Journal of Spatial Hydrology
Vol.10, No.2, Fall 2010

Practical use of SRTM digital elevation dataset in the urban-watershed modeling

Abolghasem Akbari[1], Prof. Dato' Dr. Azizan Abu Samah[2] and Dr Faridah Othman[3]

Abstract: The advent of satellite-based elevation dataset acquired by Shuttle Radar Topography Mission (SRTM) made new and novel techniques possible to model hydrological process in midsize to large scale watersheds. This application is important in regions with poor photogrammetric coverage and land use in appropriate scale. Watersheds are natural integrators of hydrological processes and as such require an integrated approach in data analysis and modeling. The first task is to delineate watershed boundaries accurately using terrain dataset. This research assessed the effectiveness of satellite base Digital Elevation Model (DEM) with photogrammetric base DEM in the Upper Klang watershed which is a complex urban area located on peninsular Malaysia. Watershed parameters include slope, area, perimeters and mean elevation are derived from two sources of elevation data. The first set of parameters is derived from a 30 m gird DEM generated by the digital topo sheets at the scales of 1:25,000 and 1:10,000. The same parameters are derived from SRTM-DEM. Arcview extension HEC-GeoHMS V1.1 is used as GIS tool for watershed boundary delineation and parameterization. An inter comparison of four geometrical parameters are investigated using Nash-Sutcliff Efficiency (NSE). It was found the general agreement of about 88% between the two derivations. The largest discrepancy occurred in delineation of the sub-watersheds in the flat urbanized areas. It is that SRTM-DEM can be used for extracting watershed parameters with a reasonable degree of confidence especially in high relief non-urbanized regions.

Keywords: *SRTM-DEM*, Watershed modeling, Hydrological model, HEC-GeoHMS

1. Introduction

Watershed models have become a main tool in addressing a wide range of environmental and water resources problems (Singh and Frevert, 2006). In most environmental studies such as water resources engineering, flood and drought modeling; erosion and sediment transports; and water quality modeling, delineation of the watershed boundaries and their physical parameters are primary and important step. This information usually is derived from Digital Elevation Model (DEM). Several researches have been conducted to utilize DEM for delineating watershed boundaries and extracting watershed parameters. Peucker and Douglas (1975) are the first investigators who attempted to determine surface area and drainage networks from DEMs. Since then, several new algorithms have been introduced by different researchers. Most of these are based on DEMs (Fairfield and Leymarie, 1991, Freeman, 1991, Lea and 1992, Costa-Cabral and Burges, 1994, Tarboton, 1997). However, some other algorithms have been developed based on Triangulated Irregular Network (TIN) and contour-line models (Jones et al., 1990, Moore and Grayson, 1991, Nelson et al., 1994). There are numerous researches that are subjected to the applications (O'Callaghan and Mark, 1984, Costa-Cabral and Burges, 1994, Garbrecht and Martz, 2000, McPherson and Henneman, 2000, Kiss, 2004), resolution (Garbrecht and Martz, 2000, Vieux, 2004, Wise, 2007), source of DEM (Ruyver, 2004, Rodriguez et al., 2005, Pryde et al., 2007) and GIS tools for DEM processing (Maidment, 2002, Koolhoven et al., 2007). The progress of satellite and airborne base dataset in the present decade, particularly digital elevation data has opened a new source of data for watershed modeling. Currently, there are several free sources of

1,3 Department of civil engineering, University Malaya, 50603 Kuala Lumpur, Malaysia
2 *Department of geography, University of Malaya, 50603 Kuala Lumpur, Malaysia*
Corresponding author's e-mail address: akbari_gis@yahoo.com

global DEMs such as GTOPO30 global dataset (Gesch et al., 2001), with a spatial resolution of 30 arc seconds (approximately 1 km), ETOPO2 with grid spacing of 2-minutes (approximately 1.853 km) at the Equator (USDC et al., 2006) and SRTM-3 with 3-arc-second or 90 m resolution at the Equator (Zyl, 2001). The new global elevation dataset known as GDEM, providing by ASTER satellite imagery (distribution started on June 29, 2009; see http://www.gdem.aster.ersdac.or.jp/), made best freely available global DEM at a higher resolution of 1-arc second approximately 30 m at the equator (Hayakawa et al., 2008). On the other hand, there is a rapid growth in Geographical Information System (GIS) technology and hydrological modeling software. This study designed to explore the use of GIS tools and DEM-based watershed configuration to efficiently extracting watershed parameters needed for hydrologic modeling.

The main objective of this research is to compare the efficiency and accuracy of SRTM-DEM (SD) with Topo-DEM (TD) for watershed modeling. Watershed boundaries, area, perimeter, slope and mean elevation are investigated for two sets of elevation datasets using commonly used GIS software.

2. Study area

The study area is the Upper Klang River Watershed (UKRB) in Malaysia. The Klang Valley is located at 10l° 30′- 10l° 55′ longitude and 3°- 3° 30′ latitude within the state of Selangor. It encompasses entirely the urbanized Federal Territory of Kuala Lumpur (see Figure1). Watershed area is about 675 km^2. Mean annual rainfall is about 2400 mm and mean monthly rainfall ranges from 200 to 400 mm (Tick and Samah, 2004). Nearly 53% of its area has been developed for residential, commercial, industrial and institutional use while 35% is covered by forests. Rapid urbanization and industrial growth have increased pressure on the flow capacities of the main rivers and its tributaries. The elevation range from 20 m at the outlet to 1420 m upstream based on the TD.

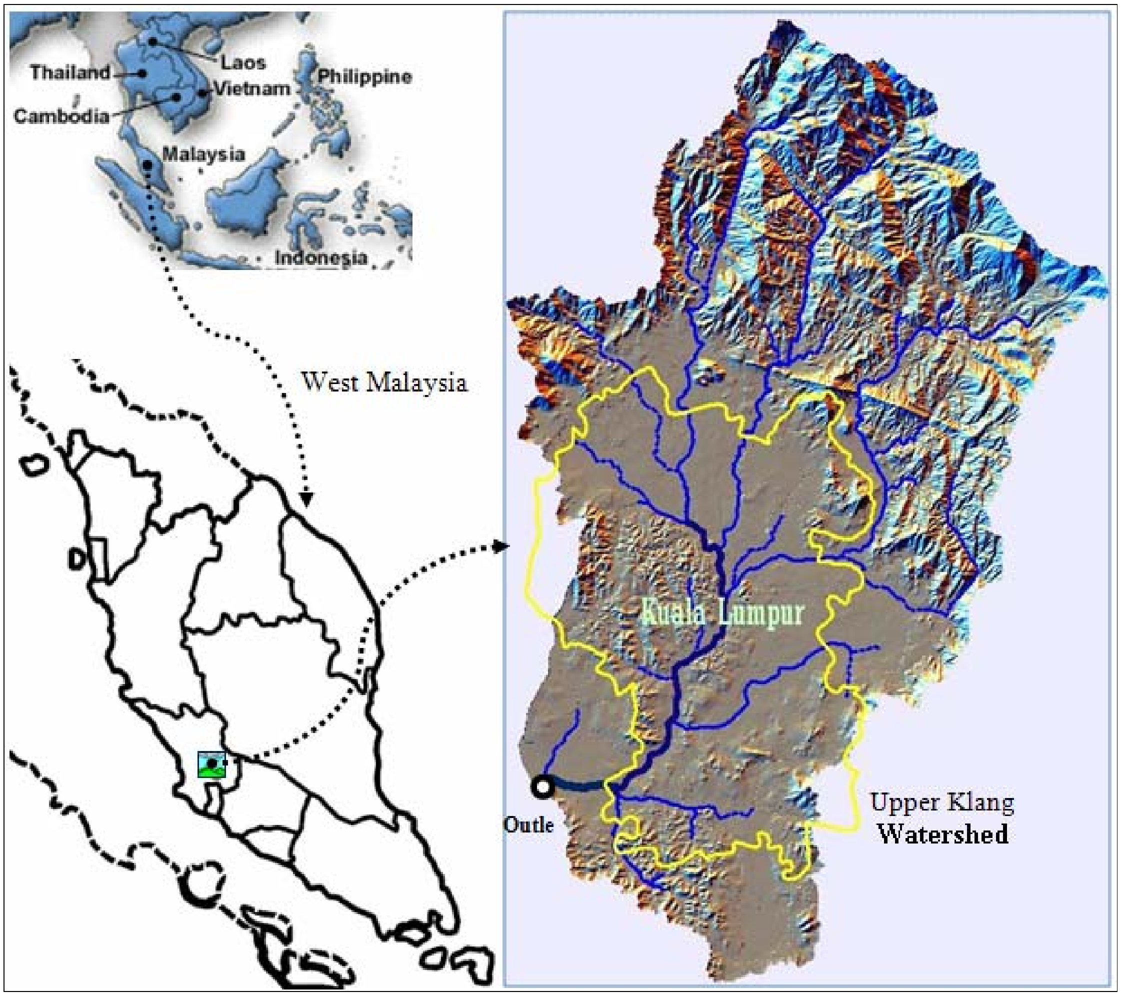

Figure 1: Study area, upper Klang Watershed located in Peninsular Malaysia

3. Material and Method

3.1 Digital topo maps

According to the index map of the study area (see Figure 2), nine digital topo sheets at the scale of 1:25,000 (series L8028, derived from the aerial photos taken in 1969, 1982, 1983, 1997) and twenty-four digital topo sheets at the scale of 1:10,000 (series L808, derived from the aerial photos taken in 1989, 1990, 1992, 1993, 1997) were obtained from the Malaysian department of surveying and mapping known as JUPEM. The relief is shown as contour lines with 20 and 5 meters interval respectively and spot heights for some selected points such as hill tops and ridges. The Digital topo sheet is a cartographic production based on aerial photographs. Projection used is the Rectified Skew Orthomorphic (RSO) and Rectified Skew Orthomorphic Grid (JUPEM, 2009). As can be seen in Figure 2, the reason for selecting two scales was due to discontinuity of some of the contour lines discovered at the scale of 1:25000.

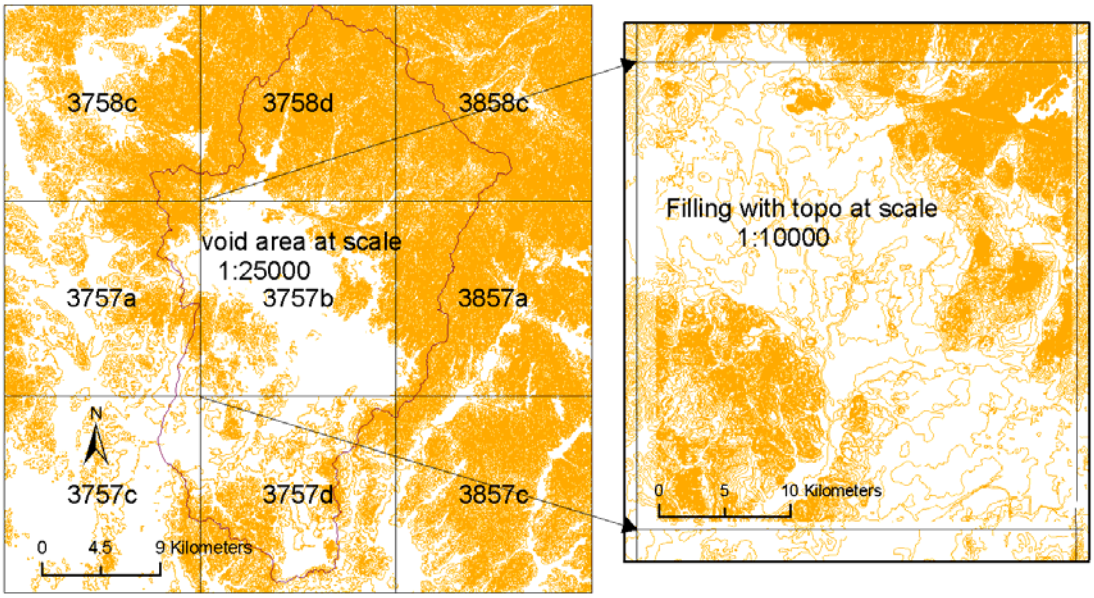

Figure 2: Filling topo at scale 1:25000 (left) in urban area with topo at scale 1:10,000 (right)

3.2 SRTM dataset

The Shuttle Radar Topography Mission (SRTM) (Zyl, 2001) is a joint project by NASA and the U.S. National Imagery and Mapping Agency (NIMA). Using C-band Space-borne Imaging Radar (SIR-C) and X-band Synthetic Aperture Radar (X-SAR), SRTM collected data during a shuttle flight in February 11, 2000. The technical process of acquisition and derivation is described by (Rodriguez et al., 2005)). The National Aeronautics and Space Administration (NASA) released the SRTM dataset for some regions, with 3-arc-second resolution for the globe, and 1-arc-second for the United States in 2003. SRTM elevation data is provided in geographic projection (latitude/longitude) referenced to the WGS84 horizontal datum, and EGM96 (Earth Gravitational Model 1996) vertical datum (Lehner et al., 2008). As shown in Table 1 SRTM elevation data are provided in different resolutions. Version 1 (unfinished data) of the SRTM data consists of the original Digital Elevation Models produced by the SRTM project. These data are unedited and contain spurious data points in areas of low radar backscatter such as water bodies.

Version 2 (finished data) results from a significant editing effort by the NGA and exhibits well-defined water bodies and coastlines and the absence of spikes and wells (single pixel errors), although some areas of missing data are still present (JPL/NASA, 2006). SRTM project is a quantum jump in spatial resolution for DEMs with nearly global coverage. It has made available a new dataset and given a new direction into the watershed and sub-watershed scale modeling and other applications. The advent of GIS and information technology has made this global dataset accessible for public use. As an example HydroSHEDS (**Hydro**logical data and maps based on **SH**uttle **E**levation **D**erivatives at multiple **S**cales) provides hydrographic information in a consistent and comprehensive format for regional and global-scale applications (USGS, 2008).

Table 1: Resolution identifier for SRTM datasets

Resolution Identifier	In sec/min	In degree	In meters/km (at the equator)

+1s	1 arc-second	0.000277	~ 30 m
*3s	3 arc-second	0.000833	~ 90 m
*15s	15 arc-second	0.004167	~ 500 m
*30s	30 arc-second	0.008333	~1 km
*5m	5 minute	0.083333	~10 km

Source:
+ USA only (Lehner et al., 2008)
* http://seamless.usgs.gov/website/seamless/products/srtm1arc.asp

4. Analysis

Several tools and techniques were utilized for analyzing digital elevation datasets using GIS software which have a capability to extract physical parameters of watershed from DEM. Software are included ILWIS version 3.4 developed by the International Institute for Geo-Information Science and Earth Observation (Koolhoven et al., 2007), ArcView GIS 3.2 developed by ESRI (2002), and The Geospatial Hydrologic Modeling Extension (HEC-GeoHMS) version 1.1 developed by US Army Corps of Engineers (Doan, 2003). Herein, process and analysis that involved for this research are briefly explained step by step.

Step 1- Editing and corrections

Based on the raw topography dataset supplied by JUPEM, these contain some errors that need editing. These are code consistency, labeling error, undefined contour line and edge matching error. Much time was spent in editing out errors especially in the urban areas. As shown earlier in Figure 2, the topo maps at scale 1:25000 have insufficient terrain information in the urban area and the topo map at the scale of 1:10,000 is needed to fill in this specific area.

Step 2- Generating TD

The TD was generated using the corrected contour lines, spot heights and drainage network using ILWIS. The initial pixel size for TD was selected at 10 meter based on the scale of the topo sheets (Wilson and Gallant, 2000). Then resampling was then performed to generate TD with coarser resolution of 30 m. It makes it possible to have comparison with SD, which has a resolution of 30 m, in which the TD will be used as a reference map.

Step 3- Delineating Topo watershed model

The HEC-GeoHMS (Doan, 2003) the TD was used to delineate the watershed boundaries through extracting secondary DEM derivations such as flow direction and flow accumulation. Detailed information for the algorithm and delineation processing is provided by Doan (2003). An 8-Square-kilometer threshold was applied for the watershed boundary delineation.

Step 4- Delineating SRTM watershed model

The 3-arc-second SRTM dataset version 2 provided by HydroSHEDS was used for delineation of upper Klang watershed boundaries. This database provides processed SD. However, for some area missing data 'voids' are still present (JPL/NASA, 2006). Seven undefined pixels were detected and filled using the majority filter as discussed by Reuter (2007). SD was transformed from geographic projection (latitude/longitude) referenced to WGS84 horizontal datum into RSO Projection (meter). To generate comparable SD with the TD, the 3-arc-second SRTM dataset, which was in raster format, was converted to a points map. Then Spline estimation method was employed to interpolate the SRTM point format data into the 30 m grid. This interpolation did not add any new detail to the original SD, but that made it possible to generate coherent surface properties in neighboring pixels. These properties are important parameters in terrain analysis (Grohmann and Steiner, 2008). Then HEC-GeoHMS was applied to SD to derive the respective watershed propitiate similar to one applied earlier for the TD.

Strep 5- Evaluation

The accuracy of the parameters estimated by SD vs. TD was assessed based on the Nash-Sutcliff Efficiency (NSE) (Nash and Sutcliffe, 1970). Equation (1) has been adapted from Nash and Sutcliffe. NSE varies from negative infinity to 1. Closer values to 1 show closer agreement of estimated SRTM parameters with TD parameters. Table 3 shows the NSE for the four parameters which shows a good agreement between the elevations and areas of the sub-watersheds for two derivations. However, there is no good agreement for slope and perimeter.

$$NSE = 1 - \left(\frac{\sum_{i=1}^{n} \left(SD\,(Ele \ldots)_i - TD\,(Ele \ldots)_i \right)^2}{\sum_{i=1}^{n} \left(TD\,(Ele \ldots)_i - TD\,Mean\,(Ele \ldots) \right)^2} \right) \qquad \text{Equation(1)}$$

Where:

$SD\,(Ele \ldots)_i$: Elevation, Area, Perimeter or slope derived from SD in each

$TD\,(Ele \ldots)_i$: Elevation, Area, Perimeter or slope derived from TD

$TD\,Mean\,(Ele \ldots)$: Mean Elevation, Area, Perimeter or slope derived from TD

5. Results and Discussion

In this study, thirty-two delineated sub-watersheds were compared. Four geometrical watershed parameters including area, perimeter, and slope and centroid elevation were used. Figure 3 shows the delineated sub-watersheds as derived from SD and TD. There is a good agreement between sub-watersheds delineated using SD (black lines) and TD (blue lines). However, in the flat and massive urban areas as highlighted by the ellipsoid, the agreements between two estimates were not as good as in the high relief areas. Values for 4 parameters of 32 sub-watersheds as derived from SD and TD are shown in table 2.

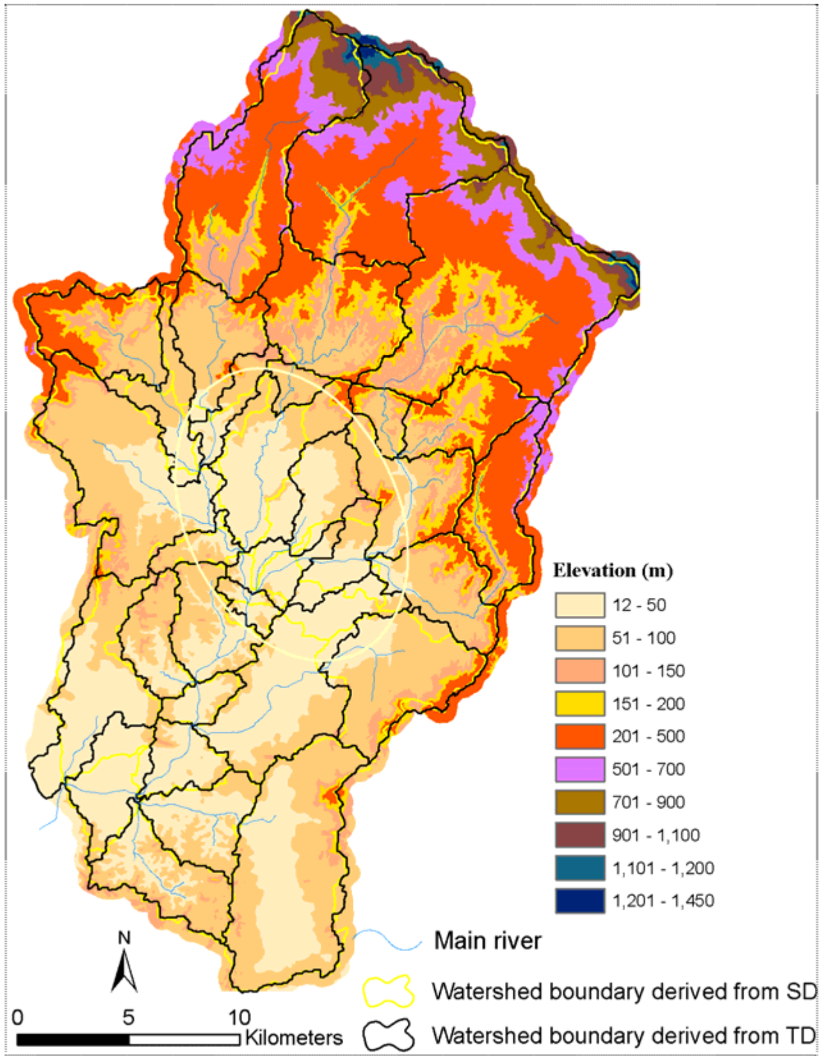

Figure 3: Watershed boundaries derived from the TD (blue line) and SD (black line)

Table 2: Geometrical parameters derived from TD and SD

Sub-watersheds name	TD (30 m resolution)				SD (30 m resolution)			
	Perimeter (km)	Elevation (m)	Slope (%)	Area (km^2)	Perimeter (km)	Elevation (m)	Slope (%)	Area (km^2)
s1	51.28	234	35.32	50.5	51.54	249	26.58	52.2
s2	50.88	260	39.4	56.7	48.48	242	27.86	56.3
s3	59.26	165	32.32	75.7	58.32	186	23.04	76.9
s4	32.9	345	36.15	19.5	31.68	337	23.23	19.6
s5	26.6	172	29.38	15.2	25.8	175	19.25	15.7
s6	14.4	59	22.48	5.9	14.1	56	15.35	5.1
s7	35.06	129	24.71	29.3	33.12	121	16.2	29.6
s8	13.18	57	14.27	4.6	12.36	58	8.17	3.5
s9	30.14	63	17.35	24.2	27.12	63	10.91	16.1
s10	29.66	110	26.9	19.7	28.68	116	19.65	18.5
s11	51.82	51	10.39	43.3	51.24	51	7.98	46.0
s12	32.24	50	19.4	19.3	31.8	53	13.16	21.8
s13	28.3	63	18.54	18.9	27.24	72	12.97	17.7
s14	35.48	62	10.04	26.6	34.44	56	8.56	26.6
s15	35.04	35	4.21	27.4	36.06	33	4.57	25.4
s16	48.46	40	7.24	47.5	46.86	23	6.41	47.8
s17	25.48	40	8.45	15.3	24.66	40	6.53	15.6
s18	31.22	39	17.11	17.6	30.42	38	9.95	17.3
s19	20.68	21	3.47	9.5	23.34	16	3.43	13.0
s20	19.02	19	7.26	10.0	19.2	19	5.99	8.9
s21	13.6	24	7.55	5.1	13.86	24	6.74	5.1
s22	26.26	70	11.3	14.1	27.24	69	7.52	15.1
s23	24.36	54	13.71	11.9	23.76	45	8.77	11.7
s24	38.76	40	5.68	26.0	42.6	33	5.32	25.8
s26	27.28	40	5.65	16.3	43.44	51	4.46	24.5
s27	36.44	46	4.73	21.2	29.1	44	3.74	15.1
s28	21.42	40	2.88	10.2	21.3	39	3.66	9.3
s29	20.48	51	7.00	6.4	26.34	52	5.59	8.4
s30	18.72	52	6.38	6.4	36.72	55	5.42	11.5
s31	11.46	39	9.52	2.8	12.48	27	6.89	3.2
s32	12.42	49	7.49	3.2	14.46	40	6.21	3.2
s33	27.42	41	2.57	10.3	33.96	41	2.11	14.8
Min	11.46	19	2.57	2.837	12.36	16	2.11	3.19
Max	59.26	345	39.4	75.651	58.32	337	27.86	76.94
Avg.	29.68	80.00	14.65	20.96	30.68	78.88	10.51	21.29
STDEV	12.46	75.93	10.82	17.09	12.10	76.64	7.18	17.23
Sum	*	*	*	675.69	*	*	*	681.34

Table 3: Nash-Sutcliffe efficiency for the investigated parameters

Elevation	Area	Slope	Perimeter
0.99	0.97	0.72	0.84

As it shown in Figure 3 some discrepancies are evident in delineated watersheds boundaries derived from two sources of DEMs, mainly in the urban areas. To assess the effectiveness of SD for the watershed modeling in two different land forms, sub-watersheds located in the urban and non-urban areas were investigated, and then NSE was calculated separately for the investigated parameters. Table 4 shows the geometrical parameters derived from TD and SD for the sub-watersheds located in the urban areas.

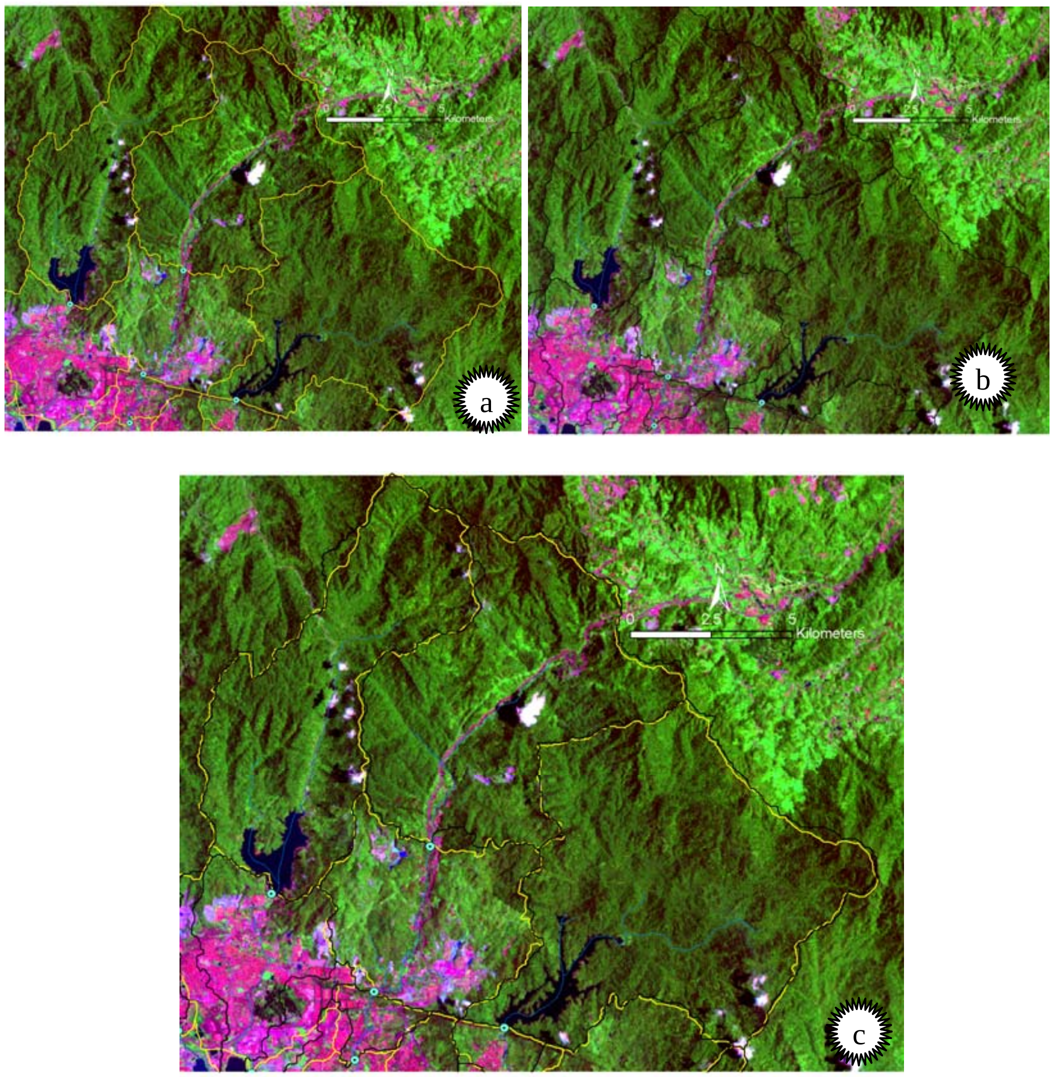

Figure 4: Watershed boundaries derived from (a) TD, (b) SD and (C) overlying two derivatives over Land sat image.

Nash-Sutcliffe efficiency calculated for these areas is shown in Table 5. In the same way, geometrical parameters and NSE were calculated which are shown in Tables 6 and Table 7. Figure 4 illustrates the watershed boundary delineated by two sources of datasets and its comparison in the upper right corner of the Klang river watershed which lies over the Land Sat imagery.

Table 4: Geometrical parameters derived from TD and SD in urban areas

Sub-watersheds name	TopoDEM30				SRTM DEM30			
	Perimeter (km)	Elevation (m)	Slope (%)	Area (km^2)	Perimeter (km)	Elevation (m)	Slope (%)	Area (km^2)
s29	20.48	51	7.0	6.4	26.34	52	5.6	8.4
s30	18.72	52	6.4	6.4	36.72	55	5.4	11.5
s26	27.28	40	5.7	16.3	43.44	51	4.5	24.5
s12	32.24	50	19.4	19.3	31.8	53	13.2	21.8
s27	36.44	46	4.7	21.2	29.1	44	3.7	15.1
s32	12.42	49	7.5	3.2	14.46	40	6.2	3.2
s33	27.42	41	2.6	15.4	33.96	41	2.1	14.8
s24	38.76	40	5.7	26.0	42.6	33	5.3	25.8
s19	20.68	21	3.5	9.5	23.34	16	3.4	13.0
s8	13.18	57	14.3	4.6	12.36	58	8.2	3.5
s9	30.14	63	17.4	24.2	27.12	63	10.9	16.1
s4	32.9	345	36.2	19.5	31.68	337	23.2	19.6
s28	21.42	40	2.9	10.2	21.3	39	3.7	9.3
s31	11.46	39	9.5	2.8	12.48	27	6.9	3.2
Min	11.46	21.0	2.6	2.84	12.36	16.0	2.1	3.2
Max	38.76	345.0	36.2	25.97	43.44	337.00	23.2	25.83
Stdv	8.95	80.72	9.1	8.02	10.11	79.34	5.5	7.59
Avg	24.54	66.71	10.2	13.22	27.62	64.93	7.3	13.56
Sum	*	*	*	185.0	*	*	*	189.9

Table 5: Geometrical parameters derived from TD and SD in non-urban areas

Sub-watersheds name	TopoDEM30				SRTM DEM30			
	Perimeter (km)	Elevation (m)	Slope (%)	Area (km^2)	Perimeter (km)	Elevation (m)	Slope (%)	Area (km^2)
s1	51.28	234	35.32	50.5	51.54	249	26.58	52.2
s2	50.88	260	39.4	56.7	48.48	242	27.86	56.3
s3	59.26	165	32.32	75.7	58.32	186	23.04	76.9
s11	51.82	51	10.39	43.3	51.24	51	7.98	46.0
s13	28.3	63	18.54	18.9	27.24	72	12.97	17.7
s22	26.26	70	11.3	14.1	27.24	69	7.52	15.1
s23	24.36	54	13.71	11.9	23.76	45	8.77	11.7
s21	13.6	24	7.55	5.1	13.86	24	6.74	5.1
s15	35.04	35	4.21	27.4	36.06	33	4.57	25.4
s20	19.02	19	7.26	10.0	19.2	19	5.99	8.9
s16	48.46	40	7.24	47.5	46.86	23	6.41	47.8
s17	25.48	40	8.45	15.3	24.66	40	6.53	15.6
s18	31.22	39	17.11	17.6	30.42	38	9.95	17.3
s10	29.66	110	26.9	19.7	28.68	116	19.65	18.5
s4	32.9	345	36.15	19.5	31.68	337	23.23	19.6
s14	35.48	62	10.04	26.6	34.44	56	8.56	26.6
Min	13.60	19.00	4.21	5.11	13.86	19.00	4.57	5.08
Max	59.26	345.00	39.40	75.65	58.32	337.00	27.86	76.94
Stdv	13.30	97.85	12.05	20.00	12.97	98.49	8.17	20.58
Avg	35.19	100.69	17.87	28.74	34.61	100.0	12.90	28.79
Sum	*	*	*	459.79	*	*	*	460.71

Table 6: NSE calculated for the sub-watersheds parameters drived from two source of DEMs located in the urban areas and non-areas.

Nash-Sutcliffe Efficiency	Elevation	Area	Slope	Perimeter
NSE_{urban}	0.756	0.736	0.781	0.276
$NSE_{non-urban}$	0.989	0.996	0.701	0.993
$NSE_{whole-watershed}$	0.995	0.974	0.723	0.844

6. Conclusion

Visually and statistically, there are no significant differences between watershed model derived from TD and SD in the hilly none-urban areas. However, significant discrepancy is evident in the watershed boundaries of the flat urban areas. Watershed area delineated by using the TD is 675.69 km^2, while the SD area is 681.30 km^2 (1% larger). This aerial error is still acceptable with regard to the large size of the watershed. Four geometrical parameters including watershed area, perimeter, and slope and centroid elevation were investigated. With regard to TD as reference, Nash-Sutcliff Efficiency indicates similarity of about 97%, 84%, 72% and 99% for watershed area, perimeter, slope and centroid elevation respectively. These findings suggest that two sources of elevation dataset; SD can explain the TD by 88 percent, which is a reasonable estimation for such a large area. Watershed boundaries delineated from SD in the flat-urban areas, do not mach as good as none-urbanized areas. In particular, sub-watersheds s19, s23, s26, s27, s28, s31, s32 and s33 that are all situated in highly developed urban areas, show significant discrepancy compared to the sub-watershed boundary delineated by TD. Good agreement was found for the areas with high relief, mostly located in hilly areas. Further study may follow by assessment of the peak and volume of watershed runoff and see how watershed response significantly changes by using those datasets.

7. Acknowledgements

Financial support for this research was provided by University of Malaya through the research fund project number PS017/2007B. Rainfall data provided by DID Malaysia. We appreciate ITC and US Army Corps of Engineers for providing free GIS software. We also acknowledge the NASA for providing global free elevation dataset.

8. References

COSTA-CABRAL, M. C. & BURGES, S. (1994). Digital elevation model networks (DEMON): A model of flow over hillslopes for computation of contributing and dispersal areas. Journal of Water Resources Research, vol.30**,** pp. 1681-1692.

DOAN, J. H. (2003). Geospatial Hydrologic Modeling Extension HEC-GeoHMS-User’s Manual. Version 1.1. Davis, California: US Army Corps of Engineers-HEC.

ESRI (2002). What's New in ArcView 3.1, 3.2, and 3.3. p.34.

FAIRFIELD, J. & LEYMARIE, P. (1991). Drainage networks from grid digital elevation models. Water Resources Research, vol. 27**,** pp. 709-717.

FREEMAN, T. G. (1991). Calculating catchment area with divergent flow based on a regular grid. Computers and Geoscience, vol. 17.

GARBRECHT, J. & MARTZ, L. W. (2000). Digital Elevation Model Issues In Water Resources Modeling. In: MAIDMENT, D. R. & DJOKIC, D. (eds.) Hydrologic and hydraulic modeling support:with geographic information systems. New York: ESRI Press.

GESCH, D., WILLIAMS, J. & MILLER, W. (2001) A Comparison of U.S. Geological Survey Seamless Elevation Models with Shuttle Radar Topography Mission Data. In: IEEE International Geoscience and Remote Sensing Symposium, July 9-13 2001 Sydney, NWS, Australia, . Institute of Electrical and Electronics Engineers, Inc., pp.754-756.

GROHMANN, C. H. & STEINER, S. S. (2008). SRTM resample with short distance-low nugget kriging. International Journal of Geographical Information Science, 22**,** 895 - 906

HAYAKAWA, Y. S., OGUCHI, T. & LIN, Z.(2008). Comparison of new and existing global digital elevation models: ASTER G-DEM and SRTM-3. Geophysical Research Letters, 35.

JONES, N. L., WRIGHT, S. G. & MAIDMENT, D. R. (1990). Watershed delineation with triangle-based terrain models. Journal of Hydraulic Engineering, vol. 116**,** pp. 1232-1251.

JPL/NASA. (2006). The Shuttle Radar Topography Mission ,http://www2.jpl.nasa.gov/srtm/ [Online]. CA,USA. [Accessed 15 May 2009].

JUPEM. (2009). Official Website For Department Survey and Mapping Malaysia (JUPEM) [Online]. Kuala Lumpur: JUPEM. [Accessed March 20 2009].

KISS, R. (2004). Determination of drainage network in digital elevation models, utilities and limitations. Journal of Hungarian Geomathematics, vol.2**,** pp.16-29.

KOOLHOVEN, W., HENDRIKSE, J., NIEUWENHUIS, W., RETSIOS, B., SCHOUWENBURG, M., WANG, L., BUDDE, P. & NIJMEIJER, R. (2007). The Integrated Land and Water Information System (ILWIS). 3.4 ed. Enschede, The Netherlands ITC.

LEA, N. L. & , I., : , (1992). An aspect driven kinematic routing algorithm. In: PARSONS, A. J. & ABRAHAMS, A. D. (eds.) Overland flow: hydraulics and erosion mechanics. London.UK: Taylor and francis.

LEHNER, B., VERDIN, K. & JARVIS, A. (2008). New global hydrography derived from spaceborne elevation data TRANSACTIONS AMERICAN GEOPHYSICAL UNION, 89.

MAIDMENT, D. (2002). Arc Hydro: GIS for (2000) Resources, New York, Esri Press.

MCPHERSON, M. M. & HENNEMAN, H. E.(2000). DEM Processing for Hydrologic Modeling Studies. In: ESRI user conference, 2000 California,US. ESRI.

MOORE, I. D. & GRAYSON, R. B. (1991). Terrain-based catchment partitioning and runoff prediction using vector elevation data. Water Resources Research, vol. 27**,** pp. 1177-1191.

NELSON, E. J., JONES, N. L. & MILLER, A. W. (1994). Algorithm for precise drainage-basin delineation. Journal of Hydraulic Engineering, vol. 120**,** pp. 298-312.

O'CALLAGHAN, J. F. & MARK, D. M. (1984). The extraction of drainage networks from digital elevation data. Computer Vision, Graphics, and Image Processing, vol. 28**,** pp. 328-344.

PEUCKER, T. K. & DOUGLAS, D. H. (1975). Detection of surface-specific points by parallel processing of discrete terrain elevation data. Computer Graphics and Image Processing, vol.4**,** pp. 375-387.

PRYDE, J. K., OSORIO, J., WOLFE, M. L., HEATWOLE, C., BENHAM, B. & CARDENAS, A.(2007). Comparison of watershed boundaries derived from SRTM and ASTER digital elevation datasets and from a digitized topographic map. 2007 ASABE Annual International Meeting. Minneapolis Convention Center, Minneapolis, Minnesota, US: American Society of Agricultural and Biological Engineers (ASABE).

REUTER, H. I., NELSON, A. & JARVIS, A. (2007). An evaluation of void-filling interpolation methods for SRTM data. *International Journal of Geographical Information Science,* 21**,** pp.983 - 1008

RODRIGUEZ, E., MORRIS, C. S., BELZ, J. E., CHAPIN, E. C., MARTIN, J. M., DAFFER, W. & HENSLEY, S.(2005). An Assessment of the SRTM Topographic Products. *Technical Report JPL.* Pasadena,CA,USA.

RUYVER, R. D. (2004). *DEM optimization for hydrological modelling using SRTM for the 'Pantanal' region, Brazil.* Master of Science, International Institute for Geo-information Science and Earth Observation (ITC).

SINGH, V. P. & FREVERT, D. K. (eds.) (2006). *Watershed Models,* Boca Raton,USA: CRC Press.

TARBOTON, D. G. (1997). A new method for the determination of flow directions and upslope areas in grid digital elevation models. *Water Resources Research,* vol. 33**,** pp. 309-319.

TICK, L. J. & SAMAH, A. A. (2004). *Weather and climate of Malaysia,* Kuala Lumpur, University Malaya Perss.

USDC, NOAA & NGDC. (2006). *Department of Commerce, National Oceanic and Atmospheric Administration, National Geophysical Data Center* [Online]. Available: http://www.ngdc.noaa.gov/mgg/fliers/06mgg01.html [Accessed 10 April,2008].

USGS. (2008). *HydroSHEDS (Hydrological data and maps based on SHuttle Elevation Derivatives at multiple Scales)* [Online]. U.S. Geological Survey Available: http://hydrosheds.cr.usgs.gov/datasource.php [Accessed May 15 2009].

VIEUX, B. E. (2004). *Distributed Hdyrologic Modeling Using GIS*, Kluwer Academic Publishers.

WILSON, J. P. & GALLANT, J. C. (eds.) (2000). *Terrain Analysis: Principles and Applications* John Wiley and Sons.

WISE, S. M.(2007). Effect of differing DEM creation methods on the results from a hydrological model. *Computers & Geosciences,* vol.33**,** pp.15.

ZYL, J. J. V. (2001). THE Shuttle Radar Topography Misson (SRTM): A Breakthoughin Remote Sensing of Topography *Acta Astronautica,* 48**,** 559-565.