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Development of MCESC software for selecting the best stormwater erosion and sediment control measure in Malaysian construction sites

Ibrahiem Abdul Razak Al-Hadu[1], Lariyah Mohd Sidek[1], Mohamed Nor Mohamed Desa[2], Noor Ezlin Ahmad Basri[2]

[1] Civil Engineering, Universiti Tenaga Nasional, Kajang, Selangor, Malaysia.
[2] Civil & Structural Engineering, Universiti Kebangsaan Malaysia, Bangi, Selangor, Malaysia.

Abstract
Malaysia located in a tropical region which is interested with a heavy rainfall through the whole seasons of the year. Construction stages usually associated with soil disturbing due to land clearing and grading activities, this combined with the tropical climate in Malaysia, will generate an enormous amount of soil to be eroded and then deposited into the adjacent water bodies. There are many kinds of mitigation measures used so as to reduce the impact of erosion and sedimentation that are generated due to the stormwater in construction sites. This paper aims to develop and apply Multi Criteria Analysis (MCA) software called Multi Criteria Erosion and Sediment Control (MCESC) software in which it can be applied in selecting the best stormwater control measure by depending on specified criteria and criterion weight. Visual Basic 6 was adopted as a development tool. This software can help the engineers, contractors on site and decision makers to find the best stormwater control measure in any construction site in Malaysia. Users of the MCESC software are given the opportunity to select the best stormwater control measure via expert's judgments that are built in the system or via their own expertise. MCESC software has many benefits since the experts are not always available and the consultancy is a costly issue which add further financial allocations to the project.

Keywords: Erosion control; Stormwater; Visual basic; Multi criteria analysis; Water pollution; Construction sites.

1. Introduction
The role of public participation in water resources and environmental management is now appreciated and acknowledged. However, public participation during planning and decision making process is not properly pursue. That's why, stakeholders' opinions may not have any impact on either the process or its outcome and thus dissatisfaction may arise [1]. In order to avoid such dissatisfactions and un sustainability of the project, stakeholder's participation must be ensured from the very beginning of the project. Nowadays, environmental awareness is increased and the number of stakeholders is more than of a few preceding decades [2]. Thus, the requirements of a holistic and analytic tool for combining ecological, social and economical aspects of a project is high [1]. Multi Criteria Analysis (MCA) also known as multi attribute decision analysis is both an approach and a set of techniques, aiming at providing an overall ordering of alternatives from the most preferred option to the least preferred one [3].

It is used to appraise a discrete number of alternatives (options) against a set of multiple criteria and conflicting objectives. MCA can be used in decision making scenarios, when a solution must be selected from a set of alternatives [4]. A key feature of MCA is its emphases on the judgements of the decision making team, in establishing objectives and criteria, and the relative importance weight, and to some extent, in judging the contribution of each option to each performance criteria. Water resources management is typically directed by multiple objectives, which measured in a range of financial and non financial approached units [5] (Gough and Ward, 1996). Often the outcomes are highly variables. That's why; these characteristics of water planning decisions make the multi criteria analysis as good-looking approach. Multi Criteria Analysis (MCA) is an effective tool for water management by adding structure, audibility, transparency, and rigour to decisions [6, 7].

The vast majority of environmental management decisions are guided by multiple stakeholder interests. The MCA is emerging as a popular approach for supporting multi stakeholder environmental decisions [8]. Nowadays MCA, have been widely used in many water resources and environmental management fields. This method facilitates learning process between analyst and stakeholders. MCA has been applied in many water resources and environment fields. Urban drainage systems represent a particular issue for developers, regulatory agencies given the increasing pressure to achieve sustainable drainage solutions. Best Management Practices (BMPs) can offer flow control and pollutant removal. The decision making process for the identification of the Best Management Practices (BMPs) systems involves various stakeholders within public and private sectors. Ref. [9] describes a web-based Multi Criteria Analysis approach that have been developed within the EU 5th Framework DayWater project so as to support the decision making and solve the conflict between the stakeholder and facilitate negotiation between them. The main objective of the MCA within the DayWater project is to assist decision makers to identify preferred options through the ranking of BMP alternatives including both structural and non structural controls.

Water resources decision making situations are usually charecterised by a wide number of alternatives, participation of multiple stakeholders with conflicting interest, complex interactions, and uncertain consequences [10]. In the past, the cost benefit analysis (BCA) was used as solutions to water resources decision making problems. Whilst the Multi Criteria Analysis (MCA) is an alternative approach and/or method which can be used for decision making and chose one alternative among few or many alternatives because the MCA allows the consideration of multiple criteria in incommensurable units (qualitative and quantitative criteria), facilitates stakeholder participation, and does not need the assignment of monetary values to social and environmental criteria.

Recent research that has applied the MCA in the water resources field includes river basin management [11]; reservoir operations [12]; planning or irrigation [13]; and water quality and ecosystem impacts [14]. In this study, MCESC software has been developed and applied for identifying the best stormwater control measure in Malaysian construction sites using Visual Basic 6 as a development tool. Multi criteria analysis process based on Ref. [15] was adopted in this study.

2. Criteria relevant for the assessment of erosion and sediment control measures

Best management practices (BMPs) for controlling construction site stormwater due to erosion and sedimentation can offer secondary benefits for water quality and amenity/ecology improvements in addition to flow control and pollution removal. The application of BMPs facilities involves a variety of stakeholders in both the public and private arenas and therefore their development and design can be subject to differing degrees of uncertainty with regard to the relevance of influencing political, technical and environmental factors. In addition to being effective in terms of long term efficiency, they also need to be cost-effective when compared with conventional systems. Sustainability criteria therefore are required to be referenced against the critical design parameters which relate primarily to water attenuation, water quality improvements and enhancement of amenity/ecological provision. Thus, design and construction, environmental/ecological impact, operation and maintenance, health and safety, social/urban community as well as economic issues become prime potential sustainability criteria to facilitate comparisons and accreditation of drainage options with regard to capital cost, resource use, acceptability, performance etc. Given such dependencies and variabilities, it is relevant to consider how multi-criteria analysis can be utilized to assess the relative importance of the factors which specifically influence the use of BMPs in erosion and sediment control. The criteria that have been adopted in this study were illustrated in Figure 1 below.

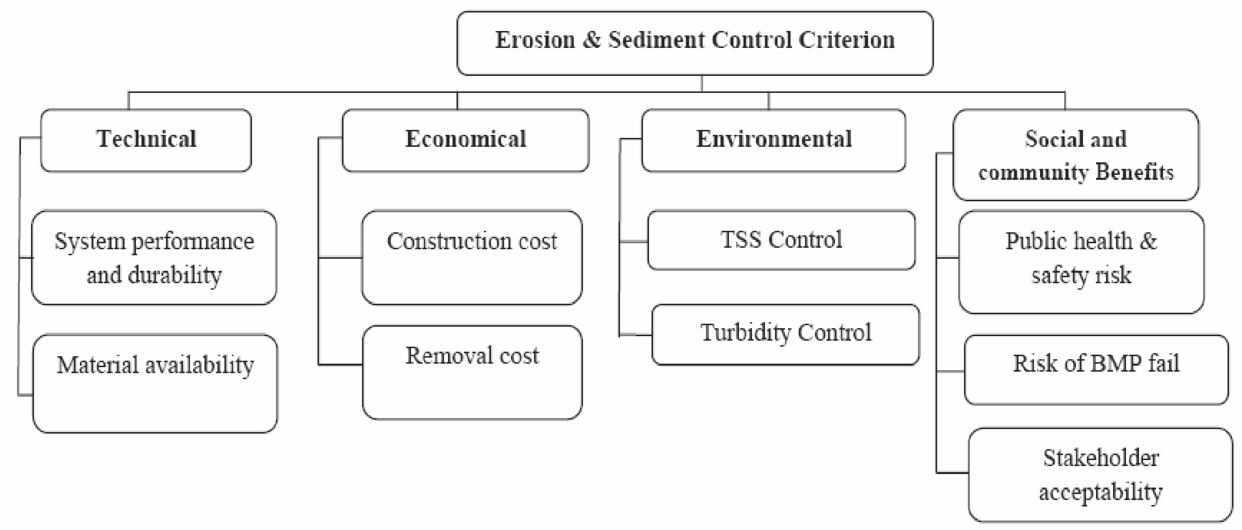

Figure 1. Erosion and sediment control criteria

3. Materials and methods

There are many alternatives/control measures for controlling the erosion and sedimentation due to stormwater from construction sites in Malaysia. These alternatives were selected based on guidelines, manuals and the most important is the human expert's opinions on which measures should be used to minimise stormwater pollution due to erosion and sedimentation generated from Malaysian construction sites. Small groups of stakeholders (11 people) were selected and interviewed for ranking all criteria. The interviews were 2 hours long in average. The interviews were made as interactive as possible. Average stakeholders' ratings were then crossed checked with expert's opinions. Based on these interviews and consultations, technical and environmental criteria were assigned with a weighed factor of 1 and the economic and social criteria were assigned with a weighed factor of 1.5 for analysis. The experts were people from Department of Irrigation and Drainage (DID), Department of Environment (DOE), university academics, and private consultants and engineers. There were two scenarios for assigning ordinal scores. When the ordinal scales of "high" and "very low" indicates the best and worst performance respectively, the score range was selected from 5 (very high) to 1 (very low). The criterion fall under this category were (1) system performance and durability, (2) material availability, (3) TSS control, (4) Turbidity control, (5) public health and safety risk, (6) stakeholder acceptability. Besides, when the ordinal scales of "high" and "very low" indicates the worst and the best performance, respectively. The selected score range was 1 (high) to 5 (very low). Criterion fall under this category were (1) construction cost, (2) removal cost, and (3) risk of BMP failure.

The expert's criteria, criteria's weights and the ranking of various control measures against the criteria were built in the MCESC software. Besides, the MCESC software gives the opportunity to the user to choose the criteria and alternative that he/she would like to find the best one of them.

There are many kinds of MCA techniques have been developed. These methods are different from each other by their methodology, type of data required as an input, easiness to understand and use, and so forth. The most essential factors for choosing the MCA technique is the easiness of understanding by the analyst, the stakeholders and use. Ref [16] stated that "from the decision maker point of view, ease of use/simplicity (time and effort required of the decision maker to reach a conclusion) and the understanding ability of the method are considered important" in decision making. In addition he added, "The quantity and quality of information (input data) needed and difficulty in obtaining them, ability to handle uncrtaines and availability of user friendly software were also concerns".

Ref [17] have recognised that the selection of a specific MCA technique is depend on the characteristics of the system being considered, on availability of data, and on objectives and constraints specified. The MCA method that has been adopted in this research is the weighted summation method. The weighted summation method has been used since sixteen of the previous century [18, 19] and has been applied widely in water resources and environmental management fields [3, 4]. In the weighted sum method, the results are mainly dependant on weight.

Ref. [20] recognised that the weighted sum method is one of the most known and widely used MCA techniques principally because of its simple and transparent computational procedure which is means low effort and time required to perform the analysis and because of the wide application of this MCA approach in the water resources and environmental fields [3, 4, 21]. The core of the weighted summation technique is the performance matrix in which it consists of a set of evaluative criteria, set of weights indicating the importance of those criteria, a set of alternatives, and a set of performance measures indicating the performance of each alternative against each criterion. The performance matrix is an *m* x *n* matrix with *m* criteria ($c_{j=1,}$ $c_{j=2}$, $c_{j=3}$,…..,$c_{j=m}$) and *n* alternatives ($a_{j=1,}$ $a_{i=2}$, $a_{i=3}$,…..,$a_{i=n}$). There is a corresponding weights vector *W* ($w_{j=1,}$ $w_{j=2}$, $w_{j=3}$,…..,$w_{j=m}$) of *m* weights which indicate the relative importance of each criterion. Typically, it holds that $\sum w_j = 1$ and $1 \geq w_j \geq 0$, for all j. That is, the weights sum to one and are non-negative. The weights can be expressed quantitatively or qualitatively depending on the particular MCA method that will be applied. Figure 2 shows the format of the performance matrix. The x_{ij} values are performance measures that represent the performance the ith alternative against jth criterion. These can be expressed in different units although may need to be standardized to common units depending on the particular MCA method applied. Variations of the performance matrix represent alternatives as the columns, and criteria and weights as the rows. Different decision making rules/methods can be applied to the data in the performance matrix in order to rank the desirability or suitability of the alternatives. The performance matrix represents the domain of factors, which the MCA model incorporates into its generation of solutions.

Criteria - j		c_1	c_2	c_3	………………	c_m
Weights - j		w_1	w_2	w_3	………………	w_m
(Alternatives – i)	a_1	$x_{1,1}$	$x_{2,1}$	$x_{3,1}$	………………	$x_{m,1}$
	a_2	$x_{1,2}$	$x_{2,2}$	$x_{3,2}$	………………	$x_{m,2}$
	a_3	$x_{1,3}$	$x_{2,3}$	$x_{3,3}$	………………	$x_{m,3}$
		.	.	.		.
		.	.	.		.
	a_n	$x_{1,n}$	$x_{2,n}$	$x_{3,n}$	………………	$x_{m,n}$

Figure 2. An effects table used in multiple criteria analysis

4. Multi criteria analysis engine

Figure 3 below shows the Multi Criteria Analysis Engine that can be used in identifying the best control measure among a list of control measures. The first stage of any multi criteria analysis approach includes the translation of the decision analysis situation into a set of alternatives and criteria. In the current multi criteria analysis engine, two scenarios were adopted in which the MCESC system gives the opportunity to the user whether to depend on the expert's judgments (i.e. the judgments which are captured from experts in erosion and sediment control in the construction sites) or depend on the user's experience. In the first scenario, the user can identify the best alternative among a set of alternatives by relying on criteria, criteria weighting, and the ranking of the alternatives that the experts were identified. If the user selects the first scenario, then he/she needs to identify the criteria that he/she want to use it for identifying the best alternative from a list of criteria built in the system. While in the second scenario, the user can depend on his own experience in making the decision of selecting the best alternative. If the user selects the second scenario, then he/she needs to enter the number of experts (up to 30 experts), number of alternatives and criteria which define the decision making problem being undertaken as shown in Figure 3. The program is restricted to assess decision problems with a maximum number of 30 alternatives and 30 criteria. The current multi criteria analysis engine adopted the weighted summation technique for both scenarios. The following sections provide a full description for the second scenario.

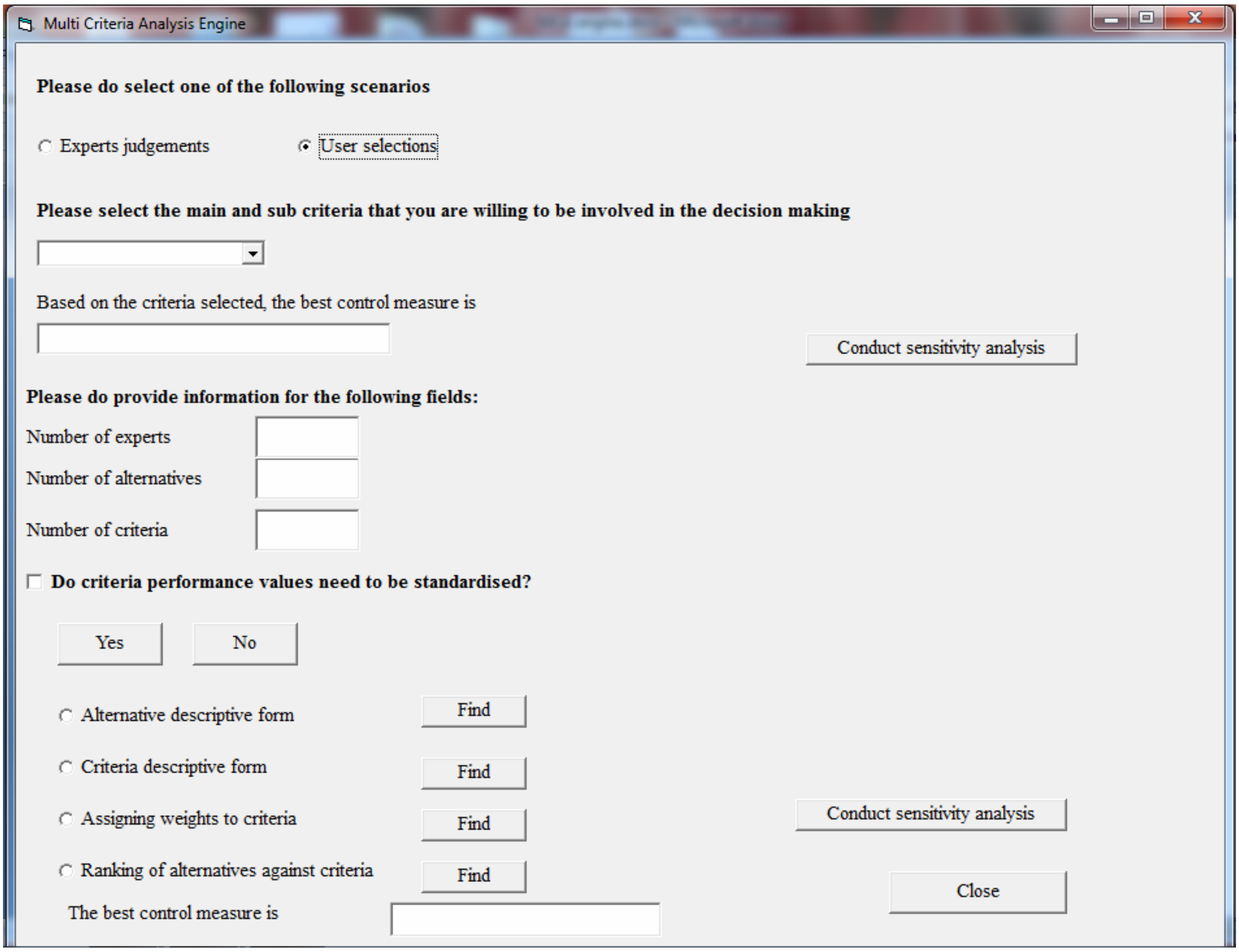

Figure 3. Multi criteria analysis engine

4.1 Alternative and input parameter description

A description of each of the alternatives and the criteria can be entered in respective forms. The preference direction whether it is Minimise or Maximise must also be selected by the user on the Criteria Description form as shown in Figure 4 below.

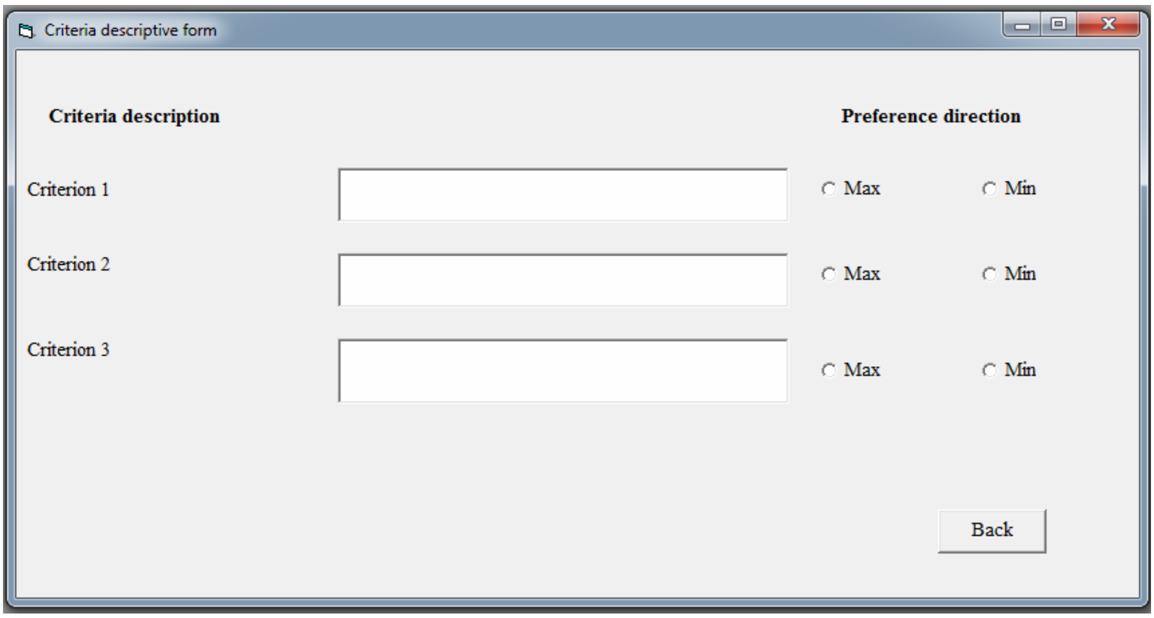

Figure 4. Criteria description form

4.2 Input parameter values

The next step in the decision analysis process is to assess the alternatives by the criteria that have previously been defined. The type of value assigned for each alternative against criteria may be quantitative or qualitative. The criteria's weight can be elicited from a scale of 0-100. Figure 5 shows the alternatives ranking against criteria. It should be noted that the performance values which are resulted from ranking of alternatives against the criteria are required to be standardised to commensurable units if the criteria were evaluated in incommensurable units. The standardisation method that has been adopted in MCESC system was recommended by Ref. [15] in which the criterion scores should be adjusted based on their distance to a maximum and/or minimum value. For example, the top performing alternative for a given criterion is given a score of 1 and the worst performing alternative is given a score of 0. All intermediate alternatives are given adjusted scores between 1 and 0. The following approach to standardization has been used in this study:

$$s_{ij} = \frac{x_{ij} - x_{j\,\min}}{x_{j\,\max} - x_{j\,\min}} \tag{1}$$

where a higher criterion score indicates better performance.

$$s_{ij} = \frac{x_{j\,\max} - x_{ij}}{x_{j\,\max} - x_{j\,\min}} \tag{2}$$

where a lower criterion score indicates better performance.
where:
s_{ij} = the standardized performance measure for x_{ij}
x_{ij} = the performance of the i^{th} alternative against the j^{th} criterion in real units of any type.
x_j max = the maximum performance score under the j^{th} criterion.
x_i min = the minimum performance score under the j^{th} criterion.

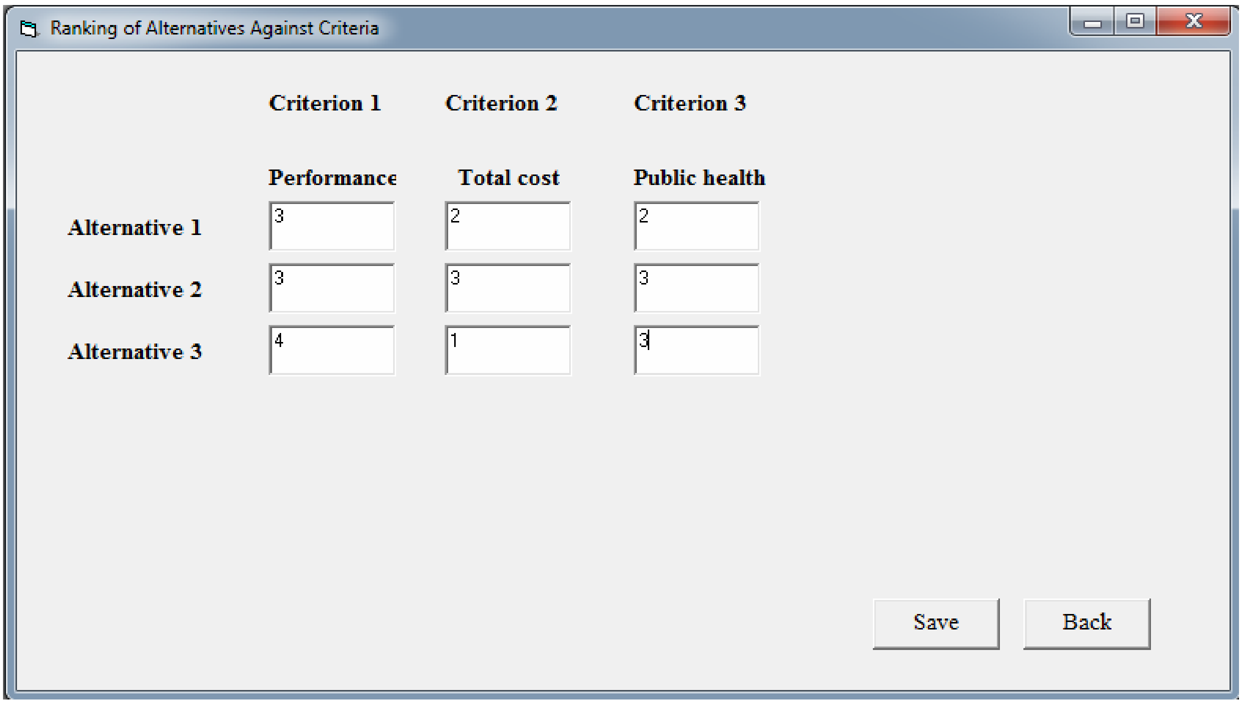

Figure 5. Ranking of alternatives against criteria

As mentioned earlier, a great many techniques available for ranking the alternatives against the criteria, the one which is adopted for the current study is the weighted summation technique. In the weighted summation technique, the performance measures that have been obtained from the ranking of all alternatives against the criteria are multiplied by the weights and then summed for each alternative so as to obtain a performance score. This is the approach taken here. The overall performance score can be calculated by equation 3 as below.

$$v_i = \sum_{j=1}^{m} s_{ij} . w_j \tag{3}$$

where,
v_i = the value (or utility) of the i^{th} alternative relative to the other alternatives.
s_{ij} = the standardized value of x_{ij} (the performance measure for the i^{th} alternative against the j^{th} criterion)
w_j = the weight of the j^{th} criterion.

According to Ref. [15], the alternative with higher performance score is considered the best alternative. The best alternative will be presented to the user as shown in Figure 6.

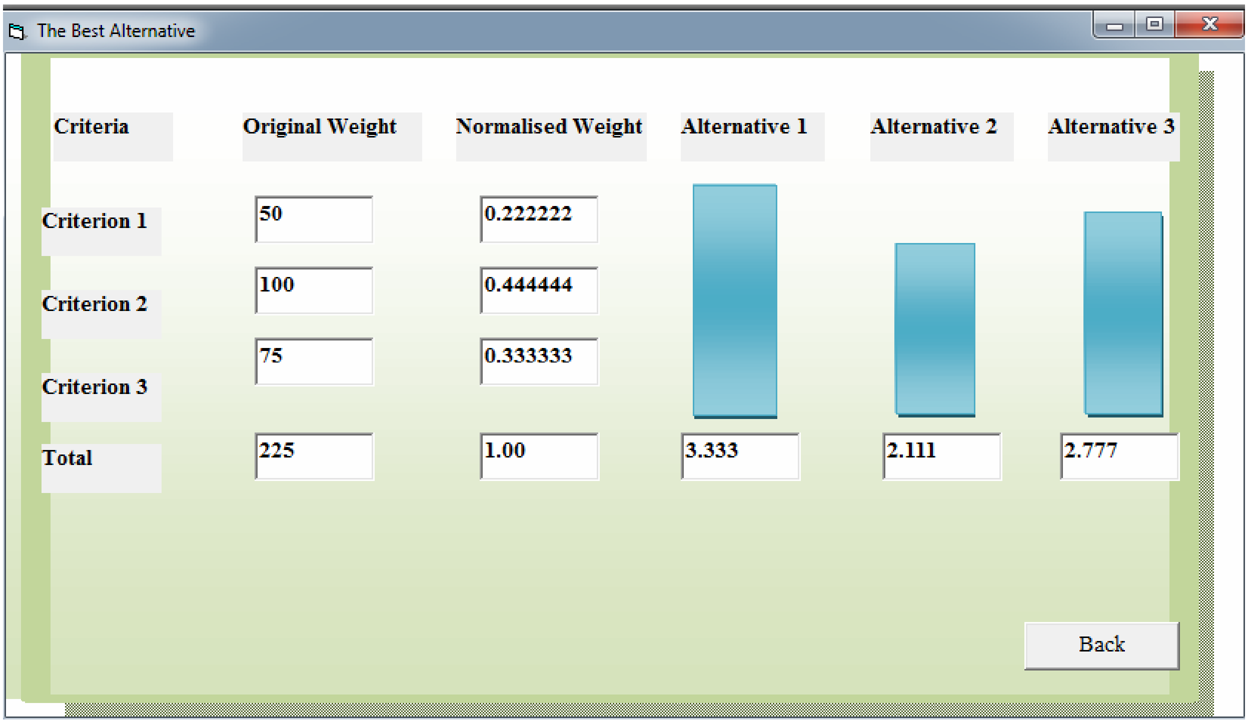

Figure 6. MCESC software results

5. Conclusion

Construction activities usually generate massive amount of erosion that will be responsible for degrading the quality of the adjacent water bodies, affecting the habitats of ecosystem, destroy fish spawning areas, increase the sediments at the bed of the river, and reduce the opportunities for the ships to pass satisfactorily. This necessitates building a decision support tool so as to be used by the construction engineers and contractors. This decision support tool can help the engineers and contractors in the construction field on which control measure is the best to be used for controlling erosion and sedimentation and for each construction stage/activity. The decision support tool that have been widely applied and now adopted in the current study is the weighted summation multi criteria analysis technique. In this study, the MCESC software has been developed for identifying the best erosion and sediment control measures.

The MCESC software has many benefits in which it can save time and money since the consultant is not always available, and in case if the consultant available, it might takes some time for him/her to identify the most feasible erosion and sediment control measure. Furthermore, the consultation is a costly issue that will shall add further financial allocations to the project.

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Ibrahiem Abdul Razak Al-Hadu PhD candidate in Civil Engineering, Universiti Tenaga Nasional, Kajang, Selangor, Malaysia. His educational background in civil engineering/ water resources and environmental management. Mr. Ibrahiem's major field of study in hydrology/ urban stormwater quality management. Mr. Ibrahiem has earned his Master in civil engineering from University Kebangsaan Malaysia.
E-mail address: ibrahiem.moadmawi.ak@gmail.com

Lariyah Mohd Sidek Associate Professor in Civil Engineering, Universiti Tenaga Nasional, Kajang, Selangor, Malaysia. Her educational background in civil engineering/ water resources. Dr. Lariyah's major field in hydrology/ urban drainage. Dr. Lariyah has earned her PhD in civil engineering from Kyoto University, Japan.
E-mail address: lariyah@uniten.edu.my

Mohamad Nor Mohamad Desa Professor in Civil Engineering, Universiti Tenaga Nasional, kajang, Selangor, Malaysia. His educational background in civil engineering/ water resources. Prof. Mohamed Nor's major field in hydrology/ urban drainage. Professor Mohamad Nor has earned his PhD in civil engineering from Lund University, Sweden.
E-mail address: MohamedNor@uniten.edu.my

Noor Ezlin Ahmad Basri Associate Professor in Civil and Structural Engineering, University Kebangsaan Malaysia, Bangi, Selangor, Malaysia. Her educational background in civil engineering/ Water Resources. Dr. Noor Ezlin's major field in solid waste management. Dr. Noor Ezlin has earned her PhD in civil engineering from University of Leeds, UK.
E-mail address: ezlin@vlsi.eng.ukm.my