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To cite this article: Suhaila Hashim *et al* 2021 *IOP Conf. Ser.: Earth Environ. Sci.* **620** 012003

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Cross Section Intervals of Flood Intervals of Flood Inundation Mapping at Ungauged Area

Suhaila Hashim^{1*}, Ernieza Suhana Mokhtar¹, Ahmad Ikhwan Abdul Halim¹, Wan Mohd Naim Wan Mohd², Nor Aizam Adnan², Biswajeet Pradhan³

¹ Faculty of Architecture, Planning & Surveying, Universiti Teknologi MARA, Perlis Branch, Arau Campus, 02600 Arau, Perlis, Malaysia

² Faculty of Architecture, Planning & Surveying, Universiti Teknologi MARA, 40450 Shah Alam, Malaysia

³ Centre for Advanced Modelling and Geospatial Information Systems (CAMGIS), Faculty of Engineering and IT, University of Technology Sydney, NSW 2007, Australia.

E-mail: suhaila.hashim@gmail.com

Abstract. Digital Elevation Models (DEMs) are essential to present the continuous surface elevation and is used for flood mapping. The use of different cross-section intervals obtained from the various spatial resolution of DEMs will affect the flood depth and inundation area estimation. Therefore, a comparison study is carried out to investigate the effect of cross-section intervals on flood expansion and flood depth which is simulated using one dimensional (1D) HEC-RAS model at Padang Terap River, Malaysia. Two digital elevation models (DEMs) imageries, Interferometry Synthetic Aperture Radar (IFSAR) and Shuttle Radar Topography Mission (SRTM) are used in this study. The result was evaluated using likelihood measures (F-statistics, root mean square error (RMSE), and mean absolute error). The findings reveal the IFSAR DEM with cross-section interval 50 m has higher F-statistics of 70% on flood inundation estimation. By proposing the methodology, flood mapping can be provided accurately by considering the error that exist in the Geographical Information System (GIS) spatial context.

1. Introduction

Flood inundation is an overflow of water onto dry land and flood inundation mapping is the area that would be flooded by a particular flood event [1]. Flood inundation maps serve as an important tool in decision making related to minimizing losses from flooding. Although the conventional method based on a ground survey is proved as an accurate approach, this method only covers a small area and consume high cost and time in data collection and processing phases [2], [3].

Hydraulic models are used to determine the flood extent at several cross-sections along the river reach assuming that the estimated extreme flood occurs in the area of interests [4], [5]. Hydraulic models that are popularly used to forecast river behavior such as Infowork MIKE-11, Soil and Water Assessment Tool (SWAT) and Hydrologic Engineering Center and River Analysis System (HEC-RAS) [6]–[9]. Several studies [4], [10], [11] have been implemented by integrating the Geographical Information System (GIS) and hydraulic modelling, and it is enabled to visualise the flood depth and



water extent by obtaining the relationships between the flood discharge, elevations, and extents with reasonable accuracy if the process is repeated for numerous flood events [12]. However, data resolution and accuracy of elevation can affect the hydraulic and hydrologic modelling results [13].

Cross-section with several intervals is part of the data input for hydraulic modelling, which is generated from DEM. The cross-section interval of the 1D model have a significant impact on the final prediction of flood inundation mapping. Earlier research suggested that surveys based on stream cross-section should have small spacing between cross-sections to provide reliable information for river channel studies [14]. However, having cross-section data at finer spacing or at every river meander (i.e. river bend) and at upstream/downstream of structures (e.g. bridges) will increase the cost of the topographical surveys. Even though the cross-section is generated from the best available DEM datasets to identify flood inundation areas, they have varying levels of uncertainties [15]. Among these various uncertain sources, topography has been reported to be one of the major contributors [16]. A 1-D model such as HEC-RAS provides water surface elevations only along the individual cross-section. Therefore, uncertainty can arise in this approach when the water surface elevations at cross-section are interpolated to create a flood inundation map, because of that it is crucial to determine the suitable cross-section intervals for hydraulic modelling

Therefore, the purpose of this research is to determine the suitable cross-section intervals for flood inundation mapping using low-medium resolution imagery, IFSAR, and Shuttle Radar Topography Mission (SRTM). This is an essential study to improve the accuracy of flood hazard maps by determining suitable cross-section intervals on different satellite imageries especially in the ungauged area.

2. Study Area

The study is focused on the flooded area at Padang Terap River starting from Kuala Nerang Town to Belimbing Kiri Village with an estimated length of four (4) kilometers with an average elevation of 29 meters (Figure 1). This river consists of water level stations located near to the river at Kuala Nerang Town. This area is selected due to the overflow water banks from the upstream part, Kuala Nerang to the downstream area in 2010 and the availability of observed hydraulic parameters that can be applied for discharge estimation. The flood happened in between October and November 2010 and the destruction of property and infrastructure that cost of almost RM 17.81 billion [17].

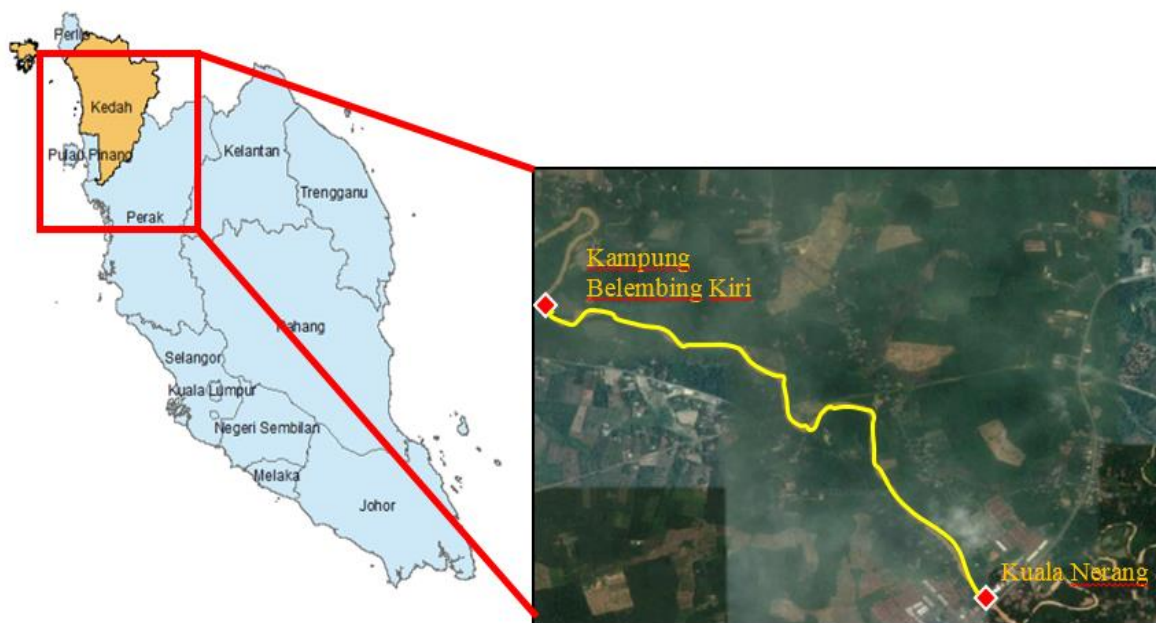


Figure 1. Location of Padang Terap River, Kedah, Malaysia

3. Methodology

3.1. Data used

The first level classified land-use data that consisted of agriculture, bare land, forest, impervious surface, and waterbody was acquired from the Federal Department of Town and Country Planning Malaysia (PLAN Malaysia) on a scale of 1:50 000 in 2009. For presenting the surface elevation in this study, the SRTM and IFSAR were used with a different spatial resolution of 30 m and 5 m respectively. The SRTM DEM can be assessed freely from United States Geological Survey (USGS) website (<https://earthexplorer.usgs.gov>) while NEXTMap Airborne IFSAR DEM which was acquired in January 2009 with 5 meters ground resolution was obtained from INTERMAP Technologies Malaysia. To verify the flood extent, TerraSAR-X imagery with 12 meters in resolution provided by Malaysia Remote Sensing Agency (ARSM) and acquired on November 4, 2010, during the flood disaster happened in Padang Terap was used to delineate the flood inundation area of Padang Terap.

3.2. Hydraulic data

The water level at the telemetry station during a peak flood event on 2 November 2010 obtained from the Department of Irrigation of Drainage (DID) and surface roughness (Manning-n) are used to predict the extent of the floods. The discharge value (951.520 m³/s) was estimated using the equation established by [18] in equation (1). The normal depth boundary condition is computed as S value by the equation where different elevations upstream and downstream are divided by the length of the river.

$$Q = 7.22W^{1.02}Y^{1.74}S^{0.35} \quad (1)$$

where Q = water discharge value, W = width of the river, Y = water depth, and S = channel slope

Furthermore, the historical flood depth was measured using measuring tape based on resident feedback. River morphology such as river centerline, riverbank, and cross-section line was digitized in Kertau rectified skew orthomorphic (RSO) coordinate system. The cross-section is generated on selected DEMs imageries. In the HEC-RAS model, Manning-n is required to present the surface roughness of the river and floodplain. Each of the land-use types will be assigned with n value which is depending on water absorption and water flowing into the river and was assigned to the layer of land-use. Table 1 shows the manning's value [19] for land-use in the study area.

Table 1. Manning's value

Surface type	Manning' Value
Cultivated and Brush	0.04
Bare Land	0.04
Developed Area	0.176
Forest	0.15

3.3. Cross-section extraction

HEC-GeoRAS software is used for this purpose. The selection of the cross-section intervals is based on the try and error process to identify appropriate cross-section interval at the ungauged area. Four different types of cross-section were extracted on DEMs with interval 5 m (CX5), 50 m (CX50), 100 m (CX100), and 150 m (CX150) on IFSAR and SRTM DEMs dataset. Figure 2 shows the cross-section interval used in flood inundation mapping estimation.

3.4. Flood extent and depth verification

The comparison between flood inundation delineated by different cross-section intervals was verified using TerraSAR imagery. This inundated area can be estimated using F-statistic equation (2) to verify the estimated value generated by hydraulic models and imagery during the flood event in 2010.

$$F = \frac{A}{A+B+C} \quad (2)$$

where A = area both observed and predicted as inundated, B = area of inundation present in model but absent in observation and C = area of inundation present in observation but absent in model. The flood depth was verified using four measured history flood depth that measured by tape at affected location in 2010.

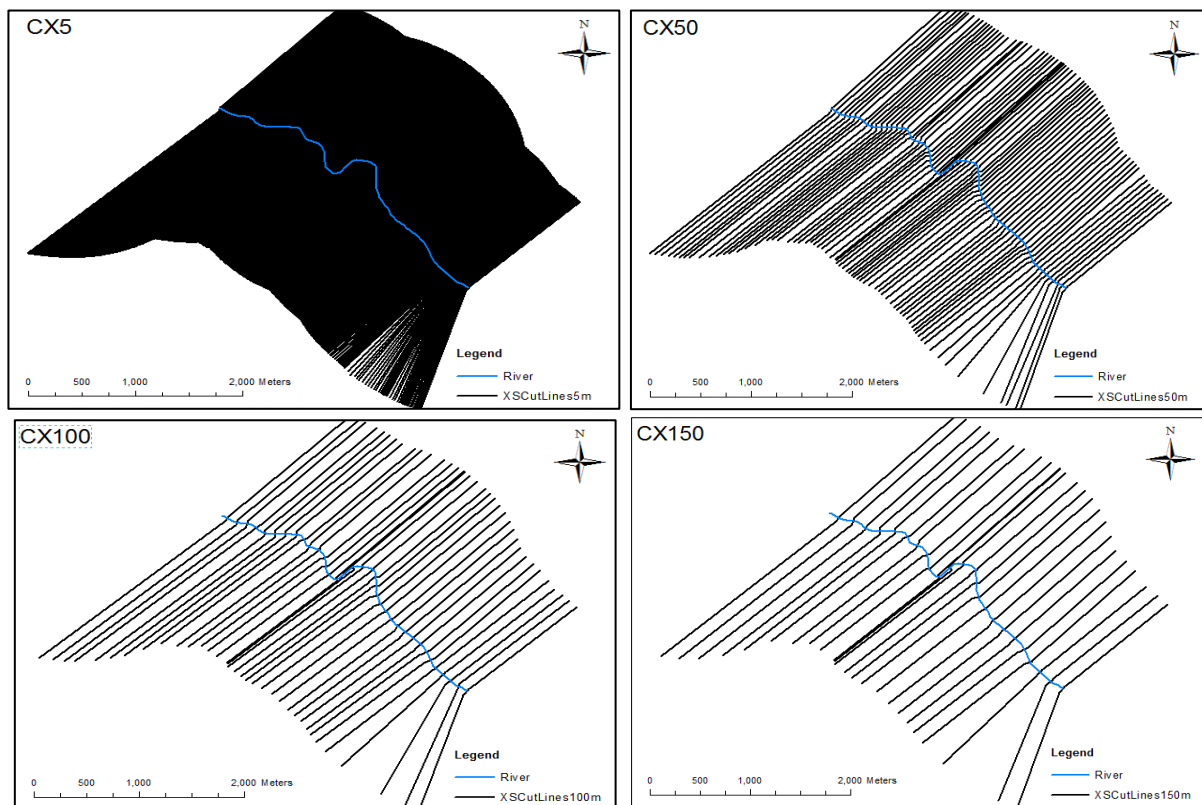


Figure 2. Cross-Section Extraction with different intervals

4. Comparing Water Extent and Flood Depth using Different Cross-section Intervals on IFSAR and SRTM DEMs

4.1. Estimation of water extent using different DEMs dataset and various cross-section intervals

Figure 3 shows the simulated flood extent maps obtained from different cross-section interval of SRTM and IFSAR DEMs (CX5, CX50, CX100, and CX150). The floodplain was simulated by the HEC-RAS model and the cross-section was delineated on images of SRTM and IFSAR DEMs with the spatial resolution is 30 and 5 m respectively. The comparison is based on the F-statistic calculated in between IFSAR and SRTM DEM. Figure 4 presents IFSAR DEM had the highest value of F-statistic in every cross-section interval as compared to SRTM DEM. The IFSAR DEM delineate estimated flood extent much better than SRTM DEM, in which the range is 0.66 – 0.70 and 0.24 – 0.26 respectively. The higher and lowest F-statistic of flood inundation comparison using IFSAR DEM is CX50 (0.70) and CX5 (0.66).

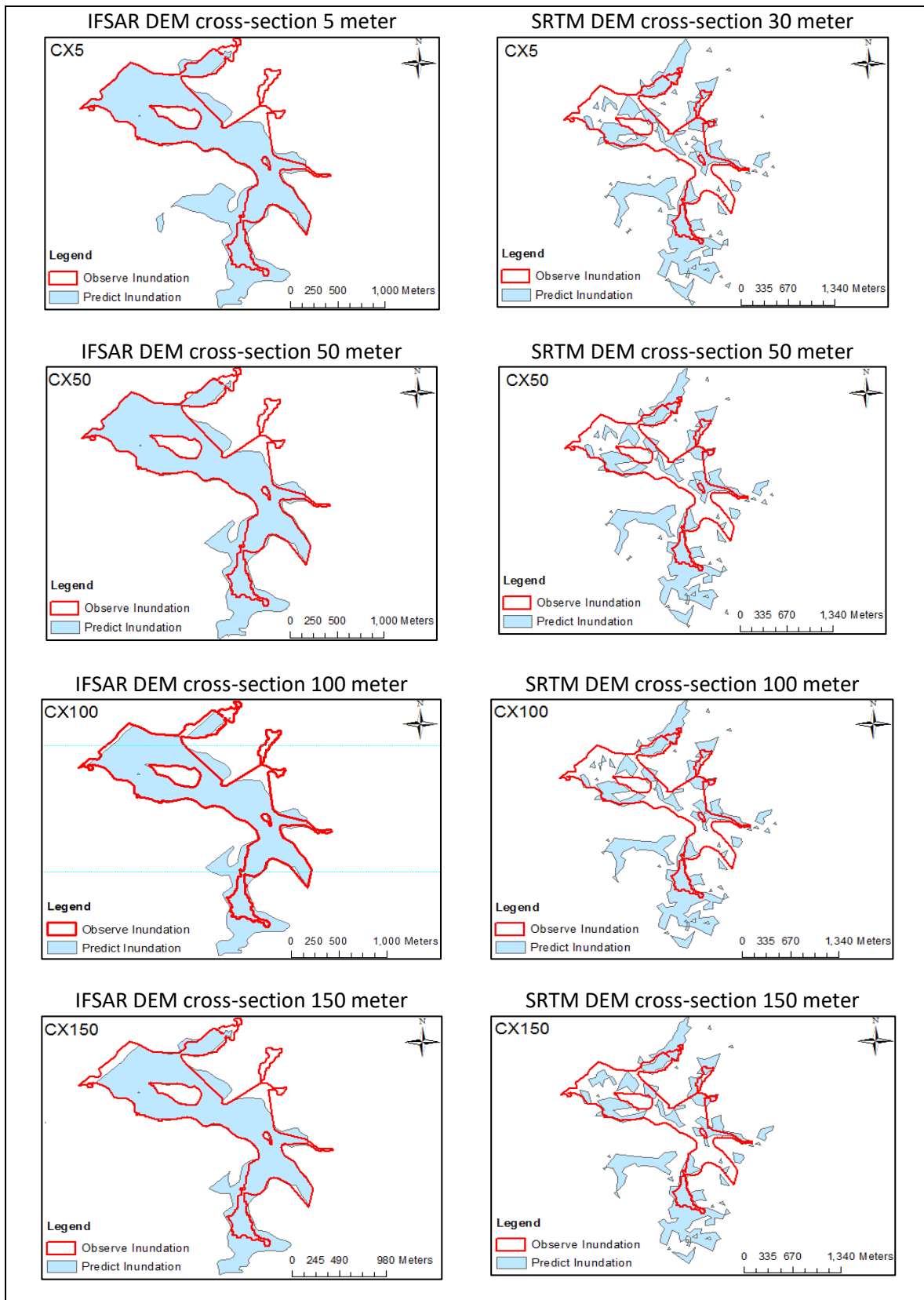


Figure 3. Flood inundation patterns from different cross-section interval between IFSAR and SRTM DEMs

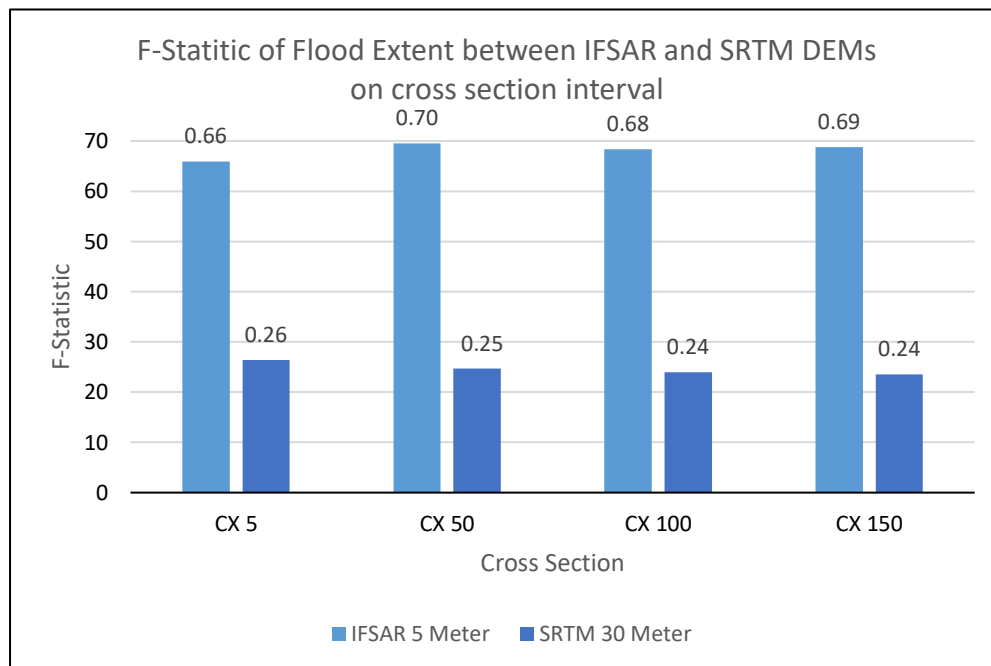


Figure 4. Comparison F-Statistic Value of Flood Extent between IFSAR and SRTM DEMs

In contradict, the F-statistic using the SRTM DEM is lowest as compared to the IFSAR DEM and was not well predicted for the flood inundation. Although the value of F statistic low, it is still significant for the area that medium resolution image is inaccessible. The flood inundation delineated from SRTM DEM showed rough surface pattern where the predicted flooding area is not smoothly representing the water body due to the low-resolution dataset (Figure 2).

4.2. Estimation Flood Depth using Different DEMs and Various Cross-Section Interval

4.2.1 IFSAR DEM

Figure 5 shows flood marks of observed flood depth that happened in 2010 which is located at Kampung Padang Lanjut, Taman Jelutong, Shell Kuala Nerang, and Pekan Kuala Nerang for verification of the flood depth. Table 2 shows the root mean square error (RMSE) and mean absolute error (MAE) between water depths estimated by the HEC-RAS model and flood marks measured by tape. The flood marks that had been selected are located at Kampung Padang Lanjut, Taman Jelutong, Pekan Kuala Nerang, and Shell Kuala Nerang. The CX5 cross-section interval presents the lowest RMSE and MAE with the value are 0.251 and 0.131 and the highest value is cross-section interval CX150 with 0.365 (RMSE) and 0.274 (MAE). The result showed that as the cross-section interval spacing increased, the RMSE and MAE also rises. Therefore, went the cross-spacing is close to each other such as CX5 it would produce the data more accurately and detail. While went the cross-spacing is interval higher such as CX150, it would be missing some data in interpolating of water depth that's make an error.

The difference between observed and predicted water depth is quite highest at Pekan Kuala Nerang location for all simulated flood depth in different cross-section interval. The result happened caused by the sub-tributary river, where two three (3) rivers of Padang Terap, Ahning, and Pedu Rivers were intersected in the area. To have a better result, the three rivers must be considered in the modeling.

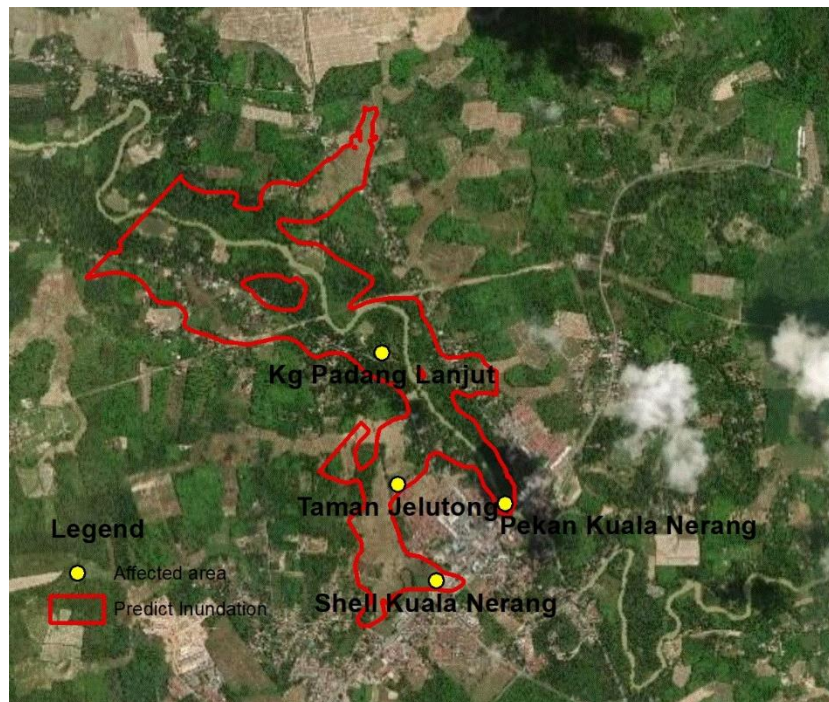


Figure 5. Location of flood marks observe on predict inundation area of IFSAR DEM
Image Source: ESRI, Digital Globe

Table 2. The difference between water depth observed from flood marks and water depth predicted by HEC-RAS using IFSAR DEM

DEM	CX	Place	Wdo	Wdp	DIFF	RMSE	MAE
IFSAR	CX5	Kampung Padang Lanjut	1.219	1.204	0.015	0.251	0.131
		Taman Jelutong	1.800	1.792	0.008		
		Pekan Kuala Nerang	3.000	2.499	0.501		
		Shell Kuala Nerang	1.200	1.199	0.001		
	CX50	Kampung Padang Lanjut	1.219	1.113	0.106	0.305	0.220
		Taman Jelutong	1.800	1.713	0.087		
		Pekan Kuala Nerang	3.000	2.415	0.585		
		Shell Kuala Nerang	1.200	1.099	0.101		
	CX100	Kampung Padang Lanjut	1.219	1.091	0.128	0.327	0.240
		Taman Jelutong	1.800	1.692	0.108		
		Pekan Kuala Nerang	3.000	2.377	0.623		
		Shell Kuala Nerang	1.200	1.098	0.102		
	CX150	Kampung Padang Lanjut	1.219	1.043	0.177	0.365	0.274
		Taman Jelutong	1.800	1.672	0.128		
		Pekan Kuala Nerang	3.000	2.312	0.689		
		Shell Kuala Nerang	1.200	1.097	0.103		

Notes: Water depth observation (Wdo), water depth predicted (Wdp)

4.2.2 SRTM DEM

Figure 6 shows flood marks of observe flood depth that can be compare with flood depth predicted of SRTM DEM which located at Taman Mesra, Opposite Taman Akasia and Pekan Kuala Nerang.

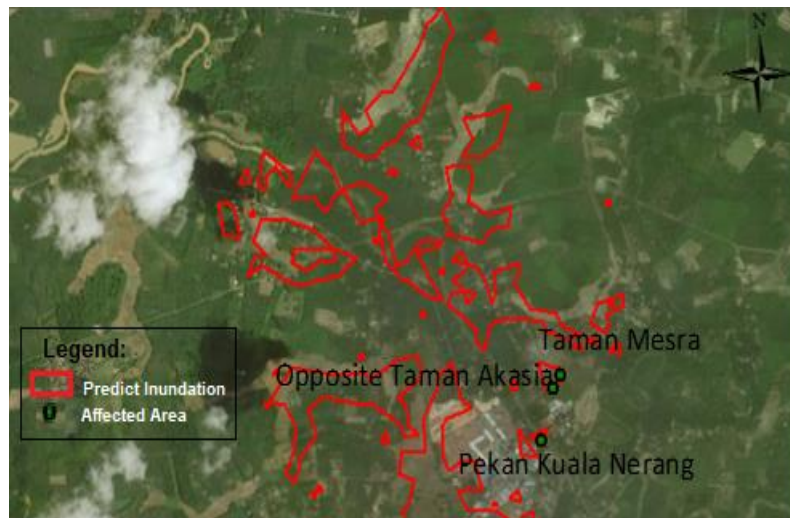


Figure 6. Location of flood marks observe on inundation area of SRTM DEM
Image Source: ESRI, Digital Globe

Table 3 presents the CX5 cross-section interval are the least value of RMSE and MAE are with the value are 1.065 and 0.887 respectively. The highest value of RMSE and MAE is the cross-section interval is CX150 with a value of 1.747 and 1.401. From the result, it shows that as the cross-section interval spacing increase the value of RMSE and MAE also increases. The water depth prediction by SRTM was underestimated due to the low resolution of the DEM.

Table 3. The difference between water depth observed from flood marks and water depth predicted by HEC-RAS using SRTM DEM

DEM	CX	Place	Wdo	Wdp	DIFF	RMSE	MAE
SRTM	CX5	Taman Mesra	0.610	0.229	0.380	1.065	0.877
		Opposite Taman Akasia	1.200	0.676	0.524		
		Pekan Kuala Nerang	3.000	1.272	1.728		
	CX50	Taman Mesra	0.610	0.155	0.455	1.309	1.087
		Opposite Taman Akasia	1.200	0.501	0.699		
		Pekan Kuala Nerang	3.000	0.892	2.108		
	CX100	Taman Mesra	0.610	0.052	0.558	1.421	1.187
		Opposite Taman Akasia	1.200	0.487	0.713		
		Pekan Kuala Nerang	3.000	0.711	2.289		
CX150	Taman Mesra	0.610	0.031	0.579	1.747	1.401	
	Opposite Taman Akasia	1.200	0.451	0.749			
	Pekan Kuala Nerang	3.000	0.126	2.874			

Notes: Water depth observation (Wdo), water depth predicted (Wdp)

The CX5 cross-section interval presents lowest the RMSE and MAE from both imageries (IFSAR and SRTM DEMs). This finding is consistent with [19] who stated that the MAE increase as the spacing increase. It means that, the CX5 is appropriate for flood depth estimation using integration of hydraulic modelling and GIS technique. Although the F-statistic of CX5 was underestimated as compared to the other cross-section interval for inundated area estimation, the result is still acceptable as the value is almost closest to the other cross-section intervals.

5. Conclusion

This paper shows that increasing the number of cross-section spacing gave a minor difference in terms of inundated area and flood depth estimation. So, it can be concluded that the smallest interval of cross-section, the better result can be gained on flood inundation mapping study. When the DEM dataset has low resolution, the big size of pixels will affect the water surface profile and produce inaccurate flood inundation. The coarser resolution in cross-section spacing would decrease the efficiency of hydraulic model in flood inundation [20]. Therefore, a study on optimizing the use of SRTM in flood inundation mapping needs further research investigation to make sure that it can be well used for ungauged station. This research suggests CX5 as suitable cross-section spacing for any of the research related to the flood inundation mapping.

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