Estimated DEM uncertainty in creating a 3-D of the UPM's Ayer Hitam Forest reserve in Selangor, Malaysia

Mohd Hasmadi I[1], Khairul Amirin M[1], Siti Noor Hidayah AL[1]

[1]Survey and Engineering Laboratory, Department of Forest Production, Faculty of Forestry, Universiti Putra Malaysia, Serdang, Selangor, Malaysia

Correspondence: Mohd Hasmadi I (email: mhasmadi@putra.upm.edu.my)

Abstract

The GIS capabilities in resource management and planning promise a large scale influence on how geographic features are spatially distributed. The visualizations of the geographical features in three dimensions (3-D) form part of the result of a GIS application available for management and planning purposes. This paper, however, presents a procedure and results which were obtained from the generation of a 3-D model and estimates the uncertainty of an elevation data in creating a DEM of the UPM's (Universiti Putra Malaysia) Ayer Hitam Forest Reserve (AHFR) in Selangor, Malaysia. The forest reserve has been granted for 80 years by the Selangor government to be managed by the Faculty of Forestry, UPM since 1996, as an important 'outdoor laboratory' for teaching, practical research and extension activities related to forestry and other environmental programmes. The databases of AHFR developed by the Faculty were further processed in the ArcGIS 9.0 version in order to make the data format usable, and finally, a 3-D model representation of the area was generated. Based on the 20 m DEM resolution analysis, the RMSE result for uncertainty estimation was 0.33 respectively. While the final result was a 3-D model flexible enough to view and render the AHFR from any perspective including the distribution of soil series, hydrological networks, road networks, etc., it was also useful in supporting the development programme of AHFR as a research forest for UPM and the State of Selangor.

Keywords: 3-D model, DEM resolution analysis, elevation data, forestry, GIS, management and planning

Introduction

The need for three dimensional information or 3-D model is growing and more significant when 3-D GIS functionality is available on the market. The 3-D GIS refers to geographic information that is viewed in three-dimensional perspectives. The 3-D images represent images in x, y and z (vertical) coordinates, viewed in stereo, and approximating the true Earth's features. Digital elevation models, also known as DEMs are frequently used by researchers in environmental analyses to create both traditional and unconventional three-dimensional views from real-world data. Nowadays, geographic features displayed from elevation and depth values are widely used to reveal the earth's surface and expose its features such as hill slopes, terrace, watershed process, etc. In addition, every earth surface can be identified by specifically geometric properties related to its linear, area and relief properties (Mohd Hasmadi & Kamaruzaman, 2006).

The 3-D GIS, with a continuous volumetric data structure and appropriate analytical function, is a tool to integrate a variety of data source, store all available information about a portion of the earth's crust and operate on solid bodies as discrete entities. But the most important advantage of using 3-D displays is the way they appeal to our brains and eyes so much so that most of current forest management and landscape planning are relying on information system, such as that pertaining to the capacity assessment of the potential location for development of eco-tourism sites. As such, the development of the 3-D GIS does provide a compatible functionality and performance whereby the spatial information services will evolve into the 3-D environment

(Zlatanova *et al.*, 2002). According to Gonzalo and Antonio (2000), the 3-D visualisations provide some assistance to human information processing, enhancing mental visualisation and the comprehension of 2-D and 3-D spatial relationships and spatial problems. However, scientific research often makes use of sophisticated visualisation techniques in 3-D representations to enhance the interpretation of the content, logic, and sensitivity of natural resource analytical models (David & Joseph, 1997).

A 3-D modelling is the creation of 3-D computer graphics based on wire frame modelling via specialized softwares. Computer visualization is spreading fast. Its appeal is obvious where visual information is processed and absorbed by human brains much more efficiently than textual, numerical and even diagrammatic data. The technology of computer graphics has been expanding for decades, but the current race to push the limits of visualization may carry profound implications to GIS users, changing expectations for more realistic and interactive 3-D visualizations.

Currently, the Ayer Hitam Forest Reserve (AHFR) maps are only available in 2-D views. Thus, this study is carried out to generate a 3-D model of the AHFR using the Arc GIS software and estimations of the elevation data point in DEM. This way, the whole 1,248 ha. of the forest area is becoming more useful, attractive and easy to understand with the 3-D model for development programmes, such as the allocation of potential recreational area within the AHFR (Lim, 2004). From a hydrological perspective, river flows and catchments areas can also be easily determined from the 3-D map. The scientific value of this study was to provide a basic 3-D model of the AHFR for future research purposes such as determining soil erosion factor, water catchments area, eco-physiology of plants as well as the aspect of wind flow through the hilly area. In this exercise several layers such as topography, elevation and soil series maps were developed in 3-D perspectives. Granted that the use of maps and other related information is useful as it is, but with the development of the 3D model, the geographical features can be made more attractive and useful for users to understand better the topography of the AHFR. Beside the DEM generation, the uncertainty of DEM was estimated and evaluated in order to determine the differences between a GIS spatial map and the actual ground survey data.

Study area

The Ayer Hitam Forest Reserve (AHFR) is located in the state of Selangor, Peninsular Malaysia (Figure 1) at Latitude of 2°56’N - 3°16’N and Longitude of 101°30’E - 101°46’E. It is 20 kilometres away from Universiti Putra Malaysia (UPM), 45 kilometres from the city of Kuala Lumpur and in close proximity to the residential areas of Puchong, Putra Jaya and Kuala Lumpur. AHFR is a logged over forest and has yet to reach fully rehabilitated state. The forest was allocated as an educational forest by the Selangor State at a Selangor State Council Meeting held on 22nd June 1994 (Kamaruzaman and Mohd Hasmadi, 1999). Being categorized as a research and educational forest, no future logging is permitted in the AHFR. Two years later, the Selangor State Government had awarded the forest to the Faculty of Forestry to be used and managed for 80 years beginning 1996. Classified as a disturbed Kelat-Kedondong-Mixed Dipterocarp type forest (Faridah Hanum, 1999), the forest is the only remaining lowland forest in the State of Selangor. As a logged over lowland forest which is still regenerating, the forest land is rich in plant diversity. Paiman and Amat Ramsa (2007) reported that 430 species of seed plant taxa in 203 genera and 72 families were found in this forest. The general topography consists of largely rolling, flat areas broken by the two hills of Permatang Kumbang and Sarang Kuang . It has a maximum elevation of 233 meters and is 202.5 meters above sea level. The slope elevation ranges from 10 %-20% from which point the scenery of Puchong town may be viewed.

The AHFR area is 4270.7 hectare in 1906 and after some area was harvested and developed the remaining area was about 1,248 hectare. It is divided into 6 compartments namely compartments 1, 2, 12, 13, 14 and 15. The average temperature is 26.6º C and the relative moisture is 83%. The two main rivers flowing here are Sungai Rasau and Sungai Bohol. The geological type in this forest is igneous rock with granite as the main component.

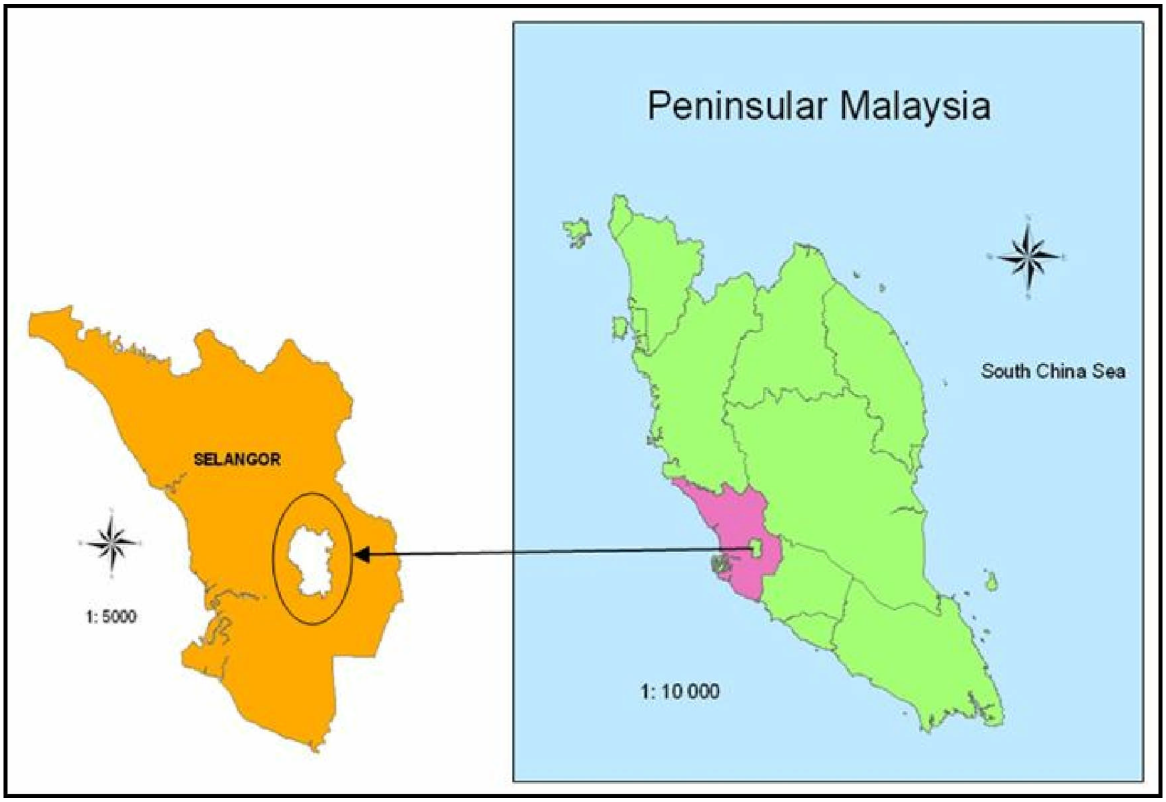

Figure 1. *The location map of the study area*

Materials and methodology

Materials

The main data used is the digital map of AHFR obtained from the Library of Sultan Abdul Samad, Universiti Putra Malaysia. Then, the digital map was converted into the Arc GIS format (*.shp). To support the digital data, the topographic map of the scale 1:10 000 from the Department of Survey and Mapping, Malaysia was used as reference to determine the distance, forest road and the boundary. The soil series map was acquired from the Agricultural Department of Malaysia. The scale of the soil series map is also 1:10 000. To create the 3-D view, a DEM was generated in GIS by draping the 2-D topographical map.

Methodology

Draping is often performed solely for purposes of visualization. ArcGIS 9.0 version was used to generate the 3-D model of the forest area. The ArcScene module was used to vary the view of the model. The summary of the steps taken to generate the model is illustrated in Figure 2.

Contour and soil series maps were created by a digitising process which has been done via on-screen digitising. Layers were generated from the selected features. Each layer has been determined as to what it represented and from this separate layer files were generated. In editing and adding values several layers were added such as spot height, road, river networks and forest compartments. A new ArcGIS project was thus created, and the data sets are added later into the ArcMap project file format (.mxd.). For all-features layers the coordinate's system Universal Transverse Mercator (UTM) projection was set to ensure that they are easily geo-referenced. Prior to this, ArcMap can set the coordinate system for a data frame. Layers added to the map will automatically transform to projection. After that, shapes and attributes of a layer may be edited regardless of the coordinate system it was stored in.

The contour lines were checked to ensure that the height information was accurately linked to the line feature that they represented. The feature of spot height was also checked for its

© 2008, ISSN 2180-2491

consistency with the height information shown in the attributes table. From these two features a TIN was created. A DEM feature was generated from a 3-dimensional elevation with values (z-values) stored within the feature's geometry. Besides geometry, the feature may have attributes stored in a feature table. The ArcScene was used for generating DEM from TIN. The cell size was 20 m X 20 m. In this case, 3-D map was developed for contour, slope and elevation and soil series layers.

After 3-D maps had been created, they were exported from a map document to an industry-standard JPEG file formats. The image was exported to JPEG format because JPEG formats are compressed image files. It can support 24-bit colour and are a good choice for use on the web because it provides control over output quality and size and can be more compact than many other file types. The Adobe Photoshop was used as a raster graphics to manipulate image file for better visualization and output.

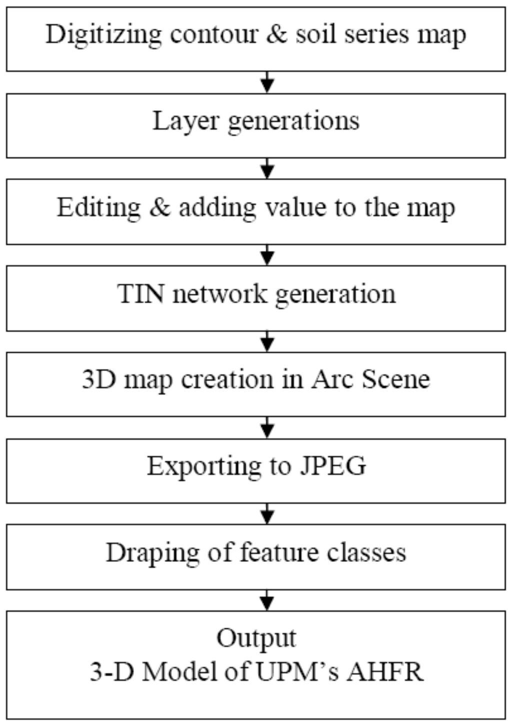

Figure 2. *A flowchart diagram of the method used in the study*

Estimation of the DEM uncertainty

The topographical contour lines of the map were at 20 m intervals and were digitized into GIS. The contour lines were assigned an attribute value according to their height in meters above the sea level. The DEM was generated using TIN and 30 spot heights and stored in a computer added design (CAD) file. The cell size was 20 by 20 meters. Adding the height information to the contour lines was the most time consuming stage of the process in generating a DEM. The conversion toolset in ArcGIS was used to generate the DEM. Based on the study by Gao (1997), the accuracy of a raster DEM is related to the contour density and the DEM resolution was derived as follows:

$$\text{DEM accuracy [RMSE (m)]} = \frac{(7.274 + 1.666\ S)\ D}{1000 + \text{Є}}$$

where, S stands for resolution in meters; D stands for contour density expressed as km km-^{2}; Є is an error term related to D. Contour density was calculated by dividing the total length of contour by the size of the study area.

The elevation data points and the DEM uncertainty were then compared to estimate the differences between them. The root mean square error or RMSE (Gao, 1997; Weshsler, 1999) statistical method was used since it was the most common way to describe the elevation accuracy of data point used to generate a DEM. The RMSE is essentially a standard deviation that assumes that the DEM errors are normally distributed, and is expressed in meters. The RMSE equation may be stated as follows:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}(y_i - y_j)^2}{N-1}}$$

where, y_i is an elevation from the DEM, y_j is the "true" known or measured elevation of a test point and N is the number of sample points.

Data collection

The data collection was carried out to collect elevation and slope data on the ground and in a GIS map. The work was carried out in three phases, namely, Phase I: the estimate elevation and slope (in GIS map), Phase II: the field data collection, and Phase III: the data analysis.

In phase I, the study site was determined on topographical map. A topographical map (1: 10000 scale) was digitized for contour and interpolated to produce a 20 m DEM. At the same time, the similar point location was determined in the GIS map and the coordinates were recorded in each sample point. The slope class of the study site was derived from the topographical map. The layout of line transects which consists of 6 lines and 66 sample points has been designed and overlaid with slope class map, and the contour map had been done. The distance of each line is 100m and the distance of each point is 20m. The layout of the line transects is illustrated in Figure 3.

In phase II, the data collection was carried out on the field based on the line transect designed in phase I. The base line for the transect lines was 100 meters long (bearing 280 degrees) off 20 m of the tie point of Sg. Rasau branch. All 6 transect lines were established by bearing 190 degrees. After measurements were taken at every point of elevation and slope, the data were then recorded in GPS and the slope values were taken using the clinometer. At the third phase, all collected data from both tasks (phase I and phase II) were keyed into the computer for further analysis. The SPSS software was then used to analyse all the collected data. The linear regression was used to calculate the value of the differences between the estimated elevation and slope from the map with the measured elevation and slope on the ground.

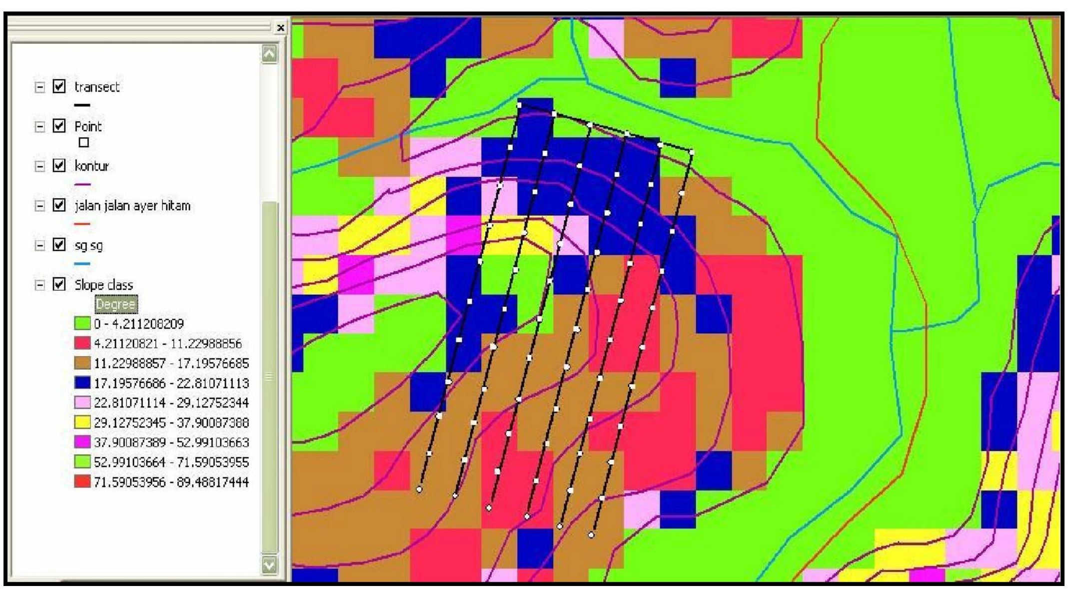

Figure 3. *Layout of the line transects in the study site*

Results and discussion

The result of this study is presented in Figure 4 showing that the creation of the 3-D is possible within the limitation of the quality of a contour data. However, this model has been improved by draping the vehicle road, walking trail, rivers and forest compartment layers as feature classes onto the DEM. In the 3-D visualization, the highest point of the forest area was determined at 202.5 meters which is located in compartment 15. The surface of the forest can also be determined by looking at the 3-D model. Another advantage of the 3-D visualization is that we can simply determine the flow of the river. In fact, and in this particular case, the catchment boundary can also be delineated. Given the available quality of the layer files, the generated 3-D model may be considered as a good representation and may be further improved and used in other applications that are specific to the AHFR as a research forest.

The slope class distribution in the 3-D view is shown in Figure 5. The brighter colour indicates the flat area while the darker colour indicates the higher slope. Five range classes were used to classify the slope class which are 0-0.14%, 0.14-0.61%, 0.61-1.47%, 1.47-3.18% and 3.18-7.44%. Meanwhile, the soil series in a 3-D illustration is shown in Figure 6 indicating a clear distribution zone of the soil series in the AHFR, namely, the Serdang-Bungor-Munchong (Sdg-Bun-Mun), Serdang-Kedah and Tanah Bercerun.

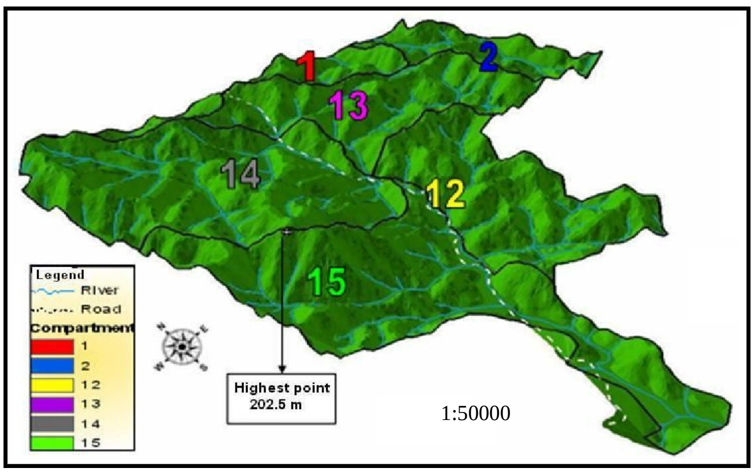

Figure 4. *The 3-D model of the Ayer Hitam Forest Reserve*

The contour density in the entire study area is 10.16km km^{-2}, thus the RMSE of the DEM created for the study area is 0.33. This value is based on the 20 m DEM resolution. Figures 7 show the differences between measured and estimated data of the slope and elevation. In particular, the results indicate a linear relationship with the measured data. The maximum and minimum data measured for slope and elevation in the study area were also observed. The maximum value for slope was 67 degrees (estimated) and 68 degrees (measured) respectively while the minimum value is 3 degrees (estimated) and 5 degrees (measured) respectively.

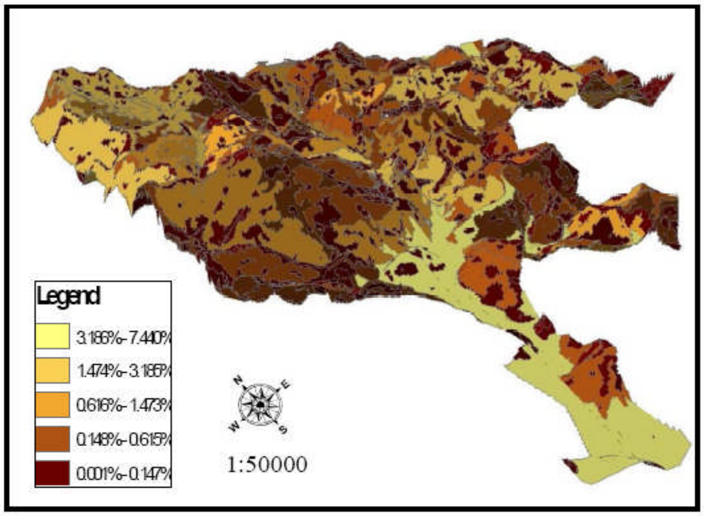

Figure 5. *The 3-D view of the slope class distribution for the AHFR*

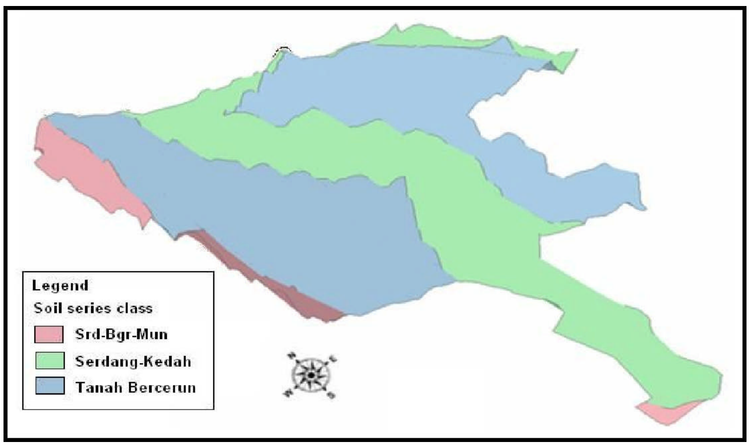

Figure 6. *A 3-D view of the soil series class distribution for the AHFR*

Most of the measured and estimated data collected were less than 30 degrees while elevation analyses showed that most of the data collected were ranged between 30 m to 70 m in respective minimum values were 3 degrees (estimated) and 5 degree (measured). It should be noted that about six data items measured were similar in value, indicating that the study sites were located at six different points of elevation (6 contours level) on the ground. The maximum values indicate that for both data the measurements taken in the field were slightly higher than those estimated from the map.

The coefficient of determination (r^2) values for both of the collected data in this analysis are 0.9591(slope) and 0.9587(elevation) at the .05 significance levels. These results imply that approximately 95% of the appraisal data of the slope and elevation data are attributable to variations on the ground surfaces and to the spatial data that are present in the spatial information. This shows that a relatively small difference occurs between estimated and measured data in generating the DEM model for the study area.

As to the data quality issues in the procedure, it must be pointed out that they pertain to the fact that the individual data set was used at a micro level. Nonetheless, since the data were generated with the intention of capturing and converting a topographical map of the AHFR into a digital form, the objective of its application has been satisfied.

© 2008, ISSN 2180-2491

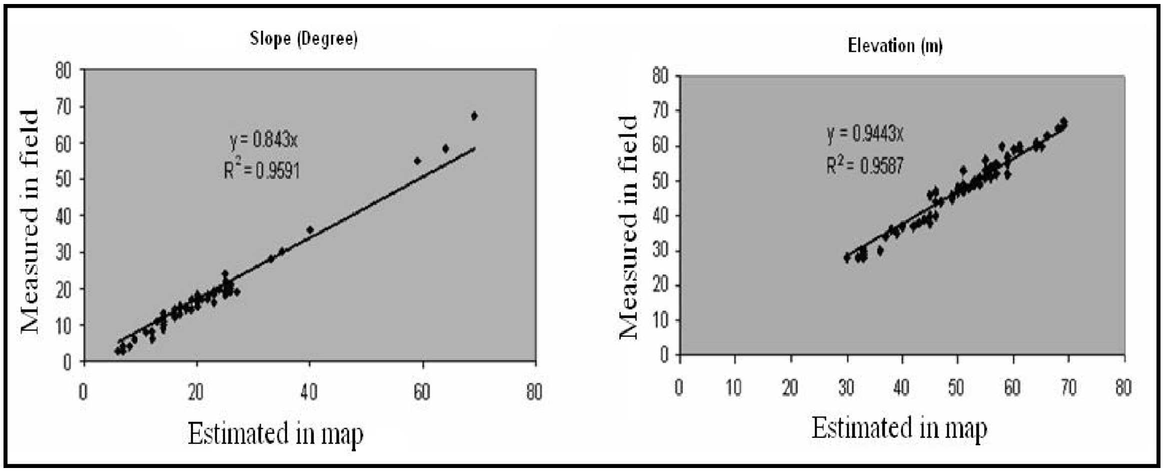

Figure 7. *The relationship of the measured and estimated slope and elevation*

Conclusion

The 3-D visualization is more attractive and intelligible. Based on the result it may be concluded that the 3-D generation for the AHFR is relatively good and convincingly shows the accuracy of the DEM analysis. Slight differences exist in sloping surfaces but negligible in the case of the flat surface. However, since the differences of both maps in the study are less than 10% (slope r^2 = 0.9591; elevation r^2 = 0.9587) the results may be concluded as reliable for nominal maps of the 1: 10 000 scale. The technique of creating the 3-D model presented can thus be used as a basic procedure for creating other information in the 3-D model. A crucial advantage of the perspective view of the 3-D model is that information items such as river network, road, slope and elevation can be viewed effectively from any angles. As such, it is recommended that future research integrates remote sensing imagery as a spatial layer, and this can be done by utilising the "image drape" technique found in the Erdas Imagine software. The 3-D model is not only useful to users, but also to the prospect of conducting many studies such as determining the soil erosion, catchments area and wind flow direction through the hilly area. Finally, this study has proven that with the extension module the GIS may be a capable and very useful tool to anyone who needs to generate quantitative variations in developing a 3-D model.

References

David JB, Joseph KB (1997) Integrating advanced visualization techniques with ARC/INFO for forest research and management. Paper presented at the 1997 ESRI User Conference, San Diego, July 1997. pp. 13.

Faridah Hanum I (1999) Plant and conservation value of Ayer Hitam Forest, Selangor, Peninsular Malaysia. *Pertanika J.Trop.Agric.Sci* **22**(2), 73-83.

Gao J (1997) Resolution and accuracy of terrain representation by grid DEM at a microscale. *International Journal of Geographic Information Systems* **11**, 199-212.

Gonzalo Z, Antonio P (2000) *Preliminary results on realistic visualization of landscape changes in a small watershed in Urdaibai Biosphere Reserve (Basque Country, Spain)*. Department of Ecology, Universidad Autonoma de Madrid, Spain. pp. 3-5.

Kamaruzaman J, Mohd Hasmadi I (1999) Ayer Hitam Forest (AHFR) from space using satellite remote sensing. *Pertanika J. Trop.Agric.Sci* **22**(2), 131-139.

Lim LH (2004) Application of virtual GIS software in eco-tourism planning: A case study of simulating 3-D forest landscape at Balah Forest Reserve, Kelantan. (B Sc. Thesis) Faculty of Forestry, University Putra Malaysia. pp. 82.

Mohd Hasmadi I, Kamaruzaman J (2006) Technique for creating digital elevation/digital terrain model/surface model. *Bulletin GIS* **2**, 1-13.

Paiman Bawon, Amat Ramsa Yaman (2007) *Ayer Hitam Forest Reserve: Multimedia super corridor-community heritage*. Universiti Putra Malaysia Press, Serdang. pp. 34.

Wechsler S (1999) Results of the DEM User Survey. Available from: http://web.syr.edu/~sperlit/survey

Zlatanova S Pilouk M, Alias A R (2002) 3-D GIS: Current status and perspectives. *Proceeding of the Symposium on Geospatial Theory, Processing and Applications*, 8-12 July 2008, Ottawa, Canada. pp. 33-48.