{N}}_{r-c}$ represents the relation of net effect of the dimension toward coastal erosion problem. From Table 10, it can be described that shoreline changes/ evolution, D_1 and wave condition, D_3 has high effect to the coastal erosion problem compared to relative sea level rise, D_2 and climate change, D_3 due to positive value of $\tilde{\tilde{N}}_{r-c}$. From Figure 2, the digraph illustrates the causal relationship of the dimension which suggested that the core of influencing of other dimension with the high relation and high prominence are wave condition, (D_3) and shoreline changes/ evolution, (D_1). Meanwhile, relative sea level rise, (D_2) and climate change, (D_4) are the minority influence of the other dimension which a low degree of influence and low prominence but high relation toward each other. In summary, the driving factors for problem solving are the core influencing dimension which are wave condition, (D_3) and shoreline changes/evolution, (D_1).

Results and Discussion

A Comparative Study

The eight step IT2-FDEMATEL procedures continue to calculate and illustrate the causal relationship diagram for critical criteria selection. Table 12 summarizes the normalization of degree of importance and net effect for critical criteria of each dimensions. For dimension of shoreline changes/evolution, D_1, the highest degree of importance that attributes to D_1 is longshore sediment transport, C_3 with the highest value of $\tilde{\tilde{N}}_{r+c}$ followed by population density, C_1 and hydrodynamic pattern, C_2. However, the high effect of critical criteria to dimension are population density, C_1 and longshore sediment transport, C_3 due to positive value of $\tilde{\tilde{N}}_{r-c}$. Sea area class, C_6 is the most importance of critical criteria of relative sea level rise, D_2 and tidal range, C_5 has the high effect for the relative sea level rise, D_2. For dimension of wave condition, D_3, the degree of importance of critical criteria has been selected that high significant wave, C_7 is the most important criteria that contributes the relationship between wave condition, D_3 and coastal erosion problem. On the other hand, maximum wave height, C_8 and wave acceleration/gusts, C_9 are also has effect to the wave condition, D_3. Last but not least, the critical criteria of wind speed, C_{14} is the highest importance that affect by climate change, D_4.

Figure 3 plotted the causal relationship diagram for the critical criteria. For the critical criteria, we can conclude that the most influencing critical criteria with high relation and high prominence toward each other are population density (C_1), longshore sediment transport (C_3), high density of current longshore

Table 12: The normalize degree of importance and net effect for critical criteria

Critical Criteria	$\tilde{\tilde{N}}_{r+c}$	$\tilde{\tilde{N}}_{r-c}$
Population density, C_1	3.4394	0.9008
Hydrodynamic pattern, C_2	3.3609	-1.0504
Longshore sediment transport, C_3	**3.8454**	0.1496
High density of current longshore, C_4	**2.7545**	0.7305
Tidal range, C_5	2.7285	0.0075
Sea area class, C_6	2.72	-0.738
High significant wave, C_7	8.2505	1.1745
Maximum wave height, C_8	9.3155	-0.3155
Wave acceleration/gusts, C_9	9.7205	0.0895
Wave pattern, C_{10}	**10.4755**	-0.9485
Wave climate, C_{11}	5.1205	1.5765
Seasonal climate (e.g.: Heavy rain), C_{12}	4.1615	-0.8235
Storm surge, C_{13}	4.3825	-0.6025
Wind speed, C_{14}	**5.4555**	-0.1505

(C_4), tidal range (C_5), high significant wave (C_7), wave acceleration/gusts (C_9) and wave climate (C_{11}). On the other hand, the minority influence of the other critical criteria which a low degree of influence and low prominence but high relation toward each other are hydrodynamic pattern (C_2), sea area class (C_6), maximum wave height (C_8), wave pattern (C_{10}), seasonal climate (e.g.: heavy rain) (C_{12}), storm surge (C_{13}) and wind speed (C_{14}). In addition, the summary of degree of importance order for coastal erosion problem using IT2FDEMATEL method, conventional DEMATEL method and Choquet integral DEMATEL-based method and IT2FDEMATEL are shown in Table 13 and Table 14. A comparative study is made in order to illustrate the different outcome which involve type-1 fuzzy sets and interval type-2 fuzzy set approach.

From Table 12, it can be seen that different MCDM method gives a different degree of importance for coastal erosion problem. Both methods of conventional DEMATEL and IT2FDEMATEL method suggested that wave condition, D_3 becomes the highest indicator that contributes to the coastal erosion while the Choquet integral DEMATEL method gives shoreline changes/evolution, D_1. However, when implementing to the critical criteria of coastal erosion problem, the IT2FDEMATEL method gives a slightly consistent value compared to the other method. Besides, the entire process of IT2FDEMATEL method takes into account both quantitative and qualitative measurements provided by the decision makers.

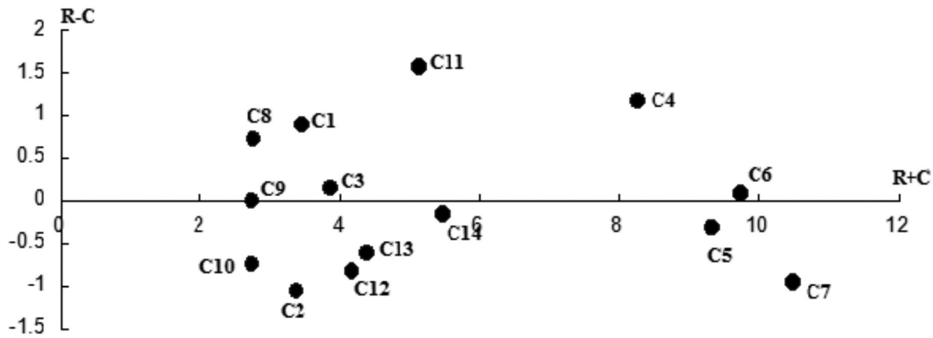

Figure 3: The causal relationship diagram for critical criteria

Table 13: A comparative value of $\tilde{\tilde{N}}_{r+c}$ by different MCDM method for dimension

MCDM Method	Conventional DEMATEL Mmethod	Choquet Integral DEMATEL Method	IT2FDEMATEL Method
Shoreline changes/ evolution, D_1	6.5257	**1.8199**	7.691
Relative sea level rise, D_2	6.2799	1.5791	8.422
Wave condition, D_3	**6.8989**	0.9315	**9.288**
Climate changes, D_4	6.6287	1.1917	8.077

Table 14: A comparative value of $\tilde{\tilde{N}}_{r+c}$ by different MCDM method for critical criteria

MCDM Method	Conventional DEMATEL Method	Choquet Integral DEMATEL Method	IT2FDEMATEL Method
Population density, C_1	4.0748	2.5603	3.4394
Hydrodynamic pattern, C_2	3.9068	0.9397	3.3609
Longshore sediment transport, C_3	4.3458	2.1288	3.8454
High density of current longshore, C_4	7.8124	2.6307	2.7545
Tidal range, C_5	7.4315	1.8775	2.7285
Sea area class, C_6	6.8332	1.3736	2.72
High significant wave, C_7	16.9061	2.2487	8.2505
Maximum wave height, C_8	18.4716	2.1733	9.3155
Wave acceleration/gusts, C_9	19.1001	2.3282	9.7205
Wave pattern, C_{10}	17.6126	2.2500	10.4755
Wave climate, C_{11}	2.8505	2.6788	5.1205
Seasonal climate (e.g.: Heavy rain), C_{12}	3.4214	1.3598	4.1615
Storm surge, C_{13}	3.3758	1.5584	4.3825
Wind speed, C_{14}	4.2819	2.0830	5.4555

Table 15: Sensitivity analysis value for coastal erosion problem

Variation Ratio	0.01	0.02	0.03	0.1	0.2	0.3
Shoreline changes/ evolution, D_1	**0.7603**	**0.7503**	**0.7403**	**0.6703**	**0.5703**	**0.4703**
Relative sea level rise, D_2	0.7384	0.7284	0.7184	0.6484	0.5484	0.4484
Wave condition, D_3	0.7126	0.7026	0.6926	0.6226	0.5226	0.4226
Climate change, D_4	0.7487	0.7387	0.7287	0.6587	0.5587	0.4587
Population density, C_1	0.6669	0.6569	0.6469	0.5769	0.4769	0.3769
Hydrodynamic pattern, C_2	**0.6743**	**0.6643**	**0.6543**	**0.5843**	**0.4843**	**0.3843**
Longshore sediment transport, C_3	0.6288	0.6188	0.6088	0.5388	0.4388	0.3388
High density of current longshore, C_4	0.6669	0.6569	0.6469	0.5769	0.4769	0.3769
Tidal range, C_5	**0.6743**	**0.6643**	**0.6543**	**0.5843**	**0.4843**	**0.3843**
Sea area class, C_6	0.6288	0.6188	0.6088	0.5388	0.4388	0.3388
High significant wave, C_7	**0.7715**	**0.7615**	**0.7515**	**0.6815**	**0.5815**	**0.4815**
Maximum wave height, C_8	0.7433	0.7333	0.7233	0.6533	0.5533	0.4533
Wave acceleration/gusts, C_9	0.7326	0.7226	0.7126	0.6426	0.5426	0.4426
Wave pattern, C_{10}	0.7126	0.7026	0.6926	0.6226	0.5226	0.4226
Wave climate, C_{11}	0.7222	0.7122	0.7022	0.6322	0.5322	0.4322
Seasonal climate (e.g.: Heavy rain), C_{12}	**0.7723**	**0.7623**	**0.7523**	**0.6823**	**0.5823**	**0.4823**
Storm surge, C_{13}	0.7608	0.7508	0.7408	0.6708	0.5708	0.4708
Wind speed, C_{14}	0.7047	0.6947	0.6847	0.6147	0.5147	0.4147

Sensitivity Analysis

In MCDM problems, to perform a sensitivity analysis is one of the prominent step in order to define the uncertainty in complex systems. Sensitivity analysis is known to ascertain how well the given model depends on each other as one input when the variation ratio is changing. Table 14 describes the results of sensitivity analysis that implemented to the coastal erosion.

Through a validation analysis, it is consistently suggested that shoreline changes/ evolution, D_1, hydrodynamic pattern, C_2, tidal range, C5, high significant wave, C_7 and seasonal climate (e.g.: heavy rain) C_{12} has the highest value which remain unchanged although the six-variation ratio have changed. Thus, it is recommended that these factors cannot be neglected while implementing the coastal risk management assessment.

Conclusion

To model the mutual relationship between decision making problems and its dimension and critical criteria selection, this study aims to develop DEMATEL-based method in the fuzzy environment approach. Since the fuzzy approach is known for handling the vagueness and uncertainty of decision makers' preference judgement, it is recommended that instead of using crisp value, the adaptation of interval type-2 fuzzy number is recognized. Thus, this study attempts to apply the IT2-FDEMATEL method by investigating the implication of the method toward coastal erosion problems. The combination of the method has the characteristic that can be both explain relationship diagram of factors selection and considering the uncertainty involve during the computation. Besides, the sensitivity analysis is performed to test the reliability of the method for the case study. From the study, it can be described that shoreline changes/ evolution is the most important risk factors to lead the coastal erosion problems followed by climate change, relative sea level rise and wave condition. In addition, the top three most contributed to the dimension is hydrodynamic pattern, tidal range, high significant wave and seasonal climate (e.g.: heavy rain). For the extension of the study, it is recommended that a group of decision maker from various fields such as NGOs and government agencies can be considered to take part in the investigation to harmonize the interaction of the factors and may also contribute some additional criterion and alternatives of coastal erosion problem. From the result observation, it is concerned that every single criteria selection actually has their own responsibilities that contribute to the coastal erosion. Thus, it cannot be neglected in order to implement the risk management and risk assessment for the erosion decision problems.

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