Developing Policy for Suitable Harvest Zone using Multi Criteria Evaluation and GIS-Based Decision Support System

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Abstract

Natural resources management often entails making choices among alternatives. Decision support tools are instruments for making rational decisions, particularly geographical information system (GIS) technology-incorporates the multi criteria evaluations (MCE) and analytic hierarchy process (AHP). Therefore, the objective of this study is to determine the suitable forest harvest zone in hill tropical forest in Peninsular Malaysia using MCE and GIS as a tool for decision support system. The implementation of the AHP method for MCE has shown the capabilities of integration of a GIS and decision support system, where the data was prepared spatially in a GIS, an analysis is performed with the systematic evaluation method. The MCE allows both constraint and criteria maps to be combined in arithmetic operation in a suitability analysis, and also allows for criteria maps to be assigned variable weights. From the weights derived from the AHP method, it can be seen that slope and elevation were strong factors in allocating the suitable harvest zone (0.63 and 0.29). The hydrological aspect is the third most important factor, with 0.07. The total suitable area for productive forest zone was 9757.30 ha (96.06%) and the designated protected forest was about 399.20 ha (3.94%). This implies the importance of certain forest land to be classified as a restricted area for logging purposes to ensure the sustainable forest ecosystem and water resources. This result demonstrated that the methodology used has high potential and functionality for determining suitable forest harvest zone from several criteria for hill forest. Finally, it can be concluded that, MCE incorporating GIS provides an ideal tool and essential in modelling with flexibility and the ability for spatial modelling operation for site suitability study in hill forest of Peninsular Malaysia.

Keywords: Suitable harvest zone, Geographical information system, Multi criteria evaluation, Analytical hierarchy process

1. Introduction

Environmental pressure and increasing harvesting operations in hill tropical forest are observable in Malaysia. Currently, Malaysia has been practising sustainable forest management with the formulation of Malaysian Criteria and Indicators (MC & I), in compliance with the rules and procedures of the International Timber Tropical Organization (ITTO) and ISO 2001 for its forest. MC & I comprise various activities and standards of performance: specific policies, regulation, procedure, plan and guideline for international certification purposes. Khali (2001) reported some of the MC & I guideline was no harvesting operation on the slopes above 40 degrees, and adequate buffer zones reserved on river banks, for soil and water protection. Allocation of suitable forest harvest zones involves decision making on how to use available forest land to satisfy user need and environmental constraints. Marshal (1988) states that the decision is based on several ecological criteria and that user preference are often conflicting. Thus, in making a decision, the impact of satisfying each objective and environmental aspects must be considered. A participatory decision making process using a GIS as a support tool can help in solving technical and logistical problems.

Although the use of the standard GIS alone can greatly assist in selecting harvesting zones that simultaneously satisfy pre-determined criteria, it does not assist the user with specific tools for evaluating and making decisions about problems involving multi criteria evaluations (MCE) and potentially conflicting objectives (Carver, 1991). The advent of GIS and its modelling capabilities allows this process to be automated and make forest zoning procedures more efficient and timely. A GIS handles enormous amounts of data that become information when a model is used to transform the data into the evaluation of possible courses of action. MCE provides a means of structuring the information needed to assess complex decision problems for determining suitable forest harvest zone. With the recent developments in GIS, forest managers increasingly have available information systems with more accessible, easily combined and flexible data that meet the requirements of environmental decision making. In these circumstances, it is expected that the decision making process should become better informed, more easily and consistently.

The objective of this study therefore to determine the suitable forest harvest zone in hill tropical forest in Peninsular

Malaysia using MCE and GIS as a decision support system. The zoning objective is to define the protected and productive forests. The protected forest zone is to safeguard water supply and prevent soil erosion, and the productive forest will supply in perpetuity wood resources for the socio-economic development of the country.

1.1 Multi criteria evaluation (MCE) and GIS

Multi criteria evaluation is a structured process to define objectives, to formulate criteria and to evaluate solutions to a decision problem (Pullar, 1999). Many land-related problems require the evaluation of multiple criteria based upon spatial properties and preferences.   GIS provides the processing capability to assess spatial criteria as a part of a multi criteria evaluation (MCE) procedure (Carver, 1991). The benefit of using a geographical information system (GIS) is that constraints can be based upon spatially related data, such as distance to a road. GIS is a suitable computing tool for performing the MCE analysis (Jankowski, 1995).

The most prevalent procedure for MCE and GIS integration for land suitability analysis use the linear weighted combination (LWC) approach developed by Eastman et al (1995).   In this approach, land information is transformed to a set of factors over the study area. These factors are combined by applying a weight to each factor, followed by overlay summation to obtain a suitability map. This map can be used directly to satisfy a single objective or multiple objective analysis procedure applied to allocate areas according to the highest ranked objective.   It can include judgment by the decision maker (as factor and weight) to influence the result. The suitability, S is computed as:

$$S = \sum (A_i \ X \ W_i) \ ………………………..(1)$$

where,

S   = Suitability

A_i = Criteria score of factor i

W_i = Weight of factor i

The logic that lies behind multiple criteria evaluation is to compute a combined suitability score for each location, and then rank the most suitable location to arrive at the best solution as illustrated in Figure 1. A set of standardised factors A_i and their respective weights W_i are combined by additive computation to produce a suitability map S. In most applications there is an additional step to identify the best sites R using a decision rule based upon a heuristic choice. Typically this is done by priority ranking the values in S and allocating the best number of sites. An example would be identifying the best amenity areas in a forest as a combination of factors for proximity to walking tracks and streams, moderate relief, and away from conflicting land uses such as logging. These factors can be computed using a cartographic model (Tomlin, 1991). Once a combined suitability score is obtained by equation above, then a specified number of hectares are chosen from the highest ranked values for further investigation as amenity land uses. Linear weight combination (LWC) of factors A_i to derive suitability scores S are evaluated by simple decision rules (e.g. choose best site R from rank order of S). In summary, a linear combination technique can be used to evaluate suitability areas and to assign the best area for a specific activity.

A primary issue in the evaluation is to assign weights to each criterion separately. A set of relative weights for influential criteria has to be developed in advance to be used as input for suitability evaluation. In this case analytic hierarchy process (AHP) is appropriate method for deriving the weights. The application of AHP in decision making was developed in the late 1970's and has become one of the most widely used techniques as shown by the extensive literature published in journals and books, mostly in areas outside natural resources management (Schmoldt et al., 2001). The AHP allows users to assess the relative weight of multiple criteria (or multiple alternatives against a given criterion) in an intuitive manner. Its major innovation was the introduction of pairwise comparisons-research which showed that when quantitative ratings are unavailable, humans are still adept at recognizing whether one criteria is more important than another. The AHP method established a consistent way of converting such "pair wise" comparisons into a set of numbers representing the relative priority of each criteria.

Several applications to forestry can be found in published material including forest management (Schmoldt et al., 1994; Mendoza, 1997); forest planning and decision making (Kangas et al., 1992, Pukkala and Kangas, 1996). As land use and land resources become more constrained and the land allocated to various activities continues to shrink, suitability analysis takes on added importance. The MCE and AHP processes not only offer some advantages over traditional decision methods, but can be integrated with other approaches such as spatial decision support systems involving GIS to take advantage of their strengths.

2. Materials and method

2.2 Description of study area

The study area is in the Sungai Tekai forest reserve in Pahang State, Peninsular Malaysia, about 240 km north-east of the Kuala Lumpur city. It is situated within latitude 04°10´N - 04°30´N and longitude 103°03´E - 103°30´E, covering an

area of approximately 10,000 hectares (Figure 2). The forest area is composed of mixed virgin hill forest, high in species diversity with predominance of Shorea species such as Meranti Seraya (*Shorea curtisii*) and Meranti Rambai Daun (*Shorea acuminate*). The elevation is mostly over 600 m above sea level. The slope gradient of the study area is undulating with steep rugged slopes ranging from 100 to 800. The annual precipitation is about 210cm with a high tropical climate with mean temperatures ranging from 20^0C -31^0C. The precipitation occurs mainly in two seasons: April to May and November to December. The relative humidity is high ranging from 62.3% to 97.0%, with a daily mean of 85.7%.

2.3 Methods

To meet the objective, several criteria needed to be identified, integrated and evaluated. The approach utilised, as the basis for the identification of a suitable harvest zone in hill forest was using spatial decision support system and MCE process. The suitability map were ranked and grouped in order to identify the zone of forested land that is most suitable for the harvest operation. This zone met the requirements specified by the chosen criteria. When determining suitable harvesting zone, the goal is to minimize negative environmental effects in the forest area. The cartographic model for the suitable allocation and the proposed solution from the decision support system are summarized in the flow chart shown in Figure 3 and 4.

2.4 Set the objective

Although the objective of the study is to determine a suitable zone for forest harvesting within the study area, the system also considers complementary objectives. Complementary objectives need to be satisfied simultaneously, e.g. the area can be zoned to combine for productive forest and protected forest. The selection of both areas must satisfy the objectives.

2.5 Collection and collation of data

The inputs to the GIS include various digitised databases of maps, remote sensing data, information from tables and reports. The selection of data sources should be influenced by the nature of the problem to be investigated. The collection of data to generate a GIS layers for this study are topographical map (scale 1:50000) and forest resource map (scale 1:50000).

2.6 Database design and development

Database design involves the identification of information required for the GIS analysis. Most of the data were available in analogue form, and then organised into GIS database to facilitate spatial modelling to generate new information and support decision making. The data were edited, georeferenced and topology constructed to make them usable for next step in GIS analysis. Simultaneously, database developments came together with the criteria which were selected. Criteria were presented as continuous value maps. Four criteria and constraint maps were created. The GIS database design in the study is shown in Table 1.

2.7 Identification/selection of appropriate criteria

Identification of criteria is a technical process, which is based on theory, empirical research or/and common sense. In this study, criteria identification was done through consulting with a group of professional foresters and the Pahang Forest Department about the suitable zone for harvest operation. In this section, the criteria for determining the suitability of forest zone for harvest are provided. It should be noted that this selection is not exhaustive, and that only those criteria for which information is available were considered. Soil series is excluded in this study because the land is covered by virgin forest, and from the foresters' point of view the soil series is not a critical for determining a suitable harvest zone.

In planning the zoning, extreme pressures of environmental constraint can be restricted to more fragile ecosystems. Two criteria groups comprising four separate sets of forest geo-environmental attributes were used for the suitability evaluation (Table 2). They are topography (slope and elevation) and hydrological aspect (River buffer and lake buffer). Topography is an important determinant of suitability assessment. Elevation is considered because high forest areas suffer from inaccessibility, are fragile to any disturbance and it is important to protect them. Slope is even more important when considering the ease of engineering forest road construction and susceptibility to land sliding. Since pollution is a concern, river buffer and lake buffer areas was taken into account due to their importance in protecting the water resources from soil erosion. The distance of harvest area to the water sources were important to control debris flow during the rain season.

2.8 Standardization (rating) of criteria

In the evaluation process of the criteria, a primary step is to ensure a standardization measurement system across all the criteria considered. Since most of the maps still hold their own cell or original value, these have to be standardised to a uniform suitability rating scale. The standardization of criteria needs to combine the factor layers in creating a single ranked map of suitability ratings for the suitability harvest area.   In this case study, scales of 1 to 4 are used. Assigning

values to specific factors amounts to making of decision rules in the shape of a threshold for each criterion. Numbers ranging from 1 to 4 were assigned to not suitable, marginally suitable, moderately suitable, and highly suitable, respectively. The fundamental terms of land suitability are adopted from the FAO framework 1977 and re-defined in forestry applications.

Standardization is performed by assigning numeric values to different levels of suitability within each factor, map layer or theme. In this standardization, it should be noted that statistical and empirical guidelines from the related national code and literature were used to determine the boundary value for rating purposes. In this case, broad categories of forest zone from the Forestry Department of P. Malaysia were applied. They were Productive Forest and Protected Forest as clarified in Table 3. The standardization criteria for these forest zones were divided into forest zone from an economic point of view and forest function. The parameters use for setting the suitability threshold with regard to economic reason were taken from National Forest policy 1992 and National Forestry Act 1993,report by Muziol (1999) under a Malaysian-German Technical Cooperation Project for sustainable forest management and conservation. In designing a hydrological buffer, reviews of related scientific literature were carried out (see Wenger, 1999; Hodges and Krementz, 1996; Keller et al., 1993; Kinley and Newhouse, 1997, Spackman and Hughes, 1995 and Mitchell, 1996). Table 4 show the class boundaries and standardised measurement employed for each criterion.

2.9 Allocation of criteria weight

A weighting process is subjective and is carried out through pairwise comparison between the criteria. Different criteria usually have different levels of importance. The analytical hierarchy process (AHP), a theory for dealing with complex technological, economical, and socio-political problems (Saaty, 1977; Saaty, 1980; Saaty and Vargas 1991), is an appropriate method for deriving the weight assigned to each factor. The weighing scale used consists of nine qualitative terms that are associated with nine quantitative values (Table 5). When the criteria on the vertical axis are more important than the factors on the horizontal axis, this value varies between one and nine. Conversely, the value varies between the reciprocal 1/2 and 1/9. The pairwise comparisons are the input of the AHP model that calculates the relative priority of each criterion. In calculating the relative priorities, AHP uses the eigenvalues and eigenvector of the pairwise comparison matrix (Saaty, 1980). However, in this study an approximation approach was applied because it is much easier to understand.

The pairwise comparisons are represented in a matrix as shown in Table 6. Three criteria, elevation, slope and hydrology, are the most appropriate for determining the suitability area for forest harvest zone based on the foresters opinions. This matrix reflects the fact that slope criteria are preferred to elevation criteria, and very strongly preferred to hydrology, while, elevation is strongly to very strongly preferred to hydrology. The main diagonal is always equal to unity (1st). The reciprocal values are allocated to the comparison: for example if the criteria of elevation are allocated the value of 6 relative to hydrology, then the hydrology criteria should receive a value of 1/6 relative to elevation. For each column the totals are calculated. The columns are then normalised by dividing each value by its column total. The normalised pairwise matrix is displayed in Table 7. Finally, Table 8 shows the relative importance or priorities for each criterion, determined by calculating the mean of the value in a row of Table 7. Thus, in this case, the following weights for the three criteria are obtained from the matrix in Table 7(Slope: 0.298, elevation: 0.632, and hydrology: 0.069).

2.10 Consistency ratio

In the construction of this pairwise comparison, the consistency of the judgement should be revealed because this matrix is a consistent matrix. To examine the consistency of selection of pairwise comparison, the parameter used to determine whether the result is acceptable or not, consistency ratio (CR) can be used (Saaty, 1977). A consistency ratio of the order 0.10 or less is a reasonable level of consistency. A consistency ratio above 0.10 requires revision of the judgement in the matrix because of an inconsistent selection of particular criteria rating. The consistency ratio (CR) was determined by the following process. The matrix for the criterion is made as follows:

$$\begin{vmatrix} 1 & 1/3 & 6 \\ 3 & 1 & 7 \\ 1/6 & 1/7 & 1 \end{vmatrix}$$

The relative importance (weight) determined for each criteria were elevation; 0.298, slope; 0.632 and hydrology; 0.069. From the weight, the Weighted Sum Vectors were evaluated by multiplying these two matrices:

$$\begin{vmatrix} 1.000 & 0.333 & 6.000 \\ 3.000 & 1.000 & 7.000 \\ 0.167 & 0.143 & 1.000 \end{vmatrix} \quad X \quad \begin{vmatrix} 0.298 \\ 0.632 \\ 0.069 \end{vmatrix} \quad =$$

(1.000 X 0.298) + (0.333 X 0.298) + (6.000 X 0.298)	=	0.923
(3.000 X 0.632) + (1.000 X 0.632) + (7.000 X 0.632)	=	2.009
(0.167 X 0.069) + (0.143 X 0.069) + (1.000 X 0.069)	=	0.209

From the weighted sum vector, the Consistency Vector was calculated by averaging the weighted sum vector:

	0.923 / 0.298		3.097	
Consistency vector =	2.009 / 0.632	=	3.179	
	0.209 / 0.069		3.029	

The average value of the above results were get (λmax) in the Consistency Vector were as follows:

$$\lambda_{max} = \frac{(3.097 + 3.179 + 3.029)}{3}$$

$$= 3.102$$

Now, the *Consistency Index* (CI) can be calculated using the following formula:

$$CI = (\lambda_{max} - n)/ n - 1$$

Where λ_{max} is the largest or principle eigenvalue of the matrix and can be easily calculated from the matrix, and *n* is the order of the matrix or criteria.

$$CI = \frac{(\lambda_{max} - n)}{n - 1}$$

$$= \frac{3.102 - 3}{3 - 1}$$

$$= 0.051$$

The Consistency Ratio, which is a measure of how much variation is allowed, can now be evaluated from CR = CI/RI, where RI is the Random Index depending on the order of the matrix (n) given by Saaty (1977) in the following table:

n	RI
2	0.00
3	0.58
4	0.90
5	1.12
6	1.24
7	1.32
8	1.41

For the selected criterion, the *Consistency Ratio* is:

$$CR = \frac{0.051}{0.58}$$

$$= 0.088$$

In this case the consistency ratio of the matrix of paired comparisons between the three influential criteria in the suitability assessment is 0.088, and is thus an acceptable range for consistency. Once a satisfactory consistency ratio is obtained, the resultant weights are applied. The weight should add up to a sum of 1.0, as the linear weight combination calculation requires. The final step in the multi criteria AHP is to combine the average normalised criteria with the criteria scores to produce an overall rating for each criterion for suitability index.

2.11 The constraints

In order to achieve the objective to define protected zones, three constraints were identified which restrict the area that can be harvested. The constraint is referred to as the local regulation and guideline. The following constraints were

specified and shown in Table 9. The constraints were expressed in the form of a boolean map in a GIS. The area which is excluded from consideration was coded zero (0) and the area which remains for consideration was coded with a one (1).

2.12 Multi criteria evaluation (MCE)

MCE with a complementary objective approach was used in modelling the suitability forest harvest zone. MCE evaluation is used to combine a set of criteria to form a single suitability map according to a specific category. The proposed approach in this study is based upon satisfying a set of constraints in the evaluation. This is illustrated in Figure 5. As before (Figure 1), the suitability zone, S, is derived with a linear weight combination (LWC) procedure, but now the decision rule weight the choice of the best area by considering a set of boolean constraints. Constraints are areas which have no suitability. The relationship can be expressed mathematically as:

$$S = \sum (A_i \times W_i) \times \pi C_j \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..\ldots(2)$$

where,

S   = Suitability to the objective

A_i = Criteria score of factor i

W_i = Weight of factor i

C_j = Value of constraint j (0/1 of constraint j)

π   = Product of constraints

2.13 Data analysis and modelling

The true strength of GIS lies in its functionality of spatial analysis and modelling. Model based-raster data were utilized in this study. According to David (2002) raster is grid cells with a fixed number of row and columns that have several tables associated with them. Raster is different from vector data model because they may represent a continuous surface instead of a discrete feature. GIS data within raster model have several advantages relative to the vector GIS data. Raster allows for faster analysis and operation, especially for any overlay and buffer type analysis (Dangermond, 1990). Raster also allows for modelling continuous surfaces such as determining optimal path through a surface. For this reason the raster data model was primarily utilised in this study. The raster grid cells were defined and represented at 5m resolutions. This permitted a closer approximation of spatial continuous geographic features.

Several map based raster cells were then generated, especially the distance calculations between raster cells (e.g. distance from river buffer and lake buffer). The data layer of criteria that affect the suitability of the forest harvest zone were then reclassified so that they could be used as the rating maps required in this process. The calculated weight values were then transferred to the Arc View GIS, to create a suitability map with a value range per cell matching that of the standardised criteria map using a range 1-4. For the suitability maps a four equal interval classification between the minimum and maximum cell value calculated was employed, e.g. assigning the four ranges in increasing order, from not suitable, marginally suitable, moderately suitable, and highly suitable, respectively. Criteria and constraint maps were combined using the map calculation function to produce a suitability site for the proposed harvest zone area using equation (2). Finally, the resulting raster map was then vectorized. The final maps of constraint and suitability area are illustrated in the results and discussion section.

2.14 Preliminary criteria and constraint maps

After the Multi-Criteria Evaluations were performed for the three groupings of criteria, preliminary MCE maps were created illustrating the areas that were most suitable for the locating of forest harvest zones related to slope, elevation and river buffer. The constraint map that illustrates suitable and unsuitable areas for harvesting forested land in terms of slope, elevation, river buffer and lake buffer was also created.   The rationale of dividing criteria and constraints into preliminary maps and then a final suitability map was based on two main reasons;(i) The division of criteria allowed for several 'checkpoints' to ensure that maps were being produced properly;(ii) This method allowed for criteria to be weighted within the preliminary MCE's based on their priority, but the weighting between the preliminary MCE's was equal. Thus, the priority of slope, elevation and river buffer could remain equal, yet the factors within each MCE had already been considered in the creation of the preliminary maps.

3. Results and discussion

The suitability harvest zone was divided into two stages. The preliminary stage outlined two main classes: (1) suitable and (0) not suitable. In the next stages, suitable class was further divided into different levels of suitability. The area illustrates the not suitable to highly suitable area using the scale of 1 to 4 categories and excludes all areas deemed unsuitable by the constraint map. The modelling results at this stage are highly sensitive to the weights applied (Van der Merwe, 1997; Dai et al. 2001). The priority weights assigned to various criteria will have an effect on the results. The final constraint map and final combined criteria map from the economic perspective for suitability harvest zone is

shown in Figure 6 and 7. The final suitable forest harvest zone map from economic perspectives was obtained by calculating weighted overlap map in arithmetic overlay function by combining the two images to produce images as shown in Figure 8.

Most of the forest area in Sungai Tekai Forest Reserve was identified as being suitable for harvesting. The forest harvest zone is clearly concentrated in the area where high topographical, steep slopes and hydrological buffer areas are avoided. This is to be expected as all of the contribution criteria for suitability harvest area are included. The major areas that are identified as suitable for harvesting lie on the south-west region of the study area. The area is appropriate since it is located below 1000 m and on slopes lower than 40 degrees. The unsuitable area is located in the eastern region. The areas identified as not suitable for harvest operations were more strongly influenced by slope and elevation than by other criteria. Statistically, the preliminary analysis of the entire study area showed that the suitable harvest zone area was about 9215 ha. There are only about 941 ha. were classified as not suitable from the economic perspective, thus remaining as a protection forest zone. This area embraces the established constraints such as excessive slope, and steepest terrain and is located in fragile zones like river and lake buffer. Tabular results were illustrated in Table 10.

The second stage of suitability classes included marginally suitable, moderately suitable, highly suitable, and not suitable classes. The predominant classes were highly suitable, followed by not suitable and moderately suitable. The substantial difference in classes between the preliminary stage and second stage is due to the fact that an individual weight for each spatial layer in GIS was included according to their importance to forest management and development. Traditionally, the evaluation and mapping suitable harvest zones were laborious and time consuming tasks because of the large amounts of data required for the manual handling and processing of spatial data. The implementation of this procedure produced a high degree of consistency and reduced time and field evaluation.

The use of MCE and AHP will enable the forestry department to evaluate the option of forest harvesting operation more thoroughly, quickly and flexibility. Thus, more forest area such as Permanent Forest Reserve can be classified into productive and protected forest, before harvesting operations take place. Hence, planning future forest harvesting areas will exclude the protected forest zone. This will reduce the areas that have potential for harvesting. This is in line with sustainable forest management practice in Malaysia. Furthermore, the system also enables planners to visualize the forest area in spatial format. The spatial map can show the spatial implications of the decision as a platform for discussion and negotiation between the forestry department and loggers.

4. Conclusion

The study of site suitability modeling and GIS draws knowledge from a wide range of disciplines; land suitability analysis, multi criteria evaluation, AHP weighting method, cartographic modeling and decision making theory. This study revealed that integrating GIS and MCE for decision making in the allocation of suitable forest harvest zones from several criteria can be important in the forestry sector. The total suitable area for productive forest zone from economic perspective is 9757.30 ha (96.06%) and the designated protected forest is about 399.20 ha (3.94%). The environmental perspective is very different, where the productive zone represents about 8221.59 ha. (80.95%) and the protected zone was 1934.90 ha. (19.05%). This implies the importance of certain forest land to be classified as a restricted area for logging purposes to ensure the sustainable forest ecosystem and water resources. The implementation of the AHP method for MCE has shown the possible integration of a GIS and decision support system, where the data is prepared spatially in a GIS, an analysis is performed with the systematic evaluation method and the result of the analysis is displayed in the cartographic form. The MCE method and GIS technology that used raster based applications are practical to use. An MCE allows both constraint and criteria maps to be combined in arithmetic operation in a suitability analysis, and also allows for criteria maps to be assigned variable weights. The technique can be easily replicated and the model could be improved with time for other forestry applications. The determination of weights for applied criteria is one of the most important challenges. From the weights derived from the AHP method, it can be seen that slope and elevation were strong factors in allocating the suitable harvest zone (0.632 and 0.298). The hydrological aspect is the third most important factor, with 0.069. It can be concluded that, MCE incorporating GIS provides an ideal tool and essential in modelling with flexibility and the ability for spatial modelling operation for site suitability study in P. Malaysia.

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Table 1. GIS database design

GIS database		
Topography	**Hydrology**	**Forest resource map**
Contour map	River	Forest boundary
Slope map	River buffer	Forest compartment
Elevation map	Lake	Timber volume map
Aspect map	Lake buffer	

Table 2. The criteria and justification in determining suitable harvest area

Criteria	Justification
Elevation (m)	The suitable harvest area should not be high because the high forest area requires protecting from excessive erosion.
Slope (Degree)	The suitable harvest area should not be on very steep slopes. It is important because of the safety and accessibility of the transportation.
Hydrological aspect (River and Lake buffer)	Harvest operation should avoid rivers and lakes. This is to protect water quality, lake ecosystem and to control the erosion of soil and debris into the water point. The establishment of hydrological buffer zone is also to protect wildlife an aquatic life.

Table 3. Definition use for Productive and Protected Forest.

Forest zone	Definition	Remark
Productive forest	This definition embraces forest area that can be harvested for the purpose of timber extraction and revenue collection. Intended to ensure supply in perpetuity of forest yield, principally timber for domestic purposes and export earning. However, the level of management or intensity of exploitation may be defined and change according to the current need and forest conditions.	The standardization was obtained from literature that refers to each criterion use.
Protected forest	Forest area legally under protection by legislation and guideline by Malaysian Forestry Department. This area must avoid any encroachment or any type of development. The protection is given priority to excessive slope, elevation and hydrological system. This includes protecting soil fertility and minimising damage by flood and erosion.	Authorised by legislation and local regulation/policy. Main objective is to protect physical condition of forest soil and environmental quality

Table 4. Standardization rating of each criterion from economic perspective

	Standardization rating/score			
Forest Zone	**Protected Forest**	**Productive Forest**		
Criteria	1	2	3	4
Slope (^{0})	$> 40^0$	$20^0 - 40^0$	$10^0 - 20^0$	$0^0 - 10^0$
Elevation(m)	$> 1000m*$	$< 1000m$		
River buffer(m)	0m-20m	$> 20m$		
Lake buffer(m)	0m-20m	$> 20m$		

1-Not Suitable; 2-Marginally Suitable; 3-Moderately Suitable; 4-Highly Suitable

*A new ruling by the Forestry Department P.Malaysia prescribed that harvesting not permitted beyond elevation of 1000 m asl.

Table 5. Scale for pairwise comparisons

Numerical judgements	Verbal judgements
1	Equal importance
3	Moderately preferred
5	Strongly preferred
7	Very strongly preferred
9	Extremely preferred
2,4,6,8	Intermediate values between adjacent scales.
Reciprocals	For inverse comparison (when compromise is needed)

Table 6. The full pairwise comparison matrix for assessing the weight of criteria

Criterion	Elevation	Slope	River Buffer
Elevation	1	1/3	6
Slope	3	1	7
Hydrology	1/6	1/7	1
Total	4.167	1.476	14

Table 7. The normalised pairwise comparison matrix

Criterion	Elevation	Slope	River Buffer
Elevation	0.240	0.226	0.429
Slope	0.720	0.677	0.500
Hydrology	0.040	0.097	0.071
Total	1	1	1

Table 8. The relative importance (weight) for the criterion.

Criterion	Elevation		Slope		River Buffer		Weight
Elevation	0.240	+	0.226	+	0.429	=	0.298
			3				
Slope	0.720	+	0.677	+	0.500	=	0.632
			3				
Hydrology	0.040	+	0.097	+	0.071	=	0.069
Consistency ratio: 0.088			3				

Table 9. Three constraints identified in finding suitable harvest area

Constraint	Justification
Elevation (m)	No harvesting operation on elevation more than 600m* (from environmental perspective) and 1000m**(from economic perspective). The high forest area is very fragile and subject to excessive erosion, land sliding and it is important to protect the forested highland water resources. *Note:* **Environmental perspective applies the old ruling adopted by most of the states, harvesting is limited to below elevation of 600m asl.* ***A new ruling by the Forestry Department P.Malaysia prescribed that harvesting is not permitted beyond elevation of 1000 m asl.*
Slope (Degree)	No harvesting operation on slope more than 30 degree*(from environmental perspective) and 40 degree**(from economic perspective). Harvesting operation on the extreme slope is dangerous for heavy machinery and workers and difficult to access. *Note:* **Environmental perspective interest (Muziol, 1999)* ***Current threshold for timber production in Malaysia*
Hydrological aspect (Buffer zone)	No harvesting operation in < 20m* of sides of the river and surrounding lake (from economic perspective) and <100m**of sides of the river and surrounding lake (from environmental perspective). These hydrological aspects must be protected in order to supply clean water. On the other hand, buffer zone is required to protect the sediment flow entering the water course. *Note:* **Currently apply for riparian buffer by most States Forestry Department.* ***Environmental perspective interest: Streamside vegetation for stabilise stream bank.(National forestry Act 1993)*

Table 10. Total areas for each suitability ranking: Economic perspective

Stage	Suitability class	Area (m^2)	Area (ha)	%
Preliminary stage	Not suitable	9411138.61	941.11	9.26
	Suitable	92153908.52	9215.39	90.74
Second stage	Not suitable	3992046.24	399.20	3.93
	Marginally suitable	7032023.51	703.20	6.92
	Moderately suitable	9327394.62	932.73	9.18
	Highly suitable	81213582.73	8121.35	79.96
Forest zone				
Productive forest (Suitable for harvest)	Marginally suitable	7032023.51	703.20	6.92
	Moderately suitable	9327394.62	932.73	9.18
	Highly suitable	81213582.73	8121.35	79.96
	Total	**97573000.86**	**9757.30**	**96.06**
Protected forest(Including river buffer, lake buffer, elevation and excessive slope)	Not suitable	3992046.24	399.20	3.93
	Total	**3992046.24**	**399.20**	**3.93**

Figure 1. Land suitability modelling to derive best site R

Figure 2. A map of Peninsular Malaysia showing the study area in Pahang State.

Figure 3. A cartographical model for suitable zone allocation

Figure 4. Flow chart for GIS evaluation for suitable forest harvest zone

Figure 5. Land suitability modelling to derive best site R, with setting of constraint C

Figure 6. The final constraint map after combining constraint factors

Figure 7. The final combined criterion map for suitable harvest zone area

Figure 8. A suitable harvest zone map for the Sungai Tekai Forest Reserve.