

# The Accuracy of Slope Images Derived from GIS Software

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## Abstract

A major part of high frequency gravity signals is governed by the masses of the topography. Practically, this effect can be evaluated by using the integration formula of terrain corrections. In this study, the topographic conditions are classified as: Block I (flat), Block II (hilly) and Block III (mountainous). The analysis of the results indicated that the terrain effects is very significant for gravity field information in rough terrains compared to relatively flat areas. A denser grid spacing of Digital Elevation Model (DEM) would contain a lot of gravitational features, especially in the rough terrains. In contrast, for the flat areas, the effect of topographic masses is insignificant, resulting in very small magnitudes as would be expected.

*Key words* : Terrain effect, Gravity Field Parameter, Numerical Integration

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## 1. Introduction

Slope is one of the main and crucial input parameters used in various environmental studies. Slope can be derived from a Digital Elevation Model (DEM) using various software packages. The accuracy of a DEM (hence the accuracy of slope) is a result of many individual parameters. Li (1992) summarised the main factors as:

- i. Accuracy of the source data
- ii. Density of the source data
- iii. Distribution of the source data
- iv. Characteristics of the terrain
- v. Method used for the construction of DEM
- vi. Characteristics of the DEM surface which is constructed from the source data.

However, only the method i.e. the algorithm used for the construction of slope is considered in this paper, because the original point data used is the same for each method. The effect of pixel size will also be investigated to find out the most suitable pixel size for a certain usage.

Various studies have been carried out to investigate the effects of the algorithms used to calculate slope and aspect from DEMs. This include work carried out by Skidmore (1989), Srinivasan and Engel (1991) and Kumler (1990). Carrara et al. (1997) compared four different techniques of generating DEM using three morphologically complex areas in which it was found out that one grid interpolator and a TIN generator both provided outcomes almost equally good in terms of accuracy.

In this paper, an accuracy analysis carried out on slopes obtained using ERDAS Imagine, GRASS and IDRISI software is reported. The slopes used were generated from DEMs derived using ARC/INFO, GRASS and IDRISI respectively. Comparison with 'true' slope values derived from a topographic map was then carried out.

## 2. Study Area

The study area is a 4 km by 4 km site located at

Langkawi Island, Malaysia. The area covers a range of elevation values from low to high so that different categories of topography are represented. Elevation data were originally obtained by digitising the 1:50,000 scale topographic map containing contour lines at 20 m contour interval. The data are available for this study in x,y,z ASCII format which represents

spot heights, hence the knowledge of contours has been lost. This data were converted to ARC/INFO, GRASS and IDRISI formats for the creation of DEMs. These were then used to generate the slope images (at 5 m resolution), as shown in Figures 1a, 1b and 1c below.

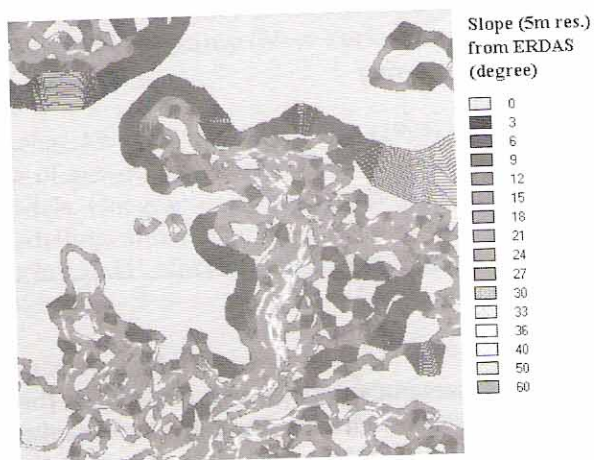


Fig. 1a: Slope from ERDAS Imagine

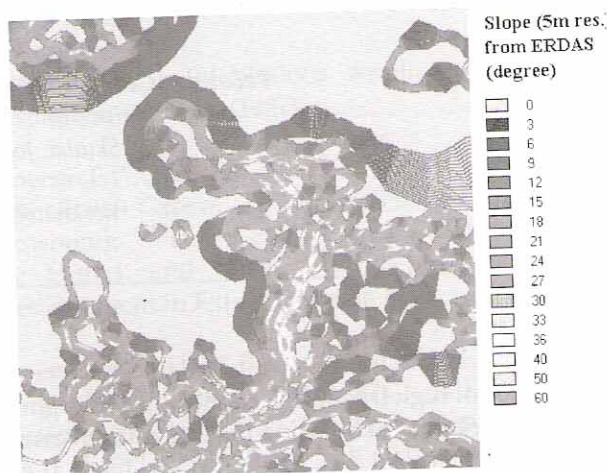


Fig. 1b: Slope from GRASS

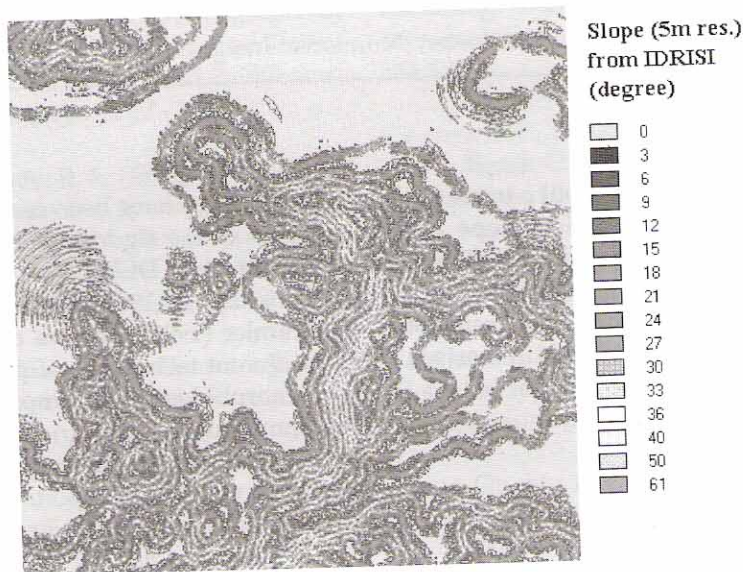


Fig. 1c: Slope from Idrisi

### 3. Slope Accuracy Analysis

The slope accuracy analysis is undertaken by carrying out three procedures on the 5 m resolution slope images. The first is to visually compare the images. Secondly is to compare the three slope images with

each other by using the overlay process in IDRISI. And thirdly is to compare the slope values with 'true' values derived from a topographic map.

### 3.1 Visual comparison

Visual comparisons of the images show that there is a distinct difference between the slope derived from ERDAS Imagine and the two slope images derived from GRASS and IDRISI. The slope images derived from GRASS and IDRISI (Figures 1b and 1c respectively) are steppy in appearance. This steppy nature is most likely due to the interpolation technique used to produce the DEM. The DEM that is used in ERDAS Imagine is produced using ARC/INFO TIN where the creation of the Delaunay triangles result in a better representation of the surface. In contrast, GRASS and IDRISI both use the Inverse Distance Weighted Interpolation technique where the best results are obtained when sampling is sufficiently dense. As the elevation points that are used in this study are generated from contour lines, the slope images that are created resulted in the steppy or contour-like appearance. This has a notable effect on the accuracy of the slope images as discussed in Section 6.

### 3.2 Overlay analysis

The slope images generated using ERDAS Imagine, GRASS and IDRISI were compared by overlaying two images at a time using the First-Second option in the IDRISI OVERLAY command. Results of the comparison are shown in Table 1 below.

Table 1: Comparison of slope (degree) from ERDAS, GRASS and IDRISI

	Erd+Gra	Gra+Idr	Idr+Erd	Mean
Min. Diff.	-53	-49	-60	54
Max. Diff.	59	47	55	54
Mean Diff	-1.58	0.03	1.55	1.05
Std. Dev.	6.35	6.77	8.19	7.10

The results above do not show the accuracy or reliability of the slope values. Although the mean difference between GRASS and IDRISI is small (0.03 deg), generally it can be said that the difference in slope values derived from the three packages are quite substantial (mean of mean difference is 1.05 degrees, mean of standard deviations is 7.10 degrees).

### 3.3 Comparison with slope values from topographic map

Ideally, the best way of checking the accuracy of the slope is to compare the values derived from slope images with the values measured independently from the ground. Alternatively, a lower resolution slope image can be compared with a higher resolution slope (assumed to be of true value), in which all elevation points are surveyed directly such as by using an analytical stereoplotter, as carried out by Chang and Tsai (1991).

As these are physically not possible within the context of this study, the alternative is to obtain the values from a topographic map of the area. With respect to this, the map used should be of a larger scale and of a smaller contour interval than the map that was originally used to derive the DEM. However as other maps are not available and the best map of the area is the 1:50,000 scale map having a 20 m contour interval that was originally used to produce the DEM, this map was also used to derive the slope. Carrara et al. (1997) also carried out a study in which DEM accuracy was evaluated in comparison with the data source, namely, the original contour lines from which they were derived through different algorithms.

Four lines in the vertical, horizontal and the two diagonal directions were selected from the area where there are changes in elevation. The lines were selected to cut across the contour lines to give a distinct change in elevation for a more accurate calculation of slope. Longer lines are preferable to ensure a sufficient number of elevation points but short lines were also used for ease of calculation.

The topographic map containing the study area was enlarged to enable a better pointing at the contour lines. The values of elevation on the lines cutting the contour lines were obtained manually from the topographic map. The distance along the line was recalculated and the elevation noted so that the elevation profile could be drawn. Various software packages were tried in drawing the profile curves. The most powerful and convenient to use is the CurveExpert 1.3 software.

#### 3.3.1 CurveExpert 1.3

CurveExpert 1.3 (Hyams, 1997) is a comprehensive curve fitting system for Windows where xy data can be modelled using a toolbox of linear regression models, nonlinear regression models, interpolation, or splines. A full-featured graphing capability with

customisable, dynamic graphs allows thorough examination of the curve fit and gives immediate feedback on curve fit quality. The software has the ability to allow the generation of tabulated values and differentiation of the curve. This gives a quick and convenient way of doing the elevation and slope accuracy analysis.

CurveExpert implements four types of spline interpolation namely linear, quadratic, cubic and tension splines. It was found out that the spline that produced the best curves through the set of elevation points are the cubic splines or the tension splines with a low tension parameter.

Cubic splines interpolate the range between data points by 3rd order polynomials. They have an aesthetically-pleasing appearance and mimic the behaviour of drafting splines used in manual drafting. A tension spline with a low tension parameter yields a spline similar to the cubic spline.

The choice of which spline curve to use depends on how best the curve goes through the elevation points. In most cases, either a cubic spline or a tension spline is the best. However, in one case a combination of both the curves produced the best result.

3.3.2 Slope values from selected lines on slope image

The four lines selected were then identified on each of the slope images produced (Figure 2). Characteristics of the four lines are shown in Table 2. Although the grid resolution of the slope image is 5m, the pixel size shown in the table is not exactly 5m.

The diagonal lines D and FD have larger pixel sizes while the horizontal and vertical lines H and V have pixel sizes of nearly 5m. The slight difference is due to rounding off. Line FD, which is the longest line, intersects the contour lines of the topographic map at 41 places thus the 41 elevation points shown in the table.

Shorter lines have fewer points. These points are used in the interpolation using the CurveExpert software to derive the equivalent number of slope values as the number of pixels on the line.

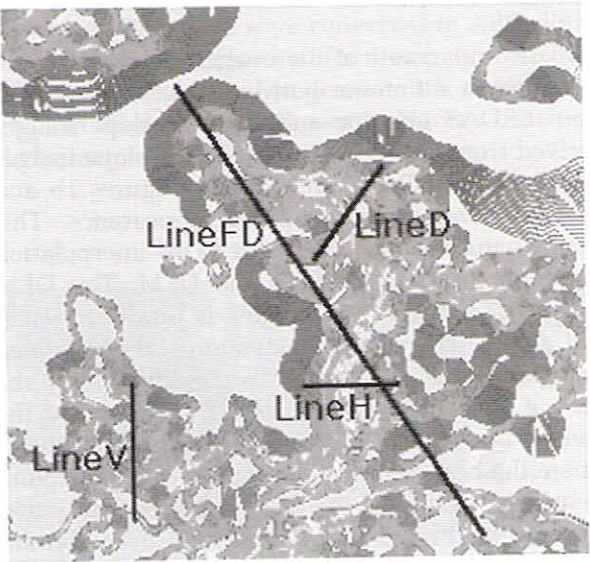


Fig. 2: The four selected lines on the Erdas Image slope image.

	Length (m)	No. of Pixels	Pixel Size (m)	No. of Elev. Pts. from Topomap
Line D.	900.9	149	6.05	16
Line FD	3899.0	658	5.9355	41
Line H	721.8	148	4.95	14
Line V	1003.0	199	5.04	16

Table 2: Characteristics of the four selected lines (for 5 m resolution)

The procedure below were carried out in IDRISI to extract the values of slope on the lines from slope images.

Procedure: To extract slope values of selected line slope image

- Display the slope image required.
- Digitise the two end points of the selected line on this image by first clicking the digitising icon, left-clicking at the end points, right clicking to end, closing the image, and saving the line vector image created.
- Create an Initial raster image by using the slope image as a base image. Convert the

line vector image into raster using the LINERAS command. Convert the line raster image to integer data type using the CONVERT command.

- Mask the line raster image onto the slope image using QUERY. A report image file is formed.
- Convert the report image file to Integer ASCII data type.

Similarly, report image files of the other lines could be created. These files were imported into Microsoft Excel for further calculations and analysis.

Figure 3 shows an example of the slope profiles of the lines derived from the topographic map using CurveExpert and the DEMs using ERDAS Imagine, GRASS and IDRISI. The differences in slope values between the line generated from the topographic map and the lines from the three DEMs were calculated and the mean slope differences, Pearson correlation coefficients and the Root Mean Square errors are tabulated in Table 3.

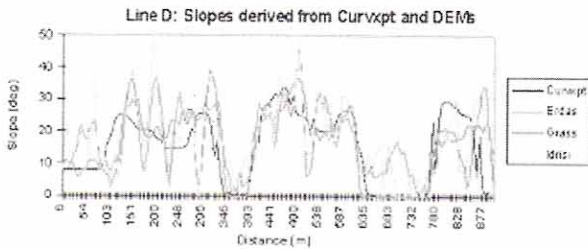


Fig. 3: Slope profiles of Line D

#### 4. Results and Discussion on Slope Accuracy

Referring to Table 3, the mean slope difference of ERDAS is 5.85 which is smaller than that of GRASS and IDRISI which are 8.46 and 8.83 respectively. ERDAS' Pearson coefficient is 0.611 which is larger than that of GRASS and IDRISI (0.470 and 0.430 respectively). The Rote Mean Square Error (RMSE) value of ERDAS is 8.49, smaller than the RMSE values obtained from GRASS and IDRISI (10.46 and 11.29 respectively). From these values, it can be concluded that the slopes derived from ERDAS are more reliable than slopes derived from GRASS and IDRISI.

Table 3: Mean slope difference, Pearson correlation coefficient and Root mean square error of slope between lines (values for Lines FD, H and V not shown) from topographic map (CurveExpert) and DEMs (5m resolution).

		Line D	Mean	Mean of mean
Mean slope diff	Cxpt-Erdas	4.68	5.85	7.71
	Cxpt-Grass	8.82	8.46	
	Cxpt-Id-risi	8.74	8.83	
Pearson Corr. Coef	Cxpt-Erdas	0.797	0.611	0.504
	Cxpt-Grass	0.496	0.470	
	Cxpt-Id-risi	0.534	0.430	
RMSE	Cxpt-Erdas	6.68	8.49	10.08
	Cxpt-Grass	10.86	10.46	
	Cxpt-Id-risi	11.00	11.29	

A mean of the mean slope difference of 7.71 degrees is quite large and a Pearson coefficient of about 0.5 is small which does not indicate a strong correlation between the slopes derived and the 'true' values. Furthermore an RMSE of 10 degrees seems to be quite large for any positive conclusion to be made. However, these values are to be expected due to the algorithms used to calculate the slope values. In the algorithms, elevation values of the 8 or 4 neighbouring pixels around the considered pixel are used in the calculation of the slope. In contrast, calculating the slope along the selected line on the topographic map, only the value of the forward pixel is used. Thus there is bound to be differences in the values obtained. However, as this analysis is carried out to find the best software (if any) and not the absolute value, it can be concluded that the slope generated by using ERDAS (where the DEM is produced using ARC/INFO) is relatively more accurate than that obtained from GRASS and IDRISI.

##### 4.1 Effect of Pixel Size

One of the factors that affect the accuracy of DEM and its derivatives such as slope and aspect is the size of grid used. Isaacson and Ripple (1990) have examined the implications that different cell sizes have for slope and aspect. Chang and Tsai (1991),

Wolock and Price (1994) and Hutchinson and Dowling (1991) have also carried out investigations on the effect of grid size. These studies showed that distributions of topographic attributes derived from a DEM depend to some degree on grid size.

Generally it was found that the accuracy of DEM, slope and aspect data decrease with lower DEM resolution (increase in pixel size). However the relationship is not straight forward, as shown by Zhang and Montgomery (1994) in which they found out that a 10m grid size provides a substantial improvement over 30 and 90m data, but not with 2 or 4m which only provide a marginal additional improvement for moderately to steep gradient topography of their study areas. Gao (1997) concluded that reduction in DEM resolution profoundly affects the gradient and its standard deviation determined from the DEM resolution but exerts little influence on the mean gradient.

It is important that the effect of grid size is investigated since grid size will determine the file size of the images used. A small grid size giving a large file size will significantly increase the computing time of the processes involved in the analysis and running of subsequent analysis especially when a personal computer is used. On the other hand, reducing the file size will reduce the extent of the area covered.

Therefore an optimum grid size is required so that the processes can be run efficiently while covering the largest area possible. The determination of an appropriate cell size is also recommended by Savabi et al. (1995) in their study on the application of WEPP and GRASS on a small watershed.

#### 4.2 Comparison between slope images

The tests and analysis that were carried out with the 5m resolution DEMs and slope images were repeated using DEMs and slope images of 20m and 50m resolutions.

Visual inspection of the slope shows that there are differences in the values of the slope generated by different software packages and produced at different pixel sizes. From Table 4 it can be seen that as the pixel size increases, the mean maximum value, mean of the mean value and the mean standard deviation decrease.

As the pixel size decrease, the effect of combining neighbouring pixels to form a larger pixel has the effect of reducing the overall value of the slope.

Table 4: Slope image statistics

Resolution	Slope Image	Max (deg)	Mean (deg)	Std. Dev.
5m	Erdas	60	7.23	9.17
	GRASS	58	8.73	9.44
	Idrisi	61	8.80	10.56
	Mean	60	8.25	9.72
20m	Erdas	44	7.06	8.23
	GRASS	41	7.91	7.72
	Idrisi	44	7.47	8.48
	Mean	43	7.48	8.14
50m	Erdas	35	6.68	6.98
	GRASS	33	7.30	6.60
	Idrisi	37	6.91	7.21
	Mean	35	6.96	6.93

#### 4.2 Overlay analysis

Table 5 shows the results of the analysis obtained when the three slope images are compared with each other for the three grid sizes. Results for the 5m grid size as discussed in Section 3.2 are also shown in the table for ease of comparison.

The mean values for the minimum difference, maximum difference, mean difference and standard deviation (-17m, 19m, 0.32m and 2.95m respectively) are smallest for the 50m grid slope images.

This strongly indicates that the slopes generated from the three software packages are similar when the grid size is 50m. At 20m grid, the slopes are less similar and at 5m grid, the values indicate that there is a great difference between the slope images. This finding is also supported by the results of other analyses in the following sections

Table 5: Comparison of slope values (deg) between slope images at 5m, 20m and 50m pixel sizes.

		5m res	20m res	50m res	Mean
<b>Min. diff.</b>	Er+Gr	-53	-18	-11	-27
	Gr+Id	149	-19	-23	-30
	Id+Er	-60	-23	-16	-33
	Mean	-54	-20	-17	
<b>Max. diff.</b>	Er+Gr	-59	20	27	35
	Gr+Id	47	15	12	25
	Id+Er	55	25	17	32
	Mean	54	20	19	
<b>Mean dif.</b>	Er+Gr	-1.58	-0.85	-0.45	-0.96
	Gr+Id	0.03	0.46	0.34	0.28
	Id+Er	1.55	0.39	0.17	0.70
	Mean	1.05	0.57	0.32	
<b>Std. Dev.</b>	Er+Gr	6.35	3.67	3.16	4.33
	Gr+Id	6.77	2.89	2.59	4.08
	Id+Er	8.19	4.36	3.09	5.21
	Mean	7.10	3.57	2.95	

A closer examination of the results indicates that there is a strong similarity of the slope images produced by GRASS and IDRISI whereby comparison of the two slope images give a small mean of mean difference of 0.28m and mean standard deviation of 4.08m.

The two software packages have different algorithms for calculating slope but in this case the slopes are similar. This could be an exceptional case or may be due to the fact that these software packages are grid based whereas the ERDAS package uses a TIN-based DEM to generate the slope image.

#### 4.3 Comparison with slope from topographic map.

Table 6 shows the characteristics of the lines used in the analysis for the 50m resolution slope image. The lines are basically the same lines used for the 5m resolution, the only difference being line H2 was increased in length to allow a greater number of pixels along the line for the calculation purposes.

Lines D and V of the 50m resolution have only 16 and 21 pixel values, which may be considered small for statistical analysis. However by examining the results obtained, this does not seem to produce any significant effect.

Table 6: Characteristics of the four selected lines (for 50m resolution)

	Length (m)	No. of Pixels	Pixel Size (m)	No. of Elev. Pts. from Topomap
<b>Line D.</b>	895.1	16	55.9	16
<b>Line FD</b>	3892.7	67	58.1	41
<b>Line H</b>	1996.4	40	49.9	14
<b>Line V</b>	1009	21	48.0	16

Table 7 shows the values obtained for the various analyses carried out for the different pixel sizes. The slope values are more accurate as the grid size increases.

The 50m resolution slope images have the best accuracy as shown by the values in the table where they have the smallest mean maximum difference (14.55 degrees), the smallest mean standard deviation (3.42 degrees), the smallest mean of the mean slope difference (4.27 degrees), the highest Pearson coefficient (0.772) and the smallest RMSE (5.50 degrees), compared to the values for the 5m and 20m resolution images. This is true for each slope image derived from the three software packages.

Comparing the three software packages, it can be seen that the slope images from ERDAS are generally more accurate than the images from GRASS and IDRISI as they have the lowest value for the mean of the mean slope difference (4.89 degrees), highest Pearson correlation coefficient (0.677 degrees) and lowest RMSE (6.90 degrees).

However at 50m resolution there is not much difference between the software packages in terms of the slope accuracy.

Table 7: Comparison of slope from slope images at 5m, 20m and 50m pixel sizes.

	5m res	20m res	50m res	Mean
<b>Mean min diff</b>	012	0.12	0.21	
<b>Mean max diff</b>	33.38	23.15	14.55	
<b>Mean Std Dev</b>	6.42	4.92	3.42	

<b>Mean slope diff (deg)</b>	Cx-Er	5.85	4.65	4.16	4.89
	Cx-Gr	8.46	5.52	4.25	6.08
	Cx-Id	8.83	5.68	4.40	6.30
	Mean	7.71	5.28	4.27	
<b>Pearson Corr Coef</b>	Cx-Er	0.611	0.655	0.765	0.677
	Cx-Gr	0.470	0.610	0.787	0.622
	Cx-Id	0.430	0.599	0.765	0.598
	Mean	0.504	0.621	0.772	
<b>RMSE (deg)</b>	Cx-Er	8.49	6.72	5.48	6.90
	Cx-Gr	10.46	7.28	5.38	7.71
	Cx-Id	11.29	7.69	5.63	8.20
	Mean	10.08	7.23	5.50	

## 5. Discussion on Effect of Pixel

It is clear that an increase in pixel size not only reduce the slope value but, as the results have shown, increases the accuracy of the slope. This finding is in contrast to the results of other studies mentioned earlier (Section 5) where it was found out that the accuracy of DEMs, including slope values, decrease as the pixel size is increased. In Section 3.1, the steppy nature of the slope images has been noted. Increasing the pixel size gives a generalisation effect to the DEM created thus reducing the effect of the individual values of the surrounding pixels used in the calculation of the slope.

Hence when the DEM is used in the calculation of slope, the slope is improved as can be seen from the smoothing of the steps.

The way to really determine the accuracy of the slope is to compare the slope with values measured on the ground. However due to the constraint of this study, ground measurement of the slope is not possible to carry out. This difference in results from other studies is not something to be alarmed at as what is important concerning this analysis is to get the best data (in this case pixel size) which resembles the true value, for further use in subsequent studies.

This is in agreement with the conclusions made by Wolock and Price (1994) who mention that, in the case of TOPMODEL, coarse resolution DEMs are not necessarily inappropriate sources of topographic information.

It would be interesting to see what the results would be like if a larger pixel size such as 100m was used in the analysis. However, this was not carried out since a 100m pixel size would result in too small a

number of pixels along the selected lines used in the analysis, which would not have been suitable for the statistical calculations.

In addition, a further increase in the pixel size means that all other data inputs used in related analyses, such as soil and vegetation types, would have to be at that larger pixel size. This will result in a less accurate overall representation of the area.

The mean of the mean slope difference value for the 50m resolution slope images is 4.27 degrees. The mean RMSE is 5.50 degrees and the Pearson correlation coefficient is 0.772 (Table 7). A slope difference and RMSE of around 5 degrees may or may not be considered sufficient for related studies such as for soil erosion purposes, depending on the models used.

A Pearson correlation coefficient of 0.772 may be too small to conclude that there is a strong relation between the slopes derived and the true values. However, this is a much higher value than the corresponding values obtained for the 5m and 20m pixel sizes (0.504 and 0.621 respectively), thus the result can be accepted in that the slopes given by the 50m grid size slope images are relatively more accurate.

## 6. Conclusion

From the results of the analyses reported in this study, the following conclusions can be made:

1. The slope images produced by ERDAS are generally most accurate, followed by GRASS and IDRISI (Table 7). However at 50m resolution the difference in accuracy is less significant between the software packages.
2. Using three pixel sizes of 5m, 20m and 50m, the slope accuracy increases as the pixel size increases. This is true for all three slope images. This is due to the smoothing of the steppy slope as the pixel size is increased.
3. The steppy appearance of the slope image is not apparent with the slope derived from ERDAS Imagine. This is due to the ARC/INFO TIN generated DEM used as its input. It is recommended that this DEM is used in future to ensure a better result in the slope values.

The conclusion of this comparative study is that the DEM (and derived slope image) produced by the ARC/INFO - ERDAS Imagine combination are the closest representation of the topographic surface represented by the 1:50,000 map. Hence the ARC/INFO - ERDAS Imagine slope data were used in

subsequent analyses requiring slope data as an input.

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