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Effects of DEMs from different sources in deriving stream networks threshold values

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ABSTRACT: Digital elevation model (DEM) is the most common surface topography data used to derive river network. DEM comes with different resolutions and can generate various topographic and hydrological features. This study investigates the effects DEM's threshold values from different sources in deriving stream networks using Geospatial Hydrologic Modelling Extension (HEC-GeoHMS). DEMs of 30m resolution were acquired from SRTM, ASTER, and NEXTMap data. In addition, topographic DEM were derived from contour data of 20 m interval to generate the stream network on the sub-basin of Jawi river, Penang, Malaysia. Subsequently, spatial comparison was made with the existing drainage networks derived from the Malaysian Department of Irrigation and Drainage (DID). The analysis reveals that the drainage network from SRTM with threshold values of 40 was closest to the referenced drainage. The result has signifies the most appropriate values for an effective stream threshold network to be considered suitable for future river sub-basin analysis.

1 INTRODUCTION

The advent availability of the Digital Elevation Models (DEMs) sources and advances in computer processing has resulted in the development of digital mapping or derived channel networks from DEMs (Tarboton, 2003). DEM is the main component of hydrologic modeling and drainage network for river morphological research (Thomas et al. 2014). Topographic maps have been widely used in decades for the estimation of topographic attributes as well as in the delineation of stream networks, which is very time-consuming to produce (Zevenbergen & Thorne, 1987). Generally, the development of Digital Terrain Analysis and DEM have been simplified through the usage of GIS and remote sensing application software such as ArcGIS instead of measuring and digitizing from topographic map (Tarboton et al. 1992). The DEM itself have been widely used in GIS processing as they automatically process the hydrological features such as terrain slope, drainage networks, drainage divides and catchment boundaries thus, reducing the time consumed to analyze the study area (Vaze et al. 2010). In spite of that, DEMs with different resolution and sources generated can lead to different varied topographic and hydrological features.

A study was carried out to investigate the effects of DEMs on deriving topographic and hydrological attributes onto two small forested watersheds located in northern Idaho, USA (Zhang et al. 2008). Six DEMs were used and the result shows that DEMs with different resolution generates varying watershed shapes and structures that gives different extracted hillslope and channel length.

This paper presents a study on the effects of DEMs from different sources in deriving stream networks' threshold values. The stream network analysis applies several DEMs data sources of different resolution in evaluating the hydrological characteristics. The DEMs sources used are namely Shuttle Radar Topography Mission (SRTM) in 30 m resolution, Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) in 30 m resolution, NEXTMap World 30 in 30 m resolution and DEM (TopoRaster) in 20 m resolution.

In signifying the sensitivities of different DEMs sources, tests on the hydrological application were made to delineate drainage network on a specific part of Jawi River, Penang. Subsequently, the delineated drainage river networks were benchmarked with a reasonably accurate data source provided by the Malaysian DID. Lastly, the results were compared with an independent river network study made by (Poggio & Soille, 2011).

2 STUDY AREA

Jawi River is located in the district of South Seberang Perai, about 315 km from the national capital, Kuala Lumpur (Figure 1). It covers a total land area of 243 km^2, stretching between latitude 5° 10'N and 5° 20'N and longitude 100° 25'E and 100° 35'E with the elevation ranges between 1 m and 273 m above

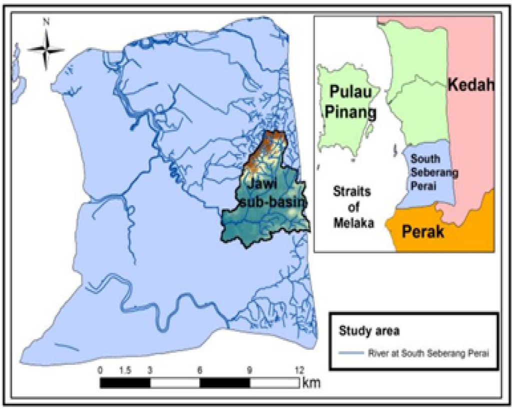

Figure 1. The study area.

mean sea level. Jawi River originates at Duri river and flowing through of Jejawi river near the coast before discharging into the Malacca Strait. There are five major tributaries of the Jawi river system namely, Bakap river with a drainage area of 65.3 km^2, Duri river with 1.54 km^2, Baung river with 6.8 km^2, Bakar Arang river with 8.5 km^2, and Badak Mati river covering 9.49 km^2. The mean temperature in the region is 27°C with high humidity varying from 50–70%. The study area has two typical monsoons, such as the northeast monsoon and southwest monsoon and sometimes experienced massive change of heavy rainfall.

3 METHODOLOGY

There are several methods of DEM interpolation in Geographic Information System (GIS). However, methods of resampling do not influence the quality of resampled DEMs significantly (Tamiru & Rientjes, 2005). Therefore, 'Topo to Raster' method was used as an interpolation technique where the tool was designed for the creation of correct hydrological DEMs as it is based on the ANUDEM program. The program was developed by Michael Hutchinson and the method was applied in ArcGIS version 10.2 for the hydrological application (Gallant & Hutchinson, 2011). The research applies different sources of DEMs with several levels of spatial resolution. River networks were individually extracted and subsequently compared with the data from Malaysian DID.

The Geospatial Hydrologic Modelling Extension (HEC-GeoHMS) was developed as a hydrology toolkit for engineers and hydrologist to extract physical parameters from DEM. Hydrology module HEC-GeoHMS was used to extract river networks from different DEMs. HEC-GeoHMS is a reliable model developed by the US Army Corps of Engineers and usable for many hydrological simulations (Halwatura & Najim, 2013). The HEC-GeoHMS model are frequently used to analyse urban flooding, flood frequency, flood warning system planning, reservoir spillway capacity and stream restoration (U.S. Army

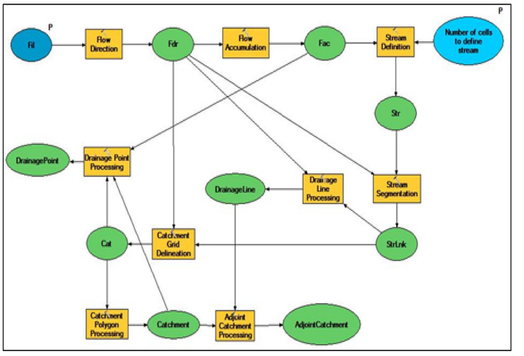

Figure 2. Flow chart showing the entire process of creating watershed delineation using HEC-GeoHMS.

Corps of Engineers, 2008). Flow direction and sinks were identified in each DEM and if sinks existed, the process will filled to revise the flow direction. The automatic process of filling the sinks uses a function that identifies the pits and raised the terrain in order to have a smoother surface that allows the water to flow freely without forming ponds (Jenson, 1991). After correcting the flow direction, the grid cells will identify the streams based on the flow accumulation threshold. The threshold will affect the density of drainage network as well as the size of the watershed area. The higher threshold value will result in a less dense stream networks with fewer internal watersheds as compared to lower threshold (Chang, 2012). By default, the stream threshold value will be 1% of the maximum flow accumulation. Thus, the different threshold numbers were applied to all data sources to facilitate comparison and to generate sufficient stream network.

4 RESULTS AND DISCUSSION

Stream threshold is one of the most important parameters that must be considered in the stream networks. Drainage networks were first extracted from each DEMs using the methodology as described in Figure 2. The number of cells for stream threshold varies based on the spatial resolution of DEM used. The linear parameters such as stream number, stream length were taken into consideration in conducting the comparison study. The test was conducted by changing the threshold number at a constant value, since the 1% of the stream threshold does not replicate all sufficient tributaries on the watershed. The effects of different threshold number are then plotted. Figures 3–6 shows the variation in stream length of each stream order at different thresholds.

The results shows variation in the number of streams in each order as it depends on the threshold value. The number of thresholds varies from 20, 40, 60, 80 and 100 for each data source. However, due to the pixel's resolution, there was split on the stream networks image when the number of thresholds increased to

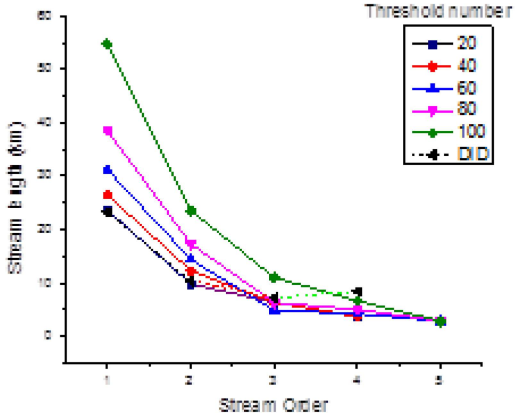

Figure 3. Graph analysis stream order for Jawi sub-basin for SRTM 30 [m].

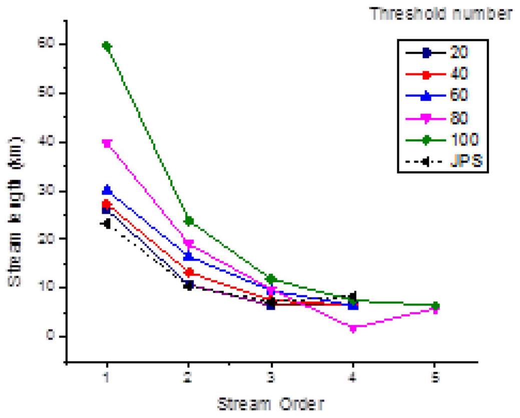

Figure 4. Graph analysis stream order for Jawi sub-basin for ASTER 30 [m].

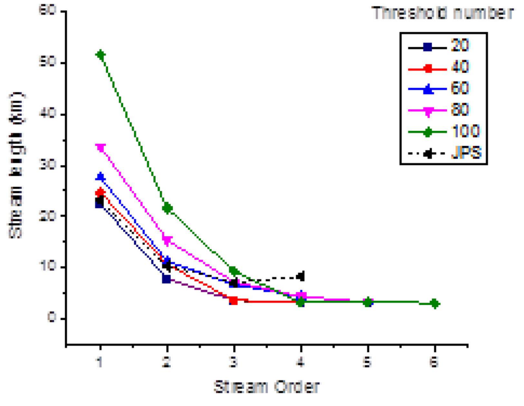

Figure 5. Graph analysis stream order for Jawi sub-basin for World 30 [m].

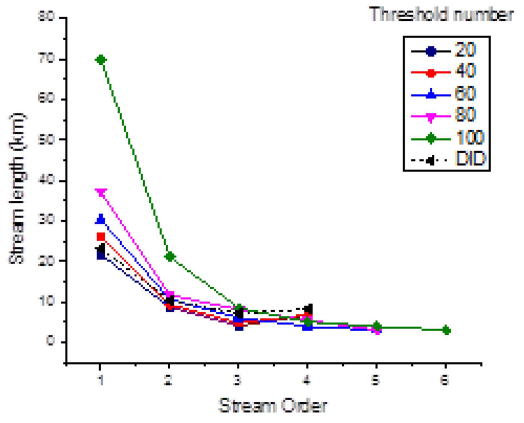

Figure 6. Graph analysis stream order for Jawi sub-basin for TopoRaster at 20 [m].

above 100. Therefore, the optimum threshold number was 100 and the lower is 20 respectively.

The plot on SRTM 30 m (Figure 3) using 20- threshold number matches the line plotted for Malaysian DID reference. The number of stream length was 23.61 km and 9.75 km respectively and achieved at 1st and 2nd stream order. The graph has shown that the stream networks match the Malaysian DID plot at these stream order points. It is found that smaller threshold value will gives denser drainage network, thereby increasing the stream length. Additionally, at stream order 3, the threshold 40 lies on the exact point of Malaysian DID i.e. 6.26 km. The highest stream length recorded was 54.78 km in the 1st order.

As for ASTER 30 m (Figure 4), it shows that the threshold 20 matches the reference point of stream network from Malaysian DID at 2nd stream order. For the 3rd order, the reference stream network from Malaysian DID falls between threshold 20 and 40 (6.44 km and 7.55 km, respectively). However, the Malaysian DID stream network nearly approached the threshold 100 at 7.51 km. The highest stream length from this data source was 59.68 km at threshold 100, while the lowest point was at threshold 80 (1.84 km) at 4th stream order.

Figure 5 shows the graph for World 30 m data source. The graph shows that the threshold 20 lies almost on Malaysian DID point (22.54 km) at the 1st order, but on the 2nd and the 3rd stream order, threshold 40 and 60 matches exactly on the Malaysian DID stream network points (10.75 km and 6.86 km, respectively). The highest stream length on this graph was 51.50 km and the lowest point was 3.24 km at threshold 100.

Lastly, Figure 6 shows the graph for DEM generated from 'TopoRaster' 20 m data. The objective is to identify whether topographic data can yield better result in a stream network as compared to satellite-derived data. The graph lines indicates the points at stream order 1, 2, 3 and 4 matches the line from Malaysian DID stream network. Moreover, threshold 60 lies exactly on the bench mark line at 2nd stream order (10.68 km). The highest and the lowest stream lengths on the graph were (69.87 km and 3.11 km, respectively) with threshold 20.

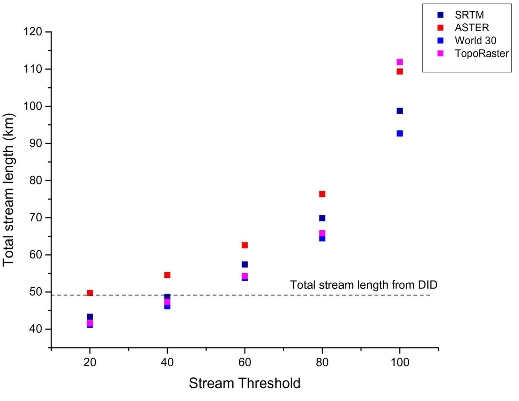

Figure 7. Graph analysis of variation in the total stream length at different threshold with various data sources.

Studying the effect of the threshold number on different sources of DEMs is essential in determining the stream network. A threshold number range 20 to 100 was selected for the study. The effects of threshold number and total stream length are shown in Figure 7.

The graph illustrates a strong positive relationship between ASTER 30m at threshold 20 with SRTM 30 m at threshold 40, having the same stream length as the Malaysian DID (i.e. 49.70 km and 48.65 km, respectively). The total stream length of the sub-basin from Malaysia DID is 49.24 km (represented as a dashed line). From the previous graph analysis, it is discovered that the SRTM 30 m was more significantly near to DID stream data at 1st and 2nd stream order. This result has shown that the threshold 40 in the SRTM 30 m was an effective stream threshold network that can be considered to be suitable for future river sub-basin analysis.

5 CONCLUSION

This study concludes that the accuracy of the automatic stream network derivation depends on the quality and different sources of the DEMs as it has an affect the outcomes of river network extraction. From literature, the SRTM 30 m was expected to be more accurate and reliable and the analysis has shown that SRTM 30 with threshold 40 delivered the best result of river network when compared with the digitized river network from Malaysian DID (i.e. 98% similarity). However, other DEM data sources having same resolution also give similar patterns as indicated in the graphs plot. DEM data from SRTM 30 m has the potential to be used for automated extraction of river networks to less than 1m resolution with superior results.

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