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Development of Multi Criteria Analysis Model for Best Sediment Management Techniques in Kuala Krai, Malaysia

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Abstract

In tropical countries like Malaysia, high rainfall intensities cause high rates of soil erosion which yields high rates of sedimentation. Soil disturbance activities (cut and fill activities) accelerate the rate of soil dislocation and results in sedimentations that impacts the ambient environment. The aim of this research is to develop a Weighted Summation Multi Criteria Analysis (MCA) Model which can be considered as a decision support tool and protocol to identify the best sediment management practices which assist the Malaysian water industry in assessing the relative sustainability of stormwater systems. A performance matrix was built between the sediment control alternatives / techniques (i.e. sediment basins, silt fence, sand bag barrier and rock filter) versus the technical, economic, environmental and social criteria which reflects the expert's opinions. Results from the study show that the sediment basin considered the best technique among other techniques in which the sensitivity analysis showed very strong decision made and not sensitive to any of the criteria adopted in the study. The developed model is helpful for the engineers and decision makers to find the best sediment control measures in any region subjected to soil disturbance activities.

Key words: Runoff, MCA, sediment, sensitivity analysis, soil erosion.

تطوير موديل تحليل متعدد المعايير لاختيار افضل تقنيات ادارة الترسبات في كوالا كراي، ماليزيا

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الملخص

في البلدان الاستوائية مثل ماليزيا ، يتسبب هطول الأمطار بكثافة في ارتفاع معدلات تعرية التربة مما ينتج عنه معدلات عالية من الترسبات. تعمل أنشطة اضطراب التربة (انشطة القطع والدفن للتربة) على تسريع معدل تعرية التربة وتؤدي إلى ترسبات تؤثر على البيئة المحيطة. الهدف من هذا البحث هو تطوير نموذج تحليل متعدد المعايير للتجميع الموزون (MCA) والذي يمكن اعتباره كأداة لدعم القرار وبروتوكول لتحديد أفضل ممارسات إدارة الرواسب والتي تساعد مؤسسات المياه الماليزية في تقييم الاستدامة النسبية لأنظمة مياه العواصف المطرية. تم بناء مصفوفة الأداء بين بدائل / تقنيات التحكم في الرواسب (مثل أحواض الرواسب ، سور تجميع الرواسب ، وحاجز أكياس الرمل ومرشح الصخور) مقابل المعايير التقنية والاقتصادية والبيئية والاجتماعية والتي تعكس آراء الخبراء. أظهرت نتائج الدراسة أن حوض الرواسب يعتبر أفضل تقنية من بين التقنيات الأخرى حيث أظهر تحليل الحساسية اتخاذ قرار قوي للغاية وغير حساس لأي من المعايير التي تم تبنيها في الدراسة. النموذج المطور مفيد للمهندسين وصناع القرار لايجاد أفضل وسائل السيطرة على الرواسب في أي منطقة معرضة لأنشطة اضطراب التربة.

كلمات مفتاحية: الجريان السطحي، تحليل متعدد المعايير، الترسبات، تحليل الحساسية، تعرية التربة.

1.Introduction

Clean and sufficient water provides the necessary need for various purposes includes irrigation, industrial and commercial use, hydropower generation and so forth. Human activities accelerate soil erosion process by soil disturbing activities. This makes it more susceptible to washout by natural forces (Brady and Weil, 1996). The sediment yielded from the eroded soils is the primary pollutant of concern (Bakr , et al., 2012). The impact of sediment on water bodies involves the offside impacts of the natural soil disturbing activities has environmental and economic impacts (Issa , et al., 2013). In Malaysia, there are around 1800 rivers comprising 150 systems that run up to 38000 km. These systems provide 97 percent of drinking water and can provide for domestic needs, aquaculture, industry, agriculture, recreational use as well as hydroelectric power.

Urban developments in Malaysia are among other land uses that have the greatest impact on the stream sediment in the main sources of sedimentation to the streams are from the earthworks (Angermeier , et al., 2004; and Goonetilleke , et al., 2005). The heavy rainfall and highly weathered soils which are also highly erodible, have caused a severe sedimentation to the adjacent water property in Malaysia as a result of land clearing and earth work activities (DID, 2010).

Cleveland and Fashokun (2006) monitored selective water quality parameters before construction, during construction, and post construction in which they indicated that the construction activity resulted in a six time increase in total solids leaving the construction site compared to pre-construction values. Houser and Pruess (2009) conducted a study to examine the water quality impacts of an earthwork activities of Abram Creek which results in high potential of sediment generation.

Runoff water quality control impose multiple criteria usually with different units that need to be considered and weigh as option. The Multi Criteria Analysis (MCA) is an effective tool to make decisions with high accuracy and it has widely been applied in water resources and environmental management fields (Yazidi, et al., 2017; IIaya-Ayza et al., 2018; Singh et al., 2018; Al-Ani , et al., 2020). (Das and Gupta, 2021) applied a multi criteria decision based geospatial mapping of flood susceptibility in India in which the predicted flood susceptibility map showed a great number of areas (38%) have high probability of flooding. (Pham, et al., 2021) assessed the flood risk using hybrid artificial intelligence and MCA in Vietnam and the results shows that the proposed methods perform well. The final flood risk map can provide a useful source for better flood hazard management of the study area and the proposed framework and models can be applied to other flood prone areas. (Jaiswal, et al., 2015) applied the MCA in prioritizing of vulnerable area of watershed in Kodar reservoir catchment, India and by analyzing the results, they concluded that the method could help in developing an implementable catchment area treatment (CAT) plan for Kodar. (Crnković ,et al., 2016) evaluated the freshwater sediments three MCA methods and proved that PROMETHEE method delivered an insight to the distribution of examined elements. Another study performed by applying the MCA to highlight the best alternative to the Malnchara Channel improvement depending on four main criteria (i.e. technical, economic, environment and social) and concluded that sodding natural channel is the best alternative and when performing the sensitivity analysis, the choice was sensitive to the social criterion (Chowdhury and Rahman, 2008). The objective of the current research is to develop a multi criteria analysis model that prioritizing the appropriate sediment control in Kuala Krai, Malaysia. The researchers found that this provides several advantages for the engineers and decision makers which is considered unbiased judgement and saving time.

2. Study Area

The proposed project of 365 ha of secondary forest into a rubber tree plantation (Timber Latex Clone) is located at Mukim Telekong, Daerah Batu Mengkebang, Kuala Krai, Kelantan. It is located 151 km North-East Gua Musang town, and 94 km South-East from Kota Bharu. The proposed development is in the Kuala Krai district, which will be planned as an Eco-tourism town under the Rancangan Struktur Negeri Kelantan 2020. Thus, due to this, most of the development in Kuala Krai will be emphasized on industrial cluster of herbs and wood products. There is a local community of Kampung Kebun Pisang, “Rancangan Pembangunan Tanah” (RPT) Kampung Pasir Jering, Kampung Dusun Ban, Kampung Batu Pagar and Kampung Dusun Gunung which is located about 12 km from the Sungai Durian junction. From the village area, it will take around 19 km to reach the boundary of the proposed project site. The proposed project site location is illustrated in Figure (1). Figure (2) shows the project’s catchment boundaries.

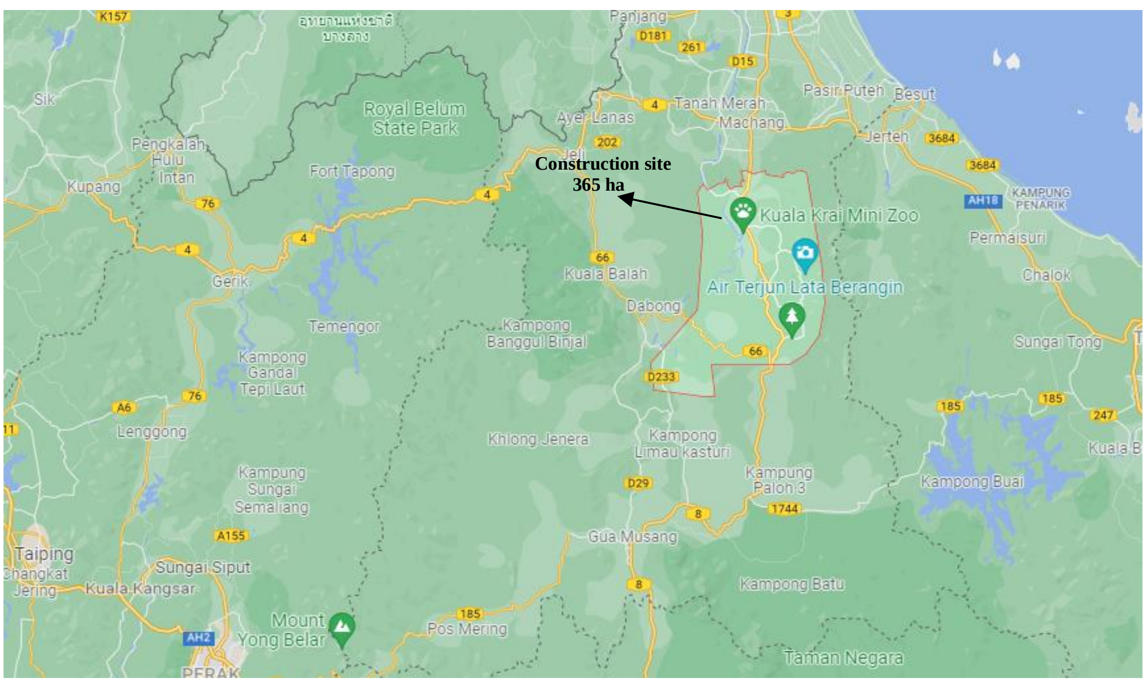

Figure 1: Location of the Project Area

3. Materials and Methods

The methods adopted in this research is sub-divided into two main parts (see Figure (2)); the first part includes the develop a Multi Criteria Analysis (MCA) Model and the second part includes the validation of the model via performing the sensitivity analysis.

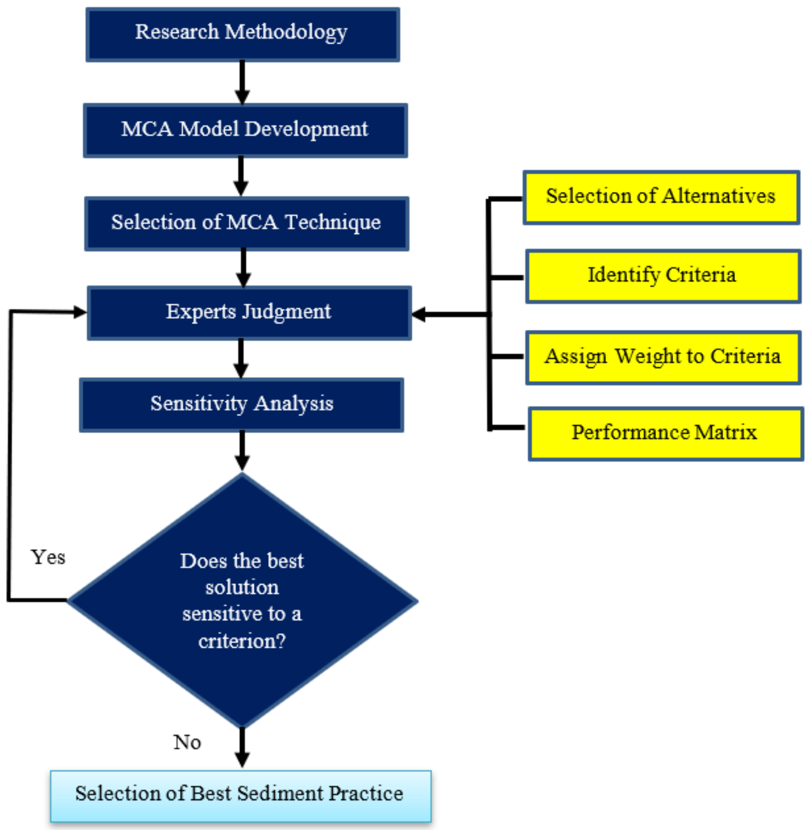

Figure 2: Methods adopted in the study

3.1 Multi Criteria Analysis Model

Four criteria (m=4) were chosen i.e. technical, environmental, economic and social. Assessment of the performance matrix X of n decision options (for alternatives) against m criteria was conducted by obtaining the performance score for decision option i, with respect to criterion j is denoted as x_{ij}., as shown in Figure (3). Each criterion is subscribed to one dimensional weight, denotes here as w_j, that is the weight assigned to the jth criterion. Ranking of alternatives indicates the performance of alternatives to be scored with respect to the criteria. In this research, the alternatives were ranked by the experts against the criteria using a five (5) point scale. There were two methods for assigning ordinal scores. When the ordinal scales of "very high" and "very low" indicate the best and the worst performance respectively, the score range was selected from five (very high) to one (very low). Criteria which fell under this method were (1) system performance, (2) material availability, (3) water pollution control, (4) stakeholder acceptability. Besides, when the ordinal scales of "very high" and "very low" indicate the worst and the best performance respectively, the selected score range was one (very high) to five (very low). Criteria which fell under this method were (1) construction and removal cost.

Criteria		C_1	C_2	C_3	C_4
Weights		W_1	W_2	W_3	W_4
(Alternatives/ BMPs-i)	A_1	$x_{1,1}$	$x_{2,1}$	$x_{3,1}$	$x_{4,1}$
	A_2	$x_{1,2}$	$x_{2,2}$	$x_{3,2}$	$x_{4,2}$
	A_3	$x_{1,3}$	$x_{2,3}$	$x_{3,3}$	$x_{4,3}$
	A_n	$x_{1\,n}$	$x_{2\,n}$	$x_{3\,n}$	$x_{4,n}$

Figure 3. The basic structure of the performance matrix in MCA to identify the best BMP

In the weighted summation MCA technique adopted herein, the performance measures were multiplied by the weights and then summed for each alternative to obtain a performance score. The overall performance score was calculated using Equation 1, as follows:

$$v_i = \sum_{j=1}^{m} s_{ij} . w_j \qquad (1)$$

where,

s_{ij} = standardized performance measure for $x_{ij;}$

v_i = value (or utility) of the i^{th} alternative relative to the other alternatives; and

The weighted coefficients of various criteria were assigned on the basis of public consultation and expert opinion. The weights for all criteria were assigned using a five (5) point scale. The averages of expert's criteria's weights have been adopted to be involved in the system (Chowdhury and Rahman, 2008). If the criterion weights have not been normalised to add up to one, then it is necessary to normalise them by simply dividing each criterion weight value by the sum of all the criteria weight values (Voogd, 1983), thus Weight normalisation for all the criteria was fulfilled. Each criterion was assigned weight which indicates the relative importance of each criterion. Typically, the $\sum w_j = 1$ and $\mathbf{0 \leq w_j \leq 1}$, holds for all the criteria; that is, the sum of the weights is equal to one and is non-negative. Variations in the performance matrix alternatives were represented as columns, and the criteria and weights as rows. The performance matrix represents the domain of factors, which is incorporated into the MCA model to generate its solutions.

3.1.1 Selection of MCA Technique

Many kinds of MCA techniques have been developed until now (Vlahavas , et al., 1999; and Eldrandaly, 2009). The MCA method that has been adopted in this research is the weighted summation method and this method is one of many MCA methods. The reasons for using this method are: (a) knowledge acquisition indicated that there was a lack of justification for a more complex method and (b) the local experts interviewed as part of the knowledge acquisition process were willing and able to identify criteria and criterion values in a manner consistent with a weighted summation method (due to its simplicity regarding the time and effort required to reach a conclusion, understandability of the method, difficulty in obtaining the input data, and ability to handle uncertainties). This method has been applied widely in the water resources and environmental management fields (Ellis et al., 2006; Sidek et al., 2008; and Hajkowicz and Higgins, 2008).

3.1.2 Selection of Criteria

The researcher has combined all the criteria that have been selected by the previous case studies, review of literature (Chowdhury, 2008; Sidek, et al., 2008) and then presented them to the local experts through comprehensive discussions so as to identify the suitable criteria that have to be adopted. The criteria and sub-criteria that were adopted in this research are presented in Figure (4) below.

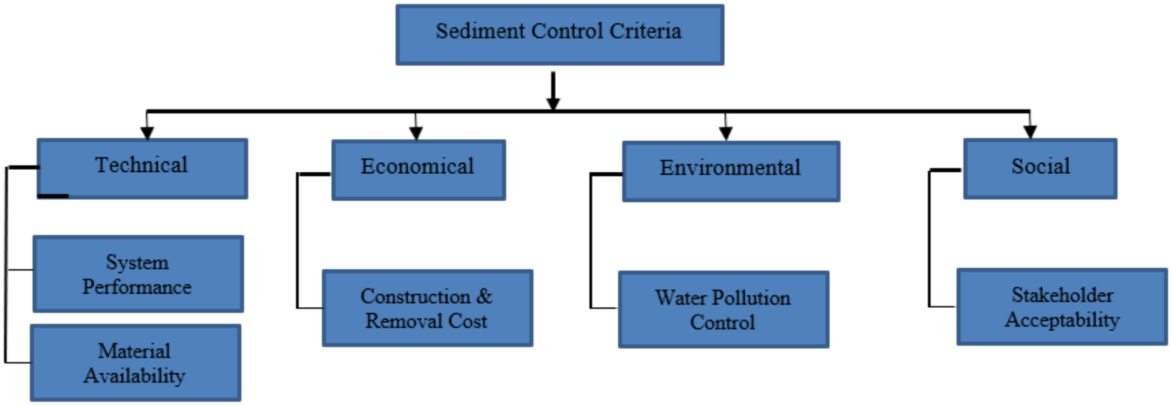

Figure 4: Criteria and sub-criterion adopted in the study

3.1.3 Selection of Alternatives

Based on the national guidelines (DID, 2000 and DID, 2010), literature review and discussions with experts, the suitable alternatives / control measures that are required to minimize water pollution deterioration of any targeted project were identified. These alternatives were explained and presented in Table (1).

Table 1: List of recommended control measures

Category	Control Measure	Description
Sediment Control	Silt Fence	It consists of a filter fabric stretched across and attached to supporting posts and entrenched.
	Sand Bag Barrier	Sand Bag barrier consists of bunds of sand bags for lining areas that are prone to soil erosion and flood.
	Rock Filter	Rock filter is a filter made of 20 to 75 mm diameter rocks placed along a level contour where sheet flow may be detained and ponded to promote sedimentation.
	Sediment Basin	A temporary basin with a controlled storm water release structure formed by constructing an embankment of compacted soil across a drainage way

3.1.4 Expert's Judgements

All the necessary information on the alternatives (sedimentation controls) from books, guidelines, manuals, site observation, conference proceedings and journals were tapped and integrated. The knowledge acquired from the multi sources were collected, summarised and then presented to the domain experts. The information from the domain experts was obtained through interview and on-site communication. Three series (meetings) of systematic consultation were organised with ten experts who were classified into two groups (i.e. local authority denoted as Group 1, and practicing engineers denoted as Group 2). The summary and the chronology of the meetings are depicted in Table (2). The interview with the experts adopted the Delphi approach so that a structured communication was performed and a convergence opinion is achieved. After each round, each answer from different experts were compiled and summarised. Following each interview session, the answers compilation from the previous round was presented to the expert panels. Note that the answers were made anonymous to minimise bias and judgement on the other panels. During this session, the experts may revise their answers back in light with other panels or remained with their prior answers. This process facilitates the coherence of feedback and decreasing the variation of answers given which eventually the specific group will conclude to unanimous "correct" answer. The interview and reiterate processes were stopped following the impediment criterion number of rounds, achievements of the consensus, and the stability of the results. The mean scores of the final rounds determine the results.

Table 2: Sequential interviews with the experts

Round	Group	Remarks
Round 1	Group 1 and Group 2	Provided background about the study, objectives, importance and concept of the expert systems and the MCA
Round 2	Group 1 and Group 2	Discussed about the relevant criteria and type of alternatives besides the criteria weights
Rounds 3 and 4	Group 1 and Group 2	Provided an anonymous summary of the experts' forecasts from the previous rounds as well as the reasons they provided for the judgments. Eventually, the reviewing of the results is fulfilled

3.2 Sensitivity Analysis

The uncertainty appears throughout the decision analysis process from its early stages of choosing the MCA approach, to the final stages of explaining and recommending the results. The implications of these uncertainties need to be examined in order to render the decision makers with the necessary confidence to make justifiable decisions with reasonable certainty.

In this paper, the sensitivity analysis was performed by changing the weight coefficient of all criteria in which when one's weighted coefficient changes, other's weighted coefficient remains constant and indicates by how much the criterion weight changes without affecting the best alternative (Chowdhury and Rahman, 2008). The procedure adopted in performing the sensitivity analysis is presented in Figure (5).

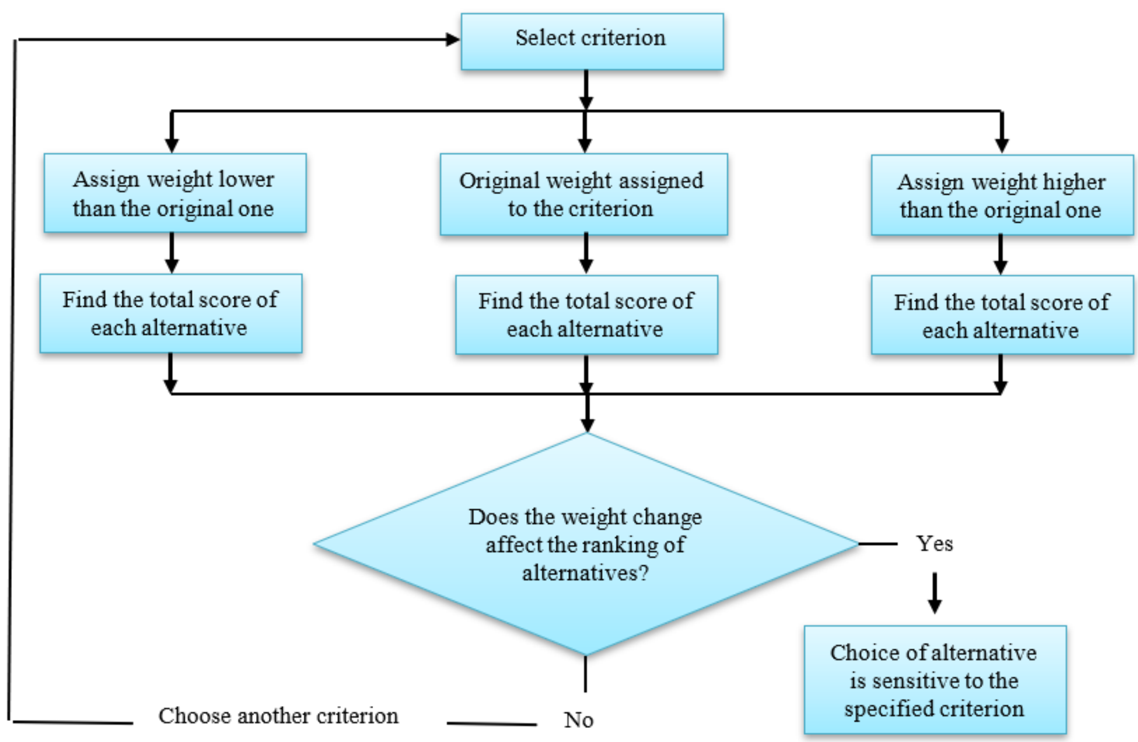

Figure 5: Procedure adopted in performing the sensitivity analysis

4. Results and Discussions

Scores of alternatives versus the selected criteria and criteria weight were fulfilled (by the experts) via developing the performance matrix for of sediment control alternatives are presented in Table (3). The scores assigned using 5 points scale in which the negative sign is used for economic criterion solely. It is observed that alternatives (I and III) were assigned similar scores for technical, economic and environmental criteria and alternative II assigned the similar scores for the technical, environmental and social criteria except for the system performance. Furthermore, alternative IV was assigned similar scores for the technical and economic criteria. Based on the ranking and by applying Equation 1 earlier, it is indicated that the sediment basins occupy the best alternative due to its capacity and efficiency in capturing a lot of sediments before the stormwater outflow to the ambient water bodies (DID, 2010). The silt fence, sand bag barrier and rock filter occupy the second, third and fourth best alternatives respectively following the sediment basins. Since all scores are not expressed in the same unit, standardization is required in which the criteria weights were normalized to one (Voogd, 1983 and Chowdhury, 2008). In assigning the scores of alternatives versus criteria, a number of uncertainties and assumptions were made and the choices were made on the basis of evaluation method. Therefore, attempt was considered to overcome the uncertainty through the decision made by the experts by performing the sensitivity analysis. The sensitivity analysis fulfilled by changing the weight of each criterion and indicate its effect on the decision of the best alternative and the results are presented in Figures (6-9).

Table 3: Scores of alternatives versus criteria

Sediment Control Techniques						
Criteria	Sub-criteria	Normalized weights	Alternatives			
			I	II	III	IV
Technical	System Performance	0.20	5	3	4	3
	Material Availability	0.20	5	4	4	3
Economic	Construction & Removal Cost	0.20	-2	-2	-3	-3
Environmental	Water Pollution Control	0.28	5	4	4	4
Social	Stakeholder Acceptability	0.12	4	4	3	2

I: Sediment basin, II: Silt fence, III: Sand bag barrier, IV: Rock filter

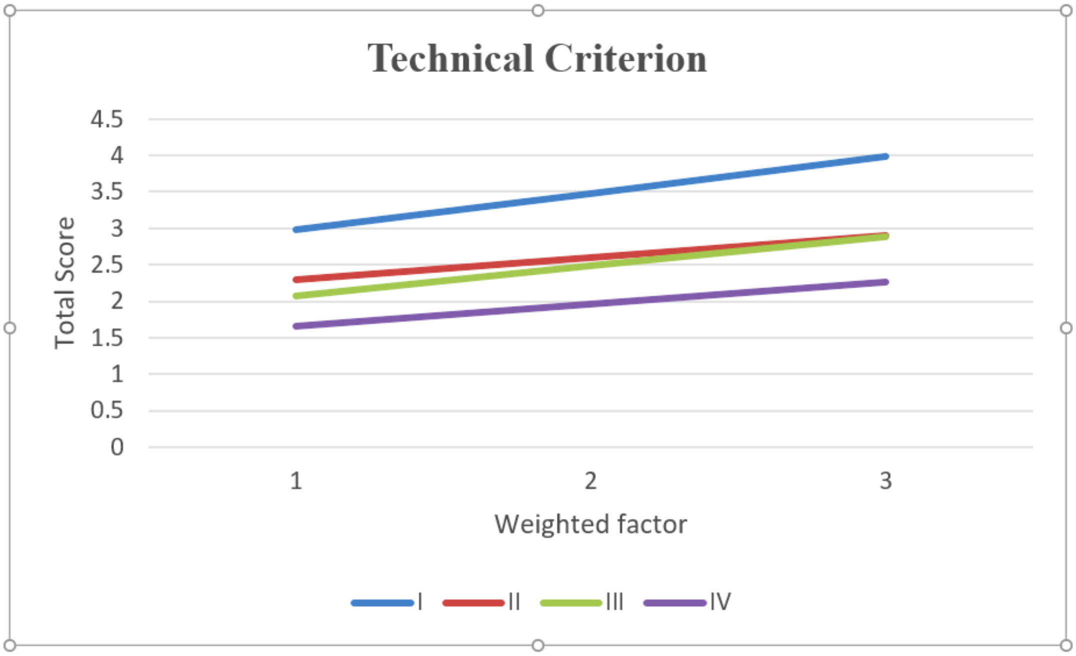

Figure 6: Effect of changing technical criterion on the choice of best alternative

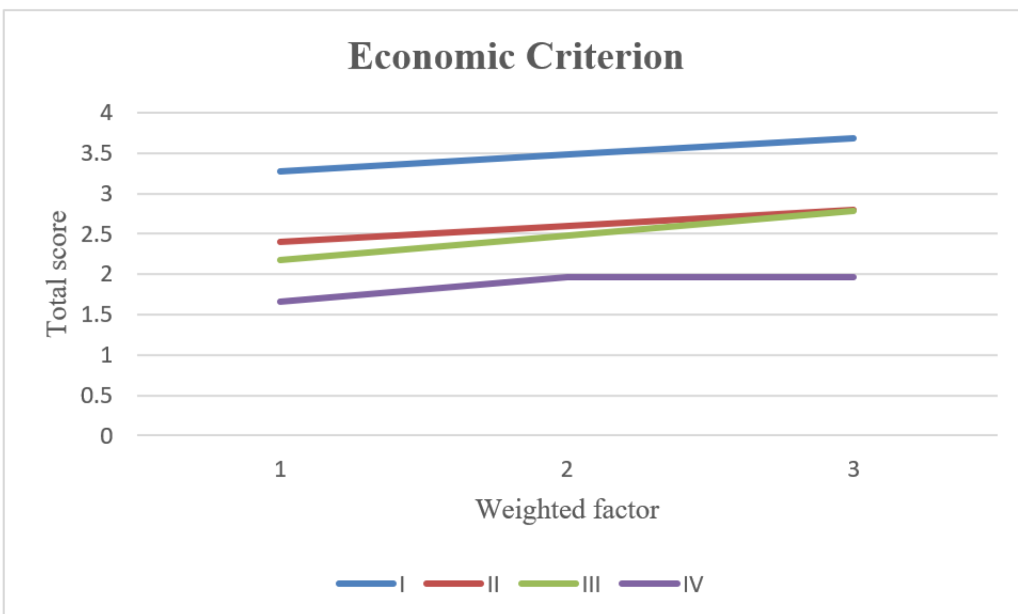

Figure 7: Effect of changing economic criterion on the choice of best alternative

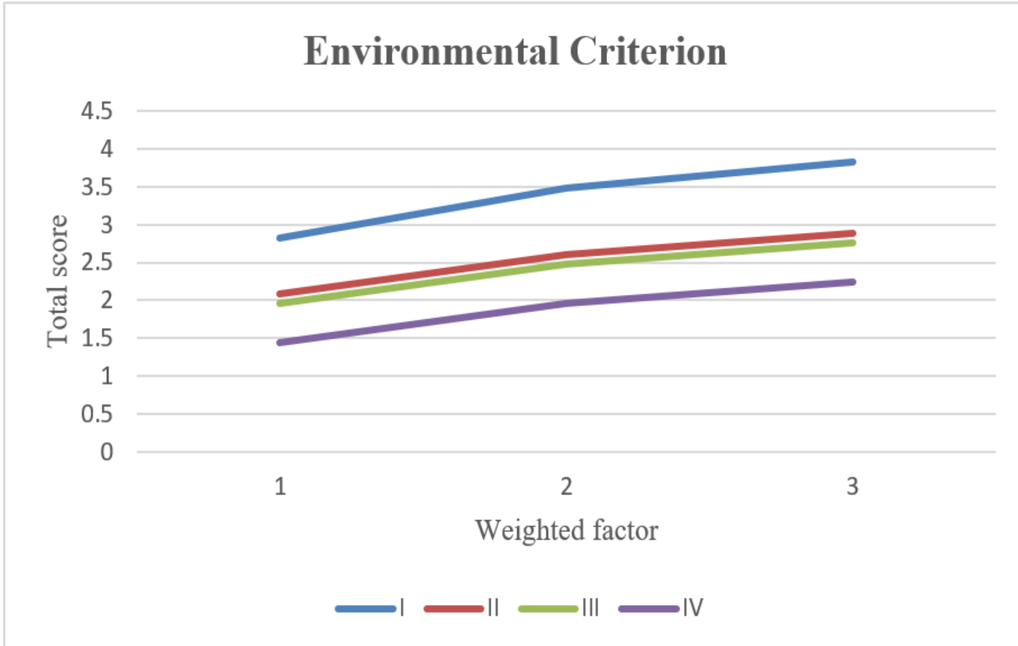

Figure 8: Effect of changing environmental criterion on the choice of best alternative

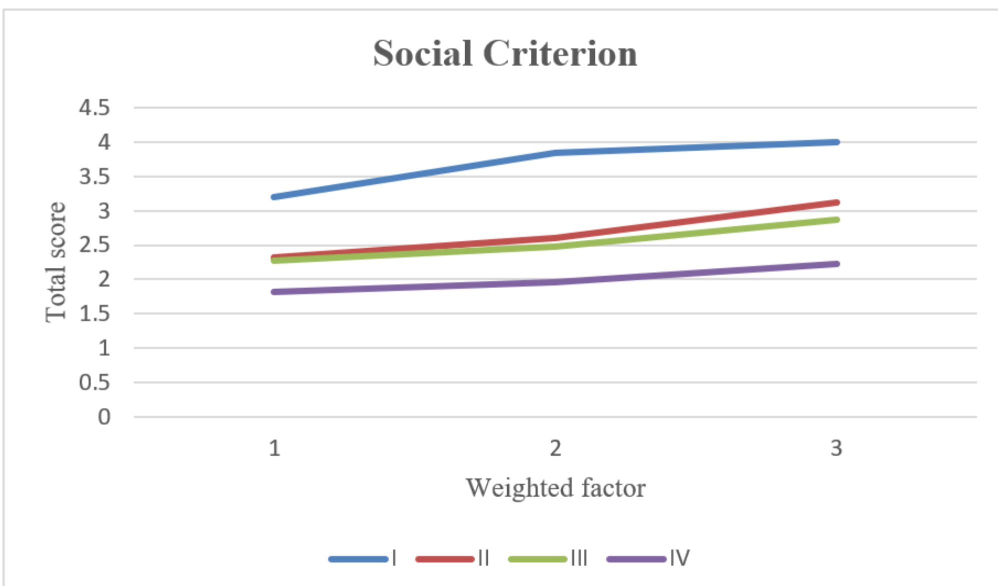

Figure 9: Effect of changing social criterion on the choice of best alternative

Figures (6-9) illustrate the effect of changing the criteria on the choice of the best alternative in which each time one criterion's weight changed to a lower and higher values (compared to the original assigned value) while the rest of criteria weight remains constant. This procedure was applied to the technical, economic, environmental and social criteria (Chowdhury and Rahman, 2008). It is clear that when changing the criteria weights to various values, it doesn't affect the choice of the best alternative and hence the decision made is strong and not sensitive to any of the mentioned criteria.

5. Conclusions

Sediment generated due to soil disturbance activities is very high in Malaysia due to the high rainfall intensities and widely varied topography which is accompanied with catastrophic impact to the ambient environment. The MCA results showed that among four main sediment management techniques (i.e. sediment basins, silt fence, sand bag barrier and rock filter), the sediment basin was highlighted as the best sediment management technique for the selected zone. To overcome the uncertainty in the decision made, the sensitivity analysis was performed by changing the weight of each criterion to different values and showed very strong decision made in which the decision is not sensitive to any of the criteria. The developed model is helpful for the engineers and decision makers to find the best sediment control measures in a targeted region subjected to soil disturbance activities.

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