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Planning of Access Road Using Satellite Technology and Best Path Modeling

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Abstract

Forest road construction for harvest operation are always been subjected to certain constrictions and limitations. Engineering practices on forest road alignment are hindered by costly environmental and operational assessment. GIS tools and related data such as remote sensing allows in allocating suitable access road by taking consideration of environmental and cost implication. The aim of this study is to present the method of integration of remote sensing data and GIS in allocating access road for forest harvesting using best path modeling. Therefore, the specific objectives of this study are to allocate the optimal forest roads network in forest operation, and to determine the density of forest road network. Allocating the best paths for forest road access for timber harvesting is a problem that can be solved by computer based approaches using spatial modeling. Spatial modeling is used to compute the indicative factors that suit road allocation. The model developed and designed using GIS to propose feasibility forest road allocation in the hill area. The method was designed to produce road layouts taking topographical features and forest environmental constraints into special consideration. In this study, four grid themes influencing the road construction were identified; elevation, slope, barrier of lake and distance to existing roads. The total of access road aligned and proposed in the respective area was 28,745.35m. Meanwhile the overall density calculated in selected compartments was about 9.93m/ha (0.80%). The densities of road paths presented here were achieved below as outlined by the forestry department. Thus, there is potential to reduce damage to the residual stand and to the ground area disturbance by the harvesting operation. The forest road alignment and information in this study provides an initial foundation on which GIS can be used for this kind of analysis in forest road planning. The result is not only associated with forest transportation, but at the same time is useful to identify a risk of road construction to the environment. This revealed that the minimum density of forest road construction can help mitigate the loss of ecological services of tropical forest subject to logging pressure and lead to greater financial benefit in future operations.

Keywords: Forest road allocation, Hill tropical forest, Remote sensing, GIS, Best path modeling

1. Introduction

Currently, most of the forest roads in Peninsular Malaysia are located in the hilly region, characterized by steep terrain and dense river of networks. The construction of a forest road has the most potential of any forest harvesting operation to cause damage to the environment. In most cases, the problem of transporting timber in tropical forests is very different from that in temperate forests, as tropical forests have seldom been subjected to rational management. Most tropical countries have not had the necessary means or tools to provide their forests with a system of roads or railways where they are required. However, one of the major problems is that extreme slopes often occur when constructing forest roads especially in hilly areas.

Harvesting operations have always been subject to certain constrictions. Restrictions and regulations on slope limitations, buffer zones, minimum cutting limits, prohibited species and road density which pose little problem to loggers in the past have now become major problems as operations are shifting from the gentler and richer flat land to the steeper and unevenly stocked terrain of tropical hill forests. This constraint represents a major impediment in use of specific areas, which restrain the use of the area for road allocation. In Brazil, FOA (1977) reported that obstacles when using of mechanization in Brazil forest are mainly from slope, elevation and soil characteristics. Thus, constraints are imposed by those factors can effect the path allocation. Muhammad and Rahman (1995) noted that the most problematic feature in the harvesting operation is to establish the accessibility of forest network into a forest area. Because roads are long-term features, their location must be carefully chosen, to meet the loggers need for safe access, avoid long-term maintenance problems, reduce potential risk of water and soil degradation, and minimize costs over the short and long term. For instance it has been reported that an estimated 90 percent or more of soil erosion resulting from timber harvesting in the tropic is directly attribute to inadequate road design (FAO, 1977).

Nowadays, computerized methods are very useful in the solution of these problems. However, a clear application of this approach is probably limited to relative simple plain conditions with homogeneous tree species and technology composition. It is not possible to evaluate in detail ecological parameters. Liu and Session (1993) have illustrated and discussed the influence of terrain topography on the quality of the planning process and relative forest accessibility. It seems that approaches in technology and ecology evaluation for more alternatives, are more effective for mountains where conditions change frequently. In planning many alternatives there may be a need to investigate in a DEM and Geographical Information System (GIS) environment before roads construction. This approach is not new but still used since it was formulated (Epstein, 1994; Kitagawa, 1995). A philosophy to understand forest operation as a scientific discipline was presented by Heinimann (1995). He also analyzed the role and need for computer technology in connection with future needs.

Forest road alignment practices are hindered by costly environmental and operational assessment. GIS tools and related data such as remote sensing data allows harvest managers and planners to dynamically assign the timing of access and haul cost attributing to the existing inventory database for several road access alternatives. When combined with other standard features such as species composition and merchantable timber volume, it is possible to analyze the effect a road network design has on delivered wood costs. Planning of forest road networks have already been discussed extensively, for example, Kanzaki (1996), Sakai (1995), Samsul (2000), and Judibal (2000). However, there is no precedent for a routing system based on the road density and cost analysis which focuses on decision making. Other studies by Yoshimura and Kanzaki (1995) were focused on forest road planning using quantitative risk assessment approaches to estimate the degrees of slope failure potentially using topographic maps. In addition, the degrees of slope failure potential were calculated automatically using DEM (Yoshimura et al. 1996). It could be applied to GIS, which made it much simpler to plan forest roads in steep areas. However, FOA (1982) reported that despite some models, developed mainly using the method of cost effectiveness analysis, none of these trials were very compatible with practical performance.

The aim of this study is to present the method of integration of remote sensing data and GIS in allocating access road for forest harvesting using best path modeling. Therefore, the specific objectives of this study are two folds: (i) to allocate the optimal forest roads network in forest operation, and (ii) to determine the density of forest road network.

2. Methodology

2.1 Description of study area

The study area is in the Sungai Tekai forest reserve at Jerantut district in Pahang State, Peninsular Malaysia, about 240 km north-east of the capital Kuala Lumpur. 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). Figure 2 illustrates the 3D view of the study area and demonstration site clipped from the entire study area, which consists of several compartments. The clipped off demonstration site of about 5758.32 ha, where from a total of 26 compartments, only 11 compartments in the area of non served forest were namely selected compartment 170, 171, 173, 174, 175, 176b, 196, 197, 199a, 199b and 200. These compartments covered an area of about 2509.13ha. 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%.

<Figure 1: Peninsular Malaysia showing the study area in Jerantut District in Pahang State>

2.2 Procedure for accessibility modeling

The model developed in this study was designed to propose feasibility forest road allocation in the presence of constraints. The suitability of forest road allocation must meet the topographical constraints and produce an acceptable level of forest road network, and meet the environmental requirements. In tropical dipterocarp forest, an area with a low timber stock to be harvested, very steep slopes, excessive high elevation and located in a sensitive area, forest operation would not be feasible from a financial and environmental point of view.

Allocating the best paths for forest road access for timber harvesting is a problem that can be solved by computer based approaches using spatial modeling. Spatial modeling is used to compute the indicative factors that suit road allocation. The method is designed to produce road layouts taking topographical features and forest environmental constraints into special consideration. The main process in designing forest road suitability allocation is to establish the weighted distance analysis by mapping the indicative factors and find the least accumulative cost from source to the destination cell or point. The shortest path function is used to route the optimal costly road through selected forest compartments.

<Figure 2: 3D view of study area (top), demonstration site clipped over Landsat TM imagery (bottom left) and selected non-served forest (bottom right)>

The accessibility factors (in grid theme) of road construction in the study area were assigned into uniform class range to show its effect on the cost of moving through an individual cell. Then, data were normalized where each of grid themes is classified on a scale of 1-4 according to the effect on the cost of constructing forest road. The grid themes of accessibility factors are then given a weighted value and added together to produce a single grid theme that identifies the appropriate path through each cell. Finally the most effective road corridor can be identified between two or each portions of forest compartment. In this study, four grid themes influencing the road construction through the study area were identified; elevation, slope, lake barrier and distance to existing roads. Classifications of factors for suitable road allocation in the study were based upon the Malaysian Forestry Department guideline, Muziol (1999) and Judibal (2000). From a forest harvesting aspect, the following factors were selected, namely (a) Slope (degree): Slope was expressed in degrees. The original slope classification was drawn up by the Department of Agriculture and modified for forestry application to the study area based on a study by Muziol (1999), (b) Elevation (m): Elevation limit/factor is different from the state legislation and new ruling by Forestry Department of P. Malaysia. In this case guideline prescribed by Forestry Department of P. Malaysia was applied, and (c) Distance from existing road (m): Transportation cost constitutes one of the largest capital expenditures in this harvesting area. The cost may vary widely depending on the terrain and distance to the processing area, which needs to be justified with the volume of timber and value of tree crop. The road constructed in the Sungai Tekai Forest Reserve concession has a simpler standard dictated by low travel speed and moderate to steep sloping.

Taking the above consideration into account, the classification of the distance of new access roads to existing roads is divided into four classes as given in Table 1. In general, there are six basic main stages required in order to generate the road location. They are: (1) Data input, (2) Data modification, (3) information derivation, (4) Computer based approach, (5) analysis and evaluation, and (6) Output. A simplified flow diagram summarizing the stages of operation is shown in Figure 3.

<Table 1: Classification factors for the harvest compartment (road allocation)>

From the entire grid theme, only the slope and distance from existing road imposed a major constraint in locating forest access. Therefore, the other constraints were expressed in terms of forest function class or class within some of the GIS layers. However the conditions of soil depth and soil type were not available as an indicative factor, since such investigation is time consuming and labour intensive to carry out. In this process, only slope on topographical map and distance from existing road theme were the salient factors to be evaluated, while the other factors were not so important but remain complementary to the optimum forest road alignment.

<Figure 3: A simplified flow diagram of suitable road allocation>

The cost path grid theme requires the entire friction theme to be merged together into one to create the total cost of road construction through each cell. The ideal surface for this application is one in which all cell values are equal since the layer takes care of the travel space and the later cost weighted function will take care of distance and direction. A weighted cost approach is taken to prepare the cost layer using cost datasets as input. Assigning weight to these cost layers was done based on personal experience and discussion with the forestry officers. Accessibility factor maps were assigned a weight by giving 80.00% to the slope, 20.00% to distance from existing road and 0.00% to the lake. A lake entry was deleted since it is impossible to move across the lake, so this lake is called absolute barrier. Each percentage then was divided by 100 to normalize the values. Using raster calculation in ArcGIS the following equation is derived which generates the required cost layer:

(0.80*[slope_cost] + 0.20*[distoexistroad_cost] + 0.00*[lake_barrier])

From the cost weighted function, the direction was created to give a raster direction of the least cost path from each cell to each source. With the cost distance and direction of raster were created, the shortest path to the destination were run automatically. A total of six destinations and 11 established target locations were created according to assumption as (i) a harvest compartment might be represented by the centroid point, unless when the centroids were located in an unsuitable point, this can be relocated at the a suitable point, and (ii) The only way to gain access to inaccessible compartments is to access one of its adjacent harvest compartments, but the road network system as a whole is designed for the entire harvest forest area. The raster of distance and direction gives the least forest path from destination to the target and back to the destination. The selected destination and target in each compartment is presented in Figure 4. Planning of new forest road path carried out from available data and at the standard scale of 1:50000 used by forestry department in planning a road at compartment level. In this study the cost of planning is considered rather than expenses cost of the road construction. In order to realize that, shortening the total cost can be made by reducing the distance and earth moved in the forest.

<Figure 4: A selected target and destination created for this study>

2.3 Road density derivation

The road system is the basis of economic timber extraction and it is the task of the engineer to plan a forest road system, which minimizes the total cost of road construction and environmental impact. Excessive length of road construction leads to high cost for cross country movement, means higher road cost are incurred and leads to a larger size of open area. The road density network represents relationship between the length of the road and the total harvest area that gravitates towards them (Session, 1992), and is expressed in meters per hectare. The density of road construction determined in this study is based on the average total length of road network in meters per total harvest area in ha. The following formulae were used to derive the density of road.

$$Y = \frac{RL}{f}$$

where,

Y = Density of forest roads network

RL = Road length (m)

f = Total harvest area (ha)

While percentage of opening of surface area was expressed as:

$$Y = \frac{RL \times RW \times 100\%}{f}$$

where,

Y = Percentage surface area

RL = Road length (m)

RW = Road width (m)

f = Total harvest area (m2)

2.4 Development of class of intensity scale

It is desirable to construct forest road density by also considering environmental conditions. The road density scale should be applied on a regional and a forest-wide basis. The development of road intensity scale should clearly define based on ecological parameters. The main objective of the design of road density scale of a forest transportation system is to find the most workable and economic road network with the lowest cost in the long term (FAO, 1982). Also, this scale should include establishment of track and road density limits for non-monetary value of multiple-use management and environmental protection. In this study the scales used are based on the per area basis.

Forestry Department of Peninsular Malaysia has produced guidelines for the standard of Malaysia classification for forest road density in the Specification for Forest Road in Peninsular Malaysia (Anonymous, 1988). Under this classification, the overall road density has been determined based on slope conditions of the harvest area [i.e. very steep (>31^0), steep (16^0-31^0) and moderate (<16^0)], and overall road density in m/ha is 140, 160 and 200, respectively. However, the classification is not practically used in practice where the forest operation management is being executed in different compartments and by different loggers. Consequently, the road density in this study is determined on compartment-by-compartment basis but still considers the general guideline by the Forestry Department of P. Malaysia. The main factor is the volume of timber to be harvested per unit area. This can determine the road layout that would in turn affect the road density. The volume of timber harvested within a particular logging area will affect the optimum density within a logging compartment. Area with timber volume that is in clusters would have lower road density as compared with the areas where the timber stands are sparsely distributed. In general, because of the low volume of harvestable log per hectares in selected study areas, the optimum road density can be set lower where selective management system is practiced. The following scale of road density followed the guideline on a compartment by compartment basis as given by the State Forestry Department and the following classes are identified as given in Table 2.

<Table 2: The scale of road density class used in the study>

Based on this classification, the study area was considered as moderate to very steep slope conditions, thus the overall proposed road density in this study area must not exceed 40m/ha.

3. Results and discussion

3.1 Proposed access road location and analysis

This section discusses the use of shortest path technique in locating access road locations. Based on the data provided by the forestry department and evaluation factors on selected compartments, the access road location was executed to determine the road net pattern. The developed access road location procedure was designed in the non-served forest compartment by constructing access roads along existing secondary forest road. In this case, in the non-served forest compartment new access roads were located to serve the harvesting process at a minimum construction cost. All cost data sets (slope, distance from existing road and lake barrier) were merged together to create one grid theme as shown in Figure 5. This output grid theme shows the total cost of constructing road paths through each cell or how suitable each location is for locating the new access road. The final cost layer was classified into four classes as Low-Moderate, Moderate-High, High-Very High and Very High. Locations with low values indicates the cell in which it will be the least costly to build a forest road path. The lake barrier in white was assigned as ‘no data’ and considered as an absolute barrier since it is impossible to build an access road through the lake.

Evaluation of cell area revealed that Very High cost class represents only a tiny portion with 19804 counted cells (about 0.85 %). This shows that allocation of access roads to very costly area can be easily avoided. Among them, a High-Very High class indicates the major portion with 950523 cells counted (40.82 %). This followed by other classes such as Low-Moderate and Moderate-High with counted cells of 694412 (29.82%) and 663494 (28.50%), respectively. With the human expertise to plan and analyses areas of interest, overlay and intersect various types of information such as slope, elevation, river network and timber volume is carried out. The locations of road design in the stable areas shall as far possible be kept away from natural streams in order to minimise stream sedimentation, exception was allowed to cross the stream with minimal construction. Therefore, the road location was designed to fit to the topography features so that only minimum alterations of the natural conditions are necessary. On the other hand, the proposed road should be located on a gentle slope on wider hill ridges and reach hill tops by as short a route as possible.

<Figure 5: Cost layer for road construction depicts the cost of road path through an individual cell>

The access road locations were determined after all cost distance and directions were performed to each created target and destination point. The cost distance calculates the least cumulative cost starting from one or several targets or destinations and travel through a cost surface. The optimal lay out of all the forest road accesses are depicted in Figure 6, which is showing exactly where the access road location has been constructed by applying 50% transparency on hill shade of DEM. The 3D views of the access road path are shown in Figure 7. In this view, it gives a clear path and direction and shows how the road locality is laid out on the elevation range and slope according to the three accessibility factors.

<Figure 6: Proposed access road location in demonstrated area>

<Figure 7: Access road from 3D views of elevation and slope range>

A profile analysis was performed in terms of elevation and slope of the terrain for road alignment. Profiles show the change in elevation and slope of the road surface along a path. Profile graphs from selected 3D lines are used for evaluating the difficulty of hilly terrain or assessing a corridor for road alignment. From the profile graph it easy to see and measure elevation and slope along the alignment road. The example series of profile graph presentation for selected road paths is illustrated in Figures 69a and 69b. In general, it is emphasized that the access road is aligned to avoid the most cost anomalies; where as noted the higher slope indicates possibly a higher construction cost. It is estimated that most of the slopes involved in the alignment are more than 10 degrees but do not exceed 40 degrees. It is concluded that the location of access path were established in the area will reduce the cost and environmental impact when building the road.

The important point to understand from this result is that it is important to spend time considering how to weigh the cost datasets to layout forest roads. The potential path to build a new forest road depends on how the weight is allocated to the cost dataset. The road line represented here is created using cost raster where each raster (slope, distance from existing road and barrier of lake) had a different influence, and where the slope input had a weight 80%. By giving the slope input a higher weight that means more attention was given to avoid steeper slopes in the forest road path. On the other hand, the structure developed in this accessibility model permitted some relative modification that could improve its capability. Inclusion of more specific indicators with more accurate description and use of different techniques in creating targets and destination points could be helpful, since this basic indicator presented here was based only on three indicators. This can be conducted by performing the cost weight and shortest path analyses on the new raster to compare the results with the previous work.

<Figure 8: Elevation and slope profile graph for path 1a>

<Figure 9: Elevation and slope profile graph for path 2a>

3.2 Density analysis of forest road

The problem of choosing the optimum forest road density is important in theory but in practice it is difficult to solve. The variables of spatial analysis such as topography (slope and elevation), and area per ha were considered. The main issue in selecting the route for a forest road is cost. To minimize the cost of forest road construction, the lower percentage of surface opening to align the forest road is required. Determining the optimal route by which transportation can get from one point to another point is a crucial element to any logging company. The initial cost of construction of a forest road is reflected in the future cost in maintenance. The improper alignment of forest road will result in high construction costs. A low quality road will also result in high road maintenance and high transportation costs.

In order to calculate the density of a proposed road in a demonstrated area, data were first summarised at the compartment levels. The summary describes the access road information considered on selected harvest compartments, the effect of topography and difficulty of terrain. Then, for each compartment, the total km of road in each of the road classes was calculated. Lastly, the lengths in km of road were totalled for the entire demonstrated area and divided by the represented study site to produce the density information. The summaries of road construction information for all harvest compartments are shown in Table 3.

<Table 3: Information of access road in selected harvest compartments>

From the analyses it can be seen that the access roads, which have been delineated in 11, selected compartments showed an overall of 9.93m/ ha. In term of length, it represents about 0.80% of the open forest floor area. Across the analysed compartments, the density of access road was highest in compartment 171, followed by compartment 200 and compartment 176b. Their densities were 23.82m/ha, 13.45m/ha and 11.95m/ha. The lowest density was in the compartment 199a with about 2.98m/ha. Apparently, the entire proposed forest road are laid out in low category density table outlined by the forestry department. However, bear in mind this evaluation does not include feeder road assessment where the information for this road type was not available to this study. The determination of access road density and network allowed on the site is based on the presumption that all other applicable standards shall be met. The maximum density established for a compartment area is not a guarantee that such densities may be obtained, nor a valid justification for varying other dimensional or constructional standards. A total of 19 road segments were merged into 11 paths, with a total length of 287,45.35 m costing RM718,750.00, which was required to construct an access road to all selected compartments. This estimation is based on RM25, 000.00 costs to construct an access road (secondary road type) per ha. in the demonstrated area supplied by the forestry department. It can be seen that more than 80% access road location are located in the class of Low-moderate and Moderate-High cost layer. The proposed access road planned by GIS capability dramatically allow forest managers to easily review the cost and modify or update forest road patterns if change is need. However in this estimation, it is important to note that this cost will be different and change if different material is used and intensity of earthwork is taken into account.

Although the approach had many advantages for access road planning, two major problems were encountered. First, as in case of the forest path model, solutions proposed by the shortest path modeling system were limited to the type and quality of data used to derived information. Ideally, access roads to new harvest compartments should consider financial criteria. However, since no financial information on timber harvest cost was contained in the modeling system, the approach of access road had to be performed from a purely an environmental point of view. Secondly, in the development of access road locations the size of the harvest compartment contained varying gradient and ground conditions that requires the development of criteria based on respective area. Despite that, the different contractors hired for each harvest compartment created a "planning conflict" for constructing new forest road access. This happened when road planning by different contractors are not connected between compartment. Determining the road alignment in the field took longer to be accomplished, therefore this aspect is important since the success of the reduced impact logging philosophy ultimately depends on the commitment of field workers.

4. Conclusion

The use of remote sensing data and best path modeling in GIS with the additional supportive information was able to facilitate design of a proposed forest road more easily. This study however has developed a key approach, which integrated the computer system into forestry application that could assist planners and foresters in the planning and design stages for establishing an optimum forest road for forest harvest operations. Specifically, in the future, development of forest roads by means of GIS can be dynamically accessed by all user agencies in managing forest road systems. The overall total of access road aligned and proposed in the respective study area is 28,745.35m. Meanwhile the overall density calculated in selected compartments is about 9.93m/ha (0.80%). The densities of road paths presented here are achieved below as outlined by the forestry department. Thus, there is potential to reduce damage to the residual stand and to the ground area disturbance by the harvesting operation. The forest road alignment and information in this study provides an initial foundation on which GIS can be used for this kind of analysis in forest road planning. The result of the study is not only associated with forest transportation, but at the same time is useful to identify a risk of road construction to the environment. Proper planning of forest road by forest managers could significantly decrease sediment production to rivers. As a result, drainage from roads planning and location can cause severe erosion. This implies that the minimum density of forest road construction can help mitigate the loss of ecological services of tropical forest subject to logging pressure and lead to greater financial benefit in future operations. Further, the result of the access road costing about RM 718,750.00 from this study should be used with constraint and local perception. The local perception on road cost planning may differ significantly with those found in other research work. Nevertheless, the procedure developed here should be helpful to further endeavor in considering the use of GIS spatial modeling for harvest road planning.

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Table 1. Classification factors for the harvest compartment (road allocation)

Factor	Class range	Class factor	Verbal class
Slope (degree)	0-10	1	Gentle
	10-20	2	Moderate
	20-40	3	Steep
	>40	4	Very steep
Elevation (m)	0-1000	1	Productive
	>1000	2	Protected
Distance from existing road (m)	0-750	1	Low
	750-1500	2	Moderate
	1500-3000	3	High
	>3000	4	Very high

Table 2. The scale of road density class used in the study

Road density description class	Road density (m/ha)
Very high	> 40
High	30-40
Moderate	20-30
Low	< 30

Table 3. Information of access road in selected harvest compartments

Path no.	Length (m)	Merged path.	Length after merged(m)
1a	894.17	1a	2503.51
1b	1609.34		
1c	2213.91	1b	2213.91
2a	1098.32	2a	3258.29
2b	2159.97		
2c	1539.24		
2d	1868.49	2b	5195.42
2e	1787.69		
3a	573.46	3a	1525.71
3b	952.25		
3c	1415.27	3b	1415.27
4a	1038.29		
4b	1657.92	4a	4999.16
4c	2302.95		
4d	1419.73	4b	1419.73
5a	1477.53	5a	1477.53
6a	1725.22	6a	3312.10
6b	1586.88		
6c	1424.72	6b	1424.72
Total	**28745.35**	**11 paths**	**28745.35**

Overall road density for 11 paths: 11.46 m/ha ; 0.92% surface area

Compartment no.	Road length (m)	Density (m/ha)
170	2147.19	10.67
171	2613.87	23.82
173	2249.46	8.00
174	2498.30	7.35
175	2924.56	9.65
176b	1970.32	11.95
196	3454.97	10.72
197	1522.07	9.39
199a	656.76	2.98
199b	1753.74	10.22
200	3132.89	13.45
Total	**24924.13**	**118.20**

Overall road density in 11 compartment: 9.93m/ha ; 0.80% surface area

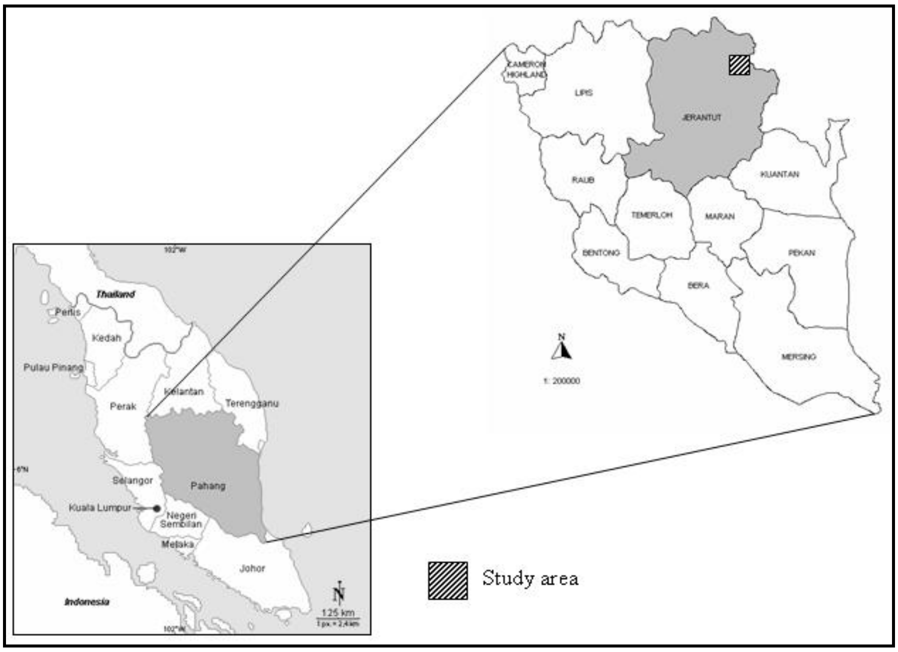
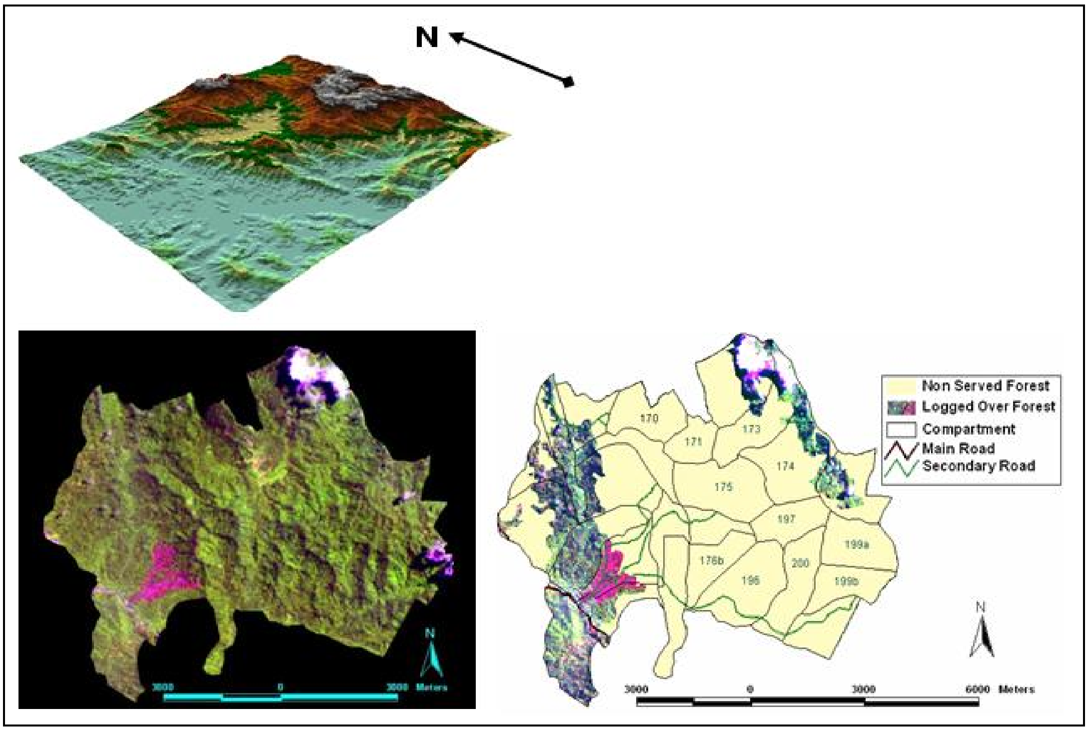


Figure 1.



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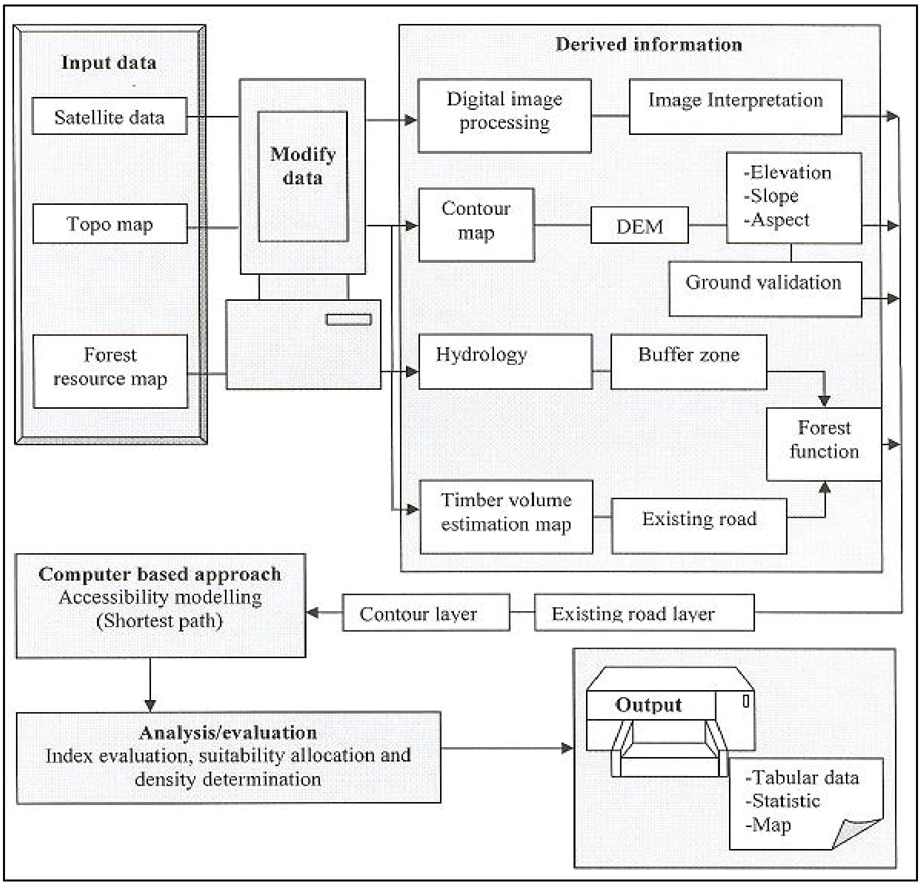

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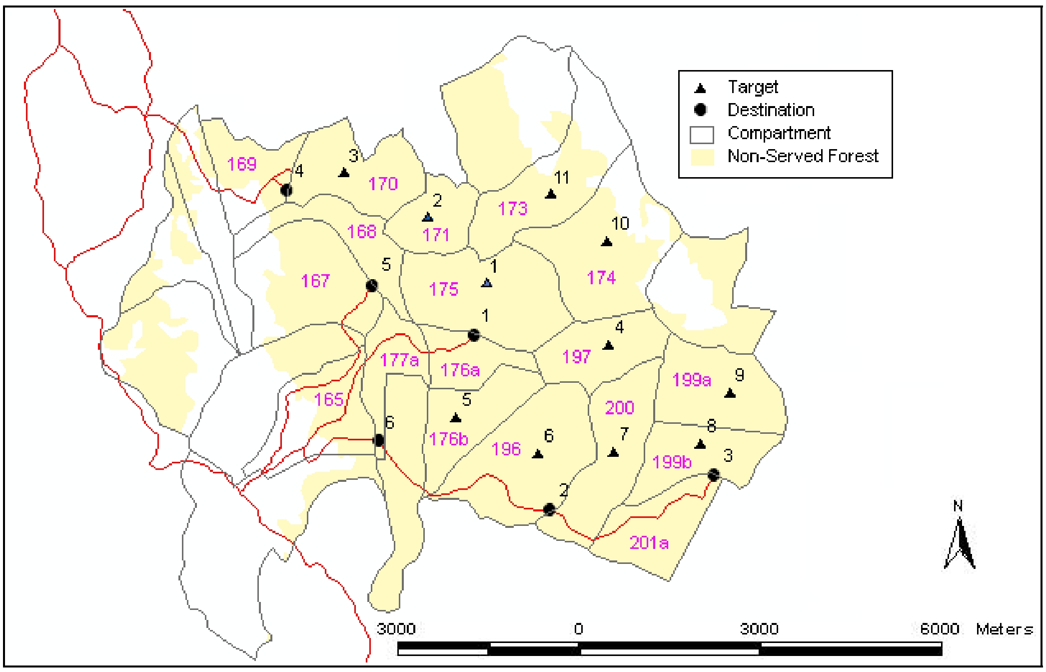

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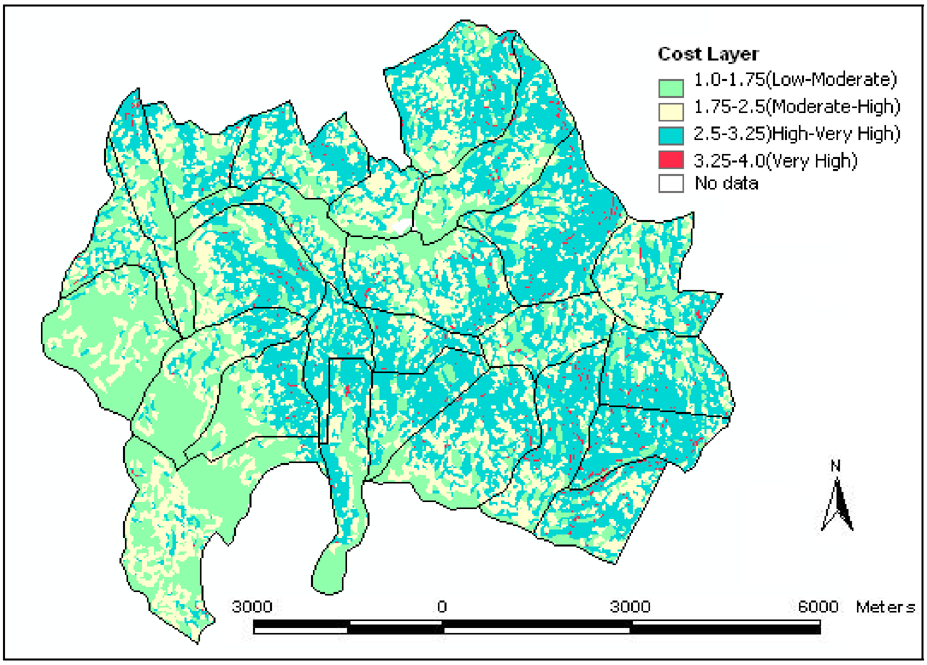

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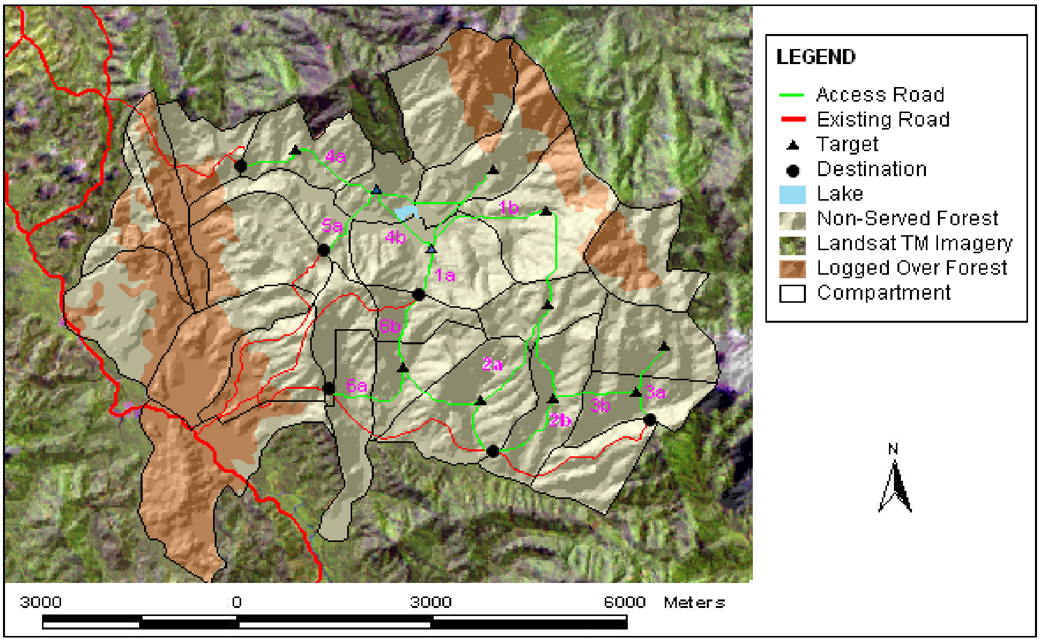

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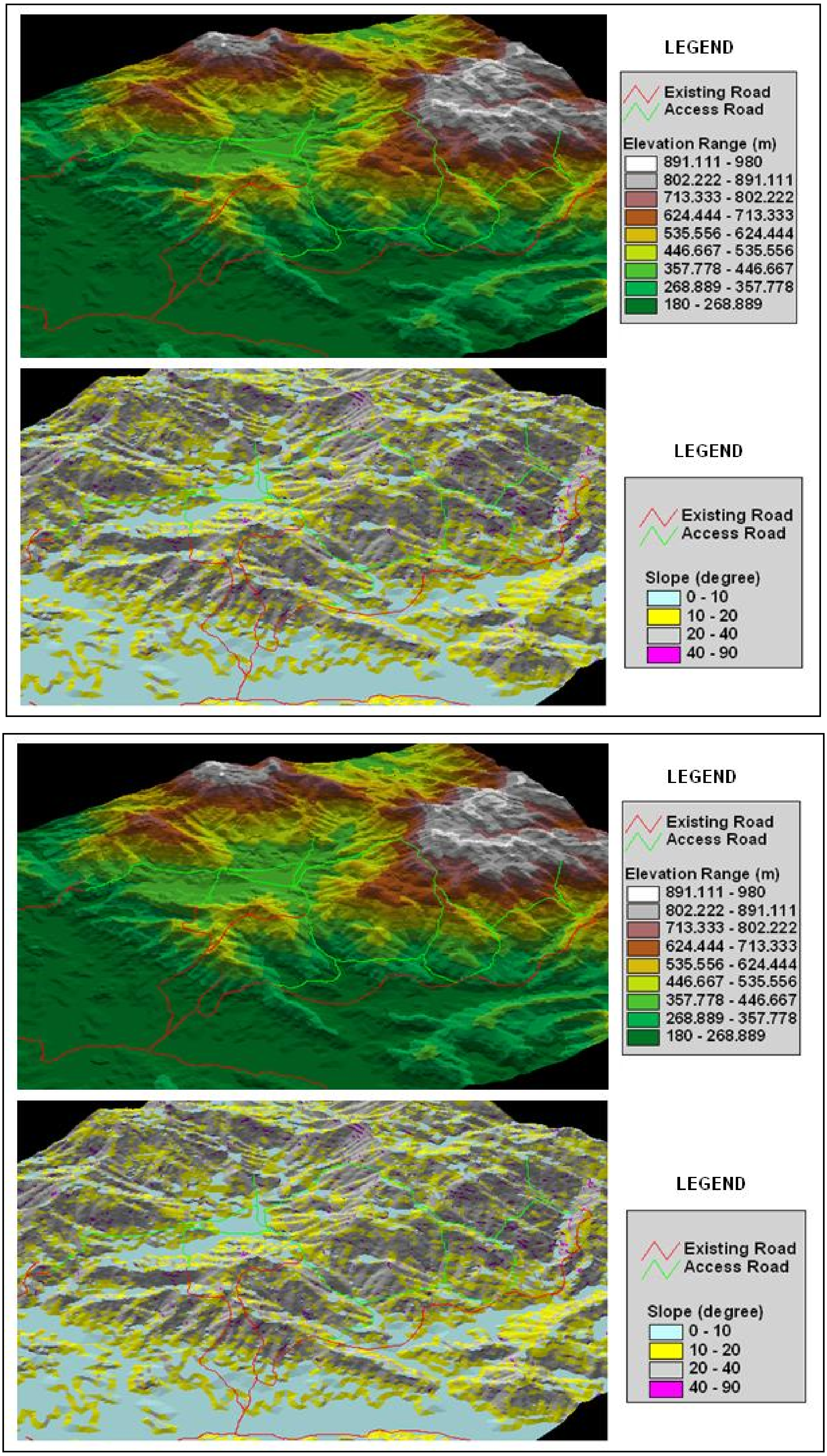
LEGEND
Existing Road
Access Road
Elevation Range (m)
891.111 - 980
802.222 - 891.111
713.333 - 802.222
624.444 - 713.333
535.556 - 624.444
446.667 - 535.556
357.778 - 446.667
268.889 - 357.778
180 - 268.889
LEGEND
Existing Road
Access Road
Slope (degree)
0 - 10
10 - 20
20 - 40
40 - 90
LEGEND
Existing Road
Access Road
Elevation Range (m)
891.111 - 980
802.222 - 891.111
713.333 - 802.222
624.444 - 713.333
535.556 - 624.444
446.667 - 535.556
357.778 - 446.667
268.889 - 357.778
180 - 268.889
LEGEND
Existing Road
Access Road
Slope (degree)
0 - 10
10 - 20
20 - 40
40 - 90

Figure 7.

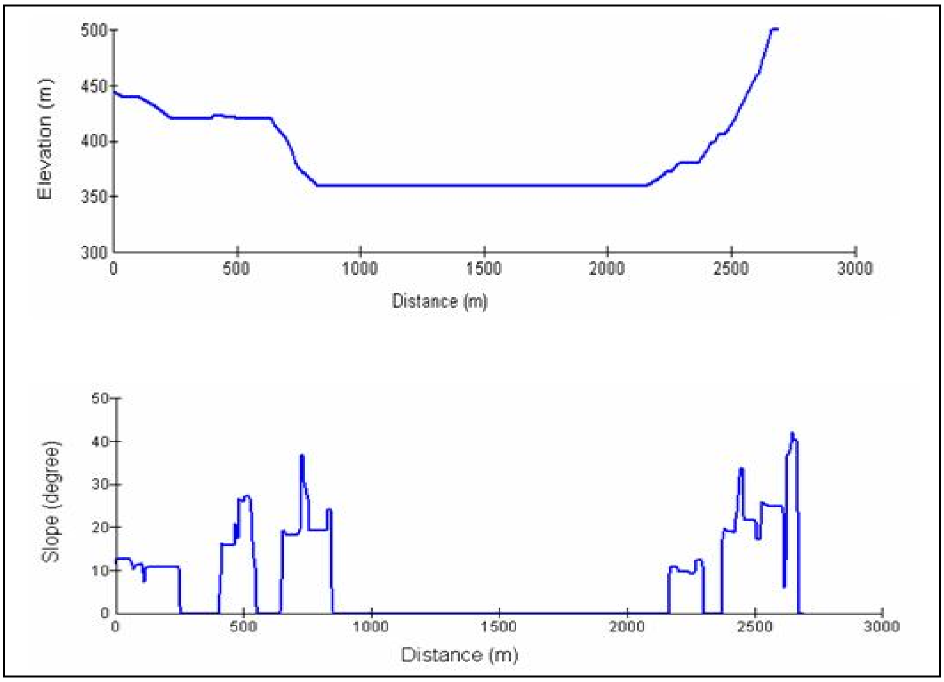

Figure 8.

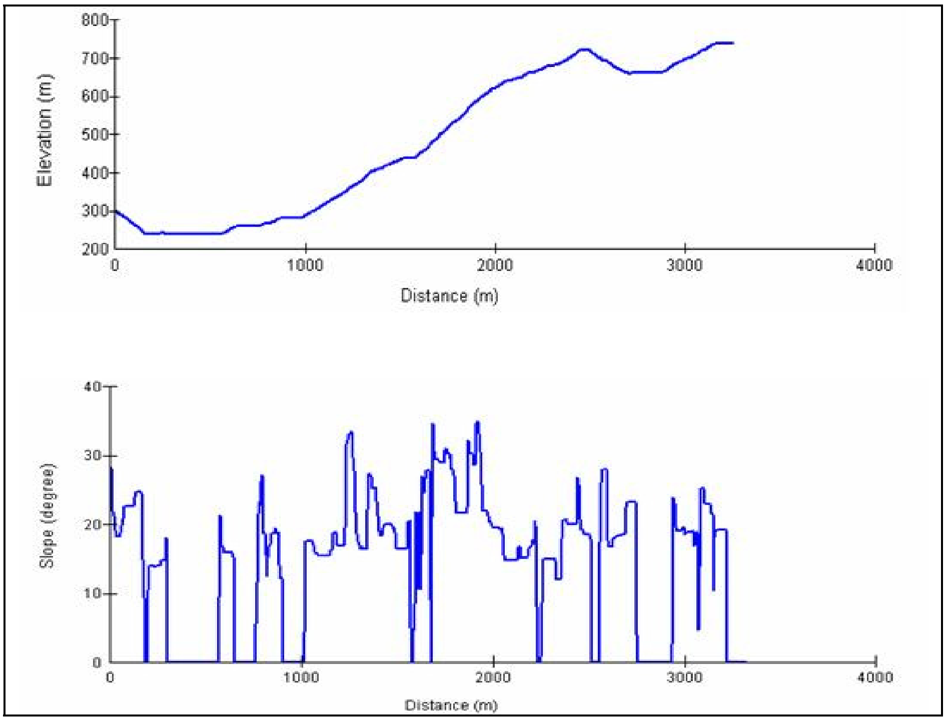

Figure 9.