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Modelling the Causal Relationship of Risk Factors Associated to Coastal Erosion Using Dematel Method

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Abstract: The coastline of Malaysia is rich with coastal resources and has abundance of natural biodiversity. The coastal zone covers almost 70% of the living population and has recognized as one of the centre of socioeconomic growth for agriculture industries, oil and gas exploitation, fisheries, tourism and reclamation. However, these activities may cause severe harms to the geographical landscapes of coastal zone such as erosion. Besides, environmental changes such as climate change, tidal wave, wind and sea level rise also may affect the coastal erosion. Since there is many other intangibles of risk factors related to coastal erosion, this study attempt to investigate the causes-effects of the coastal erosion factor using Decision-Making Trial and Evaluation Laboratory method (DEMATEL). In this study, four dimensions and fourteen critical criteria was identified as critical factors contributing to the erosion. The DEMATEL method is used due to its ability to construct digraphs of causal relationship for both dimensions and its critical criteria. The results suggest that shoreline changes/evolution, wave condition and relative sea level rise are the risk causes and however wave condition is one of the main dimension related to coastal erosion. Thus, it is hoped that the findings could be beneficial to policy makers regarding measures that need to be undertake in dealing with coastal erosion.

Key words: Coastal erosion, causal relationship, DEMATEL method, risk factors, Malaysia

INTRODUCTION

The imbalance of the supply and export material from a certain coastal profile is one of the draining away processes which affects the coastal environment such as coastal erosion. Coastal erosion is an intrusion upon the state of the ocean 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. The most prominent factors related to coastal erosion are both natural effects and human-induced 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. Besides, the unstable wave and its height may collapse and break down to the coastline. The sea level rise and the changes of climate may also causes 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.

Meanwhile, the human-induced factors and coastal developments also tends 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. The movements of the sediments also cause wave shadow area and causing erosion on the down-drift coastline. In Malaysia, the coastal areas are generally the location of human deeds and trading activities. The increasing of rapid development and economy monopoly, town planning nowadays were arbitrary with rather unhealthy and unsanitary conditions (Mokhtar and Aziz, 2003). The competition between dynamic ecosystems and human activities on the coastal zones results in inducing a negative impact on the societal value of the coastline and environmental issues (Tang *et al*., 2005). The Malaysian Government has too indicated that approximately 29% or 1,380 km was facing erosion country's coastline from 4,809 km.

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The increasing attention regarding this environmental issue, it is compulsory to identify and investigate the risk factors related to coastal erosion before implementing coastal risk management. Risk management is important to provide a set of policy recommendation to improve environmental assessment procedures, erosion planning and coastal hazard 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.

Hence, this study intends to investigate the influence risks factor related to coastal erosion problems using Decision Making Trial and Evaluation Laboratory (DEMATEL) method and construct the digraph of the causal relationship system between the investigated dimensions. The DEMATEL is used to visualize the causal relationship between the criteria and indicate the degree of factor influence to each other (Liou *et al*., 2007).

The DEMATEL method was introduced by the Science and Human Affairs Program at the Battelle Memorial Institute's Geneva research Centre (Gabus and Fontela, 1973) as a structural modelling approach about complex problems in scientific fields (Hsu, 2012). Upon the increases attention to the real decision problems, DEMATEL method has widely been used in various applications such as environmental sciences (Wu and Chang, 2015), technology (Lin and Tzeng, 2009) and management (Horng *et al*., 2013; Hsu *et al*., 2013). The DEMATEL method gathers collective information to capture the causal relationship between potential criteria and basically visualize them into digraphs (Jassbi *et al*., 2011). The strategic visualization of the digraphs will construct the linkages of the cause-effect relationship between dimensions and its critical criteria to build a causal link leads to the problems approach. The digraph portrays a contextual relation between the dimensions and is a criteria of the intangible structural system by representing the strength of influence. The digraphs also play an important role for more simpler in selecting the correct measures and targets of the problems. Besides, many studies do not imply the interrelationships between evaluation dimensions and its criteria. This weakness has been covered by DEMATEL which allow investigating and modeling the value of appropriate decision must be made upon the selected criteria.

The complex interface of the initial influence among the components of a system can be modelled by DEMATEL by a value between zero and one. The component with no influence can be represented by zero and one means that the component is an absolute influence (Lee *et al*., 2013). Then, the initial influence of the component is developed by matrix interaction of a system. The framework of the DEMATEL contains the concrete characteristics of objective concerns among the criteria selection and reflect the relationship restriction towards the characteristic with an essential system and develop the trend of causal relation (Hori and Shimizu, 1999; Chiu *et al*., 2006). Thus, this study intends to investigate both direct and indirect risk factors using DEMATEL method and computes causal relationship diagrams for coastal erosion decision problem by approaching simple linguistic preference of influential scale. The adaptation of the DEMATEL method will give a visual representation that the decision maker uses to organize and measure him/her own judgment.

MATERIALS AND MEHTODS

DEMATEL method as a modelling causal relationship: The DEMATEL technique has been successfully applied to determine critical causes for the risk assessment of decision making problems. One of the specialities of the technique is managing to evaluate the criteria interdependence ability toward the restriction of a relation in systemic and development trend (Lu *et al*., 2013). To details, the DEMATEL method can be summarized by the succeeding steps.

Step 1: Calculate the average matrix, A. Suppose the expert H and n factors are considered for the case study. Each respondent is required to indicate the measure, to which he/she considers a factor,i, affects factor j. These pairwise comparisons matrix between any two factors are denoted by x_{ij}^{k} and the linguistic scale are given an integer score 0-4 (Table 1). The average matrix, for all expert opinions can be computed by averaging score of the experts as follows:

$$A_{ij} = \frac{1}{H}\sum_{k=1}^{H} X_{ij}^{k} \quad (1)$$

Hence, the total average matrix can be defined as:

$$A = \begin{bmatrix} a_{11} & \cdots & a_{1j} & \cdots & a_{1n} \\ \vdots & & \vdots & & \vdots \\ a_{i1} & \cdots & a_{ij} & \cdots & a_{in} \\ \vdots & & \vdots & & \vdots \\ a_{n1} & \cdots & a_{nj} & \cdots & a_{nn} \end{bmatrix} \quad (2)$$

Table 1: Linguistic scale of DEMATEL method (Gabus and Fontela, 1973)

Linguistic number	Linguistic preference
0	No influence
1	Low influence
2	Medium influence
3	High influence
4	Very high influence

The initial direct that effects that a factor exerts on and receives from other constituents is shown by the average matrix. Furthermore, the cause-effect between each pair of factors in a system can be mapped out by drawing an influence map.

Step 2: Calculate the initial direct influence matrix, D. The initial direct-relation matrix D is obtained by normalizing the average matrix A as follows:

$$D = \frac{A}{s} \quad (3)$$

Where:

$$s = \max\left(\max_{1\le i\le n} \sum_{j=1}^{n} a_{ij}, \max_{1\le i\le n} \sum_{i=1}^{n} a_{ij} \right) \quad (4)$$

Since, that the sum of each row j of matrix A has represented the direct effects that factor exerts on the other factors, $\max_{1\le i\le n} \Sigma_{j=1}^{n} a_{ij}$ represent the factor of the highest direct influence on the other factors. Likewise, since the sum of each column i of the matrix A represents the direct effects by a factor I, $\max_{1\le i\le n} \Sigma_{i=1}^{n} a_{ij}$ represents the factor which is the most influenced factor by the other factors. The positive scalar is equal to the bigger of two extreme sums. The matrix D is obtained by dividing each element of A by the scalar. Note that each element di_n of the matrix D is between 0 and 1.

Step 3: Compute the total relation matrix T by T = D (I-D)$^{-1}$ where I is the identity matrix. The sum of rows and the sums of column are represented by r and be n×1 and 1×n vectors, respectively for the total relation matrix T. Denote r_i be the sum of i row in matrix T, then r_i summarizes both direct and indirect effects given by factor i to the other factors. Suppose c_j be the sum of j column in matrix T and c_j shows both direct and indirect effects by factor from the other factors. When j = i the sum (r_i+c_j) shows the total effects given and received by factor i. Thus, (r_i+c_j) indicates the degree of importance for factor i in the entire system. In contrast, the difference (r_i+c_j) represents the net effect that factor i contributes to the system. Specifically, if (r_i+c_j) is positive, factor i is a net cause, while factor is a net receiver or result if (r_i+c_j) is negative.

Step 4: Set up a threshold value to illustrate the digraph. A matrix T might provide much knowledge on how one factor affects another which is necessary for a decision maker to determine up a threshold value to filter out some insignificant effects by displaying the effects greater than the threshold value in a digraph. The threshold value can be set up by figuring the average of the elements in matrix T. The digraph can be acquired by mapping the dataset of (r+c, r-c).

Coastal erosion problems using dematel method: The main four dimensions and fourteen criteria had been discussed and identified from the pointed literature review and consultation with the expert to demonstrate the net causes of the erosion. And so, the work goes forward with the DEMATEL method which consists four simple steps involving the aggregation of decision makers' value, normalization of the initial direct-relation matrix, and calculation of net causes and net receivers of the system. The dimensions and its critical criteria that contributing to coastal erosion problems are shown in Table 2.

The designed questions item was based on these four dimensions and fourteen critical criteria that involving three experts from the related field in this case study. The demographic variables of three experts are shown in Table 3.

All the experts were agreed that the identified critical dimension and criteria need to be investigated further in order to manage the risk assessment of coastal erosion problems. The causal relationship among the four dimensions of Shoreline changes/evolution (D_1), Relative sea level rise (D_2), Wave condition (D_3) and Climate changes (D_4) using DEMATEL method is developed as below. The computation is based on the three experts X^1, X^2, X^3 and their linguistic influence factor scale:

$$X^1 = \begin{pmatrix} 0 & 4 & 2 & 1 \\ 0 & 0 & 3 & 3 \\ 0 & 1 & 0 & 4 \\ 0 & 0 & 0 & 0 \end{pmatrix} \quad X^2 = \begin{pmatrix} 0 & 4 & 2 & 1 \\ 1 & 0 & 3 & 3 \\ 4 & 1 & 0 & 4 \\ 4 & 1 & 1 & 0 \end{pmatrix}$$

$$X^3 = \begin{pmatrix} 0 & 1 & 3 & 4 \\ 4 & 0 & 1 & 1 \\ 2 & 3 & 0 & 4 \\ 1 & 3 & 14 & 0 \end{pmatrix}$$

Then, the average matrix, of four dimensions are calculated by Eq. 1.

$$A = \begin{pmatrix} 0 & 3.0000 & 2.3333 & 2.0000 \\ 1.6667 & 0 & 2.3333 & 2.3333 \\ 2.0000 & 1.6667 & 0 & 4.0000 \\ 1.6667 & 1.3333 & 1.6667 & 0 \end{pmatrix}$$

Next, the normalized initial direct influence matrix, is computed using Eq. 3.

Table 2: Four dimensions with fourteen critical criteria

Dimension	Critical criteria
Shoreline changes/evolution, D1	Population density, C1; Hydrodynamic pattern, C2; Longshore sediment transport, C3
Relative sea level rise, D2	High intensity of current longshore, C4; Tidal range, C5; Sea area class, C6
Wave condition, D3	High significant wave, C7; Maximum wave height, C8; Wave acceleration/gusts, C9; Wave pattern, C10
Climate change, D4	Wave climate, C11; Seasonal climate (e.g., heavy rain), C12; Storm surge, C13; Wind speed, C14

$$D = \frac{1}{8.3333}\begin{pmatrix} 0 & 3.0000 & 2.3333 & 2.0000 \\ 1.6667 & 0 & 2.3333 & 2.3333 \\ 2.0000 & 1.6667 & 0 & 4.0000 \\ 1.6667 & 1.3333 & 1.6667 & 0 \end{pmatrix}$$

$$= \begin{pmatrix} 0 & 0.36 & 0.28 & 0.24 \\ 0.20 & 0 & 0.28 & 0.28 \\ 0.24 & 0.20 & 0 & 0.48 \\ 0.20 & 0.16 & 0.20 & 0 \end{pmatrix}$$

The procedure is proceed to the step 3 to obtain the total relation matrix of the four dimensions:

$$T = D(I-D)^{-1}$$

$$= \begin{pmatrix} 0 & 0.36 & 0.28 & 0.24 \\ 0.20 & 0 & 0.28 & 0.28 \\ 0.24 & 0.20 & 0 & 0.48 \\ 0.20 & 0.16 & 0.20 & 0 \end{pmatrix}.$$

$$\left(\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} - \begin{pmatrix} 0 & 0.36 & 0.28 & 0.24 \\ 0.20 & 0 & 0.28 & 0.28 \\ 0.24 & 0.20 & 0 & 0.48 \\ 0.20 & 0.16 & 0.20 & 0 \end{pmatrix}\right)^{-1}$$

$$= \begin{pmatrix} 0 & 0.36 & 0.28 & 0.24 \\ 0.20 & 0 & 0.28 & 0.28 \\ 0.24 & 0.20 & 0 & 0.48 \\ 0.20 & 0.16 & 0.20 & 0 \end{pmatrix}\begin{pmatrix} 1 & -0.36 & -0.28 & -0.24 \\ -0.20 & 1 & -0.28 & -0.28 \\ -0.24 & -0.20 & 1 & -0.48 \\ -0.20 & -0.16 & -0.20 & 1 \end{pmatrix}^{-1}$$

$$= \begin{pmatrix} 0.6470 & 0.9639 & 0.9558 & 1.1239 \\ 0.7360 & 0.6040 & 0.8632 & 1.0401 \\ 0.8375 & 0.8494 & 0.7257 & 1.2672 \\ 0.6146 & 0.6193 & 0.6744 & 0.6446 \end{pmatrix}$$

Finally, Table 4 is established to represent the total summarized of direct and indirect effects for the four dimensions. The threshold value used in step 3 is calculated to obtain the average elements in the matrix.

Table 3: Demographic variables of three experts

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 (years)		
<5	2	66.67
5-10	1	33.33

Table 4: Total relation matrix and sum of influence for dimensions

Dimensions	r_i	c_j	(r_i+c_j)	(r_i+c_j)
Shoreline changes/ evolution, D_1	3.6906	2.8351	6.5257	0.8555
Relative sea level rise, D_2	3.2433	3.0366	6.2799	0.2067
Wave condition, D_3	3.6798	3.2191	6.8989	0.4607
Climate changes, D_4	2.5529	4.0758	6.6287	-1.5229

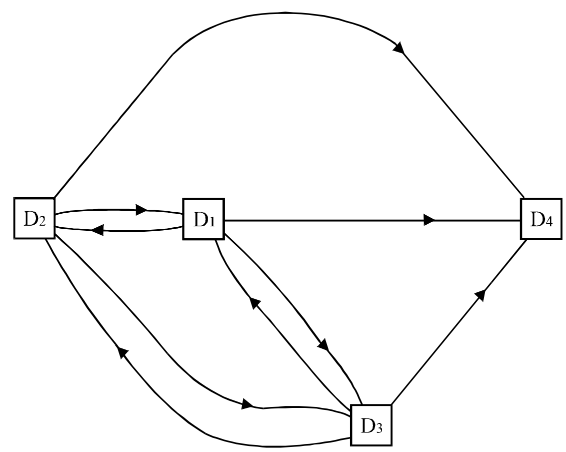

Fig. 1: The causal relationship diagram of dimensions

The threshold value for these four dimensions is set up to 0.8229 to visualize the digraph of cause-effect relationship diagram. Table 4 shows the relation matrix and the sum of influence for direct and indirect net causal of the dimensions.

From Table 4, shoreline evolution/changes, relative sea level rise and wave condition are net causes due to positive value of $(r_i\text{-}c_j)$ while climate change is net receivers because of negative value of $(r_i\text{-}c_j)$. Wave condition has the highest value of $(r_i\text{-}c_j)$ indicating the most critical dimension/risk factors to the erosion. The causal relationship diagraph for four dimensions is shown in Fig. 1.

Figure 1 describes that shoreline changes/evolution (D_1), relative sea level rise (D_2) and wave conditions (D_3) are net causes and have mutual interaction toward each other. That means, if either one of each aspect is going to affect each other. However, wave conditions are the most essential dimension and have influenced the climate change which is net receiver. Since the second highest value of, climate change also have influence toward relative sea level rise. Based on the information, the wave condition is one of the most influential dimensions to effectively contribute to the coastal erosion.

RESULTS AND DISCUSSION

The DEMATEL procedures are proceeding to compute the net causes and net receivers for critical criteria of each dimension. By further discussing, Table 5 show the overall direct and indirect influence for each critical criteria of the dimensions. From Table 5, it is suggested that population density (C_1) and longshore sediment transport (C_3) are the net causes of shoreline changer/evolution and hydrodynamic pattern (C_2) is a net receiver of the dimensions. However, longshore sediment transport is the most influential risk factor toward the shoreline changes/evolution followed by population density. For the dimension of relative sea level rise, it is shown that high density of current longshore (C_4) and tidal range (C_5) are the net causes of the critical risk factor. Sea area class (C_6) is a net receiver and high density of current longshore is also the main factor in contributing to sea level rise and erosion itself.

Next, in the potential of risk factor, high significant wave (C_7) and wave pattern (C_{10}) are both net causes to influence in wave condition for the coast. However, the most critical factor in wave condition is maximum wave height (C_8) followed by wave acceleration/gusts (C_9), wave pattern (C_{10}) and high significant wave (C_7). Last but not least, wind speed (C_{14}), seasonal climate (e.g., Heavy rain) (C_{12}) and storm surge (C_{13}) is the top three most important factors in the term of value. From the causal relationship diagram, only wave climate (C_{11}) is the net causes of the climate changes whereas the other is net receivers.

Table 5: The direct and indirect influence for critical criteria with respect to dimensions

Critical criteria	(r_i+c_j)	(r_i+c_j)
Total sum of influence for critical criteria of shoreline changes/evolution		
Population density, C_1	4.0748	1.27160
Hydrodynamic pattern, C_2	3.9068	-1.58380
Longshore sediment transport, C_3	4.3458	0.31220
Total sum of influence for critical criteria of relative sea level rise		
High density of current longshore, C_4	7.8124	0.95740
Tidal range, C_5	7.4315	0.03260
Sea area class, C_6	6.8332	-0.99000
Total sum of influence for critical criteria of wave condition		
High significant wave, C_7	16.9061	1.07870
Maximum wave height, C_8	18.4716	-0.92044
Wave acceleration/gusts, C_9	19.1001	-0.56646
Wave pattern, C_{10}	17.6126	0.40820
Total sum of influence for critical criteria of climate changes		
Wave climate, C_{11}	2.8505	1.76350
Seasonal climate (e.g.: Heavy rain), C_{12}	3.4214	-0.79600
Storm surge, C_{13}	3.3758	-0.37500
Wind speed, C_{14}	4.2819	-0.59250

CONCLUSION

This study attempted to use four identical dimensions with respect to fourteen critical criteria as several risk factors contribute to the coastal erosion using DEMATEL method. The unique characteristics of DEMATEL method lead us to interpret the influential factor into a causal relationship diagram so that we can see the direct expose causes of the coastal erosion. It is important to demonstrate their relationship in order to specify and clarify the most important risk factor that really needs to take care of. From the investigation, it can be described that wave condition is the highest percentage to lead the coastal erosion problems followed by climate change, shoreline changes/evolution and relative sea level rise. However, for the most influential factor that leads to these dimensions are longshore sediment transport, high density of current longshore, wave acceleration/gusts and wind speed. Besides, a net causes relationship of critical criteria towards dimension are population density, high density of current longshore, highly significant of wave, and wave climate.

RECOMMENDATIONS

Thus, by the conclusion of this study, it is recommended that any action can be taken to reduce the coastal erosion with the implementation of the risk assessment and risk factor management. In the future, the study can be extended by allocating a group of experts that can be participated in this research and it is essential to investigate the different criteria related to the coastal erosion. In addition, instead of using the crisp value, it can be also to apply fuzzy approach to illustrate the linguistic influence of the expert. To validate the results, it is recommended to implement the sensitivity analysis for the method.

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REFERENCES

Chiu, Y.J., H.C. Chen, G.H. Tzeng and J.Z. Shyu, 2006. Marketing strategy based on customer behaviour for the LCD-TV. Int. J. Decis. Making, 7: 143-165.

Gabus, A. and E. Fontela, 1973. Perceptions of the world problematique: Communication procedure, communicating with those bearing collective responsibility. DEMATEL Report No. 1, Battelle Geneva Research Center, Geneva, Switzerland.

Wu, H.H. and S.Y. Chang, 2015. A case study of using DEMATEL method to identify critical factors in green supply chain management. Appl. Math. Comput., 256: 394-403.

Hori, S. and Y. Shimizu, 1999. Designing methods of human interface for supervisory control systems. Control Eng. Pract., 7: 1413-1419.

Horng, J.S., C.H. Liu, S.F. Chou and C.Y. Tsai, 2013. Creativity as a critical criterion for future restaurant space design: developing a novel model with DEMATEL application. Intl. J. Hospitality Manage., 33: 96-105.

Hsu, C.C., 2012. Evaluation criteria for blog design and analysis of causal relationships using factor analysis and DEMATEL. Expert Syst. Appl., 39: 187-193.

Hsu, C.W., T.C. Kuo, S.H. Chen and A.H. Hu, 2013. Using DEMATEL to develop a carbon management model of supplier selection in green supply chain management. J. Cleaner Prod., 56: 164-172.

Jassbi, J., F. Mohamadnejad and H. Nasrollahzadeh, 2011. A fuzzy DEMATEL framework for modeling cause and effect relationships of strategy map. Expert Syst. Appl., 38: 5967-5973.

Lee, H.S., G.H. Tzeng, W. Yeih, Y.J. Wang and S.C. Yang, 2013. Revised DEMATEL: Resolving the infeasibility of DEMATEL. Appl. Math. Modell., 37: 6746-6757.

Lin, C.L. and G.H. Tzeng, 2009. A value-created system of science (technology) park by using DEMATEL. Expert Syst. Appl., 36: 9683-9697.

Liou, J.J.H., G.H. Tzeng and H.C. Chang, 2007. Airline safety measurement using a hybrid model. J. Air Transp. Manage., 13: 243-249.

Lu, M.T., S.W. Lin and G.H. Tzeng, 2013. Improving RFID adoption in Taiwan's healthcare industry based on a DEMATEL technique with a hybrid MCDM model. Dec. Support Syst., 56: 259-269.

Mokhtar, M.B. and S.A.B.A.G. Aziz, 2003. Integrated coastal zone management using the ecosystems pproach, some perspectives in Malaysia. Ocean Coastal Manage., 46: 407-419.

Tang, Z., B.A. Engel, B.C. Pijanowski and K.J. Lim, 2005. Forecasting land use change and its environmental impact at a watershed scale. J. Environ. Manage., 76: 35-45.