Development of Decision Support Tools for Urban Storm Drainage

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ABSTRACT
This paper aims to develop decision-support tools and protocols for use by the Malaysian water industry to assess the relative sustainability of stormwater systems and projects. One of the most essential parts of urban stormwater management (USWM) is the pollution control due to construction, that's why, the decision-making in any USWM project is especially complex since it involves a large number of stakeholders and large variety of domains of knowledge, i.e. both technical and managerial (planning, assessing, decision-making, etc.). The outputs from this research are represented in a multi-criteria analysis framework so as to aid the decision-makers and stakeholders in the water industry. The development of appropriate and effective tools for decision-making requires an understanding of the environmental and social contexts within which these decisions are made. Socio-political influences and existing organisational structures and formalised frameworks, which define both the stakeholders and how they interact, impose specific processes towards achieving a desired outcome. These requirements for achieving change towards greater sustainability within the water industry necessitate an action research approach to the development of incisive tools and criteria for sustainability which will be useful in formulating the masterplan for drainage.

KEYWORDS
Best management practices; multi criteria analysis; Construction sites; erosion and sedimentation; urban drainage; urban stormwater quality management

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 (Marttunen and Suomalainen, 2005). 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 (Senecah, 2004). Thus, the requirements of a holistic and analytic tool for combining ecological, social and economical aspects of a project are high (Marttunen and Suomalainen, 2005). 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 (Chowdhury and Rahman, 2004). 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 (Sidek *et al*., 2008). 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 (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. MCA is an effective tool for water management by adding structure, audibility, transparency, and rigour to decisions (Dunning *et al*., 2000; Joubert *et al*., 2003).

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 (Regan *et al*., 2006). 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 BMPs systems involves various stakeholders within public and private sectors. (Ellis *et al*., 2006) described 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 characterised by a wide number of alternatives, participation of multiple stakeholders with conflicting interest, complex interactions, and uncertain consequences (Hyde *et al*., 2005). In the past, the Cost Benefit Analysis (BCA) was used as solutions to water resources decision making problems. Whilst 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.

In this study, the MCA has been chosen as the primary decision support tool for assessing the potential value of a wide range of stormwater management alternatives e.g. drainage control 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). MCA process based on (Voogd, 1983) was adopted in this study.

Criteria relevant for the assessment of erosion and sediment control measures

Best management practices (BMPs) for controlling stormwater runoff in construction sites 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 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 variability, 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 construction sites. The criteria that have been adopted in this study were illustrated in Figure 1 below.

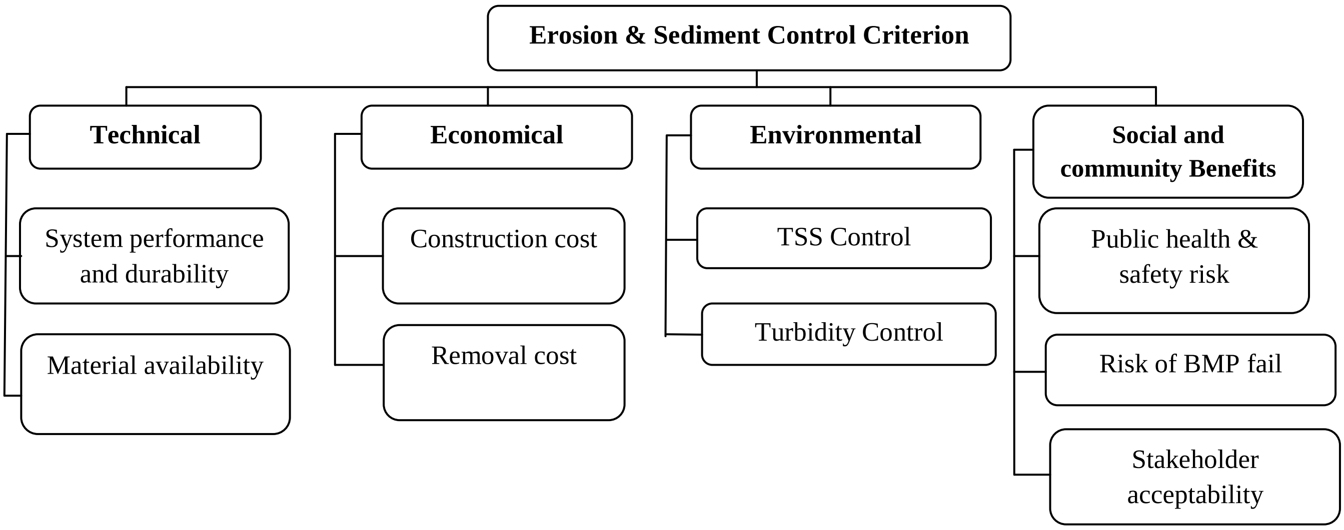

Figure 1. Assessment criteria adopted in this study

METHODS

In this study, there are many alternatives and/or mitigation measures allocated 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 construction in Malaysia. 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), Department of Public Works, University academics, and private consultants and engineers. There were two scenarios for assigning ordinal scores. The first scenario is when the ordinal scales of "very 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 scenario were (1) system performance and durability, (2) material availability, (3) TSS control, (4) Turbidity control, (5) public health and safety risk, (6) stakeholder acceptability. While the second scenario is when the ordinal scales of "very high" and "very low" indicates the worst and the best performance, respectively, the selected score range was 1 (very high) to 5 (very low). Criterion fall under this scenario 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 stormwater control measure among other control measures within each sub-construction stage by depending on the criteria shown in Figure 1 above.

Table 1. Main and sub construction activities adopted

Main construction stages	Sub-construction stages
Site preparation	Stabilising the site
Site clearance	Removing of vegetation
Site formation	Earthwork

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 (Kodikara, 2008; Barros *et al*., 2003).

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 by the Highway research record (1967, 1968) and has been widely applied recently in water resources and environmental management fields (Chowdhury, 2008; Sidek, *et al*., 2008). In the weighted sum method, the results are mainly dependant on weight.

(Kepner and Tregoe, 1965) have 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 water resources and environmental fields (Chowdhury, 2008; Sidek, *et al*., 2008; Hajkowicz and Higgins, 2008). 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 and/or 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 effect table used in multiple criteria analysis

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:

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

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.

RESULTS AND DISCUSSION

Scores of alternatives under each main and sub-construction stages with respect to all criteria were presented in Tables 2, 3, and 4 below. By using equation 1 above, the best control measure can be obtained.

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 1 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 removing of vegetation

Main construction stage	Site Clearance						
Sub-construction stage	Removing of vegetation-control erosion when land left bare more than 2 weeks						
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 1 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 4. Scores of alternatives with respect to criteria for the earthwork

Main construction stage	Site Formation						
Sub-construction stage	Earthwork- control erosion when the land left bare for more than 2 weeks						
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 1 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.

CASE STUDY

A construction site in Malaysia was used as a case study for testing and validating the MCA models developed. The objective of the case study was to evaluate the performance of the MCA models in selecting the best stormwater management control measures. The case study that has been selected is about building up road in Permas Jaya which is located in Johor Bahru State in Malaysia. The development of this project would be the culminations of two stations i.e. road section 1 will develop bridge. This section covered a total length of 6.8 km. While road section 2 will develop bridge over Sg. Lunchoo, Bridge over Sg. Rekoh, Bridge over Sg. Masai and Bridge clover leaf overpass. This section covered a total length of 8.3 KM.

The major activities in this project that are responsible for generating erosion and sedimentation to the adjacent water bodies were the removal of vegetation and site clearing and earthworks. Table 5 below shows MCA recommendation for each main and sub-construction stage.

Table 5. MCA recommendations for each main and sub-construction activity

Construction Stages	Objectives	MCA Recommendations
Site Preparation Stage		
Stabilising the Site	Diversion of Surface Runoff Surrounding the Site	Earth Bank
Site Clearance		
Removing of vegetation	Provide control measures when the land left bare for more than 2 weeks.	Seeding and Planting
Site Formation		
Earthwork	Provide control measures when the land left bare for more than 2 weeks.	Seeding and Planting

The MCA recommendations shown in Table 5 above were cross checked with the recommendations given by the engineer on-site and indicated that both of recommendations are compatible.

CONCLUSIONS

Construction activities usually generate massive amount of erosion and consequently sedimentations that are 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 rivers, and reduce the opportunities for ships navigation. These have necessitates the development of a decision support tool so as to be used for identifying the best urban stormwater control measure in the construction field by depending on criteria and criteria's weight. The criteria and criteria weights have been obtained based on recommendations from specialised experts in urban stormwater management.

The decision support tool that has been developed herein has many benefits in which (i) it can be used by the contractors or engineers for deciding on which stormwater control measure should be adopted for different construction stages, (ii) time saving (since the consultant is not always available) and, (iii) reduce overall project cost since the consultation is a costly issue that shall add further financial allocations to the project.

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