International Business Research
www.ccsenet.org/journal.html
Vol. 2, No. 2
April 2009

The Economic and Environmental Impact of a Suitable Forest Harvest Zone Allocation Using a GIS Analysis

Hj. Kamaruzaman Jusoff (Corresponding author)
Yale University
Room 119-A, Centre for Earth Observation, Environmental Science Centre
21 Sachem St, New Haven, CT 06511, USA
Tel: 203-432-1384 E-mail: jusoff.kamaruzaman@yale.edu

Mohd Hasmadi, I
Surveying & Engineering Laboratory
Department of Forest Production, Faculty of Forestry
Universiti Putra Malaysia, 43400 UPM, Serdang, Selangor, Malaysia
Tel: 60-3-8946-7171 E-mail: mhasmadi@putra.upm.edu.my

Abstract

Many countries are gradually adopting environmentally acceptable harvesting planning strategies. Various codes of practice such as FAO model code of forest harvesting have been developed for use at the international, regional and national levels to improve harvesting practices following concepts of low-impact harvesting. Since the last 20 years lowland forest in Peninsular Malaysia has declined gradually, and this has pushed harvesting operations to the hilly areas. The extent of damage to the forest environment, especially in hill forest has been alarming, mainly due to the complexity of its topography that lead to soil erosion. This study develops an integrated model of geoinformatics technology applied to forest harvest planning. The model determines the distribution and extent of allowable forest harvest zone from economic and environmental perspective using cartographical modelling and linear weighted combination approaches in a GIS. This study uses remote sensing data and geographic information system technology for data extraction, manipulation, analysis and evaluation of impacts of the difference perspective for forest harvest zone. The study revealed that by integrating remote sensing and GIS modelling, a suitable harvest zone for harvesting operations could be determined from the economic and environmental perspective, thus the impact to areal extent of a suitable forest harvest were analysed and determined.

Keywords: Economic impact, Allocation model, Environment, GIS analysis, Forest harvesting, Planning

1. Introduction

Forestry is a major element of the natural resource of Malaysia and the effects of its activities on Malaysian communities and the economy play a key role in determining its management. The long association of forestry and the local community has created an understanding of the relationships between the socio-economic and environmental aspects of decision-making. Planning for the management of forest resources has become more complex and controversial in recent years. Public attitudes and values have been steadily evolving, and today are more diverse including in environmental issues (Davis, 1992). Because of the complex in forest ecology and its interaction involved in wise management, it leads to necessary to decision-making process.

In the last two-decades, concerns about the economic and environmental problems of forest harvesting in Malaysia have emerged. In many states legislation has attempted to overcome some of these problems by establishing a framework for forest management. At the end of 2002, Malaysia had an estimated 19.93 X 10^6 ha. of forest covering 60.7% (32.86 X 10^6 ha.) of its total land area. Of this total, about 14.33 X 10^6 ha. has been designated as the Permanent Forest Estate (PFE) under sustainable management, while 2.12 X 10^6 ha. are protected by legislation for conservation purposes. Currently, forest management practices in Peninsular Malaysia are based on the Selective Management System (SMS) with the main objective of optimizing timber harvest while maintaining the sustainability of forest production. In forest harvesting, the main issues in forest resource survey are in the forest area estimation and determination of the suitable harvest zone. These issues need to be investigated in order to meet the objective of sustainable forest management and reduce the impact of logging. One of the major requirements for improving resource management is the need to have enough data. The knowledge of resource availability is very important in order to evaluate timber stock and to monitor and assess forest conditions. Thus, estimating forest area for harvest is important for rapid survey and assessment (Deppe, 1994). Data regarding the extent and forest distribution are essential inputs for inventories and harvesting activities. Many factors are considered, especially when dealing with large areas, cost, time and difficult accessibility.

The value of forest land has risen because of changes in land use. While maximizing economic efficiency continues to drive changes in forest harvesting, and since 1990's it has been linked with efforts to minimize negative environmental impacts. Allocating suitable harvest zones for forestry is designed to guide forest managers, planners and decision makers with regard to the multiple uses of forestry. The allocation system has provides options for utilizing resources in the most economic way, and at the same time aims to conserve forest to safeguard the environment. The National Forest Policy for Peninsular Malaysia (1977) has supplied to forest planner and manager to analyze the impact of decision making on all forest resources, not just the standing timber. Generally, decision making in forest management follows three phases as proposed by Simmon (1960): intelligence, design and choice. Intelligence corresponds to identifying issues, concerns and opportunities. The basic tasks of the first phase include identifying public issues and management concerns, analyzing major conflicts addressed in the scope of management problem when responding to each problem. Design invents solutions to the problem defined by the intelligence phase. The process sets standards and benchmarks, formulates and develops alternatives, estimates the effects of benchmarks, constraints and alternatives. Finally, choice refers to the selection of a particular alternative, based on the significant benefits, cost and effects of the alternatives. Making a sound decision requires consideration of how present action will affect future forest patterns, species composition, and present and future economic opportunities. It is clear that the future of harvesting plans of tropical forest will be largely dictated by the availability of integrated information technology with spatial, non-spatial and computer systems. The ability of geoinformatics to integrate data and produce meaningful information makes it invaluable to forest management. The general objective of this study is to investigate the application of geoinformatics to sustainable forest harvest planning through remote sensing and GIS modelling in maximizing harvesting of timber resources with reduced impact of logging on the forest area. Therefore, the specific objective is to develop a method of using geoinformatics to determine suitability of timber harvest zones from economic and environmental perspective.

2. Materials and methods

2.1 Description of the study area

The Sungai Tekai forest reserve was located at Jerantut district of Pahang State, Peninsular Malaysia. 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 1). The study was demonstrated within a forest management compartment which consists of several compartments namely compartments 170, 171, 173, 174, 175, 176b, 196, 197, 199a, 199b and 200, respectively. This area is chosen because harvesting operation is still on going and the result of the study is needed by the State Forestry Department for further management and planning. 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 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 200C -310C. 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%

<Figure 1. A map showing the 3D view of the study area in Pahang State, Peninsular Malaysia>

2.2 Methods

2.2.1 GIS and multi criteria evaluation (MCE)

In this study GIS-based MCE was approach was applied in order to yield the allowable harvesting zone. Multi criteria evaluation is a structured process to define objectives, to formulate criteria and to evaluate solutions to a decision problem (Pullar, 1999). The procedure GIS and MCE used for land suitability analysis were using linear weighted combination (LWC) approach developed by Eastman et al (1995). Land information was transformed to a set of factors over the study area. These factors were then 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. The suitability, S is computed as:

$$S = \sum (A_i \times W_i)$$

where,

S = Suitability

A_i = Criteria score of factor i

W_i = Weight of factor I

A set of standardised factors Ai and their respective weights Wi are combined by additive computation to produce a suitability map *S*. Weighted Linear Combination (WLC) and concordance/ dis-concordance analysis (Voogd, 1983 and Carver, 1991) were applied in GIS based multi-criteria evaluation. From above equation latter, 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:

$S = \sum (A_i X W_i) X \pi C_j$

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

2.2.2 Identification 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 officer regarding the suitable zone for harvest operation. In this section, the criteria for determining suitability of forest zone for harvest were 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 1). 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.

<Table 1. The criteria and justification in determining suitable harvest area>

2.2.3 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 were adopted from the FAO framework 1977. Standardization was performed by assigning numeric values to different levels of suitability within each factor and map layer. 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. The standardization criteria for these forest zones were divided into forest zone from an economic point of view and forest function from an environmental point of view. The parameters use for setting the suitability threshold with regard to economic and environmental 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; Bren, 2003 and Mitchell, 1996). Tables 2 and 3 show the class boundaries and standardised measurement employed for each criterion.

<Table 2. Standardization rating of each criterion from economic perspective>

2.2.4 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. For this purpose, a set of relative weights for influential criteria should be developed in advance so that it can be used as input for suitability evaluation in the next step. In this regard, 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), was 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 4). 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.

<Table 3. Standardization rating of each criterion from environmental perspective >

3. Results and discussion

3.1 Restricted and suitability forest harvesting zone

The preliminary harvest zones were outlined into two classes namely suitable and not suitable. In the next stages, suitable class was further divided into different levels of suitability. The area indicates 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 cartographies results at this stage are highly sensitive to the weights applied. The priority weights assigned to various criteria were seemed 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 Figures 2, while from environmental perspective are shown in Figure 3. The final suitable forest harvest zone map from both perspectives was obtained by calculating weighted overlap map in arithmetic overlay function by combining the two images to produce images as shown in Figures 4.

<Figure 2 .The final combined constraint and criterion map for suitable harvest zone area from economic Perspective>

<Figure 3. The final combined constraint and criterion map for suitable harvest zone area from economic perspectives.>

<Figure 4. A suitable harvest zone map for the Sungai Tekai Forest Reserve from economic and environmental perspectives>

The major areas that are identified as suitable for harvesting lie on the south-west region, where high topographical, steep slopes and hydrological buffer areas are avoid. 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 suitable harvest zone result by preliminary analysis is about 9215 ha. from the economic perspective and about 7547 ha. from environmental perspective. There are 941 ha. were classified as not suitable from the economic perspective and 2610 ha. from the environmental 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. From the economic perspective, protected forest zones are smaller in terms of area due to application of different criteria ranking, which are much lower than applied in the environmental criteria. Tabular results of both views are illustrated in Tables 5 and 6.

<Table 4. Scale for pair wise comparisons>

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.

<Table 5. Total areas for each suitability ranking: Environmental perspective>

<Table 6. Total areas for each suitability ranking: Environmental perspective>

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.

3.2 Implications of suitable harvest area from economic and environmental perspectives

Two suitability maps were produced from different standardizations of criteria (i.e. economic and environmental perspective). The areas affected by constraints of two perspectives were compared using cell value distributions across the study area by histogram function. In specific slope class, slope cells with more than 30^0 and 40^0 were defined and the numbers of cells for both classes were examined. Slope class with more than 30^0 represent about 1.77% (cell value 121271), while the cell value above 40^0 is in a very small number percentage, with only 0.2 %(cell value 2673). This implies that the slope that falls in the restricted area for harvesting (>30^0 and >40^0) does not show a significant impact to the suitability harvest zone due the fact that the highest slope across study area is only 44^0. The similar analysis was performed on elevation in order to examine the distribution of cell value contained within the elevation grid. To compare the impact elevation cell from the economic and environmental perspectives, the class were classified into two classes. The elevation that has cells with a value of 0m-600m and more than 600m, 0m-1000m and more than 1000m can be determined. The histogram displays the elevations were between 0m-1000m (100.00% cell value) from the economic perspective and 0m-600m (79.23% cell value) from the environmental perspective. There were fewer concentrations above 600m (20.77% cell value) and none (0.00% cell value) outside 1000m and above. This indicates that the profile of elevation from both perspectives can have a significant impact on the suitability harvest area. River and lake buffer themes were merged to create a new name: the hydrological buffer theme. Comparison was made of the implication of buffers from economic and environmental perspectives. Hydrological cells also showed a significant suitability for harvest area. The total of hydrological cells from the economic perspective was 92793 cells. However, from the environmental perspective hydrological cells along rivers and surrounding lake were 445206, a different of 352413 cells (79.15%). A summary of cell values counted by constraint factors from two perspectives is shown in Table 6, while Figure 5 shows a comparison of their cell values.

<Table 7. Summary of cells counted and area affected by constraints from economic and environmental perspective>

It indicates that the suitable harvest area decreases when the environmental view is taken. The area changes from no limit to approximately 2512.76 ha (24.74%) due to changed elevation criteria from 1000m a.s.l to 600m a.s.l. Buffer criterion changed from 20m to 100m, and as a result the constraint area affected from only 873.32 ha to about 3619.8 ha, respectively. The difference in elevation threshold is affected most, due to the nature of the elevation of the study area which only ranges between 180m to 980m asl. This indicates that elevation criteria are not applicable from the economic view and the entire study area is permitted for harvesting. This is followed by hydrology criteria which show a significant difference of about 35.64 % for the environmental perspective and only 8.59% for the economic perspective. However the suitable harvest area is not significantly affected by slope characteristics because the threshold of slope is only changed by about 10^0. The difference in area from both constraints perspectives is only 7.78 ha, and is considered as a minor change.

<Figure 5. Comparison of cell value distribution for each constraint factor from two perspectives>

Table 7 summarizes the area for productive forest from economic and environmental points of view. Please note that the final area extent is made up by merging all the criteria and constraint factors which take into account overlapping cells. The table illustrates the productive and protected forest after combined constraint and criteria factors. The difference in area designated for productive and protected zone reflect the criteria applied to each perspective. A significant difference was found in the protected zones, which included approximately 79.38% of the area. However, only a small percentage of difference was determined in production forest (15.74%). The results presented herein have demonstrated the great potential of GIS-based multi criteria evaluation for different views of forest land use. Therefore, it needs to be emphasized that the reliability of the evaluation depends on several factors such as quality of database, the error arising associated with data entry, manipulation, and analysis within GIS.

Allocation of forest land use and making decisions on how to use available forested land causes conflict among land users. The result of this process gives the different users a chance to view the allocation area from different perspectives before a final allocation is made. The key point for this comparison is to look into the feasibility of mutual benefit from two points of view. In other words looking into how much the suitable harvest zone is influenced by the different criteria used. Thus, the results of the map shown here are good for initial planning purposes and making judgments on which criteria threshold are more or less important from two points of view.

<Table 8. Comparison of suitable harvest area from economic and environmental view>

4. Conclusions

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 effected area from 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%), respectively. 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. However the model could be used to refine the criteria in the future, particularly for further exploitation of GIS for optimisation of forest production activities. The use of GIS as a tool for planning processes is recommended, specifically when forest land use patterns are intensive, and developments must be sensitive to environment issues, as in most parts of the tropical forest area in Malaysia. The role of the decision support system in this study is to assist the user and decision maker in selecting the optimal areas from two different perspectives. The significant advantage of the use of MCE-GIS in this study is that the model generated of the suitable forest harvest area can be presented as geographical areas and understood by the public. GIS has the ability to handle large amounts of spatial data which allows for the creation of constraint maps and criteria maps that determine sites that are either suitable or unsuitable by providing a given proximity to a given feature. The model provides a number of criteria, which can be scaled up or scaled down in order to achieve the objective. Another advantage is that the same general model of decision support system can be applied to any region of forest area that requires strategic environmental consideration. Furthermore, this model is an excellent basis for further study in decision making process and can be used as more scientific data and indigenous knowledge is available.

References

Bren,L.J. (2003). *A review of buffer strip design algorithms*. http://www.forestry-org.nz/conf2003/Bren.pdf.

Carver, S. (1991). Integrating multi criteria evaluation with geographic information system. *International Journal of Geographic Information System,* 5(3): 321-339.

Davis, N. (1992). *Congress on Renewable Natural Resources: Critical Issues and Concepts for the Twenty-First Century. Renewable Resources Journal,* 10 (3): 15.

Deppe, F. (1994). Application of remote sensing and GIS for management and planning forestry resources in southern Brazil. Ph.D (Thesis), Cranfield University,Silsoe,UK. 333p.

Eastman,J.R., Jin, W., Kyem ,A.K. and Toledano, J. (1995). Raster procedures for multi criteria/multi objective decision. *Photogrammetric Engineering and Remote Sensing,* 61(5): 539-547.

FAO. (1977). A framework for land evaluation. *Food and Agriculture Organisation. International Institute for land Reclamation and Improvement,* Publication No. 22, Wangeningen, The Netherland.

Hodges, M.F. and Krementz, D.G. (1996). Neotropical migratory breeding bird communities in riparian forest of different widths along the Attamaha River, Georgia. *Wilson Bulletin,* 108: 496-506.

Keller,C.E., Robbin,C.S. and Hatfield, J.S. (1993). Avian communities in riparian forest of different widths in Maryland and Delaware. *Wetland Journal,* 13(2): 137-144.

Kinley,T.A. and Newhouse, N.J. (1997). Relationship of riparian reserve zone width to bird density and diversity in southern British Columbia. *Northwest Science,*71(2): 75-86.

Mitchell, F. (1996). Vegetated buffers for wetland and surface water: guidance for New Hampshire municipalities. *Wetland Journal,* 8: 4-8.

Muziol, C. (1999). The zoning of production forest as a management tool. Paper presented at the *Conference on Forestry and Forest Product Research,* 20-24 November 1999,Kuala Terengganu, Malaysia. 23p.

Pullar, D. (1999). Using an allocation model in multiple criteria evaluation. *Journal of Geographic Information and Decision Analysis,* 3(2): 9-17.

Saaty, T.L. (1977). A scaling method for prioritise in hierarchy structure. *Journal of Mathematical Psychology,* 15:234-2402.

Saaty, T.L. and Vargas, L.G. (1991). Prediction, projection and forecasting. Kluwer Academic, Dordrecht.

Saaty, T.L. (1980). The analytical hierarchy process. McGraw Hill, New York, U.S.A.

Simmon, H.A. (1960). The new science of management decision. Harpar and Brother Publisher, New York, U.S.A. 51p.

Spackman, S.C. AND Hughes, J.W. (1995). Assessment of minimum corridor width for biological conservation: *Species richness and distribution along mid-order streams in Vermont, USA. Biological Conservation,* 71:325-332.

Voogd, H. (1983). Multicriteria evaluation for urban and regional planning. Pion,London, UK.

Wenger, S. (1999). A *review of scientific literature on riparian buffer width, extent and vegetation.* Office of Public Service and Outreach, Institute of Ecology, University of Georgia.59p.

Table 1. 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 2. Standardization rating of each criterion from an 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 3. Standardization rating of each criterion from environmental perspective

	Standardization rating/score			
Forest Zone	Protected Forest	Productive Forest		
Criteria	1	2	3	4
Slope (^{0})	> 30^0	$20^0 – 30^0$	$10^0 – 20^0$	$0^0 – 10^0$
Elevation(m)	> 600m*	< 600m		
River buffer(m)	0m-100m	>100m		
Lake buffer(m)	0m-100m	>100m		

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

**Environmental perspective applies the old ruling adopted by most of the states, harvesting is limiedt below an elevation of 600m asl.*

Table 4. Scale for pair wise 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 5. Total areas for each suitability ranking: Economic perspective

Stage	Suitability class	Area (m^2)	Area (ha)	%
First/Preliminary stage	Not suitable Suitable	9411138.61 92153908.52	941.11 9215.39	9.26 90.74
Second stage	Not suitable Marginally suitable Moderately suitable Highly suitable	3992046.24 7032023.51 9327394.62 81213582.73	399.20 703.20 932.73 8121.35	3.93 6.92 9.18 79.96
Forest zone				
Productive forest (Suitable for harvest)	Marginally suitable Moderately suitable Highly suitable	7032023.51 9327394.62 81213582.73	703.20 932.73 8121.35	6.92 9.18 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**

Table 6. Total areas for each suitability ranking: Environmental perspective

Stage	Suitability class	Area (m^2)	Area (ha)	%
First/Preliminary stages	Not suitable Suitable	26096177.84 75468870.13	2609.62 7546.89	25.69 74.31
Second stage	Not suitable Marginally suitable Moderately suitable Highly suitable	19349048.84 6631133.85 6355532.31 69229332.10	1934.90 663.11 635.55 6922.93	19.06 6.52 6.25 68.16
Forest zone				
Productive forest (Suitable for harvest)	Marginally suitable Moderately suitable Highly suitable	6631133.85 6355532.31 69229332.10	663.11 635.55 6922.93	6.52 6.25 68.16
	Total	**82215998.26**	**8221.59**	**80.93**
Protected forest (Including river buffer, lake buffer, elevation and excessive slope)	Not suitable	19349048.84	1934.90	19.06
	Total	**19349048.84**	**1934.90**	**19.06**

Table 7. Summary of cells counted and area affected by constraints from economic and environmental perspective

Constraint factor	**Cell value count (Constraint cell)**	**Area (ha)**	**Differential in ha and %**
Slope Economic (>40^0) Environmental (>30^0)	 12483 121271	 124.83 1212.71	1087.88 (89.70)
Elevation Economic (>1000m) Environmental (>600m)	 0 251281	 0.00 2512.81	2512.81 (100.00)
Hydrological buffer Economic (<20m) Environmental (<100m)	 92793 445206	 927.93 4452.06	3524.13 (79.15)

Table 8. Comparison of suitable harvest area from economic and environmental views.

Forest zone	Area (ha)		Differential (ha)	%
	Economic perspective	Environmental perspective		
A Productive forest (Suitable for harvest)	9757.30	8221.59	1535.71	15.74
B Protected forest (Including river buffer, lake buffer, elevation and excessive slope)	399.20	1934.91	1535.90	79.38
Differential (ha)	9358.10	6286.69		
%	95.91	76.46		
Total (A+B)	10156.50	10156.50		

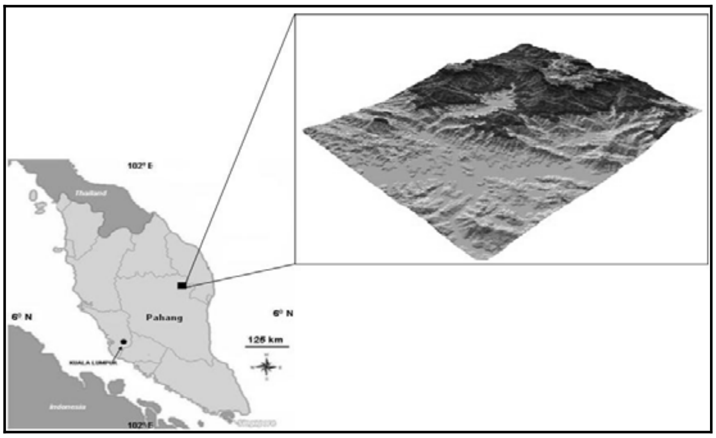

Figure 1. A map showing the 3D view of the study area in Pahang State, Peninsular Malaysia

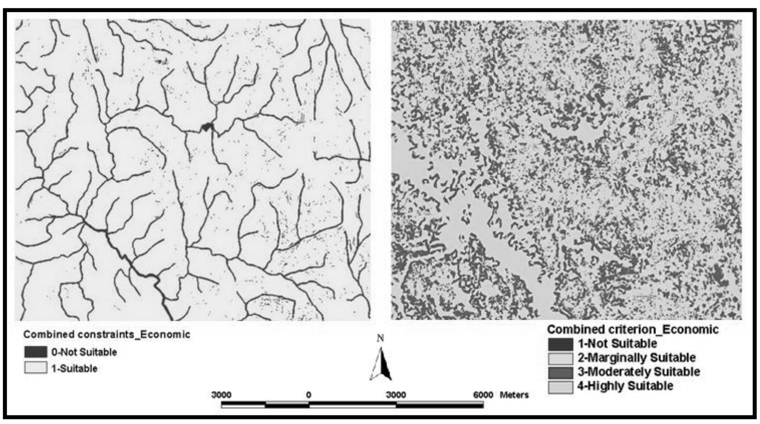

Figure 2. The final combined constraint and criterion map for suitable harvest zone area from economic perspective

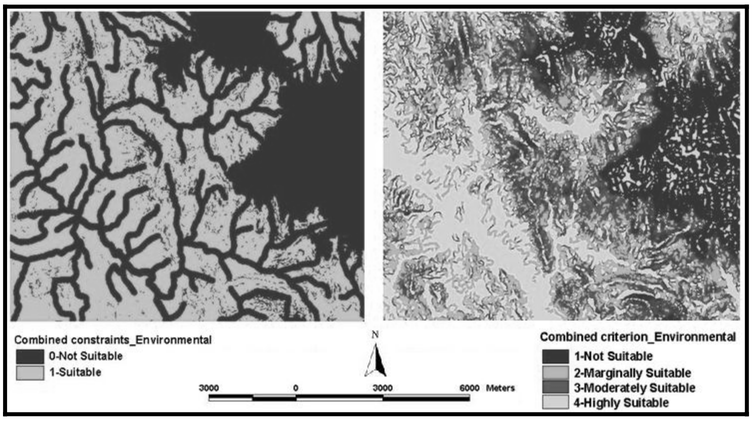

Figure 3. The final combined constraint and criterion map for suitable harvest zone area from economic perspectives

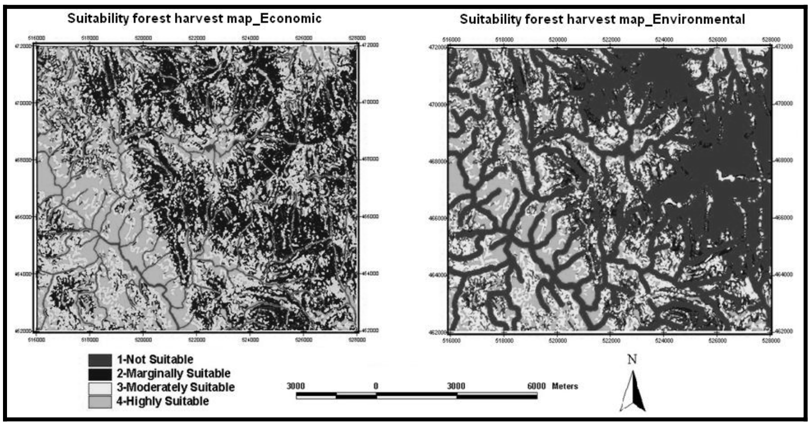

Figure 4. A suitable harvest zone map for the Sungai Tekai Forest Reserve from economic and environmental perspectives

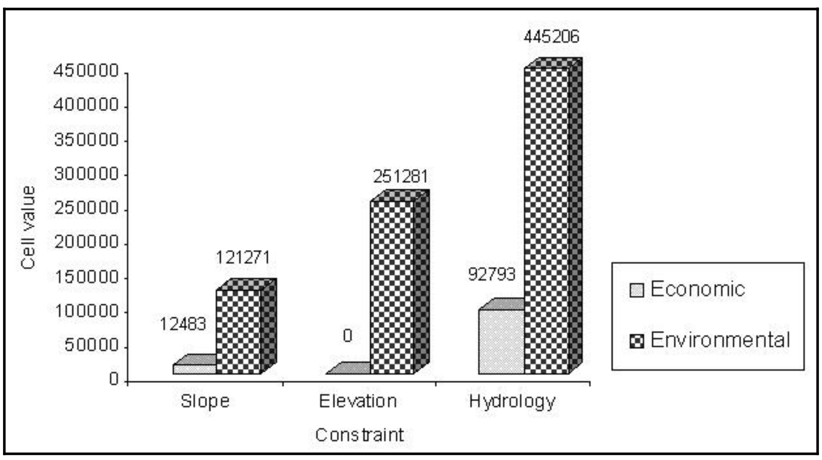

Figure 5. Comparison of cell value distribution for each constraint factor across study area from two perspectives