Hybrid knowledge-based expert system and multi-criteria analysis for minimizing erosion and sedimentation due to stormwater in Malaysian construction sites

Ibrahiem Abdul Razak Al-Ania, Lariyah Mohd Sideka, Mohammed Nor Mohammed Desa and Noor Ezlin Ahmad Basri

Abstract

Malaysia is located in a tropical zone wherein heavy rainfall occurs in all seasons of the year. Land clearing and earthwork activities combined with heavy rainfall and the widely varied topography can result in severe soil loss that shall eventually be deposited into the adjacent water bodies via stormwater. Recently knowledge-based systems have been used in many fields especially when human expertise and data are limited. In the current study, a hybrid knowledge-based expert system and multi-criteria analysis (MCA) were developed to minimize erosion and sedimentation due to stormwater in Malaysian construction sites. This system called the Multi-criteria Erosion and Sediment Control (MCESC) system. The role of MCA is to identify the best stormwater control measure based on specified criteria and the criterion's weight. Data from road construction project in Permas Jaya, Johor Bahru State, Malaysia has been utilized for testing the MCESC system's functionality in solving real erosion and sediment control problem. The MCESC system can be used by engineers, contractors, and decision makers to develop erosion and sediment control plan and environmental management plan for any construction site in Malaysia.

Key words: best management practices, expert systems, multi-criteria analysis, soil erosion, stormwater

INTRODUCTION

In the late 1970s and 1980s, urban development in Kuala Lumpur, Malaysia and in the neighboring urban centers of the Klang Valley, was particularly rapid. The rapid growth of urban development in the Kuala Lumpur area resulted in excessive soil losses from construction sites as well as from cleared sites awaiting development. Construction sites in Malaysia usually involve bare eroding slopes and drains filled with sediment. Areas subjected to construction usually experience sediment yields two to three times greater than those under natural land cover conditions (Department of Irrigation and Drainage 2000). Sediment by volume is the greatest pollutant entering Malaysian surface waters, which causes severe problems. 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). (U.S. Geological Survey 2000) conducted a study in the Dane County, Wisconsin for two small construction sites and the results showed that the sediment load from these sites was 10 times greater than typical loads from urban and rural land uses in Wisconsin. Total suspended solids concentrations showed that the construction phase has generated concentrations that were higher than pre-construction and post construction phases.
It has been also indicated that the total suspended solids concentration has dramatically reduced when the site was seeded and mulched. Because many water quality problems are associated with the construction activities in USA, erosion control measures at construction sites of larger than 5 acres have been developed and implemented since 1970s to the present. Many studies showed that the amount of sediment transported by storm water runoff from large construction sites (greater than 5 acres) with no erosion control facilities have much higher sediments than the sites that have erosion control best management practices (BMPs) (U.S. Environmental Protection Agency 1999). A study to compare the erosion produced from two similar construction sites in Lake Tahoe Basin was conducted in which one site without erosion control practices where the estimated soil loss exceeded by 100–1,000 times compared to the pre construction levels. While the other site that provided with good erosion control practices, the soil loss was only double the preconstruction condition (Dayton & Knight 1999). (Alsharif 2010) investigated the construction related stormwater pollution violations in Minnesota from 2001 to 2007 and indicates that the major type of construction stormwater violations was related to the lack of BMPs.

The multi-criteria analysis (MCA) is a structured framework for the investigation, analysis and resolution of decision problems constrained by multiple objectives. It is used to apprise a discrete number of alternatives against a set of multiple criteria and conflicting objectives (Voogd 1983). Ellis et al. (2006) described a web-based MCA approach developed in the EU 5th Framework Day Water Project supporting the decision making, conflict resolution, between stakeholders. Chowdhury & Rahman (2008) used MCA to evaluate three common alternatives, namely, sodding natural channel, lined natural channel, and box culvert for the Malnichara channel in Bangladesh.

The aim of the current study is to develop a hybrid knowledge-based expert system and MCA technique for minimizing erosion and sedimentation due to stormwater in Malaysian construction sites by recommending stormwater BMPs suitable to specific site characteristics.

**DEVELOPMENT OF THE SYSTEM**

The system that has been described in the current study is called the Multi-criteria Erosion and Sediment Control (MCESC) system which is developed according to standard knowledge-based expert system development methods. The programming language used to develop the system is Visual Basic version 6, which provides greater flexibility and adaptability in rapidly developing this prototype. This flexibility allows the knowledge engineer to present the domain knowledge more freely. However, programming languages require more time for development because the developer must first become familiar with the computer languages and he/she must still develop the program codes. In addition, debugging the program is often difficult. The system development process is guided by a five-step process, namely, task analysis, knowledge acquisition, prototype development, expansion and refinement, and verification and validation (Waterman 1986; Terry 1991; Islam 2004).

**Task analysis**

Task analysis is a methodology tool that can be used to describe the functions of expert performance in problem solving and determine the relationship of each task to the overall job (Basri 1999). The results of the analysis are used to determine the subsequent strategy, methodology and techniques employed for prototype development. The integration of MCA with the knowledge-based expert system to minimize stormwater pollution in Malaysian construction sites involves several manifold tasks. Each of these tasks has one or more sub-tasks, which form the basis of the knowledge-based modules that make up the components of the entire system. The developer must ascertain that the problem is well suited to the use of expert system technologies and the problem has not already
been solved to the approval of the client by other types of conventional programming such as modeling, decision support or databases. The tasks and subtasks within the MCESC system were described in more detail in the prototype development section.

Knowledge acquisition

The knowledge acquisition stage can be considered the most important, difficult and time consuming phase of expert system development (Basri 1999). The knowledge involved in the MCESC system was acquired from text books, journals, national and international guidelines, and attending seminars and conferences.

Knowledge in MCESC was also acquired from experts, and the information was used to clarify or expand the information received via other resources. Five meetings with 7 experts, which consisted of personnel from the Department of Irrigation and Drainage (2 experts), the Department of Environment (1 expert), and the Department of Public Works (1 expert) as well as university academics (1), private consultants and engineers (2), were organized. After the fifth meeting, the experts were asked to provide recommendations on the following topics:

- Site characteristics suitable for the adopted BMPs;
- Identifying the most important construction stages responsible for generating erosion and sediments (Table 1);
- BMPs that should be adopted in the MCESC system (Table 2); and
- The relevant criteria that should be used to rank the different stormwater management alternatives.

Table 1 | Main and sub-construction stages adopted in the MCESC system

<table>
<thead>
<tr>
<th>Main construction stages</th>
<th>Sub-construction stages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site construction facilities</td>
<td>Access road and stream crossing</td>
</tr>
<tr>
<td>Site clearance</td>
<td>Site stabilization</td>
</tr>
<tr>
<td>Site formation</td>
<td>Removal of vegetation</td>
</tr>
<tr>
<td></td>
<td>Earth work</td>
</tr>
<tr>
<td></td>
<td>Stabilizing of the disturbed site</td>
</tr>
</tbody>
</table>

Table 2 | Recommended BMPs for minimizing stormwater pollution due to construction

<table>
<thead>
<tr>
<th>Objective</th>
<th>Recommended BMPs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Access road and stream crossing</td>
<td>Construction access stabilization and tire wash; street sweeping; access road stabilization; earth bank; sand bag; and drainage swale.</td>
</tr>
<tr>
<td>Diversion of surface runoff surrounding the construction site</td>
<td>Earth bank; sand bag barrier; rock filter; and diversion channel.</td>
</tr>
<tr>
<td>Diversion of surface runoff within the disturbed area</td>
<td>Earth bank; diversion channel; and sand bag barrier.</td>
</tr>
<tr>
<td>Control of site perimeter</td>
<td>Silt fence; sand bag barrier; rock filter; and sediment trap.</td>
</tr>
<tr>
<td>Trapping sediment laden runoff before leaving the site</td>
<td>Sediment trap; dry sediment basin; and wet sediment basin.</td>
</tr>
<tr>
<td>Protection of the disturbed land when it is left bare for more than 14 days</td>
<td>Soil binder; seeding and planting; geotextiles and mats; terracing; hydraulic mulch; surface roughening; straw mulch, and wood mulch.</td>
</tr>
<tr>
<td>Drainage of top of slope runoff</td>
<td>Slope drain; earth bank; diversion channel; and sand bag barrier.</td>
</tr>
<tr>
<td>Borrow or stockpile protection</td>
<td>Silt fence; sand bag barrier; and rock filter.</td>
</tr>
<tr>
<td>Protection of drainage inlet</td>
<td>Drainage inlet protection.</td>
</tr>
</tbody>
</table>
The seven experts were interviewed for the ranking of the alternatives against the criteria via a questionnaire. The interviews were two hours long on average and conducted as interactive as possible. Two scenarios were adopted in the questionnaire for the assignment of ordinal scores. The first scenario had the ordinal scales of ‘very high’ and ‘very low’ which indicate the best and worst performances, respectively; the score ranged from 5 (very high) to 1 (very low). The criteria under this scenario were (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. On the other hand, the second scenario had the ordinal scales of ‘very high’ and ‘very low’ which indicate the worst and best performances, respectively; the selected score range was 1 (very high) to 5 (very low). The criteria under this scenario were (1) construction cost, (2) removal cost, and (3) risk of BMP failure.

Another form of knowledge acquisition was conducted via an on-site observation method, wherein the knowledge engineer visited two construction sites and observed first hand how experts solve a real problem rather than learning from plain description. The experts in the construction sites identified the suitable BMPs for each construction and sub-construction stage and conducted installation, inspection, and maintenance of the BMPs. The construction sites visited by the knowledge engineer were the Cameron Highland construction site (this site involves the development of agricultural site and some buildings in which the erosion and sediment control plan has been implemented) and another construction site inside the National University of Malaysia (This site involves development of new and big buildings inside the university campus). Using multiple sources to establish a knowledge base has many advantages because no bias is shown toward a single view: the reliance on single expert knowledge elicitation is low and the conflicting views gained represent the actual field situation, which often requires. In the development of the MCESC system, many sources of knowledge were tapped and integrated.

Prototype development

At this stage, the knowledge engineer uses the acquired knowledge to develop a working computer program. The MCESC system consists of three major tasks. The first is BMP consultation, which selects the existing site characteristics for any development project in Malaysia and helps the user identify the most suitable stormwater control measures for minimizing erosion and sedimentation in adjacent water bodies. The second task involves the MCA engine, which identifies the best stormwater control measure on the basis of the criteria and the criterion weights. The best stormwater control measure selected is provided along with some briefing information, a preliminary design, an inspection and maintenance guide, and typical drawings. The third and last task of the MCESC system is the inspection and maintenance plan for various erosion and sediment control measures. The MCESC system can provide the user with the necessary information to develop an erosion and sediment control plan, which includes information on the submission requirements for the construction activity, who should obtain approval, deadlines, minimum soil erosion, top soil prevention and other assets, access route and site management, runoff control and management, earthwork and soil control, sediment prevention control, slope stabilization, and site management. The subsequent sections provide a detailed explanation of each task in the MCESC system.

Task 1: BMP consultation

Three major construction activities were adopted in the current system. The first is the site construction facilities which mean the installation of the suitable control measures that include constructing the access road to the site and stream crossing (if any), stabilizing the site with the diversion
structures, and installation of the sediment traps and basins before the stormwater being deposited into the adjacent water bodies. The second construction activity is the land clearance which means the removing the existing vegetations and other naturally soil stabilizing materials from the site. In this activity, the MCESC system recommended to determine which areas must be disturbed for the proposed construction, note critical areas that must be disturbed, clear and grade only what is needed for immediate construction, avoid complete clearing and grading, stabilize disturbed areas as soon as possible, and divert runoff from highly erodible soils and steep slopes. The third and last construction activity is the site building which recommends suitable control measures for the earth-work activities, drainage work, stabilizing the disturbed site and the development of internal roads within the site. The MCESC system user can choose the relevant main and sub-construction activities as illustrated in Table 1. Figure 1 shows the user selections of the site characteristics for the stage of stabilization of the disturbed site, whereas Figure 2 shows the advice obtained regarding the control of the runoff surrounding the disturbed site following the user selections for the site characteristics.

![Figure 1](https://iwaponline.com/wpt/article-pdf/7/2/wpt2012042/383117/42.pdf)

**Figure 1** | User selections for the site characteristics.

![Figure 2](https://iwaponline.com/wpt/article-pdf/7/2/wpt2012042/383117/42.pdf)

**Figure 2** | Advices obtained following the user selections of site characteristics for the control of the surface runoff surrounding the disturbed site.
Different kinds of MCA techniques have been developed. These methods differ in methodology, type of input data required, ease of use, and so forth. The most essential factors in choosing an MCA technique is the ease of comprehension for the analyst and stakeholders and ease of use (Kodikara 2008).

The MCA method adopted in the current research is the weighted summation method, which has been used since sixteen of the previous century by Jessiman (1967), Schlager (1968) and has been recently widely applied in water resources and environmental management fields (Chowdhury 2008; Sidek et al. 2008). In the weighted summation method, the results mainly depend on criterion weight.

Kepner & Tregoe (1965) indicated that this method is one of the most well-known and widely used MCA techniques, primarily because of its simple and transparent computational procedure (i.e. the low effort and time required to perform the analysis) and because of its wide application in water resources and environmental fields (Chowdhury & Rahman 2008; Hajkowicz & Higgins 2008; Sidek et al. 2008). The core of the weighted summation technique is the performance matrix, which consists of a set of evaluative criteria, a set of weights indicating the importance of these 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 \( m \times n \) matrix with \( m \) criteria \((c_{j-1}, c_{j-2}, c_{j-3}, \ldots, c_{j-m})\) and \( n \) alternatives \((a_{i-1}, a_{i-2}, a_{i-3}, \ldots, a_{i-n})\). The corresponding weight vectors \( W \left( w_{j-1}, w_{j-2}, w_{j-3}, \ldots, w_{j-m} \right) \) of \( m \) weights indicate the relative importance of each criterion. Typically, \( \sum w_j = 1 \) and \( 1 \geq w_j \geq 0 \), holds for all \( j \); that is, the sum of the weights is equal to one and is non-negative. The weights can be quantitatively or qualitatively expressed, depending on the particular MCA method used. The \( x_{ij} \) values are performance measures that represent the performance of the \( i^{th} \) alternative against the \( j^{th} \) criterion. These can be expressed in different units, although they may need to be standardized using common units depending on the particular MCA method used. Variations in the performance matrix alternatives are represented as columns, and the criteria and weights as rows. Different decision-making rules and/or methods can be applied to the performance matrix data to rank the desirability or suitability of the alternatives. The performance matrix represents the domain of factors, which is incorporated into the MCA model to generate its solutions.

Figure 3 shows the MCA engine main interface developed by the authors that can be used to identify the best control measure from a list. The first stage of any MCA approach includes the translation
of the decision analysis situation into a set of alternatives and criteria. In the current MCA engine, two scenarios were adopted, in which the MCESC system gives the user the opportunity to either rely on the expert judgments or on his/her own user experience. In the first scenario, the user can identify the best alternative among a set by relying on the criteria, criteria weighting, and the ranking of expert identified alternatives. If the user selects the first scenario, then he/she needs to identify the criteria that he/she wants to use to identify the best alternative from a list of criteria built in the system. In the second scenario, the user can rely on his/her experience to select the best alternative. If the user selects the second scenario, then he/she needs to enter the number of experts, alternatives and criteria that define the decision-making problem being undertaken. The program is restricted to assess decision problems that have a maximum of 30 alternatives and 30 criteria. The MCA engine adopted the weighted summation technique for both scenarios. The subsequent sections provide a full description for the second scenario only because, as previously mentioned, in the first scenario, the best alternative is directly identified by the system, and the user only needs to select the criteria that he/she wants to use.

**Alternative and input parameter description**

A description of each of the alternatives and the criteria can be found in their respective forms. The user must select either the ‘Minimize’ or ‘Maximize’ preference direction in the Criteria Description form.

**Input parameter values**

The next step of the decision analysis process is to rank the alternatives against the previously defined criteria. The value assigned to each alternative against the criteria is quantitative only. A criterion weight from 0–100 can be assigned. The performance values result from the ranking of the alternatives against the criteria must be standardized to commensurable units if different units were used to evaluate the criteria. The standardization method adopted in the MCESC system, in which the criterion scores are adjusted based on their distance to a maximum or minimum value, was recommended by Voogd (1983). For example, the top performing alternative for a given criterion is given a score of 1, whereas the worst performing alternative is given a score of 0. All intermediate alternatives are assigned scores between 1 and 0. Equations (1) and (2) were used to perform the standardization.

\[
s_{ij} = \frac{x_{ij} - x_{j \text{ min}}}{x_{j \text{ max}} - x_{j \text{ min}}} \tag{1}
\]

(where a higher criterion score indicates better performance), and

\[
s_{ij} = \frac{x_{j \text{ max}} - x_{ij}}{x_{j \text{ max}} - x_{j \text{ min}}} \tag{2}
\]

(where a lower criterion score indicates better performance)

where

- \( s_{ij} \) = standardized performance measure for \( x_{ij} \);
- \( x_{ij} \) = performance of the \( i^{th} \) alternative against the \( j^{th} \) criterion in real units of any type;
- \( x_{j \text{ max}} \) = maximum performance score under the \( j^{th} \) criterion; and
- \( x_{j \text{ min}} \) = minimum performance score under the \( j^{th} \) criterion.

As previously mentioned, many techniques for ranking the alternatives against the criteria are available, and the one adopted in the current study is the weighted summation technique, in which the
performance measures are multiplied by the weights and then summed for each alternative to obtain a performance score. The overall performance score can be calculated using Equation (3), as follows:

\[ v_i = \sum_{j=1}^{m} s_{ij} \cdot w_j \]  

(3)

where,

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

According to Voogd (1983), the alternative with the highest performance score is considered the best alternative, which is then presented to the user (Figure 4).

**Sensitivity analysis**

In the MCA technique, choices are made on the basis of evaluation method. Therefore, attempt was taken to perform sensitivity analysis. Sensitivity analysis was performed by changing the weight coefficient of all criteria. When a weighed coefficient changes, the other weighed coefficients remain constant. In this study, it has been concluded that the change of the weight of criterion has not effect on the best alternative.

**Task 3: Inspection and maintenance plan**

The objective of inspection and maintenance is to develop a program that monitors the efficiency of the BMPs work and to evaluate whether additional BMPs are required. The inspection includes the evaluation of erosion, sediment, and conveyance control measures. The regular inspections and expected repairs for erosion and sediment control are provided. The inspection location, inspection frequency, inspection and maintenance submission checklist, erosion and sediment control plan review and modification, typical inspection program, BMP monitoring, inspection report form, and the monitoring report are provided for all BMPs.
Expansion and refinement

This step involves evaluating the performance and utility of the prototype program and revising it as necessary. It also involves checking for mistakes in knowledge acquisition to ensure that the knowledge base correctly reflects that of expert information and that the system performs at an acceptable level of accuracy, user-friendliness, and overall usefulness.

The MCESC system was presented to the experts who monitored how it solve problems; provide solutions for different site characteristics, and how it highlights the best alternative via the MCA technique. Afterward, the experts were asked to fill a questionnaire form regarding their comments and opinions on software performance and user friendliness. Results from the questionnaire were satisfactory.

Verification and validation of MCESC

Systems verification ensures that the software is syntactically and logically correct and performs functionally as specified. In the expert system's context, verification ensures that the compile time and runtime errors are eliminated (ElDrandaly et al. 2009). Validation is the process of inserting real data to the software to indicate the software’s functionality in solving certain problems. The verification of MCESC software was achieved periodically during the entire development process and after the system development was completed. Each rule was verified to remove uncertainty that might occur from various sources, such as incompleteness, ambiguity, errors in measurements, and reasoning errors. Validation substantiates a system to perform with an acceptable level of accuracy. Bryant (2001) reviewed some expert systems and indicated that many of them did not survive their implementation in an organization because of several reasons, one of them being inadequate validation. As a result, in validating the MCESC, an effective validation procedure is critical to the success and functionality of the software. The correctness, completeness of the inference rules, ability of the control strategy to consider information in the order that corresponds to the problem-solving process, agreement of the software output with the domain expert's corresponding solutions, and suitability of information about how conclusions are obtained, are the considerations that were taken into account to validate the MCESC. In MCESC validation, three validation techniques were implemented. The following sections illustrate these techniques in more detail.

Preliminary validation

MCESC was presented to a group of experts from different organizations. A combination of open-ended and close-ended questions was provided to the evaluators to judge the satisfaction and acceptability of each feature, such as system starting, system interface, user friendliness, explanation facilities, system utilities, knowledge usability, and overall system performance on a subjective weighting scale based on evaluation concepts previously mentioned (Durkin 1994). The evaluator's acceptance of the system is subjective, which is why their judgment was transformed in a comparative rating scale according to the Likert scale (Shaughnessy & Zechmeister 1990). This scale classifies the satisfaction of evaluators on the features of the expert system into five levels, namely, poor, weak, average, good, and excellent. This approach can integrate a numeric weighting scheme that can provide an overall score of the system. Using this method, the scores are given by the evaluators according to their satisfaction range of 1 (poor), 2 (weak), 3 (average), 4 (good), and 5 (excellent). The following hypothesis was adopted for preliminary testing:

Null hypothesis \( H_0: \) MCESC overall performances have no effect on the evaluator's attitude.

\( (H_0: \mu = 3, \text{ medium value of the Likert's scale}) \)

Alternative hypothesis \( H_1: \) MCESC overall performances affect the evaluator's attitude.

\( (H_1: \mu \neq 3) \)
The $t$-test is applied in this case. The estimated value of the $t$-test is obtained from Equation (4):

$$
t = \frac{\bar{X} - \mu}{S/\sqrt{N}}
$$

where

- $\bar{X}$ = Sample mean (mean of the scores in a feature)
- $a$ = median value of the Likert's scale (3)
- $S$ = sample standard deviation (standard deviation of a set of feature values)
- $n$ = sample size (number of MCESC evaluators).

Statistical analysis ($t$-test) was used to test the attitude of evaluators, with five indicating that a high significance is present between the median value of the Likert’s scale ($\text{median} = 3$) and mean values assigned by the evaluators for the general performance of each system. The mean values of all the features are usually higher than the median value of the Likert scale. This finding indicates that the evaluator’s attitude about the system functionality and performance is positive, and the testing results are satisfactory. The evaluators accepted the MCESC and trusted its performance in erosion and sediment control in development sites in Malaysia. Hence, the null hypothesis was rejected, and the alternative hypothesis was accepted.

Field validation

The results obtained from the MCESC software were compared with the EMP and ESCP for one construction site in Malaysia. The site selected was a road construction project in Permas Jaya, located in Johor Bahru State in the southern part of Malaysia. The development of the project will be the culminations of two stations. The first section covers a total length of 6.8 km, whereas the second section will develop bridges over river Lunchoo, river Rekoh, river Masai and the Clover Leaf overpass and covers a total length of 8.3 km. The site has a major impact to the adjacent rivers since the amount of cut and fill and the expected sediment to be generated are quite high. The knowledge engineer divided the system into five major tasks to achieve simplicity and knowledge organization. In each task, the type of data required, options to select, user selections, and MCESC recommendations were addressed. When the data input process was completed, results of the MCESC were determined and compared with the EMP and ESCP reports of the site. The purpose of undergoing this process is to test the system capability and to analyze whether it behaves like an expert in solving various problems related to erosion and sedimentation due to storm water in Malaysian construction sites or sites where the ESCP and EMP implementation are mandatory. Results obtained from the MCESC software were evaluated by experts, and the software was pronounced satisfactory.

Turing test

When the response of a computer along with those from a human is being presented to a blind evaluator, the process is called the ‘Turing Test’ (Durkin 1994). If an evaluator is not able to distinguish between the computer outputs from that of the human, then the computer is considered as intelligent as the human. With the Turing test, an external expert or a panel of experts evaluates solutions generated from the expert system.

To apply the Turing test in validating the MCESC, seventeen sets of problem causes were randomly sampled from each module. The MCESC consultation for the selected problems was compared with those of external experts. For conducting the Turing test, the Chi-square test which is a statistical tool has been applied. The following hypothesis has been adopted:
There exists no distinguishable difference between system and experts.

Some evidence exists for differential ability between system and experts in this task.

The following formula (Equation number (5)) has been used:

$$X^2 = \sum \frac{(O - E)^2}{E}$$

where:

O: The observed frequency of an outcome
E: The theoretical or expected frequency of an outcome.

The results obtained from the Chi-square test indicate that there was no significant difference between the expected outcome and observed outcome of the external expert opinions and the MCESC in solving the same problem. This is the reason why, the null hypothesis is accepted. This means that MCESC is able to function as good as human experts.

CONCLUSIONS

The current study presented a knowledge-based expert system (MCESC) for minimizing erosion and sedimentation generated from construction activities in Malaysia. The MCESC system consists of three major tasks. The first one is BMP consultation, the second task is the selection of the best alternative via the MCA engine, and the third is a thorough inspection and maintenance program (applicable to any construction site in Malaysia). The MCESC system provided recommendations almost like a human expert, based on a comparison of the results obtained from the on-site engineer and the expert system results besides expert’s opinions besides using the Turing test. The MCESC system can save time that is otherwise wasted when a consultant is not available. Furthermore, a consultation is costly and requires further financial allocations to the project. MCESC can be considered as a ‘Green Technology’ tool since it participates in preserving/protecting the environment. The target end users of the system are engineers, consultants, contractors, and decision makers. MCESC can be updated for application in other regions/countries that interested with the same tropical climate.

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