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COASTAL EROSION DECISION PROBLEMS USING INTERVAL TYPE-2 FUZZY ANALYTIC HIERARCHY PROCESS (IT2-FAHP)

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ABSTRACT

Development of coastal area for various economic activities such as agriculture, tourism and industrial facilities and recreational areas is inevitable. These activities may indirectly contribute to accelerated coastal erosion. Economic activities imply a pressure on natural environment for the case of coastal zones. In addition, environmental changes such as climate change, tidal wave, wind and sea level rise also may affect the erosion. There are many other intangible risks that contributed to coastal erosion. It seems that these multiple risks act simultaneously to deteriorate the situation. Thus, this paper aims to investigate thirteen selected alternatives related to coastal erosion hazards using Interval Type-2 Fuzzy Analytic Hierarchy Process (IT2-FAHP) method. The IT2-FAHP procedure includes the rank normalization steps, decision makers averaging weights and an application of trapezoidal interval type-2 fuzzy numbers. The decision makers were asked to judge the comparison matrices with respect to both criterion and alternatives involved. As a conclusion, the risk factor selected for the erosion problems is shoreline evolution with the highest percentage (8.21%) compared to the others alternatives.

Keywords: coastal erosion, coastal hazards, risk assessment, interval type-2 fuzzy sets, analytic hierarchy process, multi-criteria decision making.

INTRODUCTION

Coastal erosion is a process of draining away material due to imbalance in the supply and export of material from the coastal profile (Ministry of Natural Resources and Environment, 2009). Coastal erosion occurs when the sea encroaches upon the land by strong winds, storm surge, high waves and high tides pressure in conditions of poor sediment availability. The erosion will occur on the shore-face and the beach if the export is greater than the level of the seabed because of wave, wind and tide pressure. Coastal erosion causes significant loss of land with economical, societal and ecological values. Besides, coastal erosion results in destruction of natural sea defences and the undermining of artificial sea defences as a result of chronic sediment shortages (European Commission, 2004; Luo *et al*., 2013). Coastal erosion can be classified into two main types which are structural erosion and acute erosion (Lou *et al*., 2013). Structural erosion is a continuing process of erosion due to adaptation of the coastal system to changed conditions. For example, a reduction in sediment supply to the coast due to activities in the river and the interruption of the sediment transport of construction works. Acute erosion is caused by storm events, however, during calm periods, following the stormy period, the sedimentary beach is often restructured and the beach will be rebuilt partially (Lou *et al*., 2013).

Geographically, Malaysia has about 48, 000 km of coastline and practically 70% of the Malaysian population lives in the coastal zone. Therefore, the coastal zone has become the centre of urban and rural economic activities (EPU, 1993). The coastal areas of Malaysia are generally the locations for human working and trading activities. With rapid population growth and economic activities, town planning in those days were arbitrary with rather unhealthy and unsanitary conditions (Mokhtar and Ghani, 2003). This competition between coastal ecosystems and human activities along the coastal zones has resulted in some environmental degradation having a negative impact on the economic and social value of the coastline (Tang *et al*., 2005). Realising the increasing incidences of coastal erosion which threatens coastal population and leads to loss of properties along the shorelines, the Government has implement the National Coastal Erosion Study from November 1984 to January 1986 and the study results indicate that out of the country's coastline of 4,809 km, about 29% or 1,380 km was facing erosion (Ministry of Natural Resources and Environment, 2009). In order to cope with this problem, the Government has set up the Coastal Engineering Centre in the Department of Irrigation and Drainage (DID) in 1987 to implement coastal erosion control program throughout the country.

It is important to understand the risks contributing to the coastal erosion. These risks can be human-made or naturally occurs. The natural process such wind waves driven almost the wind wave's entire move near the shore and travel through increasingly shallow water. The continuous wave height with water depth leading to the unstable waves and collapse and break to the coastline. In addition, changes of climate change and sea level rise also can cause erosion and water flooding. A small rise in sea level along the coastline in Malaysia can increase wave energy reaching the shoreline and seriously affect the drainage systems along coastal towns and agricultural areas. Additionally, climate change also can increase wave energy along the shoreline by causing more severe storms (Ministry of Natural Resources and Environment, 2009). Moreover, human interferences and developments also tend to effects the erosion and accretion such as of trenches/ navigation channel, reclamation, artificial islands/artificial lagoon, and also ports and harbours. Trenches/navigation channels act as sinks for sediments moving along the coastline. The trenches tend to fill up with sediments moving along the shoreline. Meanwhile, ports and harbour can interrupt the long shore drift, causing accretion along the shoreline on the up-drift side of the breakwaters while erosion will occur on the down-drift side of the breakwaters. Reclamation also interrupts the movement of sediments along the coast and caused a wave shadow area, stimulating accretion in the area. Last but not least, artificial islands/artificial lagoon both can intrude the littoral drift, causing erosion on the down-drift coastline and accretion on the up-drift side (Ministry of Natural Resources and Environment, 2009).

In order to demonstrate how important coastal erosion problems, there are lots of different techniques conducted by researchers to overcome the erosion problems such as a visualization and GIS model (Brown *et al*., 2006; Ma *et al.*, 2011; Zhang *et al*., 2014), remote sensing (Klemas, 2013; Ge *et al*., 2013; Liu, 2011), forecasting model (Hapke and Plant, 2010; Corbella and Stretch, 2012) and modelling method (Hemamalini *et al*., 2009). However, there is no clear distinction between the most influential risks and the other risks. In other words, the magnitude for each risk is not immediately known. Therefore identifying the most influential risk out of many tangible and intangible risks contributing to coastal erosion can be considered as multi-criteria decision making (MCDM) problem.

This study intends to investigate the influential risks factor related to coastal erosion problems using AHP based method and interval type-2 fuzzy sets (IT2FS). The uniequenss of both AHP method and IT2 FS theory had motivate us to overlook the potential of these concepts in decision making process. AHP is known as one of the most popular method in handling the multi-cirteria decision making (Chai *et al*., 2013) while the flexibility of IT2FS managed to represent the uncertainties involve during decision process (Mendel, 2001; 2007). Instead of using crisp value introduced by Saaty's AHP (1980; 1990), the method of IT2-FAHP applies the trapezoidal fuzzy number as linguistic pereference scale and normalization weigthed priorities of the lower and upper fuzzy numbers to demonstrate the feasibility of the method. Besides, ranking fuzzy numbers is also applied to strengthen the IT2-FAHP method.

2. PRELIMINARIES CONCEPTS

This section introduces the basic definitions IT2FS and arithmetic operations between trapezoidal IT2FS, ranking fuzzy numbers and normalization of weighted priorities.

Introduction to interval Type-2 fuzzy sets

Let $\tilde{A}=\left(a_1,a_2,a_3,a_4;H_1\left(\tilde{A}\right),H_2\left(\tilde{A}\right)\right)$ be a type-1 trapezoidal fuzzy set, as shown in Figure 1, where $H_1\left(\tilde{A}\right)$ denotes the membership value of the element a_2, $H_2\left(\tilde{A}\right)$ denotes the membership value of the element a_3, $0\le H_1\left(\tilde{A}\right)\le 1$ and $0\le H_2\left(\tilde{A}\right)\le 1$. If $a_2=a_3$, then the type-1 fuzzy set $\tilde{A}$ becomes a triangular type-1 fuzzy set.

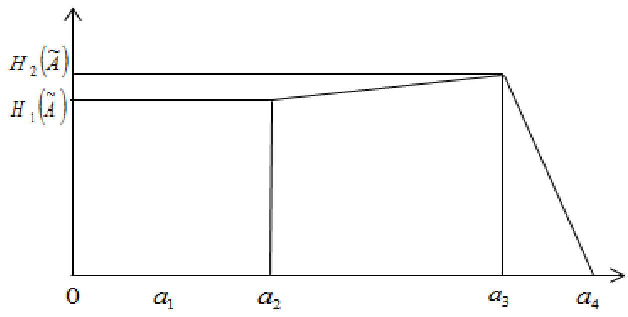

Figure-1. A type-1 trapezoidal fuzzy set.

In the following, briefly review some definitions of type-2 fuzzy sets and IT2FS explained from Mendel *et al*., (2006).

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 $\mu_{\tilde{\tilde{A}}}$ shown as follows;

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

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

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

Such that $J_x\subseteq[0,1]$ and $\int\int$ 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 $\mu_{\tilde{\tilde{A}}}$. If all $\mu_{\tilde{\tilde{A}}}(x,u)=1$, then $\tilde{\tilde{A}}$ is called IT2FS.

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An IT2FS $\tilde{\tilde{A}}$ can be regarded as a special case of type-2 fuzzy set, shown as follows:

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

where x and u are primary and secondary variable, respectively.

Remark 2.3

The upper membership function and the lower membership function of an IT2FS are type-1 membership function, respectively. The reference points are used in the universe of discourse and the heights of the upper and lower membership functions of IT2FS to characterize IT2FS. Figure 2 shows trapezoidal IT2FS where upper and lower fuzzy numbers are clearly drawn.

Let

$$\tilde{\tilde{A}}_i = \left(\tilde{A}_i^U, \tilde{A}_i^L\right) = \begin{pmatrix} \left(a_{i_1}^U, a_{i_2}^U, a_{i_3}^U, a_{i_4}^U; H_1\left(\tilde{A}_i^U\right), H_2\left(\tilde{A}_i^U\right)\right), \\ \left(a_{i_1}^L, a_{i_2}^L, a_{i_3}^L, a_{i_4}^L; H_1\left(\tilde{A}_i^L\right), H_2\left(\tilde{A}_i^L\right)\right) \end{pmatrix}$$

where $H_j\left(\tilde{A}_i^U\right)$ denotes the membership value of the element $a_{i(j+1)}^U$ in the upper trapezoidal membership function $\tilde{A}_i^U, 1 \le j \le 2, H_j\left(\tilde{A}_i^L\right)$ denotes the membership value of the element $a_{i(j+1)}^L$ in the lower trapezoidal membership function; $\tilde{A}_i^L, 1 \le j \le 2,\ H_1\left(\tilde{A}_i^U\right) \in [0,1]$, $H_2\left(\tilde{A}_i^U\right) \in [0,1], H_1\left(\tilde{A}_i^L\right) \in [0,1], H_2\left(\tilde{A}_i^L\right) \in [0,1]$ and $1 \le i \le n$.

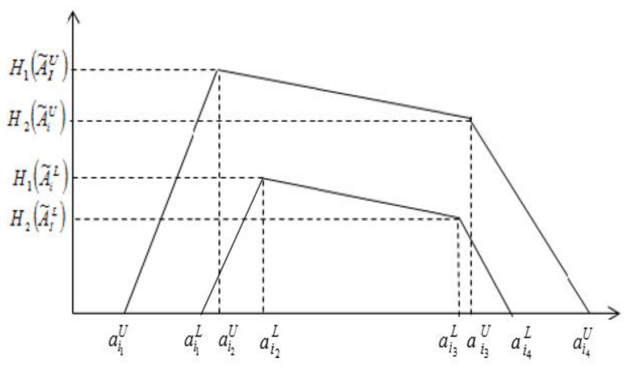

Figure-2. The upper trapezoidal membership function $\tilde{A}_i^U$ and the lower trapezoidal membership function $\tilde{A}_i^L$ of IT2FS.

Introduction to the ranking values of interval type-2 fuzzy sets and normalized weighted priorities

IT2FS is characterized by upper and lower number. In order to aggregate these numbers, the concept of ranking trapezoidal IT2FS by Xu (2001) is used. The normalization of weight priority is done using TOPSIS method.

Let

$$\tilde{\tilde{A}}_1 = \left(\tilde{A}_1^U, \tilde{A}_1^L\right) = \begin{pmatrix} \left(a_{1_1}^U, a_{1_2}^U, a_{1_3}^U, a_{1_4}^U; H_1\left(\tilde{A}_1^U\right), H_2\left(\tilde{A}_1^U\right)\right), \\ \left(a_{1_1}^L, a_{1_2}^L, a_{1_3}^L, a_{1_4}^L; H_1\left(\tilde{A}_1^L\right), H_2\left(\tilde{A}_1^L\right)\right) \end{pmatrix}$$

be IT2FS. The upper fuzzy preference matrix P^U can be obtained as follows:

$$P^U = \begin{bmatrix} p\left(\tilde{A}_1^U \ge \tilde{A}_1^U\right) & p\left(\tilde{A}_1^U \ge \tilde{A}_2^U\right) & \cdots & p\left(\tilde{A}_1^U \ge \tilde{A}_n^U\right) \\ p\left(\tilde{A}_2^U \ge \tilde{A}_1^U\right) & p\left(\tilde{A}_2^U \ge \tilde{A}_2^U\right) & \cdots & p\left(\tilde{A}_2^U \ge \tilde{A}_n^U\right) \\ \vdots & \vdots & \ddots & \vdots \\ p\left(\tilde{A}_n^U \ge \tilde{A}_1^U\right) & p\left(\tilde{A}_n^U \ge \tilde{A}_2^U\right) & \cdots & p\left(\tilde{A}_n^U \ge \tilde{A}_n^U\right) \end{bmatrix}$$

In the same way, the lower fuzzy preference matrix P^L can be obtained as follows:

$$P^L = \begin{bmatrix} p\left(\tilde{A}_1^L \ge \tilde{A}_1^L\right) & p\left(\tilde{A}_1^L \ge \tilde{A}_2^L\right) & \cdots & p\left(\tilde{A}_1^L \ge \tilde{A}_n^L\right) \\ p\left(\tilde{A}_2^L \ge \tilde{A}_1^L\right) & p\left(\tilde{A}_2^L \ge \tilde{A}_2^L\right) & \cdots & p\left(\tilde{A}_2^L \ge \tilde{A}_n^L\right) \\ \vdots & \vdots & \ddots & \vdots \\ p\left(\tilde{A}_n^L \ge \tilde{A}_1^L\right) & p\left(\tilde{A}_n^L \ge \tilde{A}_2^L\right) & \cdots & p\left(\tilde{A}_n^L \ge \tilde{A}_n^L\right) \end{bmatrix}$$

Then the ranking value $Rank\left(\tilde{A}_i^U\right)$ of the upper trapezoidal membership function $\tilde{A}_i^U$ of the IT2FS $\tilde{\tilde{A}}_i$ is calculated as follows:

$$Rank\left(\tilde{A}_i^U\right) = \frac{1}{n(n-1)}\left(\sum_{k=1}^{n} p\left(\tilde{A}_i^U \ge \tilde{A}_k^U\right) + \frac{n}{2} - 1\right) \tag{4}$$

where $1 \le i \le n$ and $\sum_{i=1}^{n} Rank\left(\tilde{A}_i^U\right) = 1$.

In the same way, the ranking value $Rank\left(\tilde{A}_i^L\right)$ of the lower trapezoidal membership function $\tilde{A}_i^L$ of the IT2FS $\tilde{\tilde{A}}_i$ also can be calculated as follows:

$$Rank\left(\tilde{A}_i^L\right) = \frac{1}{n(n-1)}\left(\sum_{k=1}^{n} p\left(\tilde{A}_i^L \ge \tilde{A}_k^L\right) + \frac{n}{2} - 1\right) \tag{5}$$

where $1 \le i \le n$ and $\sum_{i=1}^{n} Rank\left(\tilde{A}_i^L\right) = 1$.

Then, the ranking value of the IT2FS $\tilde{\tilde{A}}_i$ can be calculated as follows:

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$$Rank\left(\tilde{\tilde{A}}_i\right) = \frac{Rank\left(\tilde{A}_i^U\right) + Rank\left(\tilde{A}_i^L\right)}{2} \quad (6)$$

satisfying $\sum_{i=1}^{n} Rank\left(\tilde{\tilde{A}}_i\right) = 1$.

INTERVAL TYPE-2 FUZZY ANALYTIC HIERARCHY PROCESS (IT2-FAHP) METHOD

Method of IT2-FAHP

On the basis of the earlier theoretical analysis, an approach to solve the MCDM problems using IT2FS is developed. Decision makers (DMs) provide their relation preference scale of each criterion and alternatives in the IT2-FAHP preference scale. The seven steps of the IT2-FAHP method proposed by Abdullah and Najib (2014) are described as below:

Step-1: Construct a hierarchical diagram of MCDM problem.

The upper level of the diagram describes the focus of the problem detailed and the second level of the hierarchical structure explains the attributes or criteria of the focus problem. The bottom of the level details the alternatives of the MCDM problem.

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

In MCDM problems, responses from DMs are mainly focused on opinion of the DMs regarding rating of the criterion of the problems based on the identified criteria. The DMs were asked to specify rating using nine AHP linguistic scales varying from ‘just equal’ to ‘absolutely more important’ over the factors associated with MCDM problems. The preference scale of IT2-FAHP is used to define the DMs measurement of each criterion and alternatives of the MCDM problems. The preference scale is shown in Table-1 and Table-2.

Table-1. The Preference scale of trapezoidal IT2FN.

Linguistic variables	AHP crisp number	Trapezoidal IT2FN
EI	1	((0,0.1,0.1,0.1;1,1), (0,0.1,0.1,0.05;0.9,0.9))
IV	2	((0.1,0.2,0.2,0.3;1,1), (0.05,0.2,0.2,0.25;0.9,0.9))
MMI	3	((0.2,0.3,0.3,0.4;1,1), (0.25,0.3,0.3,0.35;0.9,0.9))
IV	4	((0.3,0.4,0.4,0.5;1,1), (0.35,0.4,0.4,0.45;0.9,0.9))
SMI	5	((0.4,0.5,0.5,0.6;1,1), (0.45,0.5,0.5,0.55;0.9,0.9))
IV	6	((0.5,0.6,0.6,0.7;1,1), (0.55,0.6,0.6,0.65;0.9,0.9))
VSMI	7	((0.6,0.7,0.7,0.8;1,1), (0.65,0.7,0.7,0.75;0.9,0.9))
IV	8	((0.7,0.8,0.8,0.9;1,1), (0.75,0.8,0.8,0.85;0.9,0.9))
EMI	9	((0.8,0.9,0.9,1.0;1,1), (0.85,0.9,0.9,0.95;0.9,0.9))

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Table-2. The preference scale of reciprocal trapezoidal IT2FN.

Linguistic variables	AHP reciprocal number	Reciprocal trapezoidal IT2FN
EI	1	((0,0.1,0.1,0.1;1,1), (0,0.1,0.1,0.05;0.9,0.9))
IV	1/2	((0.3,0.5,0.5,1.0;1,1), (0.4,0.5,0.5,1.0;0.9,0.9))
MMI	1/3	((0.25,0.3,0.3,0.5;1,1), (0.28,0.3,0.3,0.4;0.9,0.9))
IV	1/4	((0.2,0.25,0.25,0.3;1,1), (0.22,0.25,0.25,0.28;0.9,0.9))
SMI	1/5	((0.17,0.2,0.2,0.25;1,1), (0.18,0.2,0.2,0.22;0.9,0.9))
IV	1/6	((0.14,0.17,0.17,0.2;1,1), (0.15,0.17,0.17,0.18;0.9,0.9))
VSMI	1/7	((0.13,0.14,0.14,0.17;1,1), (0.13,0.14,0.14,0.15;0.9,0.9))
IV	1/8	((0.11,0.13,0.13,0.14;1,1), (0.12,0.13,0.13,0.13;0.9,0.9))
EMI	1/9	((0.1,0.1,0.1,0.13;1,1), (0.1,0.1,0.1,0.12;0.9,0.9))

Step-3: Construct the average of decision matrices.

The aggregated matrix comparison of each criterion and alternatives is constructed using Equation (7).

$$Y_p = \left(\tilde{\tilde{f}}_{ij}^{\,p}\right)_{m\times n} = \begin{bmatrix} \tilde{\tilde{f}}_{11}^{\,p} & \tilde{\tilde{f}}_{12}^{\,p} & \cdots & \tilde{\tilde{f}}_{1n}^{\,p} \\ \tilde{\tilde{f}}_{21}^{\,p} & \tilde{\tilde{f}}_{22}^{\,p} & \cdots & \tilde{\tilde{f}}_{2n}^{\,p} \\ \vdots & \vdots & \vdots & \vdots \\ \tilde{\tilde{f}}_{m1}^{\,p} & \tilde{\tilde{f}}_{m2}^{\,p} & \cdots & \tilde{\tilde{f}}_{mn}^{\,p} \end{bmatrix} \quad (7)$$

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

Step-4: Construct the weighted DMs' matrix.

Weighted DMs' matrix with respect to aggregated matrix comparison of each criterion and alternatives is constructed using Eq. (8). The importance of the DMs is considered as linguistic variables for importance of DMs. The linguistic variables are shown in Table-3.

Table-3. Linguistic variables for the importance of DMs.

Linguistic variables	IT2FN
Very important	((0.8,0.9,0.9,1.0;1,1), (0.85,0.9,0.9,0.95;0.9,0.9))
Important	((0.6,0.7,0.7,0.8;1,1), (0.65,0.7,0.7,0.75;0.9,0.9))
Medium	((0.4,0.5,0.5,0.6;1,1), (0.45,0.5,0.5,0.55;0.9,0.9))
Unimportance	((0.2,0.3,0.3,0.4;1,1), (0.25,0.3,0.3,0.35;0.9,0.9))
Very unimportance	((0,0.1,0.1,0.1;1,1), (0,0.1,0.1,0.05;0.9,0.9))

$$\tilde{\tilde{W}}_n = \left(\sum_{i=1, f_i \in F_1^U}^{n} \begin{bmatrix} \tilde{\tilde{D}}_1 & \tilde{\tilde{D}}_2 & \cdots & \tilde{\tilde{D}}_n \end{bmatrix} \otimes \begin{bmatrix} \tilde{\tilde{f}}_{11} \\ \tilde{\tilde{f}}_{21} \\ \vdots \\ \tilde{\tilde{f}}_{n} \end{bmatrix}\right) \quad (8)$$

where $\begin{bmatrix} \tilde{\tilde{D}}_1 & \tilde{\tilde{D}}_2 & \cdots & \tilde{\tilde{D}}_n \end{bmatrix}$ is linguistic preference scale of the k^{th} DMs' and matrix $\tilde{\tilde{f}}_{ij}$ are represented aggregated matrix of upper and lower IT2FS respectively.

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Step-5: Calculate the ranking value, $Rank\left(\tilde{\tilde{d}}_{ij}\right)$.

Construct the matrix for each element of IT2FS in weighted DMs' matrix. The ranking values of IT2FS $\tilde{\tilde{d}}_{ij}$ are calculated using Eq. (4), Eq. (5) and Eq. (6).

Step-6: Normalized the ranking value.

The ranking values of IT2FS are normalized via the following TOPSIS equation to obtain weight relative:

$$r_{ij}^{L} = \frac{Rank\left(\tilde{\tilde{A}}_{ij}\right)}{\sqrt{\sum_{j=1} Rank\left(\tilde{\tilde{A}}_{ij}\right)^{2}}}, \quad j = 1,2,3,\ldots,j, \; i = 1,2,3,\ldots,n \qquad (9)$$

$$r_{ij}^{U} = \frac{Rank\left(\tilde{\tilde{A}}_{ij}\right)}{\sqrt{\sum_{j=1} Rank\left(\tilde{\tilde{A}}_{ij}\right)^{2}}}, \quad j = 1,2,3,\ldots,j, \; i = 1,2,3,\ldots,n \qquad (10)$$

The average normalized ranking values of IT2 FS are calculated using

$$r_{ij} = \frac{\left(r_{ij}^{L}\right) + \left(r_{ij}^{U}\right)}{2} \qquad (11)$$

where $\sum r_{ij} = 1$

Step-7: Calculate the relative weight of priority and rank all the alternatives.

Computing the relative weight, w_i and ranks the alternatives.

$$W_i = \sum w_i A_{ij} \qquad (12)$$

where

w_i is average normalized weight for criteria *j*

A_{ij} is average normalized weights aggregated matrix for criteria *j* with respects to alternatives *i*.

An application of IT2-FAHP to coastal erosion decision problems

The quantitative data is attain by collecting the linguistic variables evaluated by number decision makers/experts whose are experienced practitioners in the coastal erosion problem fields. The personal interview was conducted for judging the selected risk factors and coastal exposed to erosion. For the selection purpose, a set of criteria, sub-criteria and alternatives makers under consideration and was well-defined by Lou et al. (2013).

Step-1: Construct a hierarchical diagram of MCDM problem.

The hierarchical structure of coastal erosion decision problems is given in Figure-3.

The criteria selected are Structural Erosion C_1, Acute Erosion C_2, Exposure extent C_3, and Deficiency in Coping Capacity C_4.

The set of alternatives can be given as $A = \{A_i\}, (i = 1, 2, \ldots, 13)$ where A_1 is erodibility (Ero), A_2 is shoreline evolution (SEvo), A_3 is wave height (WH), A_4 is relative sea-level rise (RSL), A_5 is coastal urbanization rate (CU), A_6 is storm surge (Ssurge), A_7 is tidal range (TR), A_8 is population density (PD), A_9 is gross domestic products (GDP), A_{10} is sea area class (SAC), A_{11} is budgetary revenue of local government (BRLG), A_{12} is coastal protection capacity (CP), and A_{13} is land use/cover change (LUCC).

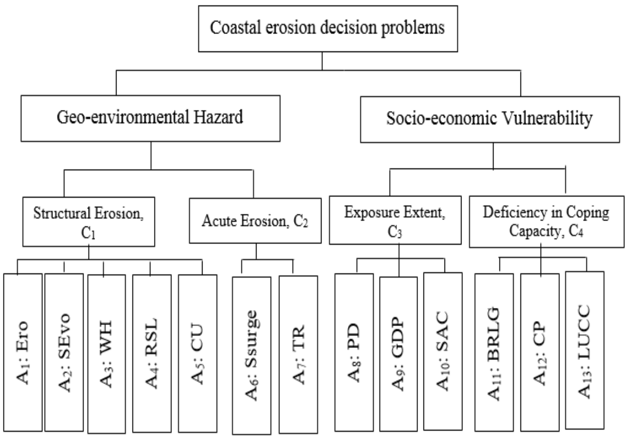

Figure-3. Hierarchical structure of the coastal erosion decision problems.

Step-2: Scaling the pair-wise comparison scale of IT2- FAHP with the preference scale of IT2FS judgment matrix.

The linguistic variables of AHP crisp number (see Table-4) is convert to the preference scale of IT2 Fuzzy Number in order to construct matrix of criterion and alternativies.

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Table-4. AHP crisp number judgement matrix of criterion.

C_n	C_1	C_2	C_3	C_4
C_1	1	3	7	9
C_2	1/3	1	7	7
C_3	1/7	1/7	1	3
C_4	1/9	1/7	1/3	1

Table-5 shows interval type-2 fuzzy judgment matrix criterion.

Table-5. Interval type-2 fuzzy judgment matrix criterion.

	C_1	C_2	C_3	C_4
C_1	((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))	((0.6,0.7,0.7,0.8;1,1), (0.65,0.7,0.7,0.75;0.9,0.9))	((0.8,0.9,0.9,1.0;1,1), (0.85,0.9,0.9,0.95;0.9,0.9))
C_2	((0.25,0.3,0.3,0.5;1,1), (0.28,0.3,0.3,0.4;0.9,0.9))	((0,0.1,0.1,0.1;1,1), (0,0.1,0.1,0.05;0.9,0.9))	((0.6,0.7,0.7,0.8;1,1), (0.65,0.7,0.7,0.75;0.9,0.9))	((0.6,0.7,0.7,0.8;1,1), (0.65,0.7,0.7,0.75;0.9,0.9))
C_3	((0.13,0.14,0.14,0.17;1,1), (0.13,0.14,0.14,0.15;0.9,0.9))	((0.13,0.14,0.14,0.17;1,1), (0.13,0.14,0.14,0.15;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))
C_4	((0.1,0.1,0.1,0.13;1,1), (0.1,0.1,0.1,0.12;0.9,0.9))	((0.13,0.14,0.14,0.17;1,1), (0.13,0.14,0.14,0.15;0.9,0.9))	((0.25,0.3,0.3,0.5;1,1), (0.28,0.3,0.3,0.4;0.9,0.9))	((0,0.1,0.1,0.1;1,1), (0,0.1,0.1,0.05;0.9,0.9))

Step-3: Construct the average of decision matrices.

The average decision matrix of criterion is shown using Equation (7).

$$\tilde{\tilde{f}}_{ij} = \left(\frac{\tilde{\tilde{f}}_{ij}^{1} \oplus \tilde{\tilde{f}}_{ij}^{2} \oplus \cdots \oplus \tilde{\tilde{f}}_{ij}^{p}}{k} \right)$$

where

$$\tilde{\tilde{f}}_{C_1}^{U} = \left(\left(\frac{0+0.2+0.6+0.8}{4} \right), \left(\frac{0.1+0.3+0.7+0.9}{4} \right), \left(\frac{0.1+0.3+0.7+0.9}{4} \right), \left(\frac{0.1+0.4+0.8+1.0}{3} \right); 1,1 \right)$$

$$\tilde{\tilde{f}}_{C_1}^{L} = \left(\left(\frac{0+0.25+0.65+0.85}{4} \right), \left(\frac{0.1+0.3+0.7+0.9}{3} \right), \left(\frac{0.1+0.3+0.7+0.9}{4} \right), \left(\frac{0.05+3.5+0.75+0.95}{3} \right); 0.9,0.9 \right)$$

$$\tilde{\tilde{f}}_{C_1} = ((0.4,0.5,0.5,0.6;1,1),(0.4,0.5,0.5,0.5;0.9,0.9))$$

$$\tilde{\tilde{f}}_{C_2} = ((0.3,0.5,0.5,0.6;1,1),(0.4,0.5,0.5,0.5;0.9,0.9)$$

$$\tilde{\tilde{f}}_{C_3} = ((0.1,02,0.2,0.2;1,1),(0.1,0.2,0.2,0.2;0.9,0.9))$$

$$\tilde{\tilde{f}}_{C_4} = ((0.2,0.3,0.3,0.5;1,1),(0.2,0.3,0.3,0.5;0.9,0.9))$$

Step-4: Construct the weighted DMs' matrix.

The weighted of DMs' matrix with respect to aggregated matrix comparison of each criterion and alternatives can be obtained using Eq.(8)

Let the importance of linguistic variables of DMs' are:

$$D = \begin{bmatrix} \tilde{\tilde{D}}_1 & \tilde{\tilde{D}}_2 & \ldots & \tilde{\tilde{D}}_n \end{bmatrix}$$

Then, we get

$$\tilde{\tilde{W}}_C = \left(\sum_{i=1, f_i \in F_1^L}^{n} \begin{bmatrix} \tilde{\tilde{D}}_1 & \tilde{\tilde{D}}_2 & \ldots & \tilde{\tilde{D}}_n \end{bmatrix} \otimes \begin{bmatrix} \tilde{\tilde{f}}_{C_1} \\ \tilde{\tilde{f}}_{C_2} \\ \tilde{\tilde{f}}_{C_3} \\ \tilde{\tilde{f}}_{C4} \end{bmatrix} \right)$$

$$= \left(\sum_{i=1, f_i \in F_1^L}^{n} \left[\begin{bmatrix} \tilde{\tilde{D}}_1 & \tilde{\tilde{D}}_2 & \ldots & \tilde{\tilde{D}}_n \end{bmatrix} \right] \otimes \begin{bmatrix} ((0.4,0.5,0.5,0.6;1,1),(0.4,0.5,0.5,0.5;0.9,0.9)) \\ ((0.3,0.5,0.5,0.6;1,1),(0.4,0.5,0.5,0.5;0.9,0.9) \\ ((0.1,02,0.2,0.2;1,1),(0.1,0.2,0.2,0.2;0.9,0.9)) \\ ((0.1,02,0.2,0.2;1,1),(0.1,0.2,0.2,0.2;0.9,0.9)) \end{bmatrix} \right)$$

$$= \begin{bmatrix} ((0.2,0.4,0.4,0.5;1,1),(0.3,0.4,0.4,0.4;0.9,0.9)) \\ ((0.2,0.4,0.4,0.5;1,1),(0.3,0.4,0.4,0.4;0.9,0.9) \\ ((0.1,0.1,0.1,0.2;1,1),(0.1,0.1,0.1,0.2;0.9,0.9)) \\ ((0.1,0.1,0.1,0.2;1,1),(0.1,0.1,0.1,0.2;0.9,0.9)) \end{bmatrix}$$

Step-5: Calculate the ranking value, $Rank\left(\tilde{\tilde{d}}_{ij}\right)$.

The ranking values of matrices of IT2 FS $\tilde{\tilde{d}}_{ij}$ are calculated using Eq.(4), Eq. (5) and Eq. (6)

As an example, the matrix of upper trapezoidal IT2 FS is

$$\begin{bmatrix} 0.2 & 0.4 & 0.4 & 0.5 \\ 0.2 & 0.4 & 0.4 & 0.5 \\ 0.1 & 0.1 & 0.1 & 0.2 \\ 0.1 & 0.1 & 0.1 & 0.2 \end{bmatrix}$$

$$Rank\left(\tilde{A}_{C_1}^{U}\right) = \frac{1}{4(4-1)} \left(\sum_{1}^{4} (0.2+0.4+0.4+0.5) + \frac{4}{2} - 1 \right) = 0.2083$$

where $1 \le i \le n$ and $\sum_{i=1}^{n} Rank\left(\tilde{A}_i^{U}\right) \neq 1$ since the final rank will normalized by TOPSIS method.

Applying the same formula, we have following ranking values:

$Rank\left(\tilde{A}_{C_1}^{U}\right) = 0.2083$, $Rank\left(\tilde{A}_{C_1}^{L}\right) = 0.2083$,

$Rank\left(\tilde{A}_{C_2}^{U}\right) = 0.2083$, $Rank\left(\tilde{A}_{C_2}^{L}\right) = 0.2083$,

$Rank\left(\tilde{A}_{C_3}^{U}\right) = 0.1250$, $Rank\left(\tilde{A}_{C_3}^{L}\right) = 0.1250$,

$Rank\left(\tilde{A}_{C_4}^{U}\right) = 0.1250$, $Rank\left(\tilde{A}_{C_4}^{L}\right) = 0.1250$.

Step-6: Normalized the ranking value.

The ranking values of IT2FS are normalized using the following TOPSIS equation to obtain weight relative by Eq. (9), Eq. (10) and Eq. (11).

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$$r_{C_1}^{U} = \frac{Rank\left(\tilde{\tilde{A}}_{ij}\right)}{\sqrt{\sum_{j=1} Rank\left(\tilde{\tilde{A}}_{ij}\right)^2}} = \frac{0.2083}{0.6667} = 0.3125$$

Applying the same trend of formula,

$r_{C_1}^{U} = 0.3125$, $r_{C_1}^{L} = 0.3125$,

$r_{C_2}^{U} = 0.3125$, $r_{C_2}^{L} = 0.3125$,

$r_{C_3}^{U} = 0.1875$, $r_{C_3}^{L} = 0.1875$,

$r_{C_4}^{U} = 0.1875$, $r_{C_4}^{L} = 0.1875$.

The average normalized ranking values of IT2FS are calculated by:

$$r_{C_1} = \frac{\left(r_{ij}^{L}\right) + \left(r_{ij}^{U}\right)}{2} = \frac{0.3125 + 0.3125}{2} = 0.3125$$

$r_{C_2} = 0.3125$, $r_{C_3} = 0.1875$ and $r_{C_4} = 0.1875$

where $\sum_{i=1}^{4} r_{C_i} = 1$

Step-7: Calculate the relative weight of priority and rank all the alternatives.

Compute the relative weight and rank the alternatives using Equation (12). The relative weight and rank is shown in Table-6.

Table-6. Priorities ranks and weights of coastal erosion decision problems.

Main criteria of the goal					
	C_1	C_2	C_3	C_4	
Weights of C_n	0.3125	0.3125	0.1875	0.1875	Priorities weight
Alternatives					
Ero	0.0748	0.0750	0.0755	0.0751	0.0751
SEvo	0.0873	0.0788	0.0757	0.0852	0.0821
WH	0.0783	0.0791	0.0787	0.0752	0.0650
RSL	0.0781	0.0755	0.0759	0.0752	0.0763
CU	0.0751	0.0788	0.0757	0.0749	0.0763
Ssurge	0.0812	0.0787	0.0787	0.0751	0.0788
TR	0.0785	0.0790	0.0759	0.0754	0.0776
PD	0.0750	0.0753	0.0789	0.0754	0.0759
GDP	0.0749	0.0752	0.0760	0.0752	0.0753
SAC	0.0749	0.0756	0.0757	0.0751	0.0753
BRLG	0.0719	0.0752	0.0755	0.0815	0.0754
CP	0.0750	0.0753	0.0755	0.0821	0.0765
LUCC	0.0749	0.0753	0.0759	0.0749	0.0752

As a conclusion, the best risk factor selection is shoreline evolution (8.21%) followed by storm surge (7.88%), tidal range (7.76%), coastal protection (7.65%), rate sea level rise (7.63%), coastal urbanization (7.63%), polutation density (7.59%), budgetary revenue of local government BRLG (7.54%), sea area class (7.53%), GDP (7.53%), erodibility (7.51%) and finally wave height (6.50%).

Comparative study of the coastal erosion decision problems using AHP-based and IT2-FAHP method

In this study, both method of AHP original basis method and IT2-FAHP is used to demonstrate the feasibility of combination between AHP methods along with interval type-2 fuzzy sets. Instead of using AHP crisp value, the method of IT2-FAHP implement the trapezoidal interval type-2 fuzzy number as preference scale. Figure-4 and Figure-5 show the ranking priorities of the coastal erosion decision problems using AHP and IT2-FAHP method. From the Figure-4, it can be seen that the priorities weights slightly not much differs with the other risk compare to AHP priorities weights (see Figure-5). Figure-4 shows that the weights are almost consistent

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among each of risks' factor relationship. The results are due to implementation of interval type-2 fuzzy set theory in gathering and calculating to handle uncertainties information involves during decision process. The IT2-FAHP method includes the computational of decision maker's weights, rank normalization and aggregation of preference variables of decision makers. Thus, this method is shown as one of the feasible to tackle the complexity in multiple choices of decision making.

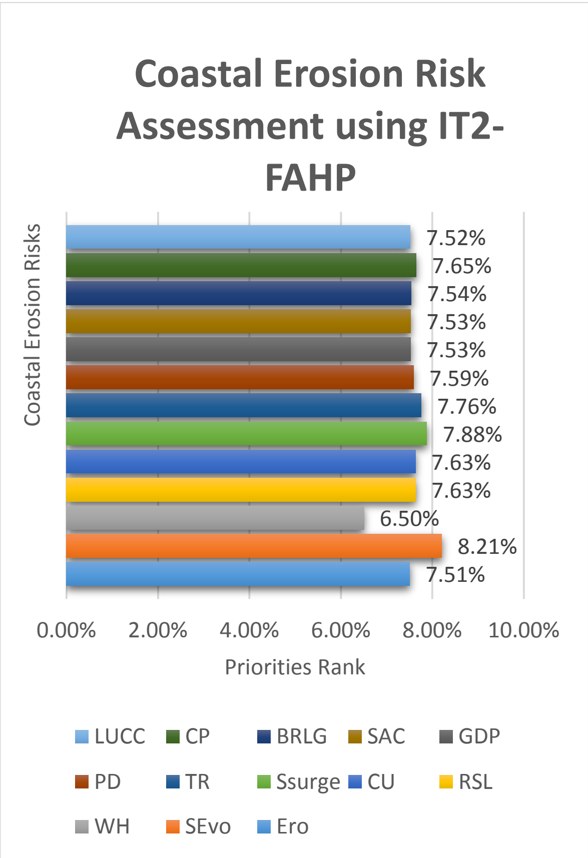

Figure-4. Coastal erosion risk assessment using IT2-FAHP method.

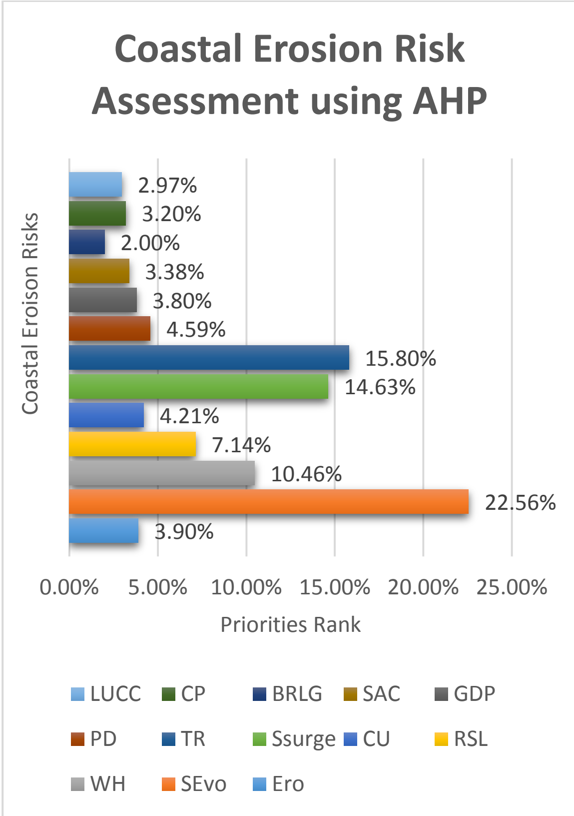

Figure-5. Coastal erosion risk assessment using AHP method.

CONCLUSIONS

The purposes of this study was to investigate the risk factor associated to coastal erosion problems using IT2-FAHP method with the characteristic of rank normalization, decision makers weights and trapezoidal interval type-2 fuzzy number preferences varibles. Since AHP method is widely known in handling multiplicity in decision making, thus the combination with interval type-2 fuzzy set gives one of prefereable ways to handling both uncertainties and multiplicities in multi-criteria decision making process. As a conclusion, this study managed to conclude that the most prominent factors and alternatives related to coastal erosion risk assessment is shoreline evolution with the highest percentage (8.21%) compare to the others alternatives. Shoreline evolution is the indicator that reflects the shoreline evolution trends which expresses the percentage of shoreline in erosion or accretion. It is hoped that, this study can be one of the useful information regarding to handle the risk assessment of coastal erosion decision poblems. To date, the research can be extended by considering more causal and impications associated to coastal erosion. Besides, the causal relationship between coastal erosion problems and its risk assessment can be one of information to predict the erosion in the coastal zone.

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