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Multi criteria analysis in environmental management: Selecting the best stormwater erosion and sediment control measure in Malaysian construction sites

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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 in 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 presents the application of Multi Criteria Analysis (MCA) tool in choosing the best stormwater control measure by depending on specified criteria and criterion weight. The results obtained from the application of MCA in stormwater pollution control have many benefits to the contractors, consultants and decision makers by making them able to select the best control measure for every stage of construction.

Keywords: Weighted sum technique; Multi criteria analysis; Erosion and sedimentation control; Construction sites; Water pollution.

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. Multi criteria analysis 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]. 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, the MCA has been chosen as the primary assessment tool to assess the potential value of a wide range of alternatives e.g. structural Best Management Practices (BMPs) because it allows a wide range of assessment criteria to be considered in qualitative and quantitative form. It also does not require a potential benefit that exists outside of a market to be expressed in monetary forms (unlike cost benefit analysis). 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.

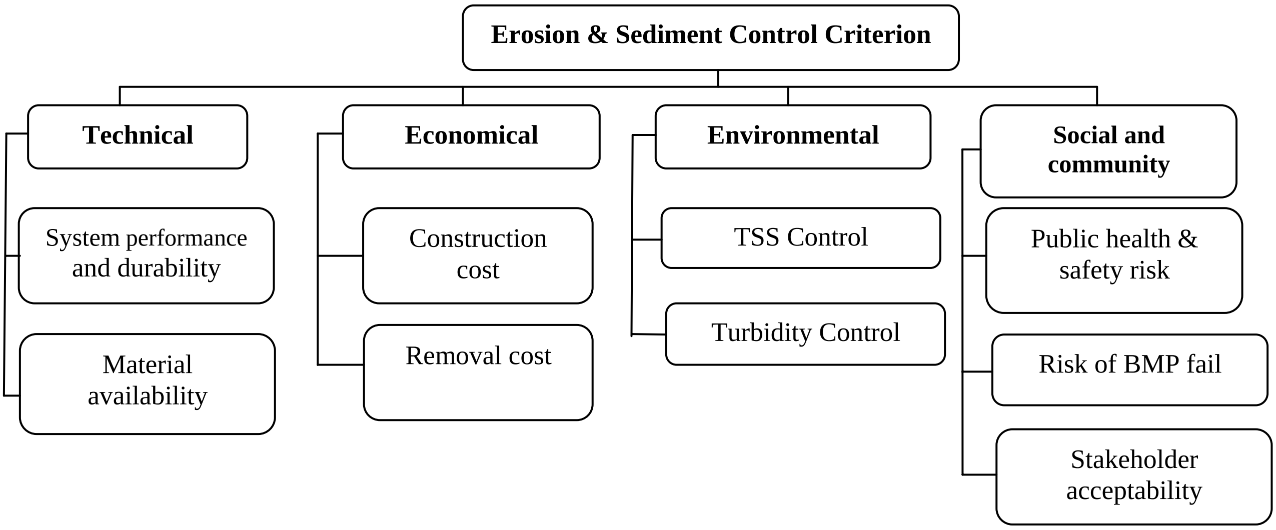

Figure 1. Erosion and sediment control criterion

3. Materials and methods

In this study, there are many alternatives/controlling 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. There are three main construction stages have been adopted in this study, they are: site preparation stage, site clearance, and site construction stage. For each of the three main constructions stages there are number of sub-construction stages. The main construction stages and sub construction stages were illustrated in Table 1. The role of multi criteria analysis is to select the best advice/alternative among other alternatives within each sub-construction stage by depending on the criterion shown in Figure 1 above.

Table 1. Main and sub construction activities adopted

Main construction Stages	Sub-Construction Stages
Site Construction Facilities	Access road and stream crossing
	Stabilising the site
	Removing of vegetation
Site Formation	Earth work
	Stabilising the disturbed site

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 indicated 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 i^{th} alternative against j^{th} 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.

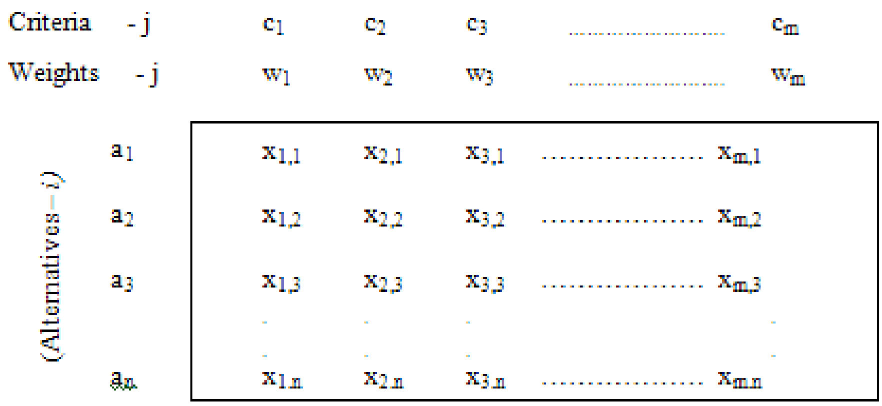

Figure 2. An effects table used in multiple criteria analysis

A key benefit of MCA is that it can handle performance measures in different units such as dollars, metres, and degree Celcius. However, most ranking algorithms require performance measures to be standardized into commensurable units. Several techniques are available for undertaking this standardization. The most commonly adopted standardization methods adjust criterion scores 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:

$$S_{ij}= (X_{ij}–X_j \min)/(X_j \max–X_j \min) \quad (1)$$

(where a higher criterion score indicates better performance)

S_{ij}= (X_j max– X_{ij})/($X_j$max– $X_j$min) (2)
(where a lower criterion 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.

There are a great many techniques available for obtaining the ranking of alternatives once the weights and performance measures have been entered into the performance matrix. The techniques primarily differ in how they handle qualitative and quantitative data, and decision maker preferences. One of the most widely applied and most easily understood techniques is the weighted summation. Using weighted summation, the performance measures are multiplied by the weights, and then summed for each option to obtain performance score. This is the approach taken here. The overall performance score can be calculated by:

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

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.

There are many alternative techniques for assigning weights to criteria and objectives. The most commonly applied MCA weighting procedures such as fixed point scoring, rating ordinal ranking, paired comparisons and judgement analysis. In ideal situations, it is desirable to apply some or all of these methods. However, practical constraints will limit the number that can be used in many situations. In the MCA model developed for this paper, percentage weights are proposed as the weighting criteria.

4. Results and discussion

All the criteria shown in Figure 1 above have no units at all, so no need to perform the standardisation that has been illustrated into equations 2 and 3. Equations 2 and 3 can be applied when the criteria have different units.
Scores of alternatives under each main and sub-construction stage with respect to all criteria were presented in Tables 2 to 9.

Table 2. Scores of alternatives with respect to criteria for the diversion of surface runoff surrounding the site

Main construction stage	Site Preparation Stage					
Sub-construction stage	Stabilising the Site-Diversion of Surface Runoff Surrounding the Site					
Criteria	Sub-Criteria	Alternatives				
		Weight	I	II	III	IV
Technical	Performance & durability	1	3	3	2	3
	Material availability	1	2	3	4	2
Economical	Construction cost	1.5	4	3	2	3
	Removal cost	1.5	3	3	1	3
Environmental	TSS control	1	2	2	3	2
	Turbidity control	1	2	3	3	1
Social	Risk of BMP failure	1.5	2	2	4	2
	Public health and safety risk	1.5	4	1	3	4
	Stakeholder acceptability	1.5	3	4	4	2

I = Earth bank, II = Sand bag barrier, III = Rock filter, and IV = Diversion channel

Based on equation 3 above, the recommended best control measure for diversion of surface runoff surrounding the construction site is earth bank

Table 3. Scores of alternatives with respect to criteria for the diversion of surface runoff within the construction site

Main construction stage	Site Preparation Stage				
Sub-construction stage	Stabilising the Site- diversion of surface runoff within the construction site				
Criteria	Sub-Criteria	Alternatives			
		Weight	I	II	III
Technical	Performance & durability	1	3	3	3
	Material availability	1	2	2	3
Economical	Construction cost	1.5	4	3	3
	Removal cost	1.5	3	3	3
Environmental	TSS control	1	2	2	2
	Turbidity control	1	2	1	3
Social	Risk of BMP failure	1.5	2	2	2
	Public health and safety risk	1.5	4	4	1
	Stakeholder acceptability	1.5	3	2	4

I = Earth bank, II = Diversion channel, III = Sand bag barrier

Based on equation 3 above, the recommended best control measure for diversion of surface runoff within the construction site is earth bank

Table 4. Scores of alternatives with respect to criteria for the controlling of the perimeter of the site

Main construction stage	Site Preparation Stage					
Sub-construction stage	Stabilising the Site-Controlling of site perimeter					
Criteria	Sub-Criteria	Alternatives				
		Weight	I	II	III	IV
Technical	Performance & durability	1	2	3	2	3
	Material availability	1	2	3	4	3
Economical	Construction cost	1.5	2	3	2	3
	Removal cost	1.5	3	3	1	4
Environmental	TSS control	1	3	2	3	2
	Turbidity control	1	2	3	3	2
Social	Risk of BMP failure	1.5	3	2	4	4
	Public health and safety risk	1.5	2	1	3	2
	Stakeholder acceptability	1.5	2	4	4	3

I = Silt fence, II = Sand bag barrier, III = Rock filter, IV = Sediment trap

Based on equation 3 above, the recommended best control measure for controlling the perimeter of the site is sediment trap

Table 5. Scores of alternatives with respect to criteria for the access road and stream crossing

Main construction stage	Site Preparation Stage							
Sub-construction stage	Access road and stream crossing							
Criteria	Sub-Criteria	Alternatives						
		Weight	I	II	III	IV	V	VI
Technical	Performance & durability	1	4	1	4	3	3	3
	Material availability	1	4	5	4	2	3	3
Economical	Construction cost	1.5	3	1	3	3	3	4
	Removal cost	1.5	2	1	1	3	3	3
Environmental	TSS control	1	3	2	3	2	2	3
	Turbidity control	1	2	2	2	1	3	3
Social	Risk of BMP failure	1.5	4	1	1	2	2	2
	Public health and safety risk	1.5	4	1	2	4	1	2
	Stakeholder acceptability	1.5	4	3	4	2	4	5

I = Construction access stabilisation & tire wash, II = Street sweeping, III = Access road stabilisation, IV = Earth bank, V = Sand bag barrier, VI = Drainage swale

Based on equation 3 above, the recommended best control measure for the access road and stream crossing is construction access stabilisation and tire wash

Table 6. Scores of alternatives with respect to criteria for the removing of vegetation

Main construction stage	Site Clearance						
Sub-construction stage	Removing of vegetation						
Criteria	Sub-Criteria	Alternatives					
		Weight	I	II	III	IV	V
Technical	Performance & durability	1	5	4	4	5	3
	Material availability	1	4	3	3	1	3
Economical	Construction cost	1.5	2	2	2	2	3
	Removal cost	1.5	1	1	3	1	1
Environmental	TSS control	1	4	4	4	4	3
	Turbidity control	1	3	3	2	3	4
Social	Risk of BMP failure	1.5	2	2	3	3	3
	Public health and safety risk	1.5	1	2	3	2	2
	Stakeholder acceptability	1.5	5	4	5	4	2

I = Mulching, II = Soil binder, III = Seeding and planting, IV = Geotextiles and mats, V = Terracing

Based on equation 3 above, the recommended best control measure for controlling erosion due to land clearing and when the area is not active for more than two weeks is seeding and planting

Table 7. Scores of alternatives with respect to criteria for the earthwork

Main construction stage	Site Formation						
Sub-construction stage	Earthwork						
Criteria	Sub-Criteria	Alternatives					
		Weight	I	II	III	IV	V
Technical	Performance & durability	1	5	4	4	5	3
	Material availability	1	4	3	3	1	3
Economical	Construction cost	1.5	2	2	2	2	3
	Removal cost	1.5	1	1	3	1	1
Environmental	TSS control	1	4	4	4	4	3
	Turbidity control	1	3	3	2	3	4
Social	Risk of BMP failure	1.5	2	2	3	3	3
	Public health and safety risk	1.5	1	2	3	2	2
	Stakeholder acceptability	1.5	5	4	5	4	2

I = Mulching, II = Soil binder, III = Seeding and planting, IV = Geotextiles and mats, V = Terracing

Based on equation 3 above, the recommended best control measure for controlling erosion due to earthwork activities and when the area is not active for more than two weeks is seeding and planting

Table 8. Scores of alternatives with respect to criteria for the drainage of top of slope runoff

Main construction stage	Site Formation					
Sub-construction stage	Stabilising the disturbed site-Drainage of top of slope runoff					
Criteria	Sub-Criteria	Alternatives				
		Weight	I	II	III	IV
Technical	Performance & durability	1	4	3	3	3
	Material availability	1	5	2	2	3
Economical	Construction cost	1.5	4	4	3	3
	Removal cost	1.5	3	3	3	3
Environmental	TSS control	1	3	2	2	2
	Turbidity control	1	3	2	1	3
Social	Risk of BMP failure	1.5	4	2	2	2
	Public health and safety risk	1.5	4	4	4	1
	Stakeholder acceptability	1.5	5	3	2	4

I = Slope drain, II = Earth bank, III = Diversion channel, IV = Sand bag barrier

Based on equation 3 above, the recommended best control measure for controlling erosion due to top of slope runoff is slope drain

Table 9. Scores of alternatives with respect to criteria for the borrow or stockpile protection

Main construction stage	Site Formation				
Sub-construction stage	Stabilising the disturbed site- Borrow or stockpile protection				
Criteria	Sub-Criteria	Alternatives			
		Weight	I	II	III
Technical	Performance & durability	1	2	3	2
	Material availability	1	2	3	4
Economical	Construction cost	1.5	2	3	2
	Removal cost	1.5	3	3	1
Environmental	TSS control	1	3	2	3
	Turbidity control	1	2	3	3
Social	Risk of BMP failure	1.5	3	2	4
	Public health and safety risk	1.5	2	1	3
	Stakeholder acceptability	1.5	2	4	4

I = Silt fence, II = Sand bag barrier, III = Rock filter

Based on equation 3 above, the recommended best control measure for the borrow or stockpile protection is rock filter

5. Conclusion

Construction activities usually generate massive amount of erosion and consequently sedimentations 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. The MCA tool depends on criteria and criteria's weights. The criteria and criteria weights have been identified based on specialised experts in the field on controlling erosion and sedimentation.

The MCA tool that has been applied herein this study 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 add further financial allocations to the project.

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