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Application of Remote Sensing in the Identification of the Geological Terrain Features in Cameron Highlands, Malaysia

(Aplikasi Penderiaan Jauh di dalam Pengcaman Fitur Terain Geologi
di Cameron Highlands, Malaysia)

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ABSTRACT

The geological terrain mapping conducted by the Department of Mineral and Geosciences, Malaysia (JMG) is time-consuming especially for inaccessible or remote area. In order to improve the current practice, remotely sensed data such as aerial photographs and Landsat imagery were used to identify geological terrain features in Cameron Highlands, Pahang. It was found that features such as hillcrest, sideslope, footslope, straight slope, convex slope and concave slope were easily delineated using aerial photographs draped over a digital elevation model (DEM) compared to using Landsat imagery.

Keywords: Aerial photograph; landsat; remote sensing; terrain mapping

ABSTRAK

Pemetaan terain geologi yang dijalankan oleh Jabatan Mineral dan Geosains Malaysia (JMG) mengambil masa yang lama terutamanya di kawasan yang susah dimasuki. Bagi menambahbaik amalan semasa, data penderiaan jauh seperti fotoudara dan imej Landsat digunakan untuk mengenal pasti fitur terain di Cameron Highland, Pahang. Hasil kajian mendapati fitur terain seperti permatang, cerun sisi, cerun kaki, cerun lurus, cerun cembung dan cerun cekung dapat dipetakan menggunakan fotoudara ditindan di atas model ketinggian digital dengan lebih mudah berbanding dengan penggunaan imej Landsat

Kata kunci: Fotoudara; landsat; pemetaan terain; penderiaan jauh

INTRODUCTION

The term ‘terrain mapping’ is defined as a process of dividing the landscape into polygons based on a terrain classification system. A terrain map shows the distribution of surficial (quaternary) deposits and related landforms on the earth’s surface. It also provides information about present day geomorphological processes (ESTFBC 1996). A terrain mapping is important for development in terms of economy and improvement of life conditions. It is done at different levels, with different techniques and corresponding results of different quality (Lazaridou & Patmios 2002).

There are few terms which are similar and closely related to terrain mapping as mentioned by Pasuto and Soldati (1999). Several authors have named based on different cases such as land system (Christian & Stewart 1953), morphological unit (Savigear 1965; Waters 1958), landform unit (Working Party-Geological Society 1982), geomorphological unit (Van Zuidam & van Zuidam-Cancelado 1979), unit areas (Kienholz 1984), terrain unit (Grant 1971; van Zuidam-Cancelado 1979), terrain mapping units (Meijerink 1988) and landform-sediment unit (Derbyshire et al. 1995).

Traditionally, terrain and landform mapping was undertaken utilising topographical map, aerial photographs and field survey (Pain 1985). Aerial photographs are the most frequently used type of remote sensing data and routinely applied in terrain mapping programme in British Columbia (Slaymaker 2001) and landslide mapping in Hong Kong (Dai & Lee 2002). Mantovani et al. (1996) identified geomorphological units utilising aerial photo interpretation and field work for large and medium scale mapping.

Many researchers have also used Landsat for identification of terrain features, landform, geology and geomorphology (Verstappan 1977; Kayan & Klemas 1978; Pain 1985; Liaqat et al. 1989; Pandi et al. 1994; Novak & Soullakellis 2000; Wolk-Musial & Zagajewski 2000; Kaya & Muftuoglu 2000; Bocco et al. 2001; Won-In & Charusiri 2003).

Landsat has been used in the analysis of terrain mapping and geomorphic features by the analysis of color composites (Pain 1985; Novak & Soulakellis 2000; Bocco et al. 2001). The false color composites: blue, green and red (with bands 7, 5 and 4) display good contrast for analyses of landform (Pain 1985) and geology (Ibrahim & Johari 1997; Won-In & Charusiri 2003).

A more complex analysis techniques of principal component analysis (PCA) have been used in the analysis of terrain mapping and geomorphic (Novak & Soulakellis 2000). PCA is a multivariate statistical technique that selects uncorrelated linear combinations of variables in such a way that each successively extracted linear combination or principal component (PC) has a smaller variance (Singh & Harison 1985). PCA can also be used to identify bare soil and landslide areas (Petley et al. 2002).

Verstappan (1977) used Landsat ERTS-1 band 5 and 7 data in bispectral plot. It was concluded that some landform types were better distinguished than others, mainly because of variations on the correlation between geomorphic units and vegetation. It was also possible to delimit photomorphic region, based on the directly observable properties of image (Townshend 1981). Band 7 of Landsat ERTS-1 was the most valuable for identifying geologic formations, tectonic fault lines and geomorphology slope contrast (Kayan & Klemas 1978). Band 5 supplemented the information obtained from band 7, by providing information on rock-soft boundaries, tectonic relationships between vegetation and structure, and vegetation tonal differences between steep slopes and flat surfaces.

Pain (1985) used Landsat MSS for landform mapping in Australia and existing landuse classification as a reference. This study has suggested the geomorphic interpretation using tone, texture, pattern and shape. Tone was found to have a little value as it usually indicated vegetation not the landform. The structures lineament, ridges and rivers were easily identified in Landsat images. The application of Landsat can quickly be mapped terrain at reconnaissance scale (1:250,000) and semi-detailed (1:50,000) levels (Bocco et al. 2001). Landsat scene provides excellent image characteristics with synoptic view of large areas in various band combinations (Rimal et al. 2001). Landsat imagery is the most cost effective tools due to its relatively low cost and moderate spectral resolution (Petley et al. 2001)

A digital elevation model (DEM) consists of an array of uniformly spaced elevation (Chang 2002). The DEM term is used to refer to the computer based model elevation values. Majority of DEM are generated from digitized contour data.

DEM has been a useful tool in recognizing geological and geomorphological features (Grover 2002) where it provides additional information beyond that available from two-dimensional imagery alone (Davis & Mason 2000). This is because humans can analyze data much easily in three dimensions than in the two dimensions that are usually represented in multispectral imagery (Ramli 2001).

The use of Landsat integrated with digital elevation model (DEM) has allowed increased discrimination of terrain feature and increased mapping accuracy (Huang & Chen 1991). DEM increased the classification accuracy in geomorphic classification (McDermid & Franklin 1997). Integration of DEMs and remotely-sensed imagery is important for the creation of realistic virtual landscape model in real time where computers have been developed sufficiently to support animated fly-through (Miller & Wherrett 2001; Alshammari & Hayes 2002).

The Department of Minerals and Geoscience of Malaysia (JMG) has carried out a meso-scale geological terrain mapping based on the method developed by the Hong Kong Geotechnical Control Office (Table 1). The Hong Kong model was chosen based on climate similarity between Malaysia and Hong Kong (Zakaria & Chow 2003). Geological terrain mapping was carried out based on the evaluation of five attributes, namely, slope gradient attributes, terrain or morphology attribute, activity attribute, the erosion and instability attributes, and cover/ vegetation. The terrain classification map has been used for the approval of development projects on the area. All the parameters utilised are listed in Table 1.

In the geological terrain mapping approach, data capture for the terrain parameters were mainly based on field survey. Therefore it is time-consuming especially for inaccessible or remote areas. The present investigation was principally aimed at identifying the terrain features in Cameron Highlands, Pahang, based on aerial photographs and Landsat imagery. The results are expected to improve the existing method of geological terrain mapping practiced by JMG.

THE STUDY AREA

The study area is located between longitudes 101^o 21' and 101^o 23' East and latitudes between 4^o 28' and 4^o 30' North. The study area covers about 4 km^2 and is characterized by undulating terrain, generally between 1,440 m to 1,660 m above the sea level. The temperature is around 16°C to 26°C, with an average rainfall of about 2,000 mm. The study area includes Brinchang and Tanah Rata town which is part of Cameron Highlands district, Pahang (Figure 1). The geology of the study area consists of granite and alluvium (KPU 1999).

METHODOLOGY

The first stage involved generation of digital elevation model (DEM) from topographical map, orthorectification and mosaicking of aerial photographs and followed by pre-processing and image processing of Landsat imagery (Figure 2).

The digitized contour lines of 1:10,000 topographic maps were used to generate DEM of 5 m pixel size. In this study, slope map, aspect map and shaded relief map were derived from the DEM for visual inspection purposes so that the general morphology of the study area may be discerned. Two panchromatic aerial photographs with serial number F1140 No 125 and F1140 No 126 were acquired on 22 February 1997 by the Department of Survey and National Mapping (JUPEM) were also utilised. In this study, the aerial photographs were acquired using Wild Universal Avioson 15 RC4 camera with a focal length of 152.79 mm. The average flying height is 2780 m, 60 percent side overlap

TABLE 1. Terrain classification attributes

Slope Gradient	Terrrain Code		Activity Code		Erosion and Instability		Cover/Vegetation			
0°-5° 1	Hillcrest	A	Natural -rock	1	No Appreciable erosion:	0	Soil Slope	Dense Vegetation	No Water seepage	a
			Slope -soil	2					Minor water seepage	b
6°-15° 2	Sideslope -stright	B	-soil and rock	3	Sheet erosion:			Moderate Vegetation	Moderate water seepage	c
	-concave	C			-minor	1			High water seepage	d
16°-25° 3	-convex	D	Cut -rock	4	-moderate	2			No Water seepage	e
			Slope -soil	5	-severe	3		Sparse Vegetation (Partially barren)	Minor water seepage	f
26°-35° 4	Footslope -stright	E	-soil and rock	6					Moderate water seepage	g
	-concave	F			Rill erosion: -minor	4			High water seepage	h
36°-60° 5	-convex	G	Fill: -rock	7	-moderate	5		Barren	No Water seepage	i
			-soil	8	-severe	6			Minor water seepage	j
>60° 6	Drainage valley:	H	-soil and rock	9					Moderate water seepage	k
					Guly erosion: -minor	7			High water seepage	l
	Flood plain:	I	Terrace -rock	a	-moderate	8			No Water seepage	m
			-soil	b	-severe	9			Minor water seepage	n
	Coestal plain:	K	-soil and rock	c					Moderate water seepage	p
									High water seepage	q
	Littoral zone:	L	Reclaimation:	d	Well defined recent landslip: (diameters) -<10cm	a				
			Mined-out:	e						
	Alluvial plain:	X			-10m - 50m	b	Partly soil-Partly covered	Partially covered with concrete/ bitumen etc. Dense vegetation in uncovered part	No Water seepage	r
			Water bodies:		->50m	c			Minor water seepage	s
	Wave cut platform:	W	-natural stream	f					Moderate water seepage	t
			-man-made chann	g	Development of general instability				High water seepage	u
	Excavated platform:	Y	-water storage	h				Partially covered with concrete/ bitumen etc. Moderate vegetation in uncovered part	No water seepage	v
			-pond	l	-recent	n			Minor water seepage	w
					-relict	r			Moderate water seepage	x
			Colluvial	m					High water seepage	y
					Coastal instability:	w			No water seepage	A
									Minor water seepage	B
									Moderate water seepage	D
									High water seepage	E
								Partially covered with concrete/ bitumen etc. Barren in uncovered part	No Water seepage	F
									Minor water seepage	G
									Moderate water seepage	H
									High water seepage	I
									No water seepage	J
									Minor water seepage	L
								Totally covered with concrete/ bitumen etc.	Moderate water seepage	M
									High water seepage	N

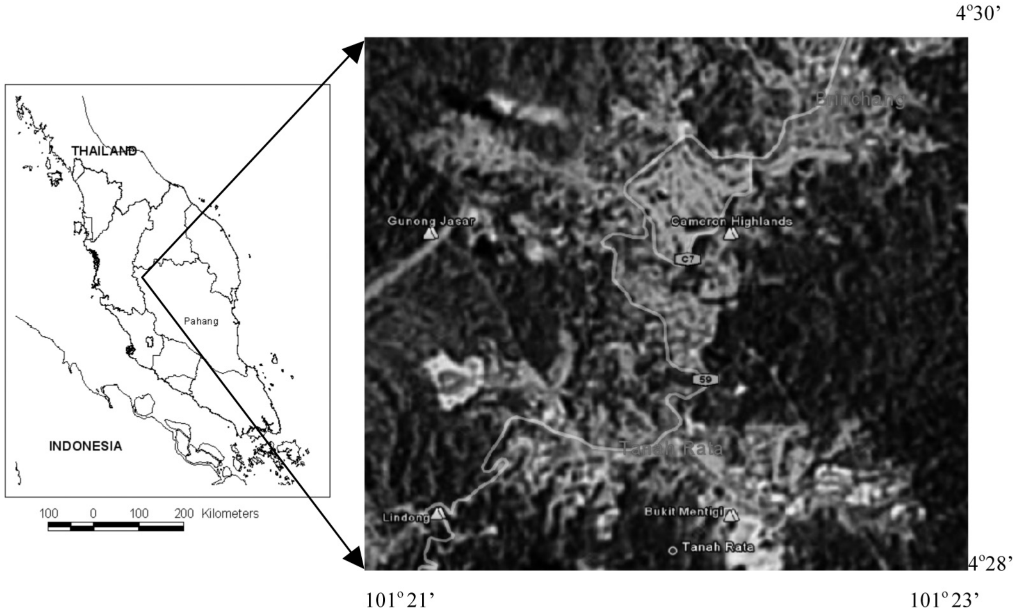


FIGURE 1. Location of study area

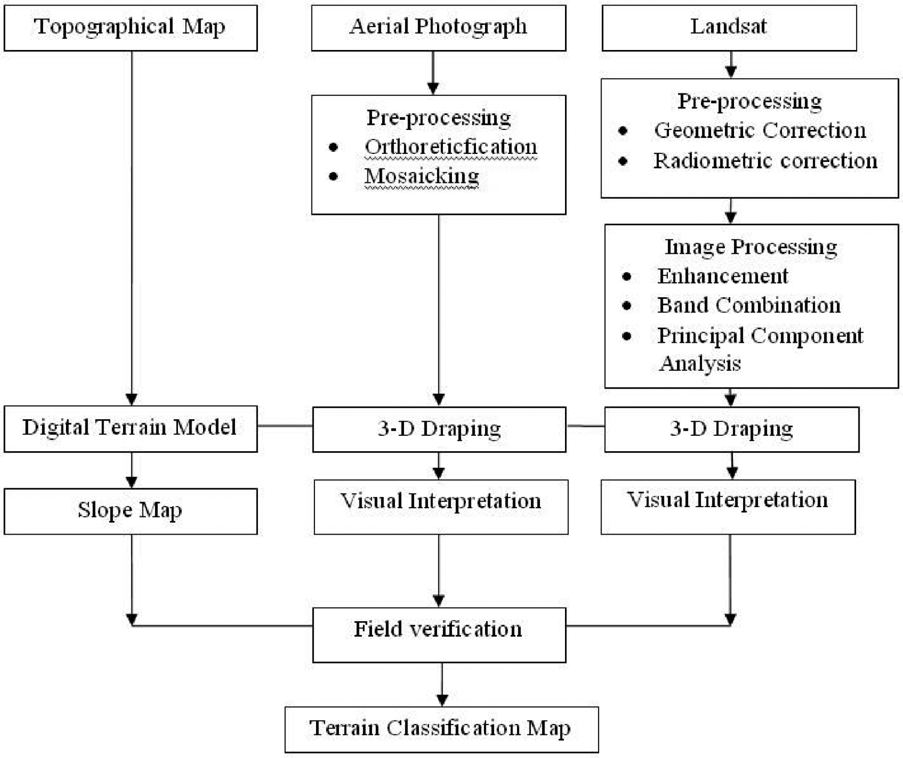


FIGURE 2. Flow chart of the methodology

with a scale of approximately 1: 20,000. The scanned diapositives were georectified using features such as roads extracted from topographic map at scale 1:10,000 turning it into orthophotograph. In order to correct the relief and tilt displacement of the two scanned aerial photographs, a digital elevation model (DEM) and the rotation parameters of the camera were computed. This process is also known as orthorectification. Orthophotograph is a plainmetrically true image that represents ground object in its true real world. A total of 25 ground control points were used in the orthorectification. A root mean square error (RMSE) of 0.9 pixels was encountered during orthorectification. RMSE is a measure of rectification error. The acceptable error for this rectification should be less than 1.0 (Erdas 1999). In order to achieve a better image transformation, a homogeneous distribution of ground control was compared to the use of a high number of selected points in the orthorectification process (Trigo & Cerrera 2000). During image resampling, cubic convolution resampling method was used to ensure high quality results (Legg 1994). The orthophotograph was resampled at 0.25 m per pixel on ground. Two orthophotographs have been used to create photomosaic of the study area. Mosaics are valuable because they provide broader coverage than the individual photograph (Sabins 1997).

For Landsat imagery, linear contrast stretching and histogram equalization introduced by Liu (1991) were used in this study. Image enhancement is a general term referring to a number of operations designed to increase the amount of useful information from the scene. Linear stretching spreads the data uniformly, whereas histogram stretching spreads the data with equal probability to the full dynamic range of the imagery. Some 20 combinations of original bands were tested for color composite images. A Principal Components Analysis (PCA) approach using RGB 123 FCC suggested by Petley et al. (2001) was also used. The PCA has the following advantages: (1) most of the variance in a multi-spectral data set is compressed into one or two PC images; (2) noise may be relegated to the less-correlated PC images; and (3) spectral differences between materials may be more apparent in PC images than in individual bands (Sabins 1997).

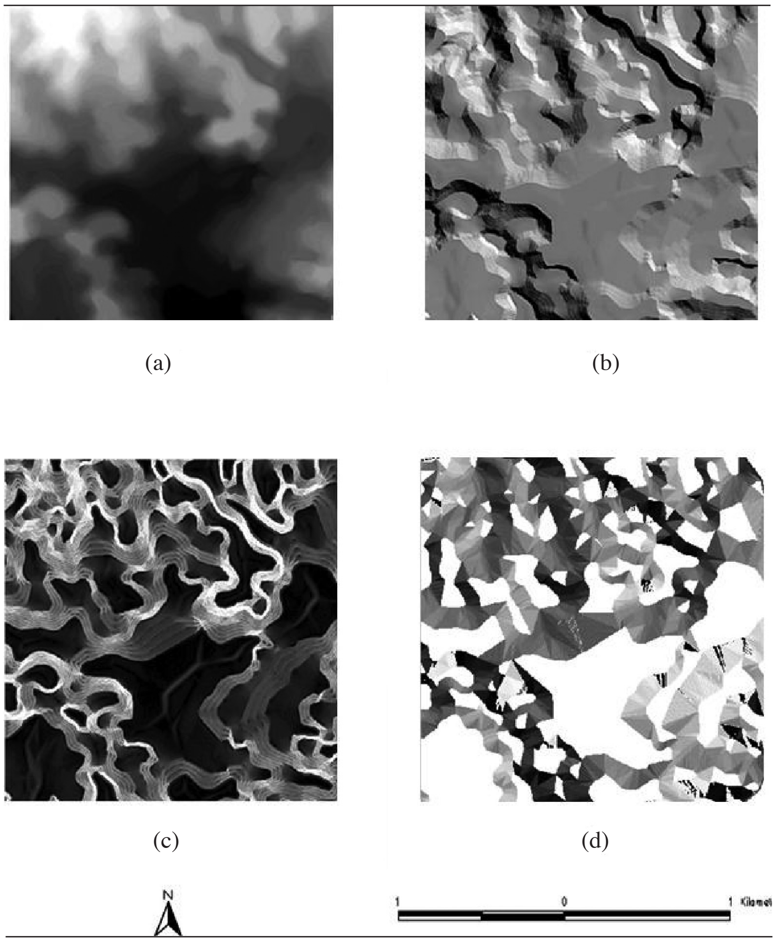
In the second stage, draping process of orthophotograph and Landsat imagery over DEM was carried out. This process enables geological terrain features to be observed not only from the normal vertical view, but also to be viewed from different scale, orientations and perspectives (Miller & Wherrett, 2001; Alshammari & Hayes 2002). In the third stage, the field verification was carried out to verify the geological terrain features as well as landuse areas. The data used for the study with their sources are given in Table 2.

RESULTS AND DISCUSSION

The digital morphometric maps of the study area were computed from the digital elevation model (DEM) i.e. slope, aspect and shaded relief maps (Figure 3). Slope map showed changes in elevation over distance and identifies the maximum rate of change in value from each cell to

TABLE 2. Details of various data sets used in the present study

Type of Data	Details of Data	Source of Data
Topographical map	Sheet no Pa.9a 1998 (scale 1:10,000)	Department of Survey and National Mapping (JUPEM)
Aerial photographs	F1140 No 125 and F1140 No 126 (22nd February 1997)	Department of Survey and National Mapping (JUPEM)
Landsat	Path/row 127/057 (20 September 2001)	Malaysian Center for Remote Sensing (MACRES)



(a) (b)

(c) (d)

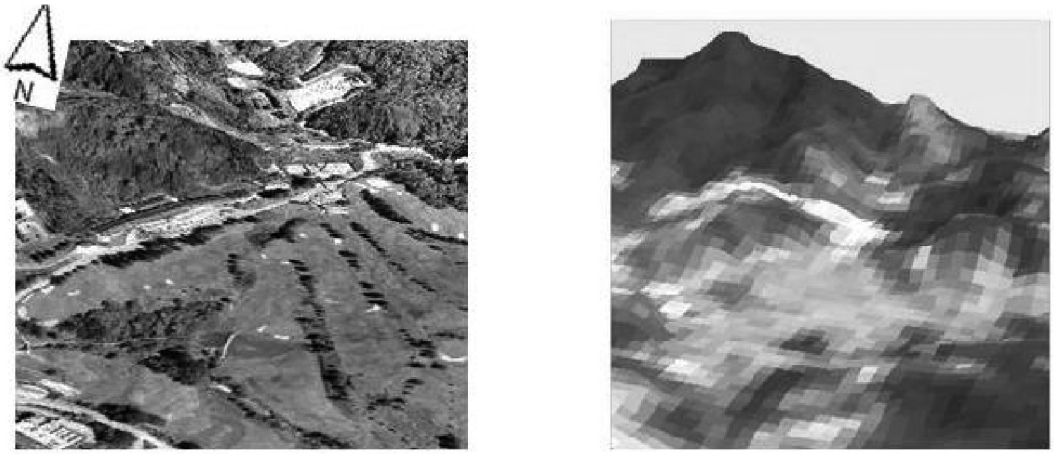
FIGURE 3. Morphometric maps derived from the DEM; (a) grey-level representation of the DEM; (b) shaded relief; (c) slope map; (d) aspect map

its neighbors, while aspects map shows the prevailing direction that a slope faces at each pixel. The shaded relief image emphasize on subtle morphological features. These features are important in understanding the topographical background of the study area

In 3-D draping, orthophotograph gave a better result compared to Landsat in terms of features recognition. The draping of Landsat imagery over the digital elevation model (DEM) did not produce good result due to low spatial resolution (Figure 4).

In this study, geological terrain features identification was based on systematic observation of elements such as topography, drainage pattern and texture, erosion, image tone, vegetation and landuse. Several features such as flood plain, coastal plain, littoral zone and alluvial plain were not present due to the nature of hilly study area. Floodplain and alluvial plain normally occurred in low land areas while coastal plain and littoral zone related to coastal areas.

The aerial photographs interpretation considers the basic elements such as shape, size, pattern, tone (or hue), texture, shadows, site, association, and resolution. Hillcrest, sideslope, footslope, straight slope, convex slope and concave slope were accurately delineated using aerial photographs draped over a DEM (Figure 5). The hillcrest is defined as a summit of hill. Meanwhile ridge refers to a long narrow elevated section of the hill with steep sides. The sideslope and footslope were distinguished by the



(a) (b)

FIGURE 4. 3-D draping; (a) orthophograph over DEM (5 m): (b) Coarser result for Landsat draped over the DEM

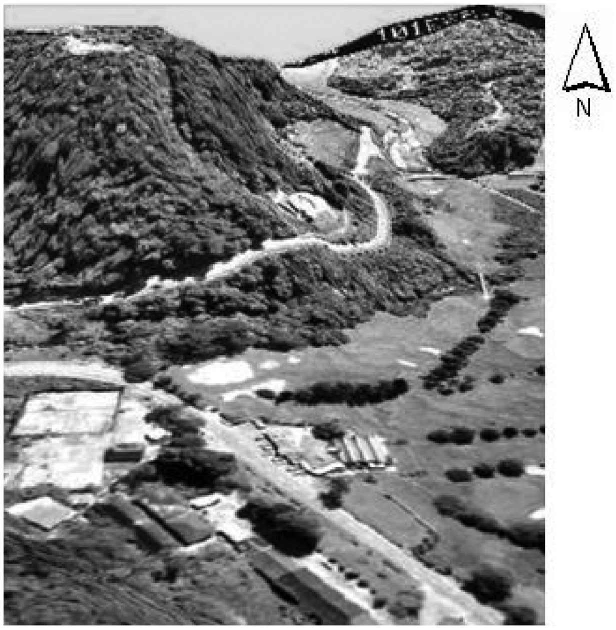


FIGURE 5. Perspective view of orthophotograph draped over the DEM

site factor of the object. The sideslope represented the terrain between footslope and hillcrest. The footslope described a zone of deposition which usually occupied a basal position in the terrain. The straight slope defined the slope which extends uniformly in a same direction, without curve or bend. The concave slope is the outer of a curved slope, with the centre of the curve inwards the hill. Meanwhile the convex slope is the inner of a curved slope, with the centre of the curve away from the hill. The contour lines showed a concave slope on a map will be closely spaced at the top of the terrain features and would be widely spaced at the bottom. For the convex slope the contour lines would be widely spaced at the top and closely spaced at the bottom.

In aerial photographs interpretation, water bodies like ponds and natural stream were easily mapped. Natural features like ponds has irregular boundaries, smooth texture and usually show up as the darkest areas on an aerial photographs. The natural stream in the study area is coarse-textured pattern and associated with bridge structures. Drainage valley consists of channel and bank of a drainage line. The identification of this feature was largely dependent upon the scale of the survey and of the aerial photograph.

The terrace and cut slope were also recognized from the aerial photographs. Terrace by its rectangular pattern, straight edges, and distinct boundaries and related to cultivation purposes, while the cut slope showed light toned. The cut slope consists of surface which remains after volume of soil and/or rock has been excavated.

The features related to erosion and instability such as sheet erosion, rill erosion, and gully erosion, recent and relict landslide can be observed in aerial photographs. Sheet erosion is the uniform removal of soil or decomposed rock by the surface flow of water or a mixture of water and sediment. It appears as lighter tone which indicates the absence of vegetative ground cover. Recent landslide was also appeared as a light toned area on aerial photographs, while relict landslide which was covered by vegetation required field observation. In high altitude aerial photographs gully erosion could easily being confused with landslide (Ng et al. 2002).

From the Landsat imagery, geological terrain features such as hillcrest, sideslope and foot slope were not visible except for bare soil which might be related to landslide features and water bodies. Landuse area was distinguished clearly by using the equalization enhancement technique. Forest was identified by dark green, blue for water bodies and light blue for urban area (Figure 6).

The use of non-directional filters and directional filters did not show a significant improvement in terms of textural expression. The quality of textural expression was similar to that of the unfiltered imagery.

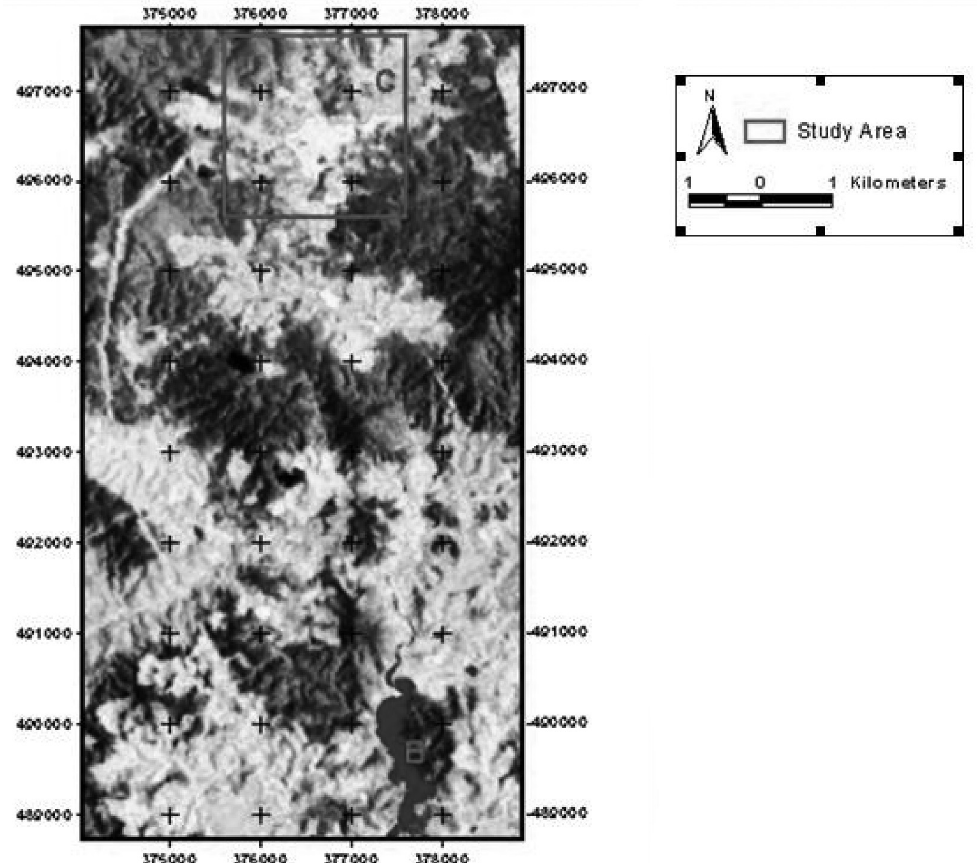


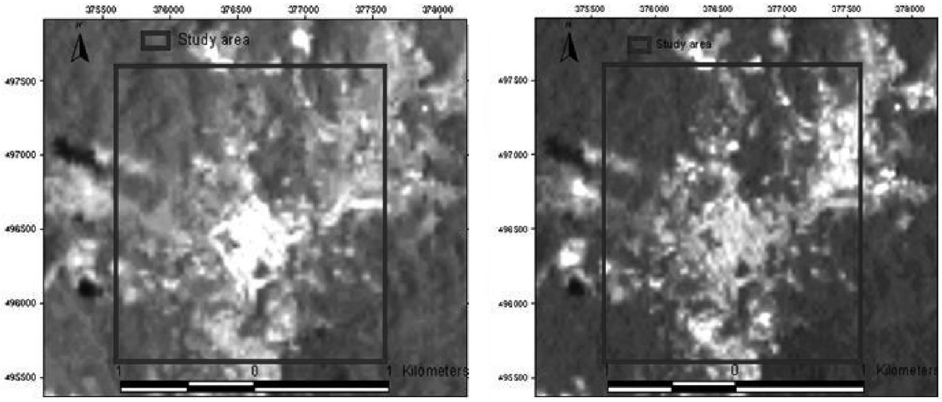
FIGURE 6. Image enhancement of Landsat TM5, 453 false color composite using equalization enhancement methods: A= forest; B= water; C= urban

The single band images, band 4, band 5 and band 7 were useful in a geological terrain mapping interpretation. Band 4 is very useful in delineation of water bodies. Bare soil or open areas appear in light tones on the band 5 (Figure 7). Band 7 is the near infrared wave length that suffers less attenuation, which give a clearer image and is also recommended for geomorphological slope contrast.

From 20 combinations of original image bands tested for image enhancement qualities, only three offered satisfactory enhancements in false colour composites (FCCs). The FCCs (in red, green and blue) were 4-3-2, 5-4-2 and 4-5-7 (Figure 8). The appearance of different features for different colour composites is summarized in Table 3.

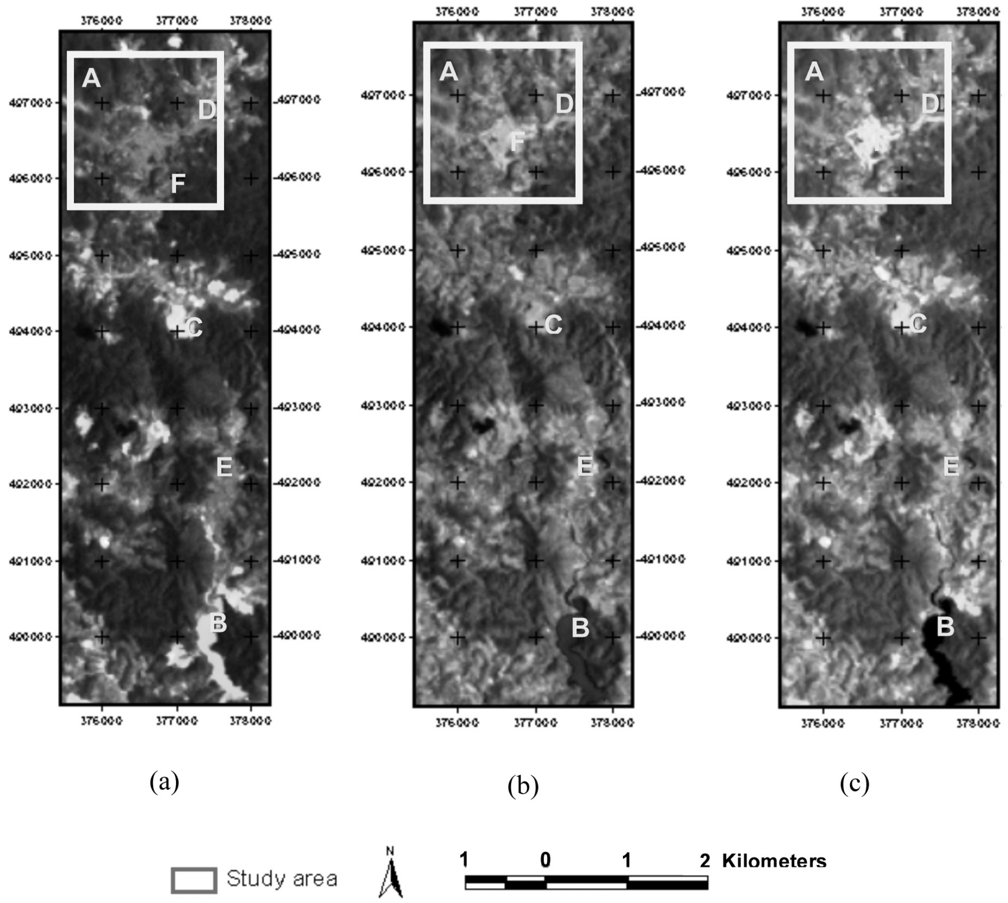
The result of Principal Components Analysis (PCA) approach using the RGB 123 FCC exhibited a very diverse range of colours (Figure 9). The area of bare soil was almost represented by white colour.

The summary of detectability and interpretability of geological terrain features based on this study is shown



(a) (b)

FIGURE 7. Landsat TM5 of study area: (a) Band 5; (b) Band 7



(a) (b) (c)

FIGURE 8. False color composite: (a) 4-5-3 (R-G-B); (b) 5-4-2 (R-G-B); (c) 4-5-7 (R-G-B) where A = forest, B = water, C = bare soil, D = urban, E = agriculture

TABLE 3. Features appearances on composite images

	4-3-2 (R-G-B)	5-4-2 (R-G-B)	4-5-7 (R-G-B)
Forest	red	shades of green	dark brown
Water	shades of blue	black to dark blue	black
Bare soil	blue to gray	magenta or pale pink	yellow greenish
Urban areas	blue to gray	lavender	light blue
Agriculture	pink to red	shades of green	magenta

in Table 4. The shape of the slope (concave, convex and straight slope) may only be detected by draping aerial photographs over the DEM.

In this study, aerial photographs offered better result in recognizing the geological terrain features. This is due to a higher spatial resolution compared to the Landsat (Mantovani et al. 1996). The obvious disadvantage of black and white aerial photographs interpretation, that it has to be manually undertaken which is time consuming. Furthermore, information on geological terrain features is limited to only one band.

The geological terrain features could not be identified with the Landsat image because of coarser spatial resolution except for water bodies and drainage valley. However the use of false colour composite (FCCs) which was suggested by Petley et al. (2002) highlighted the bare soils areas which might be related to landslide and erosion features. Landsat image also provided synoptic overview which is suitable for recognition of large scale features (Mantovani et al. 1996).

The DEM has played a crucial role in this study. Aerial photographs and satellite images were draped over the DEM to provide 3-D information. It had been shown by many studies that the application of DEM may increase the geological and geomorphological interpretation capability (McDermid & Franklin 1997; Bolongaro-Crevena et al.

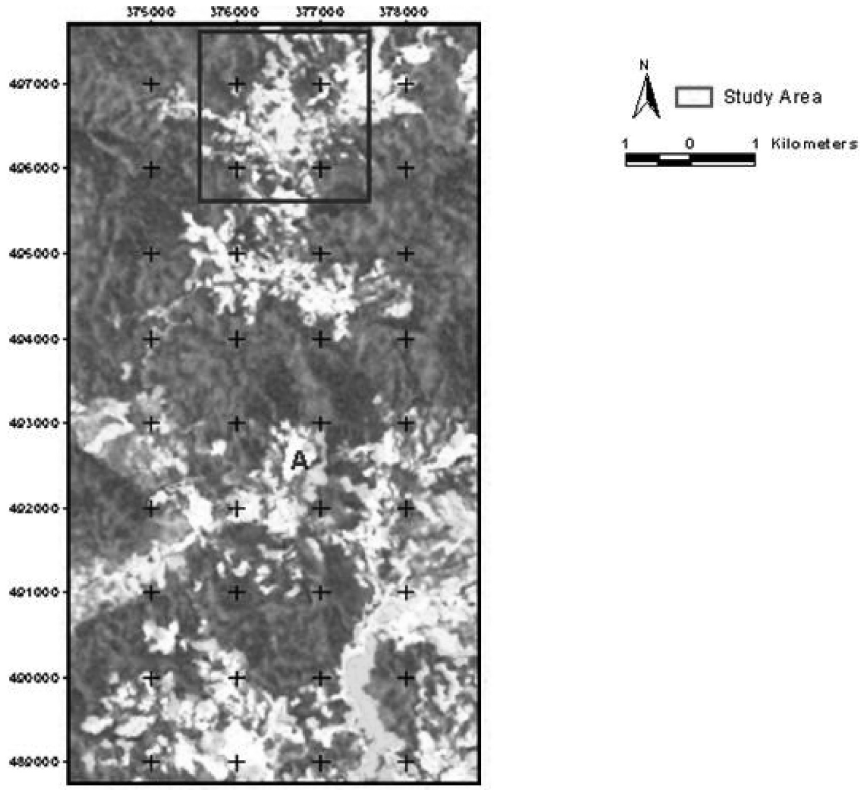


FIGURE 9. Principal Component image RGB 123 FCC: A = Bare soils

TABLE 4. Summary of detect ability and interpretability of geological terrain features.

Geological terrain features	Aerial photographs	Landsat	DEM
Hillcrest	Identified	Detected	Required
Sideslope	Identified	Detected	Required
Footslope	Identified	Detected	Required
Straight slope	Not	Not	Required
Concave slope	Not	Not	Required
Convex slope	Not	Not	Required
Drainage valley	Identified	Identified	Not
Cut	Identified	Detected	Not
Fill	Identified	Detected	Not
Terrace	Identified	Detected	Not
Water bodies	Identified	Identified	Not
Sheet erosion	Detected	Detected	Not
Gully erosion	Detected	Detected	Not
Rill erosion	Detected	Detected	Not
Landslide	Detected	Detected	Not

2005; Mohammad et al. in press) The advantage of this process is that it enables geological terrain features such as hillcrest, sideslope, footslope, straight slope, concave slope and convex slope to be observed not only from the normal vertical view such as in stereoscope, but also to be viewed from different scales, orientations and perspectives. The vertical exaggeration of the DEM could also aid in the interpretation of areas, enabling the features to be more easily, and spatial relationship between them to be determined (Tragheim & Westhead 1996).

The application of aerial photographs draped over the DEM allowed the delineation of geological terrain features such as hillcrest, sideslope, footslope, straight slope, concave slope and convex slope.

CONCLUSIONS

Although the interpretation of geological terrain features is a very subjective subject (depend on the knowledge of the interpreter), it proved that the application of aerial photographs, satellite images and DEM is a potentially efficient, reliable, reproducible and effective technique for under taking geological terrain mapping.

The orthorectification and mosaicking techniques may save a lot of time in aerial photographs interpretation compared to existing technique of using stereoscope. The advantage of 3-D draping technique compared to the conventional stereoscope interpretation is that the geological terrain features such as hillcrest, sideslope, footslope, straight slope, concave slope and convex slope can be observed not only from the normal vertical view but also to be viewed from different scales, orientations and perspectives.

The use of aerial photographs and Landsat may reduced the cost, man power and time compared to the current practice of geological terrain mapping conducted by the Department of Minerals and Geoscience and it is useful in undertaking geological terrain mapping for inaccessible areas.

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