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Comparison and Suitability of SRTM and ASTER Digital Elevation Data for Terrain Analysis and Geomorphometric Parameters: Case Study of Sungai Patah Subwatershed (Baram River, Sarawak, Malaysia)

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Determination of suitability of satellite-derived elevation data sets in terrain characterisation in a tropical region was carried out on the Sungai Patah subwatershed in the interior of Sarawak, East Malaysia. The goal was to facilitate rapid assessment of topographic variables and spatial parameters related to the morphometric aspects of the region. The freely available SRTM (90 m) and ASTER (30 m) elevation data sets were compared and used to generate spatial and aspatial parameters. The cross-validation of SRTM and ASTER elevation surfaces with toposheet-derived elevation for 200 random points shows root mean squared errors (RMSE) of ± 35.08 m and ± 44 m, respectively. The spatial and aspatial parameters derived show certain major and minor variations in the outputs, which can be attributed to the differences in spatial and spectral resolutions of the data acquisition systems. The results and the findings of the present study suggest that both SRTM and ASTER elevation data sets can be used for terrain characterisation in regions similar to the study area, by replacing the traditional toposheet-derived elevation surfaces. However, minor errors are present when either set is used independently. This can be avoided by the concurrent use of SRTM and ASTER elevation data sets, which will reduce data errors and artefacts in both data sets and improve the accuracy of terrain variables and watershed parameters derived from them.

Keywords: *SRTM, ASTER, DEM, geomorphometry, hypsometry*.

1 Introduction

The elevation of an area, which controls the hydrological, geomorphological and evolutional characteristics of the region, has significant importance in the field of geomorphic analysis. Spatial variation in the relief of an area makes it more exposable and vulnerable to denudational processes, which operate in the region. In order to estimate relief-related parameters in shaping the surface and controlling the processes that operate, it is necessary to have good quality, high-resolution elevation data sets. In general, toposheet-contour-derived elevation data have been used conventionally for assessing the relief parameters. This may be more erroneous because accuracy depends on the capability of the analyst who generates the data sets. This can be overcome by replacing the conventional toposheet-derived data sets by satellite-derived digital elevation models (DEMs). Satellite-derived digital elevation models, along with the advancement in the geographical information systems (GIS), have enabled rapid progress in the field of geomorphometric analysis at varying scales and ranges (Zomer, Ustin, & Ives, 2002; Hilton, Featherstone, Berry, Johnson, & Kirby, 2003; Kamp, Tobias, & Jeffrey, 2005; Prasannakumar, Shiny, Geetha, & Vijith, 2011; Cook, Murray, Luckman, Vaughan, & Barrand, 2012; Czubski, Kozak, & Kolecka, 2013; Jozsa, Fabian, & Kovacs, 2014). A number of studies have been reported on the application of satellite-derived digital elevation models in various fields like morphometric analysis, hydrogeology, soil erosion mapping, slope management, flood plain delineations and regional neotectonic analysis (Kervyn, Ernst, Goosens, & Jacobs, 2008; Henkel *et al.* 2010; Hosseinzadeh, 2011; Sleszynski, 2012; Saleem, 2013). Most of the studies have used high ground resolution data sets (10 m or less) for detailed assessment of terrain characteristics for local large-scale studies. The freely available moderate resolution data sets (≥ 30 m) have been used for regional studies. Due to the increased availability of free, moderate resolution and highly accurate digital elevation models, many regional studies derive major elevation parameters from these sources only. The most commonly used free elevation data sets are derived from Shuttle Radar Topographic Mission (SRTM) and Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) with a ground resolution of 90 m and 30 m, respectively, and a vertical accuracy of ± 17 m (Rodriguez *et al.*, 2005; Tachikawa *et al.*, 2011).

The present study was framed with an objective of determining the usefulness of freely available digital elevation models, for generating and analysing the topographic parameters for terrain characterisation in the interior region of Sarawak, Malaysia. Determination of the best suitable satellite-derived DEM will accelerate scientific studies in the region in the fields of soil erosion, landslide modelling, morphotectonic analysis and drainage basin characterisation, because local and regional scale studies based on such data sets are currently absent. Hence, in the present study, a highly undulating area in the interior of the Baram river basin (Northern Borneo) was selected and the SRTM and ASTER elevation surface-derived terrain characteristics were cross compared and evaluated.

2 Materials and methods

2.1 Study area

The Sungai Patah subwatershed study area is one of the major subwatersheds of the Baram River, the second largest river in Sarawak (Northern Borneo, Malaysia). The subwatershed is elongated and has a total area of 1029 km^2. It extends between latitude 3° 20’ 23” to 3° 41’ 45” N and longitude 114° 35’ 17” to 115° 9’ 58” E (Figure 1). The elevation of the area varies from approximately 20 m to above 1,500 m above the sea level and exhibits varying landforms of highly undulating nature. The drainage pattern in the Sungai Patah subwatershed is dendritic to trellis. Geologically the area is composed of intensely folded sediments and meta-sediments of 3 different ages: Palaeocene deep water sediments, Oligocene sediments, and Miocene sediments, with Oligocene sediments being predominant. The tropical area receives high average annual rainfall in excess of 4500 mm and average minimum and maximum temperatures of 20°C to 30°C, respectively.

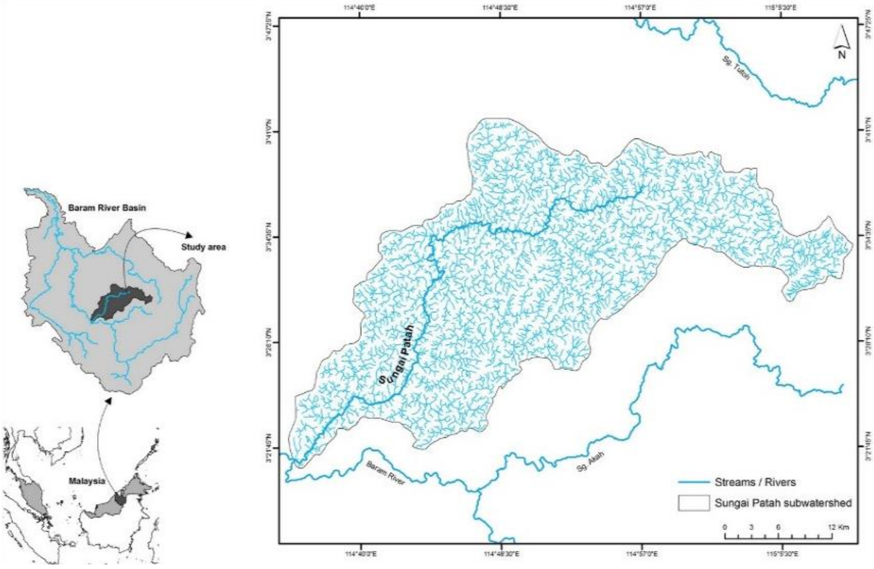

Figure 1. Study area location map.

2.2 Elevation data sources

2.2.1 Shuttle Radar Topography Mission (SRTM) data

A space shuttle based mission, jointly operated by the space agencies in the USA, Germany and Italy, aimed to map and generate elevation surface details of the globe between ± 60° and covered 80% of the total globe in 10 days in February 2000 (Farr, & Kobrick, 2000; Werner, 2001; Smith, & Sandwell, 2003; Rabus, Eineder, Roth, & Bamler, 2003; Farr *et al.*, 2007). In the present study, the latest version of SRTM data (version 4.1), available in the CGIAR consortium for spatial information (http://www.cgiar-csi.org) with a ground resolution of 90 m, was downloaded and analysed. In this version, maximum errors have been removed and data gaps have been filled using auxiliary data sets in order to provide better horizontal and absolute vertical accuracy of 8.8 m and 6.2 m fat a confidence level of 90% for the study region (http://www.cgiar-csi.org).

2.2.2 Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) data

Another mission, which was jointly conducted by NASA and Japan Ministry of Economy Trade and Industry (METI), using the Terra spacecraft, started collecting data of the earth surface and other atmospheric parameters in February 2000, using its 5 on-board remote sensors (GLCF, 2004). ASTER has the capability of off-nadir views (± 27°), which facilitate stereoscopic observation with a 30 m ground resolution. More details about the mission and data sets can be found in Abrams, Hook, & Ramachandran, 2002. The ASTER Global Digital Elevation Model (GDEM) generated from this data set is freely available from the website of Japan Space Agency since June 2009 (http://gdem.ersdac.jspacesystems.or.jp). In the present study, ASTER GDEM version 2 was used. It has horizontal and vertical accuracy of 8.68 m and 17.01 m at a confidence level of 95% (Tachikawa *et al.*, 2011).

2.3 Methodology

Before generating terrain variables and morphometric parameters from the SRTM and ASTER DEMs, both data sets were cross-compared with toposheet-derived (1:50,000) elevation data through 2 different kinds of analysis. In the first approach, random point elevation cross matching and, in the second approach, unique area based comparison of statistical parameters were carried out. Following the direct comparison of SRTM and ASTER data sets with the toposheet-derived elevation surface, a number of spatial and aspatial (geomorphometric) parameters were then derived from both DEMs for the Sungai Patah subwatershed. Derived spatial parameters are slope, slope aspect, and relative relief. The calculated aspatial parameters are standard geomorphometric parameters (linear, relief, and aerial parameters), and the detailed methodology adapted for the calculation is given in Table 1.

Table 1. Formulae used for computation of morphometric parameters with references.

Morphometric parameter		Formula	Reference
	Area (km^2) – (A)	Total area contributing	
	Perimeter (km) – (P)	The outer boundary of the watershed that enclosed its area	
Linear	Stream Order – (U)	Hierarchical rank	Strahler (1952,1964)
	Number of Segments – (N_u)	$N_u = N_1+N_2+\ldots\ldots+N_n$	Horton (1945)
	Stream Length (m or km) – (L_u)	$L_u = L_1+L_2+\ldots\ldots+L_n$	Horton (1945)
	Mean Stream Length – (L_{sm})	$L_{sm} = L_u/N_u$	Strahler (1964)
	Stream Length Ratio – (R_L)	$R_L = L_u/L_u\text{-}1$	Horton (1945)
	Bifurcation Ratio – (R_b)	$R_b = N_u / N_u+1$	Schumm (1956)
	Mean Bifurcation Ratio – (R_{bm})	Average of R_b	Strahler (1964)
	RHO coefficient – (ρ)	$\rho = R_L/R_b$	Horton (1945)
Relief	Basin Relief – (B_h)	$B_h = H\text{-}h$	Hardely and Schumm (1961)
	Relief Ratio R_h	$R_h = B_h / L_b$	Schumm (1963)
	Ruggedness number R_n	$R_n = R_h * D_d$	Patton and Baker (1976)
Aerial	Drainage Density D_d	$D_d = L_u/A$	Horton (1932, 1945)
	Stream Frequency F_s	$F_s = N_u/A$	Horton (1932)
	Texture Ratio T	$T = N_1/P$	Horton (1945)
	Form Factor R_f	$R_f = A/Lb^2$	Horton (1945)
	Circulatory Ratio R_c	$R_c = 4*\pi*A/P^2$	Miller (1953)
	Elongation Ratio R_e	$R_e = 1.128*\sqrt{A}/Lb$	Schumm (1956)
	Constant Channel Maintenance C	$C = 1/D_d$	Schumm (1956)
	Length of overland flow L_g	$L_g = 1/2D_d$ or $C/2$	Horton (1945)
	Shape Index S_w	$S_w = 1/R_f$	Horton (1945)
Elevation – Area	Hypsometric curve Hypsometric integral (I_{hyp})	Graph: h/H against a/A $I_{hyp} = (h_{mean} - h_{min})/(h_{max} - h_{min})$	Strahler (1952)

where N_1 *= Number of segments in particular order,* L_u*-1 = stream length of next lower order,* N_u*+1 = number of streams in next higher order, H = maximum height of the basin, h = minimum height of the basin, Lb = basin length, Π = 3.14, h/H = proportion of the total height, a/A = proportion of the total area, H = total relative height, A = total area of the basin, a = area of the basin above a given line of elevation h,* h_{mean}*= average height of the area,* h_{max} *= maximum height of the area,* h_{min} *= minimum height of the area*

Two other important geomorphometric parameters, i. e., hypsometric curve and integral and longitudinal profile, which ultimately help to characterise and classify the watershed, were also derived from both DEMs. The successful extraction of these parameters from the DEMs will facilitate the rapid analysis and interpretation of terrain variables by substituting the traditional topographic-sheet-derived contour-based analysis of terrain parameters.

3 Results and discussion

3.1 *Cross validation of SRTM and ASTER DEMs with toposheet-derived elevation surface*

Two approaches were taken to compare and validate data quality and error factors associated with the data sets before deriving and analysing morphometric parameters for the Sungai Patah subwatershed. In the first approach for the whole area, a random point generation method was used in which a total of 200 points were generated and elevation values corresponding to each point were extracted from the toposheets, SRTM and ASTER digital elevation surfaces (Figure 2).

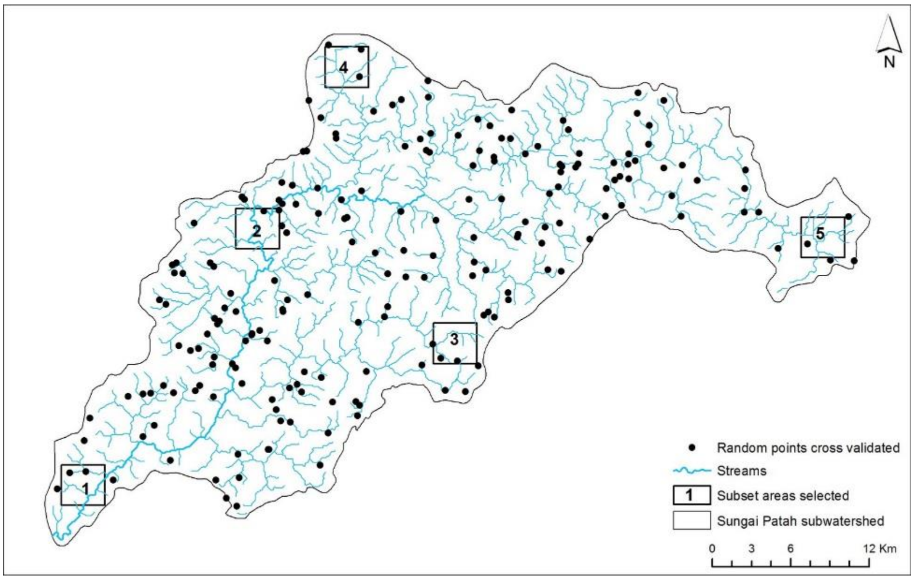

Figure 2. Cross-validation points and sample areas selected.

The mean elevation for the 200 points was found to be 427.8 m, 430.74 m, and 424.2 m, respectively. Although the mean elevations differed by only a few meters for a very small number of sampling points, differences of up to approximately 150 m were found. Elevation values derived from the toposheets were plotted against the SRTM and ASTER elevation values, which indicated a good correlation with correlation coefficient of $r = 0.98$ and $r = 0.97$, respectively (Figure 3).

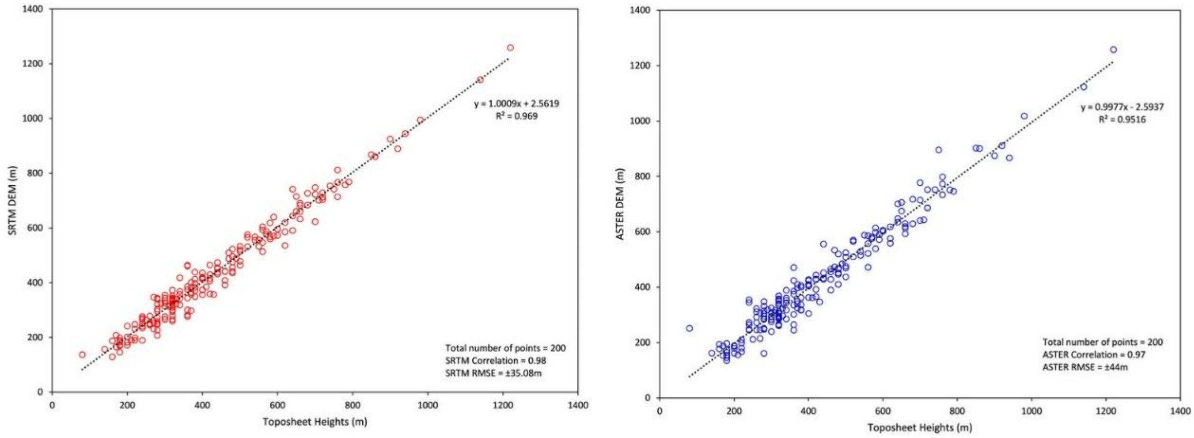

Figure 3. Correlation plots of common random points selected from SRTM and ASTER DEMs against toposheet elevation showing RMSE of ± 35.08 m and ± 44 m, respectively.

The average elevation residual values for both data sets were found to be in the range of ± 3 m (SRTM) to ± 4 m (ASTER) when compared with the toposheet-derived elevation points; however, the root mean square error of the compared data sets was ± 35.08 m and ± 44 m. In the second approach, 5 distinct areas of uniform size (10 km^2) were selected from the study area (at varying elevations and terrain conditions), the DEMs were clipped and the data for the 5 subsets were analysed statistically. Though the spatial resolutions of the DEMs are varying, the results of the statistical analysis show certain similarities and are given in the Table 2. The general statistical parameters, such as minimum, maximum, mean, and standard deviation of these selected subsets, are comparable, generally differing by less than 40 m, while the RMSE is quite variable, ranging from ± 10.81 m to ± 68.81 m, with an average RSME of ± 29.73 m. These findings support the choice of using SRTM and ASTER elevation data sets instead of toposheet-derived elevation surface in the present analysis.

Table 2. Comparison of selected statistics of topo, SRTM and ASTER DEMs.

	DEM	Min	Max	Mean	STD	RMSE
Subset 1	Topo	80	460	228.5	96.3	
	SRTM	61	494	237.1	97.8	±27.54
	ASTER	33	493	234.3	99.0	±40.61
Subset 2	Topo	120	320	205.4	49.8	
	SRTM	123	335	205.4	43.9	±10.81
	ASTER	24	336	197.2	51.9	±68.81
Subset 3	Topo	400	1000	631.6	127.1	
	SRTM	424	1004	645.1	117.0	±17.20
	ASTER	400	1020	663.5	120.4	±14.14
Subset 4	Topo	280	900	570.7	136.4	
	SRTM	292	938	590.3	137.5	±28.17
	ASTER	247	937	568.3	142.9	±35.05
Subset 5	Topo	680	1140	818.9	93.81	
	SRTM	648	1160	815.5	100.3	±26.68
	ASTER	598	1140	802.7	100.9	±57.98

3.2 Spatial parameters

The spatial parameters, such as slope, slope aspect, and relative relief, which play a major role in the analysis of hydrological and denudational processes, were generated and evaluated for the study area using ArcGIS software. The comparison of SRTM- and ASTER-derived elevation surface reveals differences in the minimum and the maximum values and spatial distributions. For the Sungai Patah subwatershed, the elevations derived from SRTM range from 43 m to 1,530 m, while those derived from ASTER have a greater range from 11 m to 1,566 m (Figure 4a, 4b). The variation in the basic statistical parameters such as mean and standard deviation for both data sets is within the tolerable limit and varies in between ± 1 to ± 5. Both DEMs show a highly developed fluvial network with some isolated residual hills.

In mountainous terrains, most of the denudational processes are related to the action of flowing water and controlled by the terrain slope (Anbalagan, 1992; Vijith, Krishnakumar, Pradeep, Ninu Krishnan, & Madhu, 2013). Slope of the area plays a major role in hydrogeology, soil erosion, landslide and other related geo-environmental parameters and processes. Figures 4c and 4d show terrain slopes in the Sungai Patah watershed as derived from the SRTM and ASTER DEMs, respectively. The maximum slope derived from SRTM is 50°, whereas the slope derived from ASTER exceeds 80°. The discrete class analysis of slope surfaces indicates that, for the SRTM-derived slopes, the majority of the pixels (>83%) fall in the slope range of 5–25°, where only 64% of the pixels of the ASTER-derived slopes are in that class range. Over 20% of the pixels of the ASTER-derived slopes fall in the higher sloping 25–35° class. Steep sloping areas have higher influence on landslide occurrence and soil erosion and the ASTER data set appears to be the better tool for this sort of analysis as it gives a better representation of steep slopes.

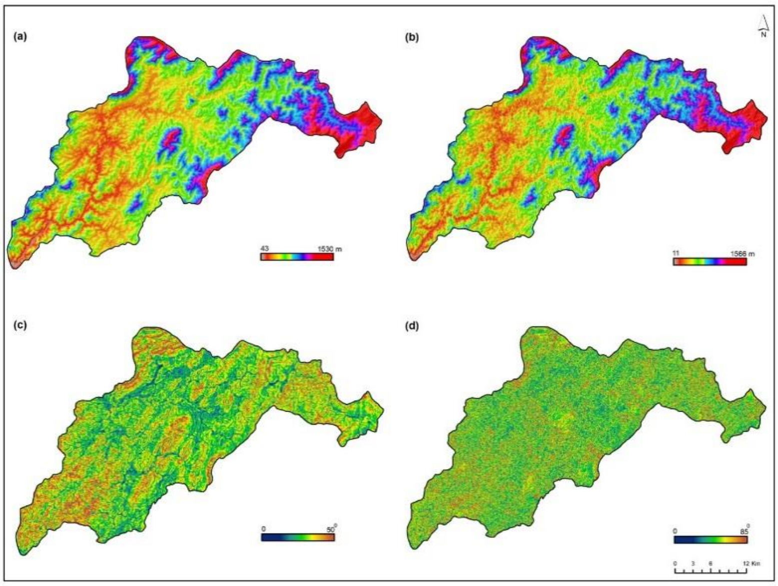

Figure 4. Spatial parameters derived from SRTM and ASTER DEMs. Elevation surfaces: a) SRTM, b) ASTER. Slope: c) SRTM, d) ASTER.

Another parameter considered is slope aspect, the direction towards which the terrain slope faces with respect to the north. This parameter is important as there may be directional influence on terrain processes. Generally, the aspect is expressed in compass degrees with the values varying from 0 to 359° or is designated as -1 for flat areas. The numerical value of the slope aspect may be classified into 8 compass directions (N, NE, E, SE, S, SW, W and NW) or it may be considered flat (no slope aspect). The slope aspect has the potential to influence physical properties of the terrain, such as temperature, moisture, vegetation content, etc., which ultimately influence the susceptibility of the terrain to weathering and erosional process (Rajakumar *et al.*, 2007). The aspect surfaces generated from the SRTM and ASTER DEMs are shown in Figures 5a and 5b, respectively. Both DEMs show similar mean and standard deviation of the slope aspects: the mean of 187.53° and 182.64°, demonstrating the predominance of south facing slopes, and the standard deviation of 102.16° and 102.71°, but with significant spatial variation.

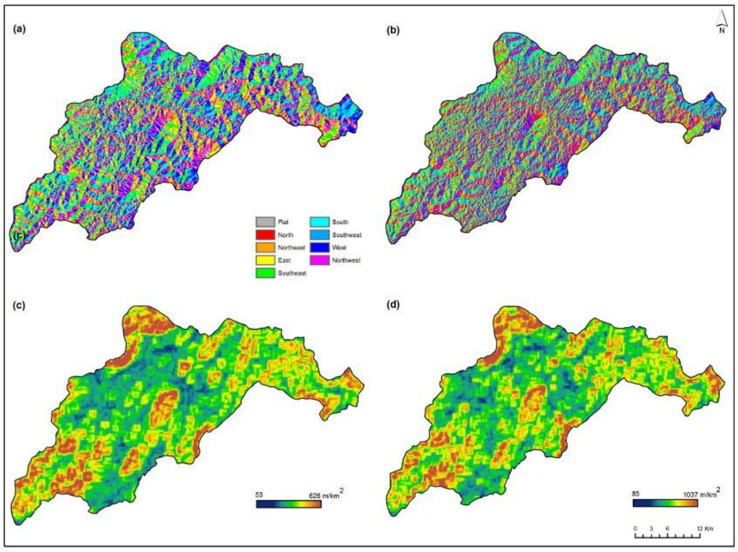

Figure 5. Spatial parameters derived from SRTM and ASTER DEMs. Aspect: a) SRTM, b) ASTER. Relative relief: c) SRTM, d) ASTER.

Relative relief is another parameter of importance in geomorphometric studies and represents the elevation variation per unit area as it influences the down slope movement of sediments and other earth materials and it plays a crucial role in terrain evolution (Vijith, & Madhu, 2007; Prasannakumar, Shiny, Geetha, & Vijith, 2011). In order to identify the elevation changes in the Sungai Patah subwatershed per unit area, relative relief maps were calculated from the available SRTM and ASTER elevation surfaces (Figure 5c and 5d). The relative relief maps, thus, generated from both elevation surfaces show the minimums of 53 m/km^2 and 85 m/km^2, the maximums of 626 m/km^2 and 1037 m/km^2 with means of 225.23 m/km^2 and 273.08 m/km^2 and standard deviations of 81.59 and 85.25, respectively, for SRTM- and ASTER-derived maps. Although the ranges of the relative relief are different between the 2 DEMs, the spatial distribution of the relative relief is remarkably similar. The results show similarity in the spatial pattern with differences in the minimum and the maximum values, which is due to the changes in resolution.

3.3 Geomorphometric parameters

Before assessing the geomorphometric parameters from the SRTM and ASTER DEMs, the basic characteristics of the selected subwatershed and streams obtained from these elevation models were cross-compared with those derived from the topographical map. In the present analysis, the subwatershed boundary derived from the topographical map was used to extract the elevation surfaces from the SRTM and ASTER DEMs (because of that the area, perimeter, and basin length were the same). After extracting the study area from the elevation surfaces, the basic parameters needed for the geomorphometric analysis, the stream network with order and length were generated using the ArcHydro extension of ArcGIS 9.3. Table 3 shows the total number of streams, number of first-order streams and order of the subwatershed, assessed from the 3 data sources. While comparing the data, it was noted that the topographic-sheet-derived information was comparable only with the subwatershed order assessed from the ASTER-derived stream networks. A major difference was observed in the total number of streams and the number of first-order streams. However, a common spatial pattern of stream network is observed. The spatial pattern of the stream networks (Figure 6) shows the lateral shift and order variations in the streams derived from both DEMs. The difference in the stream networks derived from the different resolution DEMs demonstrates the sensitivity of the elevation surfaces to the hydrological analysis. The lower ground resolution SRTM data classified the subwatershed as the 5th order, while the ASTER-derived stream networks and the topographic sheet both classified it as the 6th order subwatershed. The number of the stream orders and the number of the first-order streams are underestimated by the lower ground resolution of the SRTM data.

Table 3. Basic characteristics of drainage networks derived from SRTM and ASTER.

Data	**Scale or ground resolution**	**Total no. of streams**	**No. of 1st order streams**	**Order of the subwatershed**
Toposheet	1:50,000	3,204	1,640	6
SRTM	90 m	617	316	5
ASTER	30 m	4,081	2,101	6

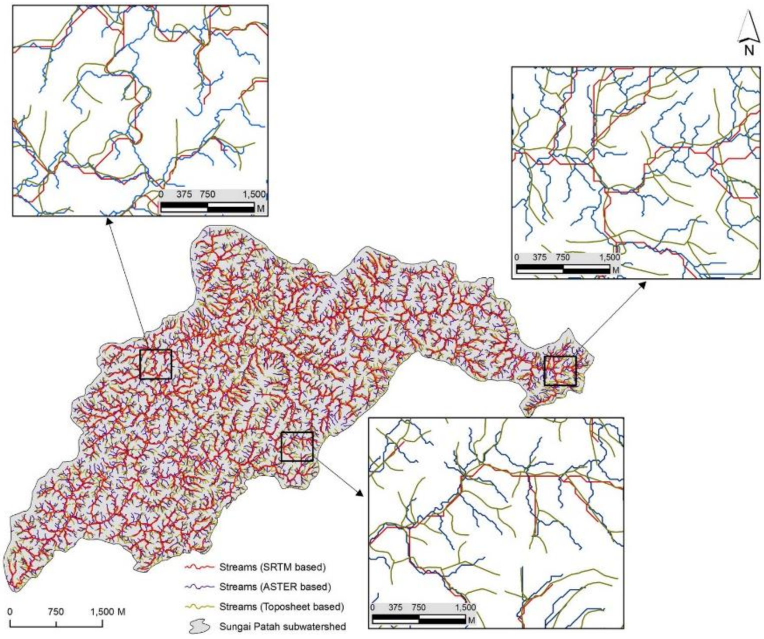

Figure 6. Cross-comparison of drainage networks derived from toposheets, SRTM and ASTER DEMs.

Geomorphometric analyses give insight into the geological, hydrological and topographical characteristics of the area (Strahler, 1952, 1964; Pike, & Wilson, 1971; Pike, 2000). The analysed geomorphometric parameters based on the standard methods of the calculation given in Table 1, using the stream networks and the elevation values derived from the SRTM and ASTER DEMs, were grouped into the following 4 categories: linear, relief, aerial, and elevation-area parameters; the results are provided in Table 4.

The analysis was started by comparing the subwatershed order, number and length of stream segments of each order. The lower ground resolution SRTM-derived stream network consists of fewer streams (particularly of lower order), with significantly shorter stream length than the higher ground resolution ASTER-derived stream networks. The SRTM-derived stream network shows a total of 617 streams with 5th as the higher order of the stream. The ASTER-derived data show a total of 4,081 stream segments with 6th as the highest order. This difference resulted in the length of each segment and the total length of streams, which vary from 978 km to 2,416 km, respectively, for SRTM and ASTER derived stream networks. As a result of the discrepancy in the number of segments and stream length, significant differences are also apparent in the mean stream lengths, which are 1.35 km and 0.52 km, respectively. Other geomorphometric parameters, which are derived from stream length and/or number of segments are also affected, such as stream length ratio (0.84 and 0.59), drainage density (0.95 and 2.35 km/km^2), stream frequency (0.60 and 3.97 km^2), ruggedness number (0.02 and 0.05 km/km^2), texture ratio (1.55 and 10.28 km^{-1}) and constant of channel maintenance (1.05 and 0.43 km), respectively, for SRTM- and ASTER-derived stream networks. The basin relief was found to be 1,555 m with the higher resolution ASTER DEM, compared with 1,487 m for SRTM. Geomorphometric parameters which are not directly derived from stream length and/or number of segments were generally found to be in good agreement between the 2 DEMs. This is the case for mean bifurcation ratio (1.81 for both data sets), Rho coefficient (0.29 and 0.31), and relief ratio (0.0204 and 0.0214). Other parameters, such as form factor (0.19), circularity ratio (0.31), elongation ratio (0.50), and shape index (5.15) are equivalent for both data sets since they are based on common factors, such as area, perimeter, and basin length. The results obtained for the Sungai Patah case study indicate that both DEMs can be used to derive basic geomorphometric parameters, but those derived from ASTER DEM are closely matched to the toposheet-derived parameters and should be used preferentially where number of segments, stream order, and stream length are critical. Based on the calculated geomorphic parameters, the terrain can be considered as structurally complex, highly dissected and prone to the fluvial erosion process due to high runoff potential.

Table 4. Geomorphometric parameters calculated for Sungai Patah subwatershed from SRTM and ASTER data sets.

Type of parameter	Parameters calculated for Sungai Patah		SRTM	ASTER	Unit
	Common parameters from topographical sheets (identical to both data sets)*	Area (A)*	1,029.24		km^2
		Perimeter (P)*	204.44		km
		Basin Length (Lb)*	72.81		km
Linear parameters	No. of segments (Nu)	1st Order	316	2,101	No.
		2nd Order	129	878	No.
		3rd Order	87	535	No.
		4th Order	32	296	No.
		5th Order	53	134	No.
		6th Order	-	137	No.
		Total	617	4,081	No.
	Stream length (Lu)	1st Order	589.37	1,415.08	km
		2nd Order	176.32	450.51	km
		3rd Order	118.25	281.42	km
		4th Order	29.99	139.28	km
		5th Order	63.86	63.50	km
		6th Order	-	66.32	km
		Total	977.79	2,416.12	km
	Mean stream length (Lsm)	1st Order	1.87	0.67	km
		2nd Order	1.37	0.51	km
		3rd Order	1.36	0.53	km
		4th Order	0.94	0.47	km
		5th Order	1.20	0.47	km
		6th Order	-	0.48	km
		Average	1.348	0.521	km
	Stream length ratio (RL)	1st Order	-	-	-
		2nd Order	0.30	0.32	-
		3rd Order	0.67	0.62	-
		4th Order	0.25	0.49	-
		5th Order	2.13	0.46	-
		6th Order	-	1.04	-
		Average	0.837	0.586	-
	Bifurcation ratio (Rb)	1st Order	2.45	2.39	-
		2nd Order	1.48	1.64	-
		3rd Order	2.72	1.81	-
		4th Order	0.60	2.21	-
		5th Order	-	0.98	-
		6th Order	-	-	-
	Mean bifurcation ratio (Rbm)		1.813	1.806	-
	RHO coefficient (ρ)		0.29	0.31	-
Relief parameters	Basin relief (Bh)		1,487.00	1,555.00	m
	Relief ratio (Rh)		0.0204	0.0214	-
	Ruggedness number (Rn)		0.02	0.05	km/km^2
Aerial parameters	Drainage density (Dd)		0.95	2.35	km/km^2
	Stream frequency (Fs)		0.60	3.97	km^{-2}
	Texture ratio (T)		1.55	10.28	km^{-1}
	Form factor (Rf)*		0.19		-
	Circularity ratio (Rc)*		0.31		-
	Elongation ratio (Re)*		0.50		-
	Constant of channel maintenance (C)		1.05	0.43	km
	Length of overland flow (Lg)		0.53	0.21	km
	Shape index (Sw)*		5.15		-
Elevation-area parameter	Hypsometric integral (I*hyp)*		27.62	28.17	%

The comparison of area and elevation data of drainage basins provides detailed information about the geomorphic evolutional history and the stages of landscape development. This can be achieved through generation and analysis of hypsometric curve and hypsometric integral, which work on the basis of area-altitude relationship (Pike, & Wilson, 1971; Hurtrez, Sol, & Lucazeau, 1999; Singh, 2008; Kurse, 2013). Before analysing the hypsometric characteristics of the Sungai Patah subwatershed, a general assessment of area-elevation relationship was carried out by classifying the SRTM and ASTER elevation surfaces into 100 m elevation classes from 0 to 1400 m (Figure 7).

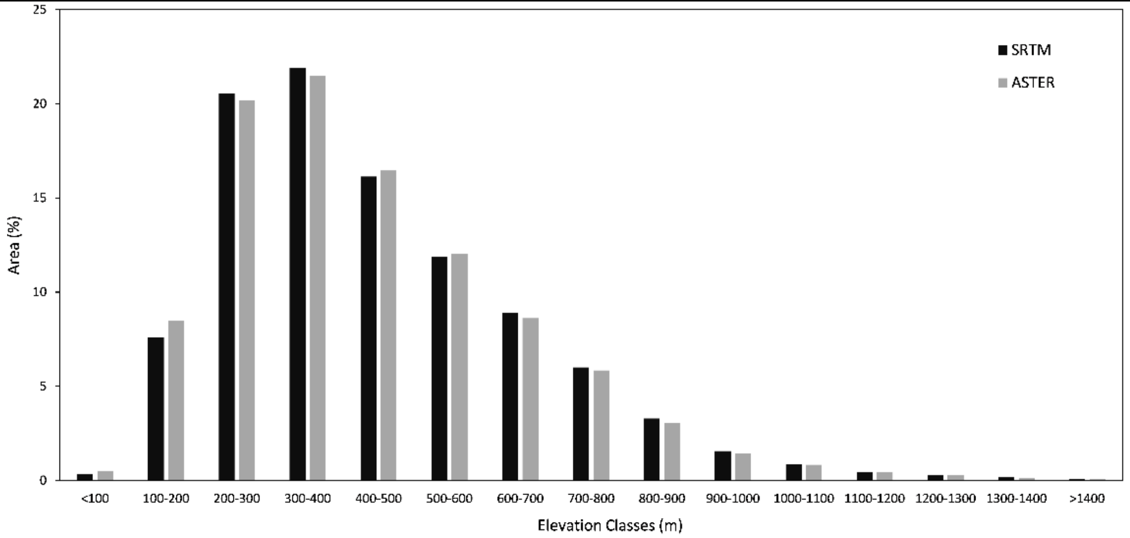

Figure 7. *Area-elevation relationship and distribution assessed from SRTM and ASTER DEMs.*

It is noted that 70% of the subwatershed area (>70%) falls between 200–600 m for both the SRTM and ASTER elevation surfaces, indicating the usability of both DEMs in terrain analysis. These results facilitated the generation of a hypsometric curve, a non-dimensional area-elevation curve, which allows a ready comparison of catchments with diverse areas by plotting the proportion of the total height (h/H) against the proportion of the total area (a/A) of the subwatershed and the hypsometric integral (*Ihyp*). The hypsometric integral is an indicator of geomorphic maturity (Strahler, 1952). Both SRTM and ASTER DEMs indicate similarly S-shaped hypsometric curves with a concave upward upper region and with very closely matching hypsometric integrals of 0.2762 (27.62%) and 0.2817 (28.17%), respectively (Figure 8).

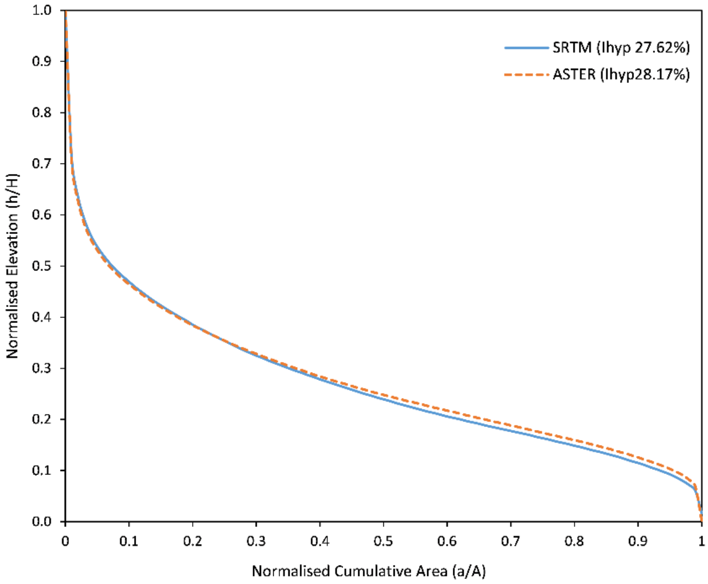

Figure 8. *Hypsometric curves and integrals derived for the study area.*

The hypsometric integral values are low and this suggests that the Sungai Patah subwatershed drainage basin has reached the old age (monadnocks) stage of evolution (Strahler, 1952). Low hypsometric integrals indicate that fluvial erosion processes operating in a mature fluvial network are dominant over erosive hillslope processes. Both data sets lead to a similar hypsometric integral value and conclusions indicating that they are both suitable in such a kind of analysis.

Another important parameter which can be derived from digital elevation models is a longitudinal profile of streams, which shows altitude against distance and can give insight and real evidence of geological processes operating in watersheds and their influence over river networks (Ferraris, Firpo, & Pazzaglia, 2012; Giaconia *et al.*, 2012). The longitudinal profile of streams reflects available relief, base level changes (due to tectonic disturbances), and the processes of erosion and deposition (Aiken, & Brierley, 2013; Ambili, & Narayana, 2014). In order to generate the longitudinal profile of Sungai Patah, elevation values were extracted from both SRTM and ASTER elevations surfaces for a series of sampling points at a 1-km distance along the stream (Figure 9).

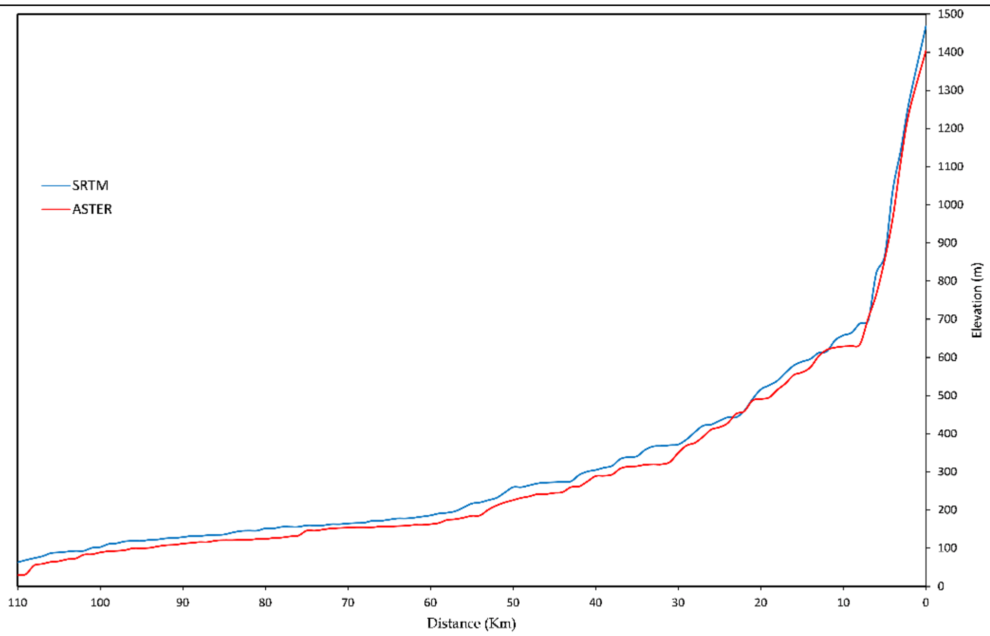

Figure 9. Longitudinal profile of Sungai Patah extracted from SRTM and ASTER DEMs.

The profiles generated from both DEMs showed a very similar pattern with only slight variation in the elevation values. The SRTM DEM gives a higher curve, by approximately 30 m. Both profiles indicated evidence of disturbances in the base level of the river. These are evident from the longitudinal profile, where they are marked with knick points and breaks of slope, indicating modification of the terrain in response to tectonic disturbances and/or lithological changes. Both DEMs are equally suited for this type of analysis.

4 Conclusion

The present study demonstrated the usability and potentiality of available moderate resolution digital elevation data sets (SRTM and ASTER) for basic terrain analysis in the interior regions of Sarawak, Northern Borneo. The data sets can be used in the geo-environmental applications like soil erosion modelling, tectonic indices derivation and landslide prediction. The assessment of basic error factors and statistics indicates good agreement with the toposheet-derived elevation values, but with differences in spatial distribution. While generating stream networks for the geomorphometric analysis, stream networks derived from SRTM gave a coarser stream network than the ASTER-derived streams. The lower ground resolution of SRTM leads to underestimation of the number of stream segments, stream lengths and the subwatershed order, while the ASTER data give slightly overestimated results. Both data sets are found to be very useful in generating secondary derivatives like slope, slope aspect, relative relief and the quantitative information needed for geomorphometric analysis. They can also provide valuable information for studying the evolutional history of the basin, through the hypsometric analysis and longitudinal profile extraction, for which both data sets provided consistent results. In general, it is suggested that, besides using the SRTM and ASTER DEMs independently for terrain analysis, they can be used concurrently to overcome the limitations in both data sets and can substitute for the use of toposheet-contour-derived elevation surfaces in areas which exhibit similar terrain conditions.

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SRTM ir ASTER skaitmeninės aukščio informacijos palyginimas ir tinkamumas vietovės analizei bei geomorfometriniai parametrai: Sungai Patah subbaseino (Baram upė, Sarawak, Malaizija) atvejo studija

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Šiame tyrime buvo nustatytas iš palydovo gautų aukščio informacijos rinkinių vietovei charakterizuoti tinkamumas tropiniame Sungai Patah subbaseino regione, Sarawak viduje, Rytų Malaizijoje. Šio tyrimo tikslas buvo palengvinti greitą topografinių kintamųjų ir erdvinių parametrų, susijusių su morfometriniais regiono aspektais, įvertinimą. Buvo palyginti viešai prieinami SRTM (90 m) ir ASTER (30 m) aukščio informacijos rinkiniai ir jie panaudoti kuriant erdvinius ir neerdvinius parametrus. Kompleksinis SRTM ir ASTER aukščio paviršių, gautų iš topografiniuose lapuose atsitiktinai parinktų 200 taškų, patikrinimas parodė, kad vidutinės kvadratinės šaknies (RMSE) paklaidos buvo atitinkamai ± 35.08 m ir ± 44 m. Gauti erdviniai ir neerdviniai parametrai rodo tam tikras dideles ir mažas variacijas, kurios gali būti susijusios su informacijos priėmimo sistemų erdvinių ir spektrinių rezoliucijų skirtumais. Šio tyrimo rezultatai parodė, kad SRTM ir ASTER aukščio informacijos rinkiniai gali būti naudojami į tyrimo regioną panašiai aplinkai charakterizuoti, pakeičiant iš tradicinių topografinių lapų gautus aukščio paviršius. Vis dėlto kai rinkiniai naudojami atskirai, atsiranda nedidelės klaidos. To gali būti išvengta naudojant SRTM ir ASTER aukščio informacijos rinkinius kartu, kas sumažintų informacijos klaidas ir trikdžius abiejuose informacijos rinkiniuose bei pagerintų aplinkos kintamųjų tikslumą ir iš jų gautus baseino parametrus.

Raktiniai žodžiai: *SRTM, ASTER, DEM, geomorfometrija, hipsometrija.*