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Development of a Hybrid Expert System-multi Criteria Analysis on Erosion and Sediment Control in Construction Industry

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Abstract

Construction activities combined with heavy rainfall can results in severe soil loss which eventually will be deposited into the adjacent water bodies via stormwater. The Best Management Practices (BMPs) adopted to minimise the erosion and sedimentation during construction activities are usually determined by standard guidelines and expert engineers. However, when the expertise and data are limited, knowledge-based systems have been proved as an effective alternative in making decision. A new algorithm of hybrid knowledge-based expert system and Multi-Criteria Analysis (MCA) was developed to minimise erosion and sedimentation due to stormwater in Malaysian construction sites. In this Eco-Friendly Erosion and Sediment Control (ECO-ESC) system, decision tables were developed based on the knowledge acquired from the domain experts specialised in erosion and sedimentation control and guidelines. The MCA was used to identify the best stormwater control measures based on the specific criteria and criterion's weight. The ECO-ESC was validated in three stages: preliminary by the experts, field and statistical validations. Results of comparison have shown high correlation for recommended BMPs, sediment yield, and the water quality monitoring and proved that the ECO-ESC performs as good as the human expert in solving different problems related to the erosion and sediment control.

Keywords: *erosion and sediment control, construction sites, expert systems, multi-criteria analysis, best management practices*

1. Introduction

Uncontrolled land disturbance and construction activities resulted in an exposure of bare land to rainfall and runoff, which subsequently caused excessive erosion and sedimentation, particularly for a tropical environment. Urban developments are among other land uses that have the greatest impact to the stream sediment, and the main sources of sedimentation to the streams are from the earthworks (Angermeier *et al.*, 2004). Erosive forces of wind and high volume of runoff from heavy rainfall contributes to the entrainment of sediment and transported into the nearest water streams. The bare surface areas, slopes from excavation, embankments are prone to be eroded during the earthwork prior sediment control management of grass vegetation restoration or artificial stabilisation (Faucette, 2004).

Soil losses from erosion may be inconsequential when compared to the damage resulting from sediment transport and deposition into the surface waterways. The sedimentation in general has a significant impact on the macroinvertebrates and other species available in streams (Chen, 2009; Bakr *et al.*, 2012). Aquatic habitats such as fish spawning areas are prone to be destroyed due to the deposition of sediment on the bed or river bottoms. Not only that, high sediment loadings affected macrophytes and maroinvertebrates (Hogg, 1991; Jones, 2012). Anthropogenic activities such as land-use have been found out to cause decrease reproductive success and survival of fishes, decreases the survival of benthic macroinvertebrates due to deposition of silt on the gills, and impacts the feeding performance of fishes (Jones *et al.*, 2001; Sweka and Hartman, 2001).

Things get more critical if the incoming sediment is fine sediment which contributed to high concentration of suspended solids. This suspended sediment inhibits light transmission, which subsequently interrupt the photosynthesis process and may diminish aquatic food supply. The conveyance of fine sediment discharge reduces water quality, may affected reservoir capacities via sediment deposition and acts as transport medium for heavy metals and toxic compounds (Sthiannopkao *et al.*, 2007; Owens and Walling, 2002; and Sciera *et al.*, 2008).

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The rapid development in Malaysia caused an increasing concern due to soil erosion, siltation, deposition and deterioration of water quality in rivers (DOE, 2008). Land clearance in Malaysia due to land development has caused soil erosion and river siltation that lead to severe pollution of water (Muyibi, 2008). The government spent about RM 7 million for cleaning up the rivers every year in 2004 and the amount has been increased to 25 million for years 2011-2014 (DID, 2011). One of the major contributors was identified as lack of Best Management Practices (BMPs) particularly during construction activities (Alsharif, 2010). As such, erosion and sedimentation control plan is made part of the National Policy on Environment and National Physical Plan of Malaysia to ensure an environmentally sound and sustainable development. The plans offer procedures and solutions of onsite and off-site BMPs for both erosion and sediment controls during construction stages.

The available standard and plans act as guideline to assist the engineer to choose the best alternatives of BMPs suitable for their construction sites, where the decision is usually made by experienced engineers. However, these experienced engineers are not widely available and the consultation fee can be quite expensive. Therefore, a system specifically for erosion and sediment controls is necessary to assist the less experienced engineer to effectively choose the best management practices in controlling the on-site sediment management. In this respect, the Expert Systems (ES) proved to be a very useful and very effective tool for making the decision especially when the number of experts available is little (Prasad *et al.*, 2003). ES is one of the branches in applied Artificial Intelligence (AI) and is a powerful method for obtaining solutions when other methods are not available (Liao, 2005). The basic idea behind ES is task-specific knowledge is transferred into a computer or system from human, and when needed, the system is capable to arrive to a decision or conclusion (usually to non-specialist) with similar capability as the human experts. Judgment, experience, rule of thumb, human intuition and reasoning are incorporated to provide knowledgeable advice and capable to function as experts in making higher-level decisions (Basri, 1999; Saunders *et al*., 2005). The usefulness of expert systems in solving difficult practical problems, however, has become recognized and their development is being pursued in many fields. As an example, expert systems have been developed to give recommendations in areas like medical diagnosis (Keleş *et al*., 2011); Osuagwu and Okafor, 2010), emergency management (Liu *et al.*, 2011), urban design (Xirogiannis *et al.*, 2004) and wastewater treatment (Baeza *et al.*, 2000).

The construction activities impose multiple criteria, usually with different units need to be considered and weigh as option, Multi-Criteria Analysis (MCA) is an effective technique to improve the transparency, reviewing process and high accuracy in making decisions (Dunning *et al.*, 2000; Hajkowics, 2007). MCA have been used in various fields of application such as energy planning (Pohekar and Ramachandran, 2004), financial decision making (Steuer and Na, 2003) and water resource management (Hajkowics, 2007; Ryu *et al*., 2009).

Incorporating both ES and MCA, this study attempts to develop a hybrid knowledge-based expert system, specifically for erosion and sediment control plan due to stormwater at construction sites. Taking account the tropical weather, the best alternative of BMPs suitable and appropriate for a specific construction site is feasible. We believe that this hybrid system will provides several advantages such as objective decision is allowed, unbiased judgment, saving time and budget particularly for high priority projects.

2. Methodology

Prior to the development of the ECO Erosion and Sediment Control (ECO-ESC), some initial pre-development of the problem to be solved is normally conducted to determine whether the use of the expert systems for minimising erosion and sedimentation is warranted and viable. The required decision has some characteristics which indicate that the application of the expert system would be suitable for the current problem since the erosion and sedimentation due to stormwater is addressed internationally in particular where the number and availability of experts are limited. Thus, the scope of the problem can be compartmentalised and limited. Besides, the incremental development of the expert system is possible.

The ECO-ESC employed ES methodology using knowledge-based system, which is human centered. The ECO-ESC system was developed sequentially using Microsoft Visual Basic (VB) 6 as interface, starting with the task analysis process, knowledge acquisition, algorithm development (coding), and system's testing as illustrated in Fig. 1. The knowledge base was developed by acquiring knowledge from various sources such as books,

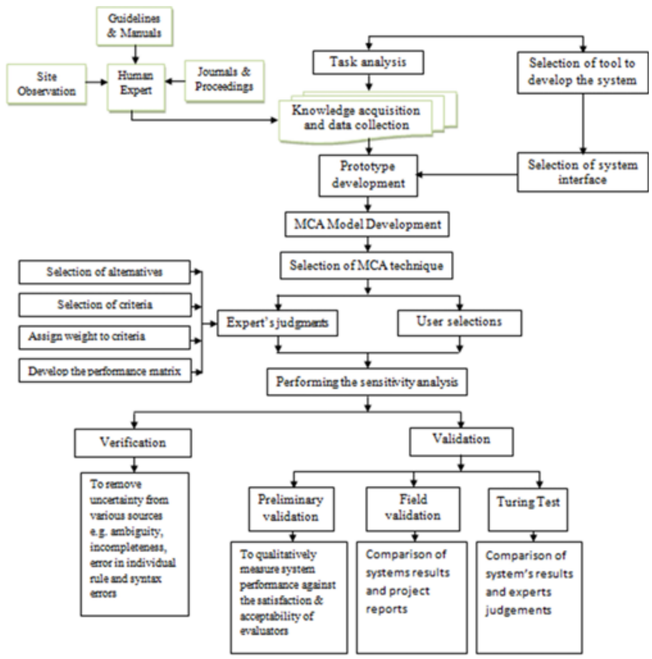

Fig. 1. The Overall Framework Adopted in Developing the ECO-ESC System

guidelines (both local and international), journals, site observation, and the most important was to gather information from a group of experts in the erosion and sediment control in Malaysia. Following the development of the knowledge base, the system's algorithm was developed and eventually the system was verified and validated using three validation techniques which will be explained in more detail in the subsequent sections.

2.1 Knowledge Acquisition and Data Collection

The progress of the ECO-ESC system starts with the development of the knowledge base, where all the necessary information on the erosion and sedimentation control 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. Five series (meetings) of systematic consultation were organised with ten experts who were classified into three groups (i.e. local authority denoted as Group 1, university academics denoted as group 2, and practicing engineers denoted as Group 3). The summary and the chronology of the meetings are depicted in Table 1.

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.

The first consultation is important to build rapport with the experts and the researchers. During the interview, the specific goals and questions for the knowledge acquisition session were prepared. A set of representative problems was formulated and discussed them with the experts. Some other issues that have been discussed include the main and sub-construction activities which are responsible for generating erosion and sedimentation to the adjacent water bodies, construction site characteristics, desired BMPs, prediction of soil loss and sediment yield, and relevant water quality parameters. After the final meeting, the experts identified the appropriate erosion and sedimentation control plan, including its associated relevant BMPs, their respective construction stages that contribute major impact on site erosion, water quality parameters, and the applicable criteria used to rank the different available BMPs for each construction stage.

2.2 Algorithm Development

Once the data has been gathered, a forward chaining expert system was developed. All the facts were first listed then the rules were written to form a small prototype program. Initially, this prototype handled a small domain focused on a small portion of the entire system which involves only one construction activity (that was the site construction facilities). In site construction facilities, the system is able to give recommendations based on the selected site characteristics. This prototype was used to give a clear idea to approach the larger domain. From the small prototype, the program was expanded and improved by adding new facts and clauses locally or introducing new modules of program and linked to the existing prototype. All these small units of program are linked together to form a single stand-alone expert system program, i.e. ECO-ESC The program maximising the use of available data sources and minimise user input requirements since it is integrated into Microsoft Access database which supports the user with tabular data for performing various calculations together with a convenient and user friendly graphical user interfaces. Furthermore, the database supports the user with information on various BMPs and the performance measures of the MCA module. One of the system highlight is the database can be easily updated and revised to be aligned with the latest products and system available in the software market.

The ECO-ESC system consists of four major modules. The first is the BMP decision guide, which recommends the suitable BMPs to be installed based on the site characteristics for the construction projects in Malaysia. The second module involved the MCA optimization, which highlights the best BMP specifically for each construction site. The third is the prediction of sediment yield, calculated using the Modified Universal Soil Loss Equation (MUSLE) for every construction stages. Finally, the fourth module conducts the water quality monitoring plan that involves recommendations for the sampling locations, sampling frequencies,

Table 1. Sequential Interviews With the Experts

Round	Group	Remarks
Round 1	Group 1, Group 2, and Group 3	Provided background about the study, objectives, importance and concept of the expert systems and the MCA
Round 2	Group 1, Group 2, and Group 3	Discussed about the relevant criteria, type of BMPs, construction stages, and site characteristics
Round 3	Group 1, Group 2, and Group 3	Discussed about the soil loss and sediment yield from the USLE and the MUSLE
Rounds 4 and 5	Group 1, Group 2, and Group 3	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

Table 2. Recommended BMPs for Minimizing Erosion and Sedimentation Due to Construction Activities

Main activity	Sub-activity	Recommended BMPs
Site construction facilities	Access road and stream crossing	Construction access stabilization and tire wash; street sweeping; access road stabilization; earth bank; sand bag; and drainage swale.
	Diversion of surface runoff surrounding the construction site.	Earth bank; sand bag barrier; rock filter; and diversion channel.
	Diversion of surface runoff within the disturbed area	Earth bank; diversion channel; and sand bag barrier.
	Control of site perimeter	Silt fence; sand bag barrier; rock filter; and sediment trap.
	Trapping sediment laden runoff before leaving the site	Sediment trap; dry sediment basin; and wet sediment basin.
Site clearance	Protection of the disturbed land when it is left bare for more than 14 days	Soil binder; seeding and planting; geotextiles and mats; terracing; hydraulic mulch; surface roughening; straw mulch, and wood mulch.
Site building	Drainage of top of slope runoff	Slope drain; earth bank; diversion channel; and sand bag barrier.
	Borrow or stockpile protection	Silt fence; sand bag barrier; and rock filter.
	Protection of drainage inlet	Drainage inlet protection

water quality monitoring, pollutant load estimation and river water quality estimation. The details of each module will be discussed in the following sub-sections.

2.2.1 BMP Decision Guide

Three main construction activities were identified and integrated in this ECO-ESC system i.e. site construction facilities, land clearance and site building. In site construction facilities section, several important activities were listed including constructing the access road to the site and stream crossing, stabilising the site with the diversion structures and installation of the sediment traps and basins. Land clearance involves in the removal of existing vegetations, plants and clearing the site. In this activity, the ECO-ESC system gives appropriate recommendations on which critical areas to be disturbed, consideration of clearance location, taking into consideration on the local environmental sensitivity. In the later stages of building and site supervision, suitable control measures for earthwork, the construction of drainage and run-off streaming, stabilising process on the disturbed area and the network of internal roads within the site are suggested accordingly. The BMPs for each activity as tabulated in Table 2 can be recommended by the ECO-ESC system based on the site characteristics include the type of soil, catchment area, flow characteristics and type of the closest water stream.

2.2.2 Multi-Criteria Analysis (MCA)

Multi-criteria value functions, using the weighted summation method were adopted, which was introduced and developed by Jessiman (1967) and Schlager (1968). This method is one the most used technique applied in the water resources and environmental management fields (Hajkowics and Collins, 2007; Chowdhury, 2008; Sidek *et al*., 2008). Four criteria ($m = 4$) were chosen i.e. technical, environmental, economical and social. Assessment of the performance matrix X of n decision options (for BMP 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 Fig. 2. Each criterion is subscribed to one dimensional weight, denotes here as w_j, that is the weight assigned to the jth criterion.

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_{1n}	x_{2n}	x_{3n}	$x_{4,n}$

Fig. 2. 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 Eq. (1), as follows:

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

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 number of the recommended BMPs differs according to each construction stage. Each criterion was assigned weight which indicates the relative importance of each criterion. Typically, the $\Sigma w_j = 1$ and $0 \le w_j \le 1$, holds for all the criteria; that is, the sum of the weights is equal to one and is non-negative. Criteria weights were assigned by the experts in whom they have been normalised to add up to one. Variations in the performance matrix alternatives/BMPs 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.

An important part of the MCA performance matrix was the ranking of the BMPs against the criteria. Four main criteria and their weights were identified by the domain experts; that are technical, environmental, economical, and social and community benefits criteria. Each of these criteria was sub-divided into two

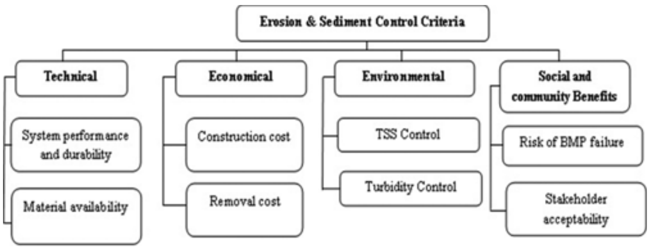

Fig. 3. The Hierarchy of Erosion and Sediment Control Adopted ECO-ESC System

sub-criterions as illustrated in Fig. 3. The ranking was performed based on the type of criterion whether it is benefit or cost criterion. The benefit criteria had the ordinal scales of 1 to 5, where 1 and 5 indicate the criteria of "very low" and "very high", respectively. Six important criteria were considered as the following; (1) system performance and durability, (2) material availability, (3) total suspended solids control, (4) turbidity control, (5) public health and safety risk, and (6) stakeholder acceptability.

To ensure consistency, the cost criteria too had the similar ordinal scales of "very high", indicated by the scale 5 and "very low", presented as scale 1. For the cost analysis, three major criteria were listed that are the construction cost, the removal cost, and the probability/ risk of BMP failure.

As suggested by Voogd (1983), the best alternative was considered as the one with the highest performance score x_{ij}. Due to the choices made in MCA were on the basis of evaluation method, sensitivity analysis is needed to be conducted. The sensitivity analysis was performed by alternately changing the weight coefficient for all four criteria i.e. technical, environmental, economic and social. When the weight for one criterion was changed, weights for other three criterions remained fixed.

2.2.3 Predicting Soil Loss and Sediment Yield

Assessment of soil loss and sediment yield is given option either to adopt the Universal Soil Loss Equation (USLE) or Modified Universal Soil Loss Equation (MUSLE). In this study, the soil loss A for various development stages were estimated by applying the USLE, described as

$$A = R, K, LS, CP \tag{2}$$

where, A = Computed soil loss per unit area

Predicting the soil loss using USLE, five main factors of Rainfall erosivity (R), soil erodibility (K), topographic parameters including Slope Length and Slope Steepness (LS), Cover management (C) and Support practice (P) were taken into account. The R value may be estimated either using the readily available iso-erodent maps, developed by DID for each Malaysian state or using the equation as follows,

$$R = \frac{1}{n}\sum_{j=1}^{n}\left[\sum_{k=1}^{m}(E)(l_{30})_k\right] \tag{3}$$

Where,

E = Total storm kinetic energy,
l_{30} = Maximum 30 minute rainfall intensity,
j = Index for the number of years used to compute the average
k = Index of the number of storms in each year
n = Number of years to obtain average, and
m = Number of storms in each year.

The soil erodibility factor (K) value can be estimated based on the Malaysian soil maps or by using the following equation

$$K = [10 \times 10^{-4}(12 - OM)M^{1.14} + 4.5(S-3) + 8.0(P-2)]/100 \tag{4}$$

where,
M= (% silt + % very fine sand) × (100 - % clay),
OM= % organic matter
S= Soil structure code, and
P= Permeability class.

Equation (4) was developed by Tew (1999) and is deemed to give the most satisfactory estimation of K factor for Malaysia soil series.

The rate of soil erosion by water is significantly affected by both slope length (L) and slope steepness (S) in terms of gradient/percent slope. The LS factor can be estimated based on slope length and slope gradient and can be directly obtained from the guideline. Both the cover management (C) and practice support (P) factors are two management factors that used to control soil loss at a specific site. C factor represents the type of covers introduced to protect the bare ground. Should erosion have taken place, then the P factor is needed to stop the silt and sediment in flowing water.

The sediment yield Y, estimation of a catchment is obtained by implementing the Modified Universal Soil Loss Equation (MUSLE), defined as

$$Y = 89.6(VQ_p)^{0.56}(K, LS, C, P) \tag{5}$$

where,
Y = Sediment yield per storm event (tonnes)
V = Runoff volume in cubic meter
Q_p = Peak discharge in m^3/s

In predicting the sediment yield using the MUSLE, the peak runoff and runoff volume was predicted using the rational method or time area method. The guideline has specified that when the catchment area is less than 80 ha, the rational method is to be used, where else the calculation is obtained using the time area method.

2.2.4 Water Quality Monitoring Plan

The water quality monitoring plan describes and gives suggestion on the appropriate sampling locations and frequency of sample collection. Based on the knowledge base and recommended by the experts, seven basic physical water quality parameters included i.e. Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Dissolved Oxygen (DO), pH, Ammonia Nitrogen (NH3-N), Total Suspended Solids (TSS) and Turbidity. The values for water quality parameters obtained for pre, during and post construction values were compared with the Malaysian guideline set as Class IIB Interim National Water Quality Standard (as required by the Department of Environment). Pollutant load was estimated only for the TSS using the Event Mean Concentration Method (EMC) since the EMC values for the land use "construction" is only available for the TSS within the DID (2000, 2011).

2.3 ECO-ESC Testing and Verification

The developed ECO-ESC software was tested and validated using three techniques; preliminary validation, field validation, and Turing test. The test outputs generated from each module were evaluated and assist in the improvement and modification of the ECO-ESC system. The subsequent sections explain each technique into more detail.

2.3.1 Preliminary Validation

In the preliminary validation, focused on the adequacy of the software itself, the ECO-ESC system was presented to a group of experts consisted of 11 experts from different organizations (i.e. university academics, engineering consultancy companies, postgraduate students, and local authority). The preliminary standard of the ECO-ESC was evaluated through a set of both open-ended and close-ended questions given to the experts. Five main categories of the ECO-ESC features were assessed i.e. ease of use, nature of questions, presentation of results, system utilities and general considerations. Each category has associated sub-element and the validity of the ECO-ESC's features were assessed based on the subjective rating according to the Likert scale. The scale ranged from 1 to 5, which categorises the suitability on the physical features of the ECO-ESC system as poor (1), weak (2), average (3), good (4), and excellent (5).

To perform the preliminary validation and to prove that the overall performance of the ECO-ESC affect the evaluator's attitude, the T-Test statistics was applied using the SPSS software. In the T-test, the $T_{calculated}$ values predicted from Eq. (4) was compared with the T-tabulated values. $T_{tabulated}$ values can be obtained by identifying the Degree of Freedom (*DF*) and the confidence level. The DF value equals to the sample size -1.

$$t = \frac{\bar{X} - \mu}{\frac{s}{\sqrt{N}}} \quad (6)$$

where,
$\bar{X}$ = Mean score,
μ = Median value of the Likert's scale (3),
s = Sample standard deviation, and
n = Total population.

In the data analysis, the following hypothesis was adopted:
Null hypothesis H_o: the performance of ECO-ESC is independent from the evaluator's attitude.
(H_o $\mu = 3$, medium value of the Likert's scale)
Alternative hypothesis H_1: the performance of ECO-ESC is affected by the evaluator's attitude.
(H_1: $\mu \neq 3$)

2.3.2 Field Validation

To assess the ECO-ESC performance on an actual construction site, a 365 ha (and was divided into five sub-catchments) of rubber tree plantation located at Mukim Telekong Daerah Batu Mengkebang, Kuala Krai, Kelantan state, Malaysia was selected. This development as shown in Fig. 4 was planned as an eco-tourism town. The slope of flow path ranges between 0.11 to 0.16% and length of runoff path varies between 900 to 2050 m.

Four modules from the ECO-ESC system were chosen for validation. The modules that have been considered were soil loss and sediment yield prediction (using MUSLE equation), BMP decision guide to recommend the suitable BMPs based on the site characteristics, MCA optimization which highlights the best BMP on the basis of discussed criteria and criteria weights, construction of sediment basin and water quality monitoring plan. Data from the construction site including the site location, type of landuse, type of soil, average slope length and steepness, type of stream, and catchment area were fed into the ECO-ESC system.

In the MCA technique, choices were made based on the evaluation method. Therefore, attempt was taken to achieve the sensitivity analysis. In the present study, technical and environmental criteria were assigned a normalised weight coefficient of 0.2607

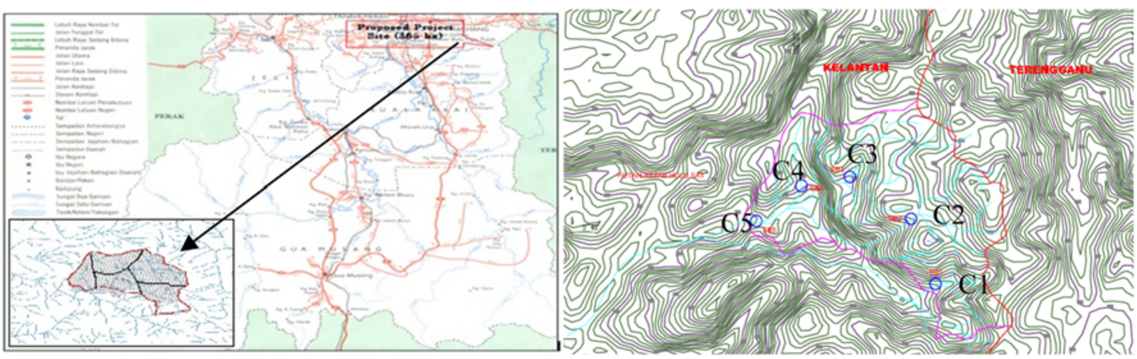

Fig. 4. Location of the Rubber Tree Plantation used for Field Validation. Left Image Shows the Location of Five Sub-catchment Within the Study Area

whereas social criterion was assigned as 0.2423. The economical criterion has the lowest normalised weight with 0.2361. Sensitivity analysis was performed by changing the weight coefficient of all criteria. When one's weighted coefficient changes, other's weighted coefficient remains constant.

Five catchments at the study area were assessed in terms of sediment yield and water quality monitoring plan. Specific sampling locations and frequency were obtained from the site. Water quality parameters of BOD, COD, TSS, Turbidity, pH, NH_3-N, and DO were collected for the base line and during the construction, to be compared with the standard value of Interim National Water Quality Standard for Malaysia.

2.3.3 Turing Test

In order to evaluate the performance of the ECO-ESC system to have the similar argument as an expert, Turing Test was performed. Seventeen sets of problem were randomly sampled and performed on all the modules. The output generated by the ECO-ESC was made to compare with those given by the external experts (similar experts as discussed previously).

For each set of problem, Chi-square test was performed with the following hypothesis:

H_o: No distinguishable difference of output between produced by the ECO-ESC and experts.

H_1: There are some differential ability between the ECO-ESC and panel of experts.

3. Results and Discussion

The verification of ECO-ESC system was done periodically as the development of the system progresses and final verification was conducted once the whole system was completed. The periodical verification processes allow update of the system by removing uncertainties, possibly from incompleteness, ambiguity, measurement and reasoning errors. The ECO-ESC system was made a rigorous validation process and trust to be a comprehensive and valid replacement of the experts. The following sections provide a thorough description for the validation techniques adopted in validating the ECO-ESC system.

3.1 Preliminary Validation

Table 3 compares the results obtained from the respondents (i.e. 11 experts as highlighted in section 2.4.1) against the ECO-ESC features. Data shows that the features ease of use, nature of questions, system utilities, and general considerations were satisfactory since the mean values were consistently higher than the median value of the Likert's scale, where mean values is between $4.00 \le \bar{X} \le 4.73$. Specific sub-element of complete under the category of presentation of the result was found weak (i.e. $T_{calculated} = 2.193 < T_{tabulated} = 2.23$ with DF = 10 and it was preliminary rejected. The evaluators asked for more information to be presented with the results of the ECO-ECS, for example explanation, design information, inspection and maintenance

Table 3. Results of the Preliminary Validation

ECO-ESCES features	Evaluators satisfaction											$\bar{X}$	SD	t-test (2 tails) with DF = 10	Acceptability
	Poor 1		Weak 2		Average 3			Good 4		Excellent 5					
	1	2	3	4	5	6	7	8	9	10	11				
Ease of use															
Starting the system	5	5	5	4	4	5	4	4	5	4	4	4.454	0.522	9.238	Acceptable
Obtaining explanations	5	4	4	4	5	5	4	5	4	5	5	4.545	0.522	9.815	Acceptable
Help facilities	4	5	4	5	3	3	3	4	4	4	5	4.00	0.774	4.282	Acceptable
Interface techniques	4	4	5	5	4	5	4	5	4	4	5	4.454	0.522	9.238	Acceptable
Exiting the system	5	5	4	4	4	4	4	4	4	4	3	4.090	0.539	6.708	Acceptable
Nature of questions															
Clarity of terms	3	5	5	5	4	4	3	4	4	4	5	4.181	0.7507	5.221	Acceptable
Answers complete	4	5	5	4	5	5	4	5	5	5	5	4.723	0.467	12.264	Acceptable
Clarity of questions	4	4	4	5	4	5	4	4	5	4	5	4.363	0.504	8.964	Acceptable
Nature of explanations	4	4	5	4	5	3	5	4	4	4	4	4.181	0.603	6.500	Acceptable
WHY explanations	5	4	4	3	4	5	4	4	5	4	3	4.090	0.700	5.164	Acceptable
HOW explanations	3	5	4	4	4	4	3	4	5	4	5	4.090	0.7006	5.164	Acceptable
Presentation of results															
Easy to follow	5	4	4	4	5	4	5	4	4	5	4	4.363	0.504	8.964	Acceptable
Complete	4	2	3	4	4	3	4	3	3	4	4	3.454	0.687	2.193	Not acceptable
System utilities															
Easy to access	4	5	5	4	5	5	5	4	4	5	4	4.545	0.522	9.815	Acceptable
Knowledge usability	4	5	4	5	4	5	4	5	4	4	4	4.363	0.504	8.964	Acceptable
Complete	4	4	5	4	4	4	5	4	4	4	5	4.272	0.467	9.037	Acceptable
General considerations															
Speed of system	4	4	5	4	5	5	5	4	3	4	5	4.363	0.674	6.708	Acceptable
System usefulness	5	4	5	4	5	5	4	5	5	5	5	4.727	0.467	12.264	Acceptable

guide, location guide, and the real picture for each recommended BMP. After modifying the system based on the evaluator's comments, the system was re-tested for the said sub-element only. As shown in Table 3, the result was found to be very good with a mean value of 3.818 and $T_{Calculated}$ value of 3.614. As such the feature was accepted.

All sub-elements discussed in the ECO-ESC features received mean score of more than the median value μ = 3, with standard deviation SD between $0.52 \le SD \le 0.77$. It can be said that the results validate the ECO-ESC features and the performance of the system was accepted in great confidence. As such, the null hypothesis H0 is dropped and the alternative hypothesis H1 was approved.

3.2 Field Validation

Results of the ECO-ESC recommended for four modules assessed were compared with the application implemented at site. The erosion and sedimentation control plan at site was not only being extracted from the project documents and the relevant environmental management plan reports, but also was obtained from on-site interview with the site engineer. The module of soil loss and sediment yield prediction will be first discussed.

3.2.1 Soil Loss and Sediment Yield Prediction

The development of the site was predicted to give an annual erosion rate of 4222.14 tonnes. Soil loss for catchment 5 is the highest with 1417 tonnes/year and is believed due to the increase in elevation difference compared to the existing condition. Sediment yield is estimated in a sediment basin for each catchment is shown in Table 4. Catchment no 5 has the highest estimated sediment storage volume as it is located at the lowest point within the study area. Similar values were obtained from the calculation design and was confirmed with the experts i.e. engineer at site. The similarity between the predicted and designed for the construction site indicated that the ECO-ESC performed well and satisfactorily.

Table 4. Prediction of Soil Loss and Sediment Yield for the Study Site

Catchment No.	Predicted (ECO-ESCES)			
	Soil loss (Tonne/yr)	Runoff vol. (m^3)	Q_P (m^3/s)	Sediment yield Y (tonnes)
1	512.55	19196.07	2.666	28.574
2	911.60	32803.25	4.5560	54.196
3	649.76	22756.91	3.1606	36.970
4	731.33	24567.22	3.4121	41.996
5	1416.9	43511.39	6.043	87.140

3.2.2 Best Management Practices

Table 5 shows the similarity between practices suggested by ECO-ESC system and at construction site for chronological specific construction activities. The similarity for each construction activity was defined as percentage of the same practices implemented on-site as suggested by ECO-ESC over the list of recommendations.

Suggestions by ECO-ESC for five construction activities i.e. stabilising the site, site clearance, earthwork, construction of surface drainage and development of roads were all found to be applied at construction site. Two activities of access road and stream crossing and stabilising the disturbed site received similarity percentage of about 66.7% and 75%, respectively.

The recommended BMPs by the ECO-ESC for sediment control were sand bag carrier and rock filters for access road and stabilising the site activities, respectively. Furthermore, earth banks require minimal maintenance and are deemed (by the experts) as the best BMP for the study area. Earth bank and check dam were suggested and implemented as BMP for runoff management whereas approach to trap the sediment laden runoff was varied. Sand bag carrier was constructed on site as sediment control. However, as Malaysia receives rather heavy rainfall throughout the year, implementing sand bag carrier would not be attractive as it needs regular maintenance.

Whenever several options were available, MCA analysis was imposed to select the best approach. Here, an example is shown

Table 5. Suggestions of BMP's by ECO-ESC and Associated Practices On-site for Specific Construction Activities

Construction activities	ECO-ESC recommendation	Field practices	Similarity (%)
Access road and stream crossing	Exit and entrance stabilization and outlet tire wash Street sweeping and vacuuming Construction road stabilization Earth Bank Sand bag carrier Drainage swale	Exit and entrance stabilization and outlet tire wash Street sweeping and vacuuming Construction road stabilization Earth bank	66.7
Stabilising the site prior construction	Earth bank	Earth bank	100
Site clearance/removing of vegetation	Preserving of existing vegetation, stream buffer of 20 m	Preserving of existing vegetation, stream buffer of 20 m	100
Earthwork	Excavation of cut and fill area, contaminated soil management	Excavation of cut and fill area, contaminated soil management	100
Stabilising the disturbed site	Earth bank, Check dam, Rock filter Sediment basin	Earth bank, Check dam Sand bag barrier Sediment basin	75
Construction of surface drainage	Sweeping and tire wash	Sweeping and tire wash	100
Development of roads	Construction road stabilization	Construction road stabilization	100

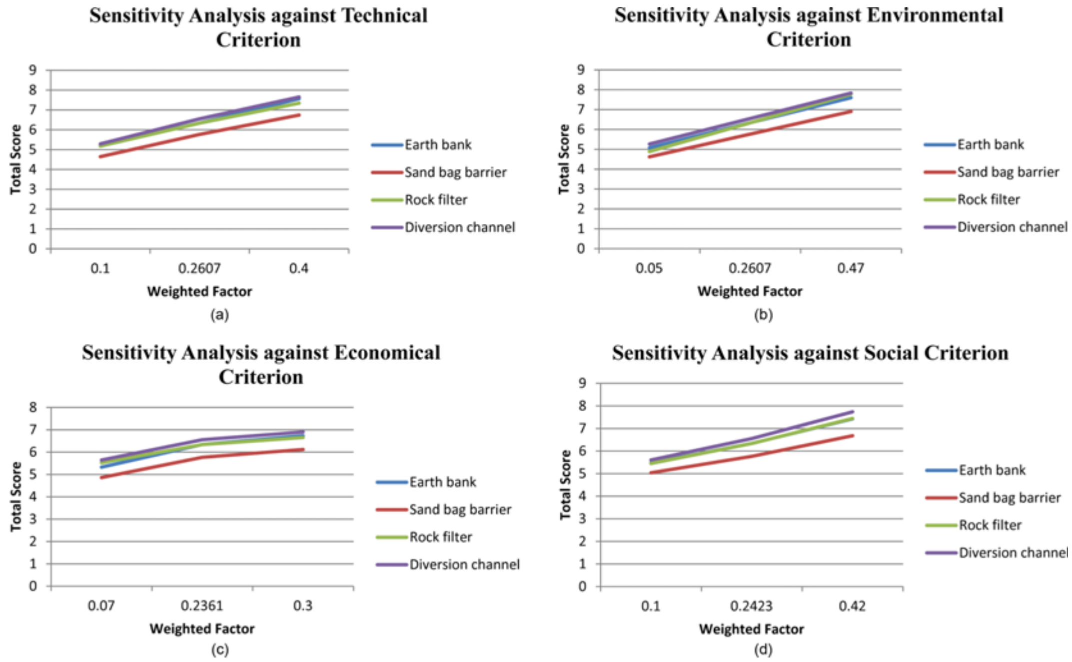

Fig. 5. Performing the Sensitivity Analysis by Changing the Weight of the: (a) Technical, (b) Environmental, (c) Economical, (d) Social Criteria

for the stabilising the site case, where four options of earth bank, sand bag carrier, rock filter and diversion channel were suggested. The best control measure was chosen based on sensitivity analysis and changes of criteria weights on the MCA criteria. Through the sensitivity analysis, the decision maker is able to judge how much of the uncertainty in the output of a model is influenced by the uncertainty in its input parameters. Impact of the sensitivity analysis on the choice of the best alternatives is given in Fig. 5, where clearly the technical, environmental, economical, and social criteria have no effect on the best alternative (i.e. earth bank). This implies that MCA results are consistent throughout the ranges of weight discussed here.

3.2.3 Design of Sedimentation Basin

Sediment basin is one of the sedimentation controls BMP's, which was both suggested and implemented on site. Common practices in Malaysian construction scenario is to made compulsory for disturbed area greater than 2 hectares, where the study site discussed here is well above the limit. In this section, detailed comparison on the sediment design as suggested by ECO-ESC and what was constructed on site is discussed.

A sediment basin serves as the last protection to trap sediment before runoff leaves the construction site and discharge to the nearest water streams. The basin is a temporary measure with life span usually in the range of 12 to18 months and has to constantly maintain throughout the construction period. Table 6 summarises the design of the five dry sediment basins for five sub-catchments. The predicted lengths of sediment basin at both top water level and base are consistently lower than what were constructed on site. On the other hand, fluctuating trend was observed, that is the predicted values for both width at base at top water level do not necessarily over predict or under predict the designed on-site widths. The correlation value for similarity between the predicted lengths and observed lengths was about $R^2 = 0.54 - 0.56$, whilst for width parameter proved to have higher correlation with $R^2 \approx 0.99$.

ECO-ESC system predicted the same value of depth of settling zone as what was designed at site. Sediment basins 1 and 2 were

Table 6. ECO-ESCES Results and Field Results for the Design of Five Dry Sediment Basins

Sediment basin (SB)	Observed (Field study)									Predicted (ECO-ESCES)								
	Overall basin dimensions									Overall basin dimensions								
	W_{TWL} (m)	L_{TWL} (m)	W_B (m)	L_B (m)	Settling zone depth (m)	Sediment storage depth (m)	River dis-charge (m^3/s)	Spillway discharge Q_{10} (m^3)	Total basin depth (m)	W_{TWL} (m)	L_{TWL} (m)	W_B (m)	L_B (m)	Settling zone depth (m)	Sediment storage depth (m)	River discharge (m^3/s)	Spillway discharge Q_{10} (m^3)	Total basin depth (m)
1	55	110	50	108	0.6	0.7	0.93	3.555	2.2	45.62	118.199	41.5	115.39	0.6	0.7	0.93	2.496	2.2
2	82	120	78	120	0.6	0.7	0.93	6.320	2.2	77.62	118.589	73.5	115.78	0.6	0.7	0.93	4.924	2.2
3	57	117	51	114	0.6	0.65	0.96	4.294	2.2	54.12	118.067	50	115.26	0.6	0.7	0.93	3.1265	2.2
4	63	113	58	111	0.6	0.65	0.96	4.601	2.2	58.12	118.675	54	115.87	0.6	0.7	0.93	3.449	2.2
5	122	102	117	100	0.6	0.65	0.96	1.429	1.9	117.12	104.049	113	101.24	0.6	0.7	0.93	6.8225	2.2

Table 7. The Suggestions for Water Quality Monitoring by ECO-ESC and What was Implemented at the Study Area

	Task	ECO-ESC	Observed at field
1	Sampling location	Upstream of the site and outsite the disturbed area Discharge points from all sediment basins.	Upstream, downstream and outsite the disturbed area.
2	Sampling frequency	Rainfall occurrence: within first two hours of rainfall event and to be collected during daytime No rainfall: one sample per month	Rainfall occurrence: within first two hours of rainfall event and to be collected during daytime No rainfall: one sample per month
3	Water quality parameters	TSS, Turbidity, BOD, COD, DO, PH, and NH3-N	TSS, BOD, COD, DO, PH, NH_3-N, E-Coli, and temperature
4	Pollutant load estimation	TSS	TSS

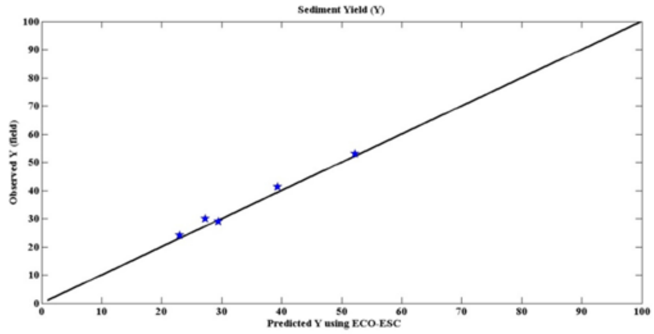

Fig. 6. Percentage Difference between the Predicted Sediment Yield Via ECO-ESC and the Observed Sediment Yield From the Field For Five Sub-catchments

Table 8. Water Quality Parameters Data for the Baseline, during Construction Phases and Associated Standard Value Based on INWQS

Water quality parameter	Baseline phase			During construction phase			Class II B INWQS
	P1	P2	P3	P1	P2	P3	
TSS	10	7	8	12	6	11	50
BOD	2	2	2	10	8	2	3
COD	7	13	37	9	9	28	25
DO	5.7	6.2	5.9	6.1	6.3	5.4	6
pH	6.0	6.8	7.1	6.0	6.3	5.6	7
NH_3-N	0.07	0.07	0.07	0.01	0	0	0.3

similarly predicted, while SB3-SB5 was slightly over predicted. We would like to highlight that the predicted spillway discharge for all sediment basin was lower than what was measured at the on-site spillway for SB1 to SB4. The higher discharge values are probably due to the higher design storm criterion that is 6 month ARI, compared to the common 3 month ARI as what was input in the ECO-ESC system. The 6 month ARI was taken (by the design engineer), perhaps due to the regular monsoon flood events at Kelantan. Higher spillway discharge values are consistent with the larger basin widths (i.e. larger area) found at the construction site.

3.2.4 Water Quality Monitoring

In the water quality monitoring plan, as shown in Table 7, the recommended sampling locations, sampling frequencies, and the water quality parameters by the ECO-ESC were the same with

Table 9. Turing Test Results

Event		Chi-Square value	Degree of Freedom (*DF*)	*P*-Value
Compatible	Non-compatible			
16	1	0.567	1	0.452

that recommended in the site. Furthermore, the pollutant load predicted from the ECO-ESC was compared with the observed values in which very little difference was indicated that is ranges from 0.1 to 0.3% for the five catchments. This difference could be attributed to the EMC values adopted in ECO-ESC (adopted TSS values from MSMA) and the one from the field (observed TSS values from the field). All the ECO-ESC results that have been compared with the observed results are reviewed and approved by the experts.

Figure 6 compared the sediment yield obtained from the ECO-ESC the observed concentration on site. Data shows that the measured and predicted sediment yield were falls closely on the line of agreement. As such, sediment yield obtained from the ECO-ESC system is proved to be valid and credible.

Table 8 listed the measured water quality parameter before and during construction phases with standard value for each parameter is listed in the last column. The sediment control BMP's applied clearly worked effectively as the concentration of TSS during the construction is well below the standard. The parameter BOD however, has significant higher values than standard (i.e. 3 mg/L) for P1 and P2. ECO-ESC recommended inspecting the site for possible high organic pollutant due to untreated sewage waste, plant waste or littering disposal. The construction site is advised and revised on its current waste management.

Note that sampling point P3 recorded discharge with COD exceeding the standard even before construction. Although the value decreased to 28 with several BMP implementations, it is still above the standard. ECO-ESC suggested the contractor to conduct site inspection, particularly for sewage water. The parameter DO is effectively at the borderline of class II B standard and ECO-ESC suggested to take precautions on sewerage and land clearing management so that the level of DO is not well below the standard.

The discharges during constructions phase at three sampling points were slightly acidic. Possible sources identified are agricultural runoff and development of algae blooms. The parameter NH_3-N showed minimal presence in the discharges, both for baseline and during construction phases and is well below the standard value.

3.3 Turing test

As shown from Table 9 above, the Chi-Square value obtained from the SPSS equals to 0.567 with degree of freedom (*DF*) equals to one. Data shows that there was no significant disparity between the outcome from ECO-ESC and the external human experts. The *P*-value accompanied with the Chi-Square test equals to 0.452 which is higher than 0.05 (the level of significance).

Some conclusions can be drawn from this test in which it eliminates the bias. The Turing test used herein has provided an objective evaluation of the human expert's performance. The goodness of the test is in not being able to distinguish between the ECO-ESC outcomes and that of the human expert. Thus, the ECO-ESC performs as good as the human expert.

4. Conclusions

Knowledge-based systems and the MCA can be valuable tools for the development of selection and prediction tools that can assist engineers, consultants, contractors, civil engineering students, and decision makers in the minimising the stormwater pollution due to construction activities. In this research, the ECO-ESC system was developed for minimising erosion and sedimentation due to stormwater in Malaysian development sites.

ECO-ESC building process successfully adopted the hybrid approach since it's integrated the expert system with the MCA technique for optimising the best control measure based on criteria and criteria's weights. Results from the ECO-ESC system were compared with the field (observed) results for recommended BMPs, the prediction of the sediment yield, and water quality monitoring. ECO-ESC is efficient in minimising erosion and sedimentations by recommending the suitable BMPs according to site characteristics and for each development stage.

ECO-ESC managed to recommend the runoff management and sediment control plan similar to what are being practiced at the construction site to a high degree of accuracy. Results from the sensitivity analysis were very consistent in which when changing the weight of the technical, environmental, economical, and social criteria, ECO-ESC produced consistent results despite varying ranges of weights. High correlation was also found between the predicted and observed values for the sediment yield within the five catchments. For water quality monitoring, results from the ECO-ESC and the observed results for the sampling locations, sampling frequencies, and water quality monitoring during construction were similar with the observed results in the field.

The ECO-ESC effectiveness was achieved by performing preliminary validating, field validation, and Turing test. In the preliminary validation, the T-test value calculated by the Statistical Product Service Solutions for all the features were higher than the t tabulated values which means that the evaluators accepted ECO-ESC features. Furthermore, in Turing test, the Chi-Square value equals to 0.567 and the Probability (P-value) equals to 0.452 which was higher than 0.05 (level of significance) and hence it can be said that the ECO-ESC performs as a real expert. As such, in the absence of experts, ECO-ESC is a valuable tool to help less experienced engineer in making decision for better erosion and sediment control plan for stormwater control in a construction site.

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