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THE EFFECT OF DIGITAL ELEVATION MODEL SCALE FACTOR ON SOIL EROSION STUDIES: CASE STUDY IN CAMERON HIGHLANDS, MALAYSIA

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The Digital Elevation Model (DEM) is the simplest form of digital representation of topography and it is widely used. A study was conducted to determine the accuracy and precision of data derived from two different DEM topographic scales, namely 1:10000 DEM and 1:25000 DEM produced by the Department of Survey and Mapping in Malaysia. The difference in slope angle was found to be substantial, while the differences for slope aspect and LS factor was not significant. It is recommended that DEM users be aware of the existence of error in DEMs generated from different topographic map scales.

INTRODUCTION

A digital elevation model (DEM) is a digital model that represents the earth's topographic surface and consists of an array of regularly grid spaced elevation values. It is known as Digital Terrain Model (DTM), if additional information such as rivers, valley lines, cliffs and ridges are included (Wood, 1996). However, the terms DEM and DTM are frequently used interchangeably (Soeters and van Westen, 1996). The term DEM is used in this study since the main focus of this study is the elevation value.

The DEM could be created using a variety of techniques such as manual digitizing of contours from hardcopy topographic maps (Weng, 2002), interpolation of spot heights (Hilton et al., 2003), manual profiling from photogrammetric stereomodels (Weng, 2002; Hilton et al., 2003) and performing autocorrelation via automated photogrammetric systems (USGS, 2001).

Quality of the DEM depends upon a number of interrelated factors such as the methods of data acquisition, the nature of the input data, and the methods employed in DEM generation (Weng, 2002). Data acquisition is the most critical factor affecting the DEM accuracy.

A survey by Wechsler (1999) to evaluate the perceptions of DEM uncertainty found that 52 % of the respondents rarely or never notice the existence of uncertainty in the DEM application and only 22 % believed that the DEM's uncertainty is "appreciable". This result definitely indicates a lack of awareness of the DEM users on the quality of the DEM used.

Two parameters, namely Mean Absolute Error (*ME*), and the Standard Deviation of the Mean Error (SDE) have been suggested to indicate the accuracy of *DEM* (Wechsler, 1999; Wang, 2002). *ME* is calculated using Equation 1.

$$ME = \frac{\sum_{i=1}^{n} |Pc - Pp|}{n} \qquad (1)$$

where

Pc = check point value

Pp = DEM derived value

n = number of sample points

It represents an average difference between predicted and actual values of a test. For a perfect line fit, $Pc = Pp$, and thus, $E = 0$. The *ME* index would range from zero to infinity, where zero corresponds to an ideal case that shows no systematic error present. The larger the *ME* value, the greater the error and the lower the accuracy of the DEM (Wechsler, 1999).

The *SDE* is generally used to indicate precision of measurement or vice versa for indicating the presence of any random errors (Equation 2). The *SDE* shows spread of height between a check point and its derived value, which for this study are from the DEM. It is represented by the following relation

$$SDE = \sqrt{\frac{\sum_{i=1}^{n} \left(|Pc - Pp| - ME\right)^2}{n-1}} \qquad (2)$$

The larger the *SDE* value, the greater will be the spread of different height and conversely the lower the precision of the DEM (Wechsler, 1999).

The general availability of DEM has induced widespread scientific applications (Sawal, 1997) such as in soil erosion studies in Malaysia (Yusof and Baban, 1999; Buyong and Suratman ,2000; Rainis et al., 2002; Rainis, 2004 and Ramli et al., 2005).

Yusof and Baban (1999) and Buyong and Suratman (2000) utilized DEM for soil erosion analysis in Langkawi Island using the Universal Soil Loss Equation (USLE). The main application of USLE is in soil loss estimation on slope (Renard et al., 1991). One of the main components in USLE is the calculation of the topographic factor, which represents slope length (L) and slope steepness (S) for soil erosion estimation. L and S are relative values and represent the relative erodibility of a particular slope length and steepness (Wang et al., 2001).

Yusof and Baban (1999) utilized the 1:100000 DEM for his study. However Buyong and Suratman (2000) did not mention the DEM resolution or how the DEM was derived for a LS factor determination. Ramli et al. (2005) utilized digital topographic maps of 1 : 25 000 scale for the LS factors derivation which was obtained from the Survey and Mapping Department, Malaysia (JUPEM). RUSLE was used for the soil erosion assessment in Langkawi instead of using USLE as done by Buyong and Suratman (2000). The RUSLE is an erosion prediction tool born from the improvement and updating of the Universal Soil Loss Equation (USLE) (Renard et al., 1994). Rainis et al. (2002) derived DEM from the digitized topographic maps with a scale of 1:50 000 in their study on the estimation of sediment yield and assessment of impacts of land use changes on a small catchment in Penang Hill, Malaysia. Rainis (2004) also used similar data to assess the effect of slope information from three different geographic information system (GIS) software packages. The differences may exist between the actual heights and their associated digital elevations portrayed in geospatial datasets. Generally, there is no standardized specification or established method to determine accuracy of DEM because the quality of DEM is not just accuracy but also depends on appropriate description of the terrain surface. In fact, Ackermann (1996) stated that the quality is subjective and may vary significantly, depending on the terrain conditions or their applications. However, it is generally accepted that the differences should be reported so that users can share informed decisions on the fitness of the data for specific applications (Goodchild et al., 1999). Thus, it is important to state the accuracy and precision of data derived from DEM for further analysis or assessment. This paper presents the effect of the scale factor on the accuracy and precision of a topographic analysis used in an erosion study.

METHODOLOGY

The study area used is located at longitude 4^{o}28' and latitude 101^{o}23', and occupies an area of 12,304 hectares in the state of Pahang, Malaysia (Figure 1). The area is located between 1070 m to 1830 m above mean sea-level. Cameron Highlands was chosen for the study due to availability of the two different scales of topographic maps to enable comparison to be made. Two criteria were used to evaluate the DEM. The first criterion is the application of *ME* and *SDE* as accuracy and precision indicators, and the comparison of slope angle and slope aspect generated from both DEMs. The second criterion is LS factor generation, which are the main factors used in the soil erosion assessment where the comparison of LS values between both DEMs was possible.

Both the 1:10000 map with 5 m contour interval and 1:25000 scale map with 20 m contour interval were obtained from Department of Survey and Mapping Malaysia (JUPEM). The 1:10000

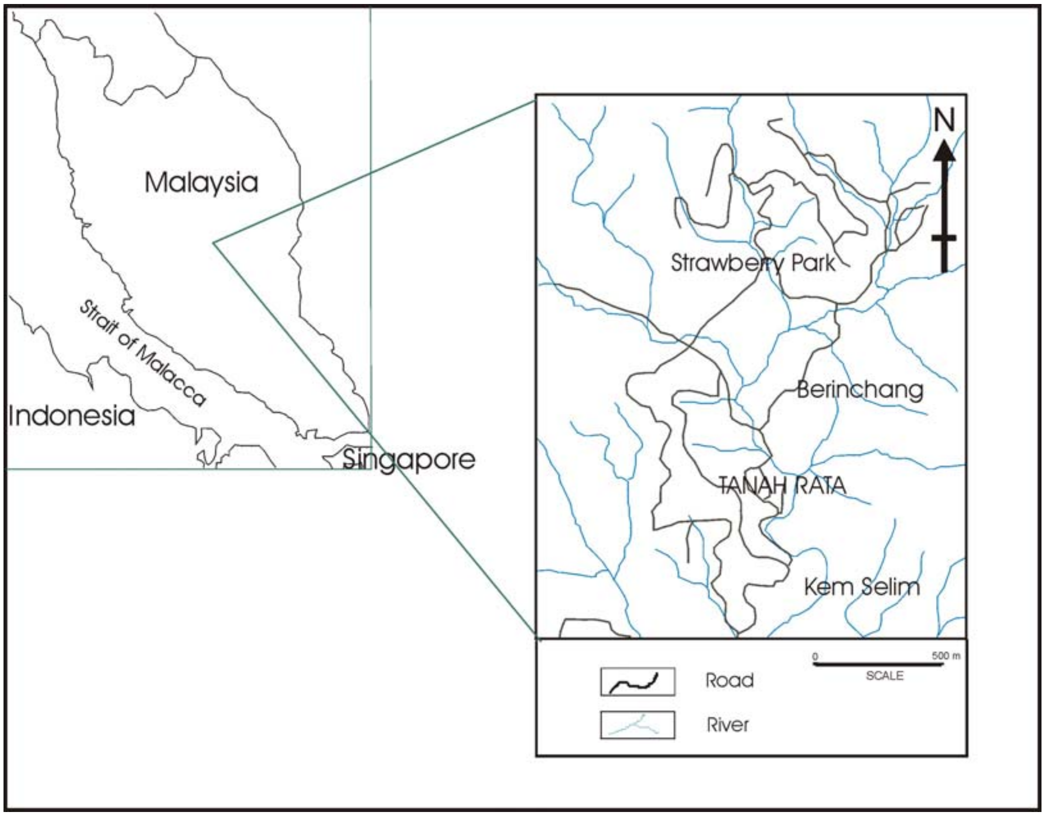

Figure 1. Location of the study area

map and 1:25000 map were produced in 2002 and 1998, respectively. The DEM from 1:10000 scale map is deemed to be of higher quality than the DEM derived from 1:25000 map. Thus the points derived from DEM of 1:10000 map can be used to calculate the accuracy (*ME*) and precision (*SDE*) of the DEM from 1:25000 maps (Weschler, 1999).

For the first criterion, a higher resolution of DEM with 5 m contour was derived from the hardcopy topographical map of 1:10000 scale. The map was scanned and imported as TIFF format in ArcView. The scanned map was georegistered by using Smartimage Evaluation extension, and then the contours were digitized. The contours were converted from polyline into point themes. The point will be used as a check point against the lower resolution of the DEM.

A lower resolution of DEM with 20 m contours were derived from the digital topographical map of 1:25000 scale. The contour layer in the map was imported into ArcView for processing. The DEM was derived by using 3D Analyst Extension in ArcView which allowed the conversion of contour datasets to a 3D shapes, surface modeling and real-time perspective visualization. The DEM then was converted into grid data.

The Geoprocessing extension in ArcView was used to match the study area between the two maps. The difference of Z or vertical value between two points were extracted within the 'Terrain Analysis' extension. The difference in elevation were then calculated by using Equations 1 and 2 for the uncertainty prediction of the DEM.

The second criterion involves the LS generation for both DEMs. The contour data were imported into the Geographical Resources Analysis Support System (GRASS) environment.

Within the GRASS environment, the LS factor for both DEM were generated and their values were then compared between the two DEMs.

RESULTS AND DISCUSSION

The *ME* indicated the accuracy of the 1:25000 DEM to be 12.53 m as compared to the 1:10000 DEM. This means that a difference in the height value of 12.53 m can be expected if the DEM was derived from 1:25000 map instead of 1:10000 map. The precision or *SDE* was 11.47 m. This shows that the spread of the different heights or *SDE* is 11.47 m about the average. Thus, the accuracy and precision of the 1:25000 DEM can be reported as 12.53 ± 11.47 m.

The minimum elevations for 1:10000 DEM and 1:25000 DEM were found to be 1318.06 m and 1332.23 m, respectively (Table 1). The maximum elevations are 1841.78 m and 1850.12 m for the 1:10000 DEM and 1:25000 DEM, respectively. The range of 1:10000 DEM is 523.72 m while the range of 1:25000 DEM is 517.88 m, showing that the 1:10000 DEM has the larger range. The range value is expected to be higher in the 1:10000 DEM because DEM generated from higher scale of map may generate more detail information compared to the lower scale of map. The mean elevation and standard deviation for 1:10000 DEM are 1517.52 m and 68.98 m respectively. For the 1:25000 DEM, the mean elevation is 1520.82 m and standard deviation is 69.34 m. The differences of the mean elevations and standard deviation are small. 3.30 m and 0.36 m respectively. The differences may be attributed to the difference in minimum values.

Topographical attributes such as slope and aspect can be calculated directly from the DEM (Kenward et al., 2000). Both minimum values of elevation are similar but the 1:10000 DEM has a higher slope angle of 66.45^o compared to the 1:25000 DEM with 52.11^o (Table 2). The 1:10000 DEM also showed a larger slope angle range of 66.45^o compared to 52.11^o for the 1:25000 DEM and also a larger mean and standard deviation with a difference 5.26^o and 1.93^o, respectively as compared to the 1:25000 DEM. Thus, this study indicated that for a slope angle generation from the DEM, the higher the DEM resolution, the steeper the slope angle. This is probably due to the nature of slope generation itself, where a denser contour in higher DEM resolution will generate steeper angles. For ease of explanation, the slope class has been divided into five classes as presented in Table 3.

From the slope angle classification, 35.59 % of the area of study for the 1:10,000 DEM is under class 1, whereas for 1:25000 DEM class 1 occupies a larger area i.e. 52.63 % giving a 17.04 % difference. The difference in class 2 is only about 3 %, followed by class 3, 12.99 % and lastly class 4 only 1.25 % as demonstrated in Figure 2. The result showed that DEM resolution is the main factor in determining slope angle generation, and different resolution may give different slope

Table 1. Statistical indicator for the DEM.

Elevation (m)	1:10000 DEM	1:25000 DEM
Minimum	1318.06	1332.23
Maximum	1841.78	1850.12
Range	523.72	517.88
Means	1517.52	1520.82
Standard Deviation	68.98	69.34

Table 2. Statistical indicator for slope angle.

Slope angle (°)	1:10000 DEM	1:25000 DEM
Minimum	0.00	0.00
Maximum	66.45	52.11
Range	66.45	52.11
Means	20.20	14.94
Standard Deviation	11.65	9.72

Table 3. Slope angle classification for the study area.

Slope angle class	Slope angle (°)
1	0 – 15
2	15-30
3	30-45
4	45-60
5	60-90

angle. However, apart from the resolution or scale factor, other sources of possible error in DEM data generation are the age of the data, incomplete density of spatial observation and the measurement errors such as positional inaccuracy, data entry faults, or observer bias, and the processing errors such as numerical errors in the computer, interpolation errors and generalization problems (Wechsler, 1999).

The values of minimum, maximum, means and standard deviation of slope aspect do not show much difference between the one generated by 1:10000 compared to the 1:25000 map (Table 4). The min and max values are similar. The means and standard deviation showed only about 1 % difference of the slope. For ease of explanation, the slope aspect has been divided into 12 classes as shown in Table 5. The histograms in Figure 3 showed that there is a small difference in every class which is less than 1%. The nature of the slope aspect generation can be self-explained because during generation the most important factor is the direction of the contour. In lower and higher DEM resolution, usually the direction or aspect of the slope is more or less uniform, whereas for

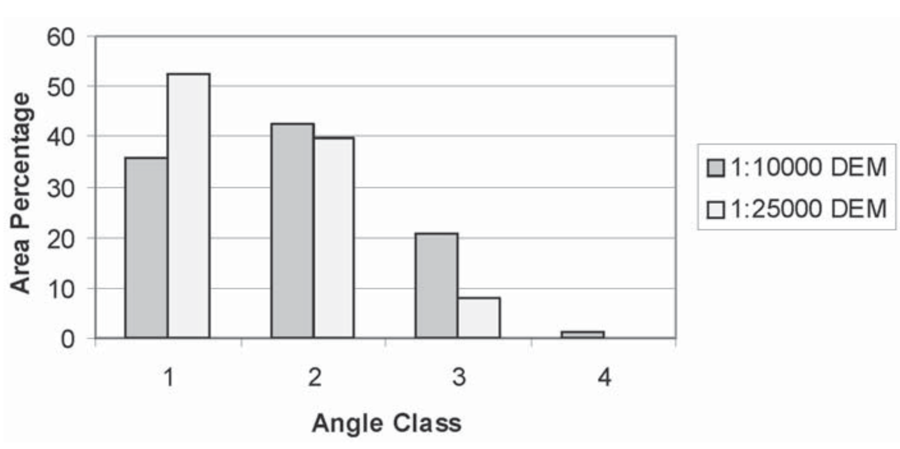

Figure 2. Histogram of the comparison of the slope angle classification.

slope angle generation, the denser the contour, the steeper the slope that is generated.

There is little difference in the minimum values for LS (Table 6). However, the difference of the maximum values for LS between the DEMs is apparent; they are 191.95 m and 105.37 m, respectively with 86.58 m difference (Table 6). However, the difference of means and standard deviation of the DEMs are small; they are 1.20 m and 0.47 m, respectively (Table 6). Histograms are used to illustrate the difference as depicted in Figure 4. The slope aspect ratio is divided into seven classes as shown in Table 7. There is no significant difference between DEM (Figure 4). Although the difference of the maximum values for LS factor between two DEMs is larger i.e. 86.58 m, it does not have much impact on the application. This is due to the fact that extreme values of LS factor only cover about 0.01 % of the total area of study.

Table 4. Statistical indicator for slope aspect.

Slope aspect	**1:10000 DEM**	**1:25000 DEM**
Minimum	0	0
Maximum	360.0	360.0
Means	188.25	187.07
Standard Deviation	96.75	95.21

Table 5. Slope aspect classification for the study area.

Slope aspect class	**Slope aspect (°)**
1	0 – 30
2	30-60
3	60-90
4	90-120
5	120-150
6	150-180
7	180-210
8	210-240
9	240-270
10	270-300
11	300-330
12	330-360

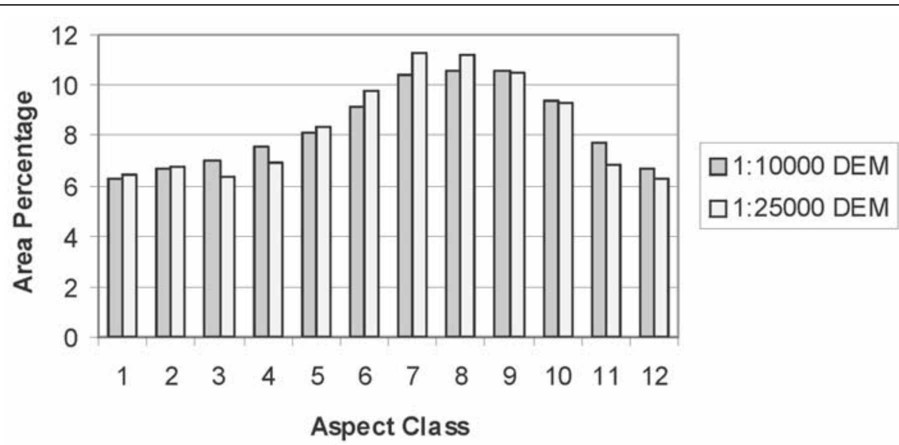

Figure 3. Histogram of the comparison of slope aspect.

Table 6. Statistical Indicator for LS factor.

LS Factor	1:10000 DEM	1:25000 DEM
Minimum	0	0
Maximum	191.95	105.37
Means	9.52	8.32
Standard Deviation	8.83	8.36

Table 7. LS factor classification for the study area.

LS factor class	LS value
1	0 – 30
2	30-60
3	60-90
4	90-120
5	120-150
6	150-180
7	180-210

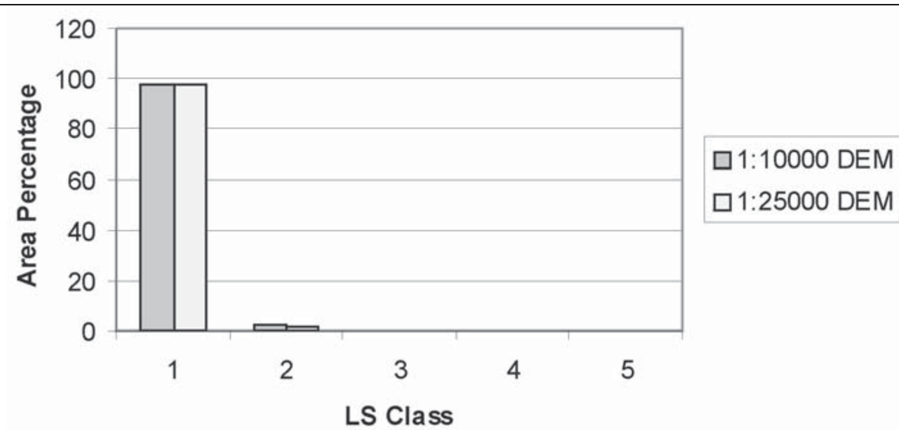

Figure 4. Histogram of the comparison of the LS factor

CONCLUSIONS

Different DEM resolution will produce different slope angle, slope aspect and especially LS factor, which are crucial factors in soil erosion studies. The difference in slope angle was found to be substantial while the differences for slope aspect and LS factor do not appear to be significant. The user should be aware that the generation of DEM for soil erosion studies from different scales will produce errors.

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