ASSESSMENT OF SPATIAL INTERPOLATION TECHNIQUES FOR RIVER BATHYMETRY GENERATION AND INTEGRATION IN LIDAR DTM: IMPACTS IN RIVER FLOW SIMULATIONS

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ABSTRACT: LiDAR DTMs produced by conventional LiDAR sensors and techniques cannot accurately represent terrain covered by water due to the incapability of the lasers emitted by the LiDAR sensor to penetrate water especially at high flow conditions. Intermediate steps are usually taken to integrate or merge river bed elevation/bathymetry data gathered from field surveys into the DTM, prior to using it as input into flood simulation models. Nowadays, Acoustic Doppler Current Profiler (ADCP), echosounder and total station instruments are basically used to measure and determine river bathymetry but generated datasets is mainly discrete format. Interpolation techniques are generally utilized to developed statistical surface of river bathymetry. In this paper, assessment of different spatial interpolation techniques has been carried out to determine the appropriate method for bathymetry generation. IDW, Kriging, Kernel Interpolation with Bariers, Local Polynomial Interpolation and Topo to Raster have been used to generate the bathymetry of Surigao river in Mindanao, Philippines as a case study area. The analysis reveals that the IDW generated the best interpolation with the lowest RMSE among the different techniques. On the other hand, the impacts of the interpolation techniques in river flow simulations were also assessed by integrating each of the generated river bathymetry into a LIDAR DTM. This bathymetry-integrated LIDAR DTMs were then used as inputs into a 2D numerical model for river flow simulations. Results show that the different spatial interpolation techniques produced different simulation results in terms of depth, velocity, and extent of inundation.

1. INTRODUCTION

Light Detection and Ranging (LiDAR) technology has made possible the availability of very high spatial resolution topographic datasets, particularly Digital Terrain Models (DTM), allowing flood modellers to generate highly detailed flood hazard maps (Turner et al., 2013). LiDAR DTMs, with spatial resolution of 1x1 m or better, are usually used as inputs into one-dimensional (1D), two-dimensional (2D) or even three-dimensional (3D) flood simulation models as source of topographic information necessary to simulate such processes like river flow hydraulics and flood routing. However, it is an accepted fact that LiDAR DTMs, particularly those produced by conventional LiDAR sensors and techniques (i.e., those without bathymetric mapping capabilities), cannot accurately represent terrain covered by water due to the incapability of the lasers emitted by the LiDAR sensor to penetrate water especially at high flow conditions (Caviedes-Voullième, 2014).

Prior to using it as input into flood simulation models, river bed elevation data gathered from field surveys are usually interpolated and integrated into the DTM, (Mandlburger et al., 2009). Field surveys using equipment like single or multi-beam SONAR (Sound Navigation And Ranging) combined real time kinematic Global Positioning System (GPS) are commonly employed to measure discrete points or cross-sections representing river bed elevation (Hilldale and Raff, 2007; Merwade, 2009). Since these techniques have limitations to produce continuous data, interpolation techniques are commonly applied such as Inverse Distance Weighted (IDW), Kriging, Kernel Interpolation with Bariers, Local Polynomial Interpolation, and Topo to Raster. These techniques estimate elevation values at unmeasured/unsampled points from measurements made at surrounding sites (known values of sampled points) (Weng, 2006).

The accuracy of interpolated river bed surfaces must be ensured before it is integrated into the LiDAR DTM and utilized as input into flood models, especially that river bed topography plays a critical role in numerical modelling of flow hydrodynamics (Merwade, 2009). Commonly available interpolation methods such as triangulation, IDW, splines or kriging are reported to yield inaccurate river bed topography (Goff and Nordfjord , 2004; Merwade et al. 2006). Other study showed that kriging yielded better altitude estimations than IDW irrespective of the landform type and sampling pattern (Zimmerman et al.,1999). In other studies neighborhood approaches such as IDW or radial basis functions were found to be as accurate as krigging or even better (Guarneri et al., 2012). Although there have been many studies on the accuracy of interpolation techniques for the generation of river bathymetry but there are still no consistent findings about the performances of the spatial interpolators (Panhalkar et al., 2015)

In this work, we assessed the Inverse Distance Weighted (IDW), Kriging, Kernel Interpolation with Bariers, Local Polynomial Interpolation and Topo to Raster interpolation techniques to determine the appropriate method for bathymetry generation particularly in this area using the surveyed bathymetry data. In addition, the study also assessed the impacts of the interpolated river bed integrated into the LiDAR DTM used as inputs into a 2D numerical model for river flow simulations.

2. DATASETS AND METHODS

2.1 River Bathymetric Survey Data

To illustrate how spatial interpolation techniques affect the river flow simulations, we focused on generation of river bed topography of a portion of the Surigao River with LiDAR DTM located in Surigao River Basin, Surigao del Norte, Mindanao in Philippines (Figure 1). This portion is approximately 800 meters in length, with an average width of 90 m. The bathymetric data of this portion was collected through a combination of on-boat and manual bathymetry surveys. On-boat surveys were conducted using an integrated RTK GNSS (South S86T) and Single-beam Echosounder (South SDE-28S) equipment (Figure 2). Riverbed elevations were referred to the Mean Sea Level (MSL) datum. Manual surveys were conducted using RTK GNSS equipment in shallow areas where boat navigation is difficult. The surveys followed pre-determined bathymetry route in a manner shown in Figure 3. Basically, bathymetry route covered the leftmost and rightmost portions of the river near the banks, its centerline, and zigzag direction at 100-m interval including sea portion near at the mouth of the river.

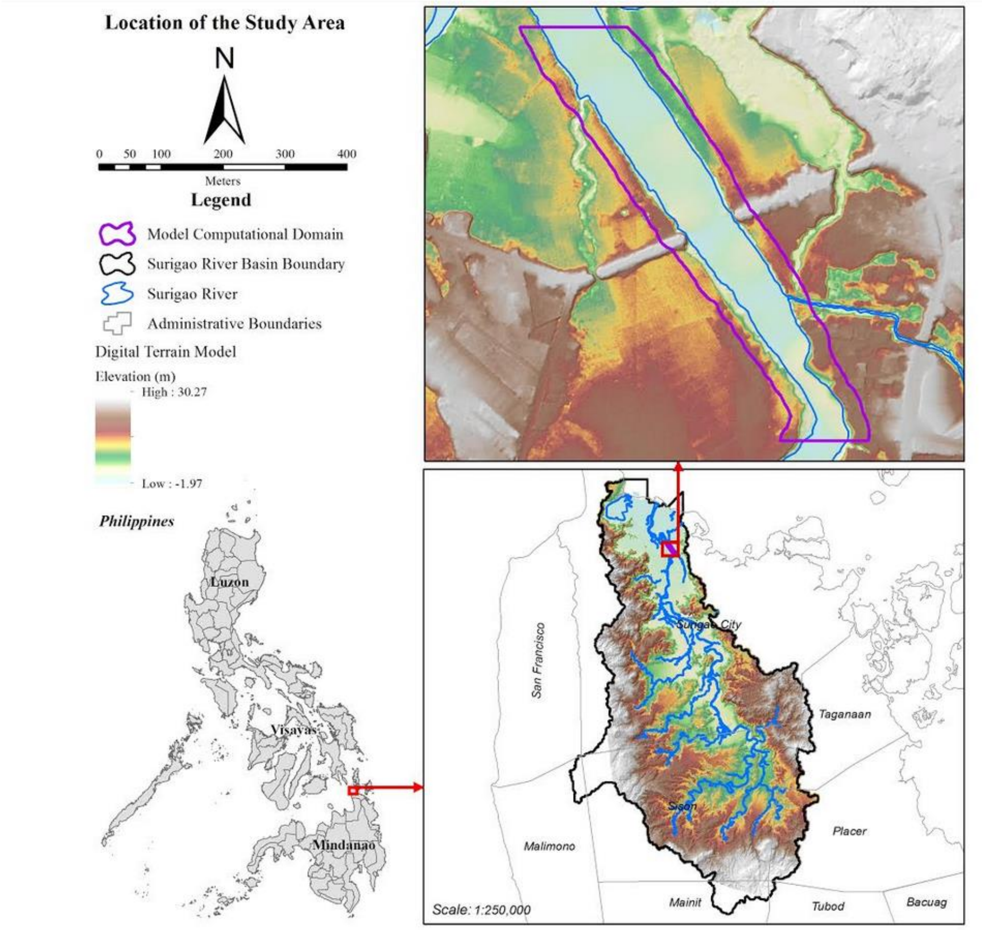


Figure 1. Map of the study area.

Figure 2. Set-up of the bathymetric surveys.

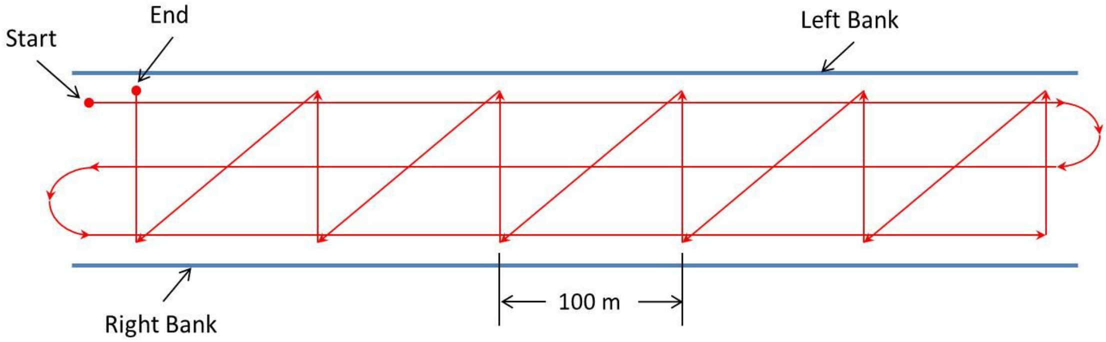


Figure 3. Route during the conduct of echosounder and manual bathymetry surveys.

2.2 River Bed Topography Generation and Accuracy Assessment

The surveyed bathymetric data (Figure 4) was partitioned into interpolation and validation points (Figure 5). A total of 4,345 (or 95% of the total collected points) were used for interpolation while the remaining 5% or 229 points were used as input for validating the interpolated surface.

We used the IDW (n=2), Kriging, Kernel Interpolation with Bariers, Local Polynomial Interpolation and Topo to Raster interpolation methods. The parameters that were set for each interpolation method are shown in Table 1. The accuracies of the interpolations were assessed using 5% validation points. We used Root Mean Square Error which is one of commonly used quantitative methods to assess accuracy (Merwade, 2009). Since the validation points are unique, these points can be used as basis in determining which interpolation methods are the most superior in terms of accuracy. In addition, we also compared the actual cross-section data conducted along the river with the interpolation results. The interpolated river bed surfaces were then be clipped and integrated into the 1 m x 1 m resolution LiDAR DTM using available tools in ArcGIS 10. Overall, a total of 5 bed-integrated DTMs were generated.

Table 1. Parameters that were used for each interpolation methods.

Interpolation Methods	Parameters
Inverse Distance Weighted (IDW)	Power = 2; Major axis = 125; Minor axis = 75; Angle = 65 Max and Min Neighbors = 3;Sector Type = 4 sector with 45^0 offset
Kriging	Kriging Method = Ordinary; Search Radius = Variable Number Points = 6
Kernel Interpolation With Barriers	Kernel Function = EPANECHNIKOV; Bandwidth = 60 Order of polynomial = 1; Ridge Parameter = none Output surface type = Prediction
Local Polynomial Interpolation	Order of polynomial = 1; Search Neighborhood = Smooth Circular Smoothing Factor = 0.2; Kernel Function = EPANECHNIKOV Bandwidth = 60
Topo to Raster	Maximum Number of Iterations = 20

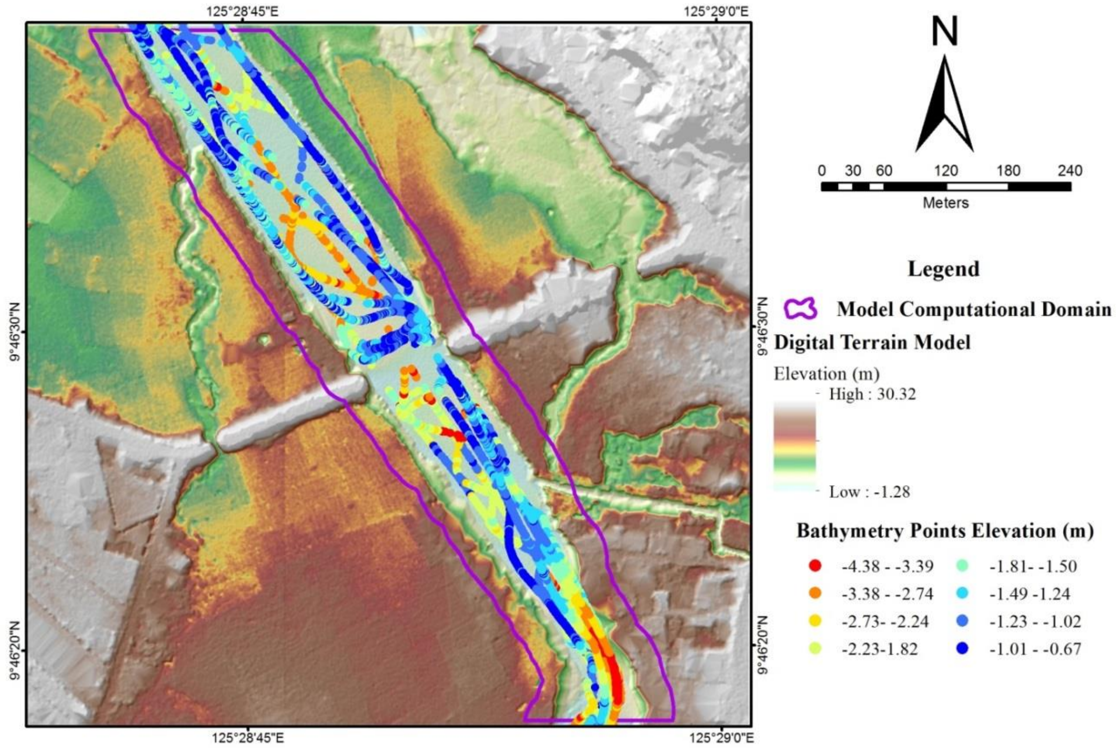


Figure 4. Map showing the LiDAR Digital Terrain Model (DTM) and river bathymetric data.

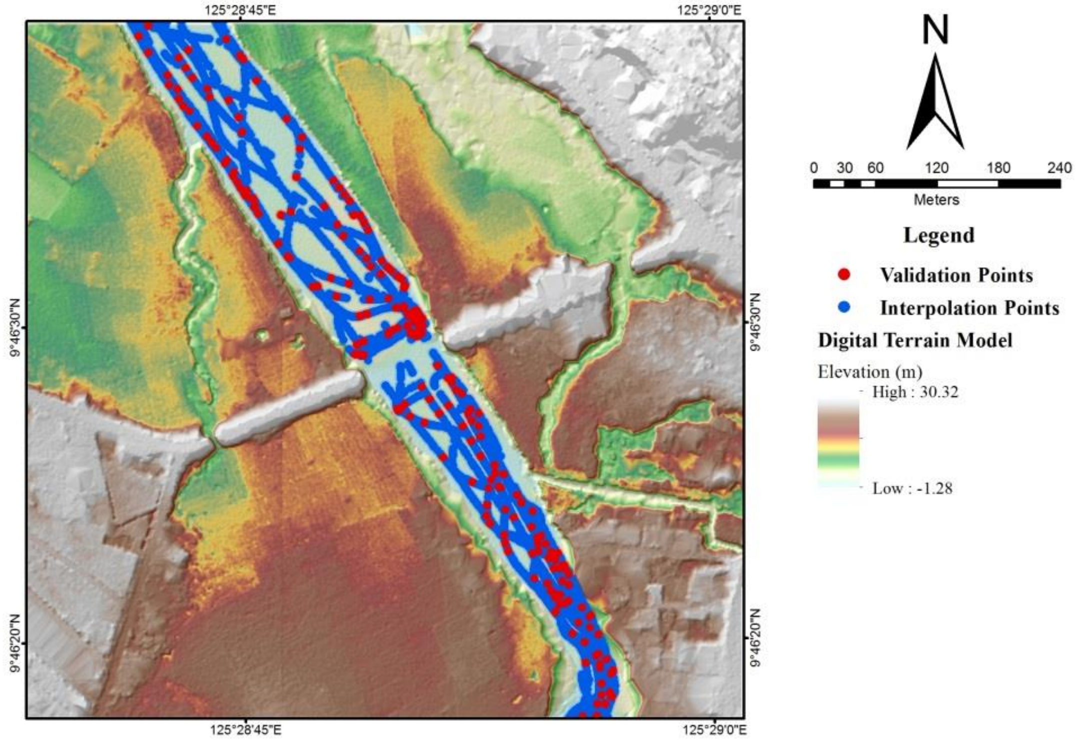


Figure 5. Map showing the interpolation and validation points of bathymetric data.

2.3 River Flow Simulation using HEC RAS 2D Hydraulic Model

The 5 bed-integrated DTM were each used as input into a 2D hydraulic model based on the latest version of HEC RAS (Version 5.0.1; USACE HEC, 2016). The model was constructed for it to use the topographic data provided by the bed-integrated DTM in simulating river flow. The model domain was focused only on the portion of the river where the bed elevations were interpolated (Figure 6). We used a single Manning's roughness value of 0.04 for all portions of the model domain. We used a computational mesh size of 2 m x 2 m containing 27,608 cells. The decision of not using the full resolution of 1 m x 1 m as computational mesh size of the model is order to have faster computation times.

Each of the configured 2D models is then used to simulate the flow of water entering the upstream portion of the river. The river was set as initially dry before the simulation. A 24-hour hydrograph with a peak flow of 986.62 m3/s was utilized as the inflow boundary condition (Figure 7). This hydrograph was computed by a calibrated hydrologic model for this portion. For the downstream portion, we assigned a "Normal Depth" boundary condition (friction slope = 0.004 based on the average longitudinal slope of the river bed). For a stable model simulation, we set the computational time interval to 10 seconds.

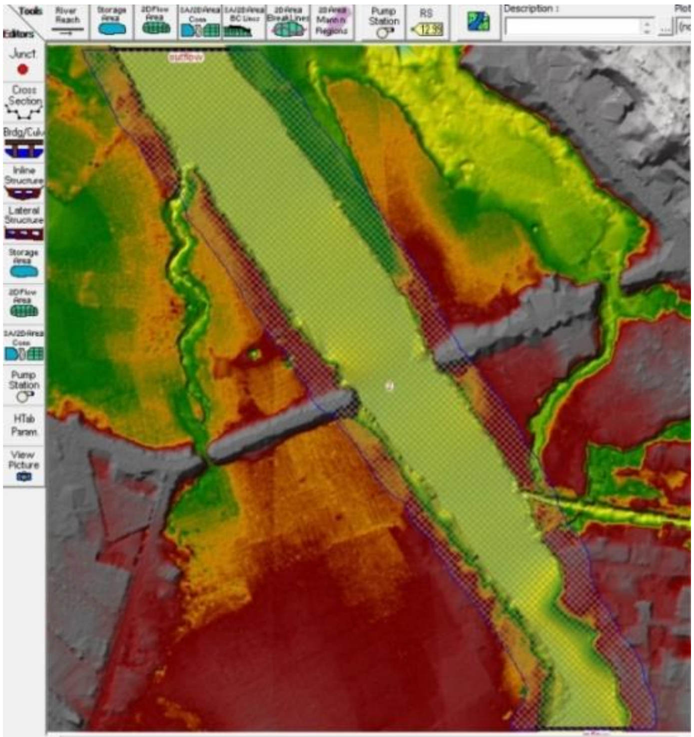


Figure 6. The HEC RAS 2D computational domain overlaid in the LiDAR DTM.

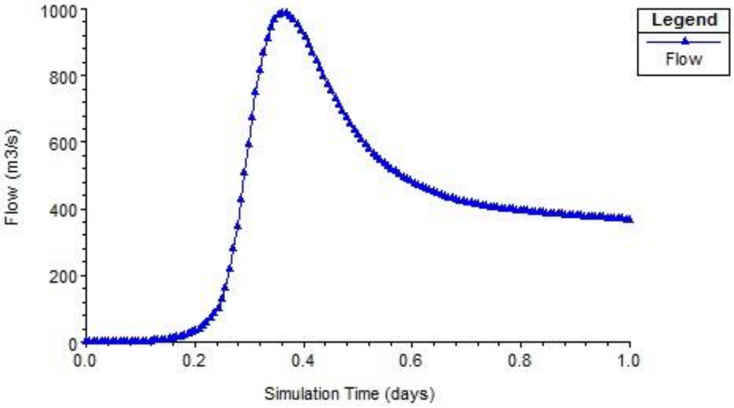


Figure 7. The inflow boundary condition utilized in the 2D river flow simulation

2.4 Assessment of the 5 Bed-Integrated DTM used as Inputs to River Flow Simulation

The effect of different interpolation techniques was assessed by examining the result in terms of the simulated depth, velocity, and flood extent by the 5 2D hydraulic models with different bed-integrated DTMs as inputs. By comparing each model output, we determined the similarities or differences in maximum depth, flood extent and velocity. The differences in depth and velocity between the 5 bed-integrated DTM were assessed using the 3 cross-sectional and 3 longitudinal (one near left bank, one at a center and one at right bank) transects. Each cross-sectional and longitudinal transects containing approximately 100 points at 1-m interval was used to extract the simulated depth and velocity. The locations of the transected cross-sectional and longitudinal are shown in Figure 8.

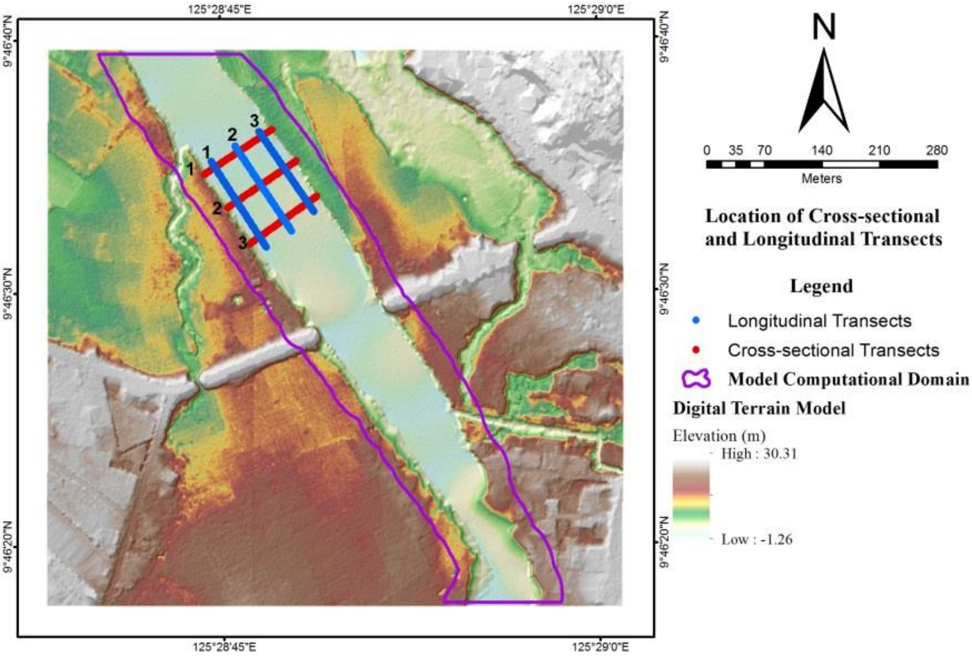


Figure 8. Location of cross-sectional and longitudinal transects.

3. RESULTS AND DISCUSSION

3.1 Interpolated River Bed Surfaces

Figure 9 shows the result of the IDW, Kriging, Kernel Interpolation with Bariers, Local Polynomial Interpolation and Topo to Raster interpolation methods. For the interpolation using IDW, differences in elevation ranges were least obvious than those interpolation using Kriging and Topo to Raster except Kernel Interpolation with Bariers and Local Polynomial Interpolation. The Kernel Interpolation with Bariers and Bariers and Local Polynomial Interpolation interpolations displayed almost flat interpolated surfaces.

The RMSEs of these interpolated surfaces based on independent set of validation data points range from 0.18 m to 0.35 m (Figure 10). These computed RMSEs show that IDW is much appropriate interpolation techniques as per the various validation methods. The graph showing the comparison of the cross-section data and the interpolated river bed surfaces is shown in Figure 11. Surveyed cross-section data is plotted against IDW, Kriging, Kriging, Kernel Interpolation with Bariers, Local Polynomial Interpolation and Topo to Raster generated cross-sections, it also shows that IDW generated cross-section are much more than accurate than others.

3.2 River Flow Simulation Results

Figure 12 and 13 show the maximum flood depth and velocity simulated by 2D hydraulic model using different bed-integrated DTM. As observed, the maximum flood depth simulated using Kernel Interpolation with barriers was underestimated compared to IDW, Kriging and Topo to Raster in which they produced maximum flood depths that were similar to each other. Among the 5 bed-integrated DTM, IDW, Kriging and Topo to Raster interpolation techniques produced almost same areas of the flood extent. Local Polynomial Interpolation got bigger area of the flood extent. It can be observed that each bed-integrated DTM produced different model results (Figure 14 to Figure 25).

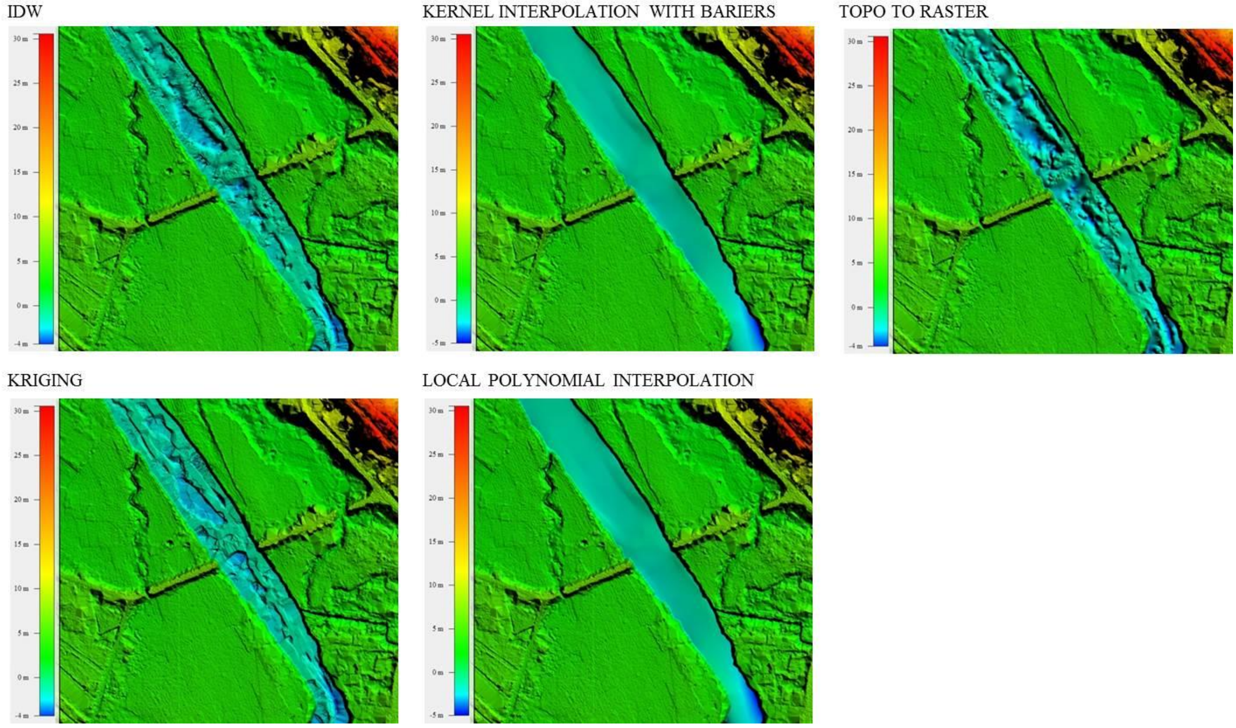


Figure 9. Results of the IDW, Kriging, Kernel Interpolation with Bariers, Local Polynomial Interpolation and Topo to Raster interpolation methods.

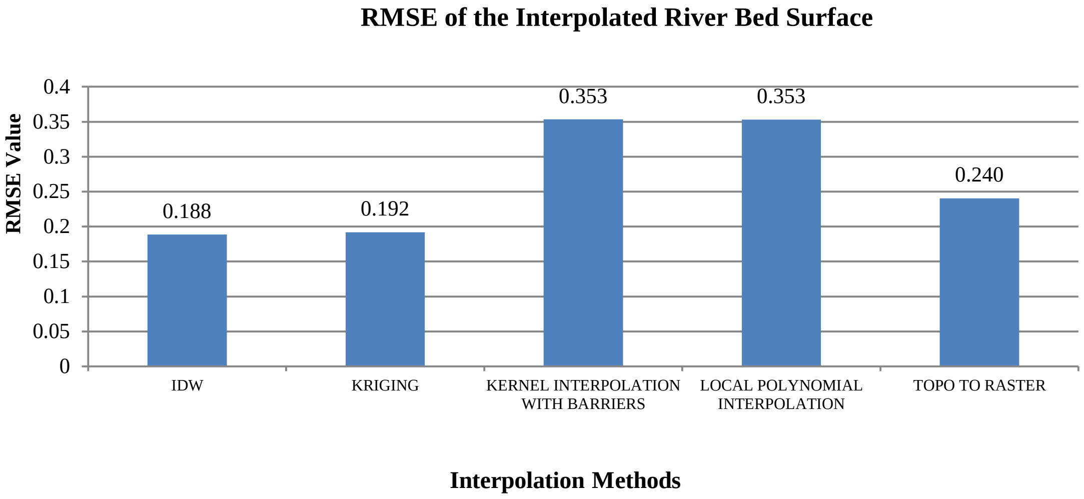


Figure 10. Root Mean Square Error (RMSE) of the interpolated river bed surfaces using the validation points.

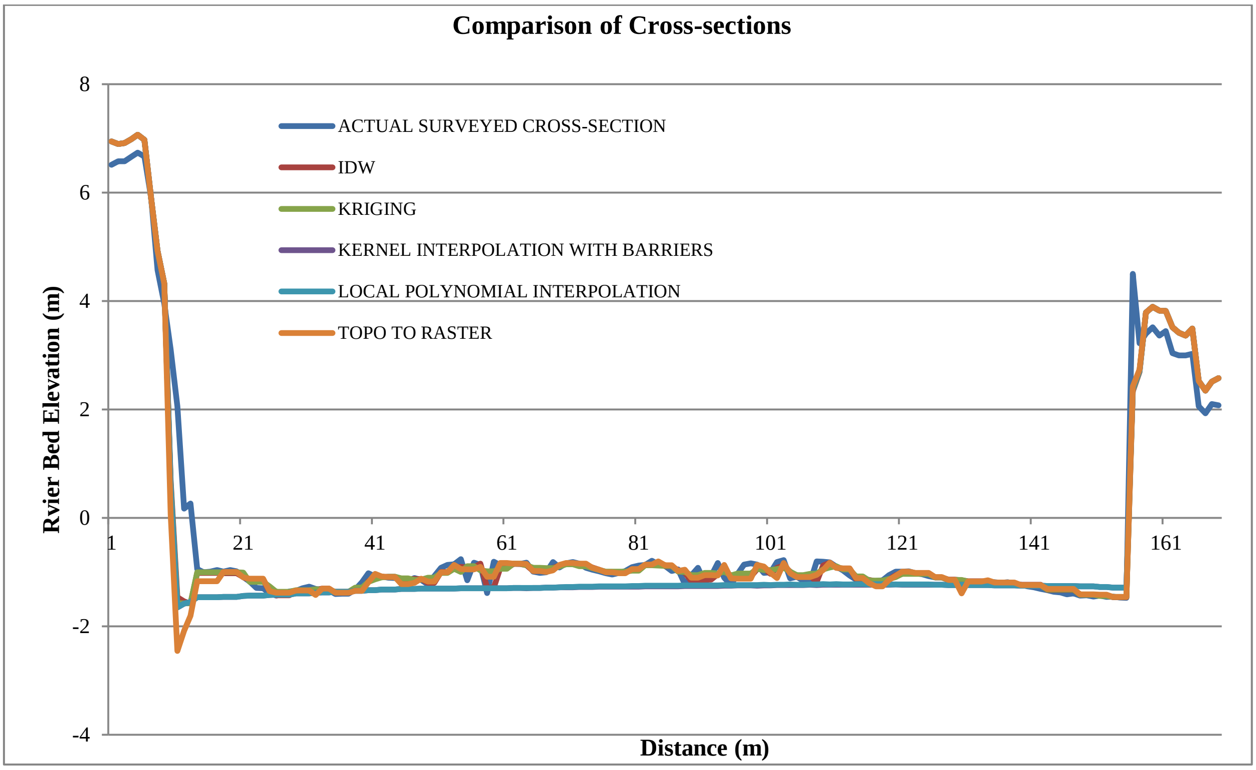


Figure 11. Comparison of actual surveyed cross-section and cross-sections generated from interpolated river bed surfaces.

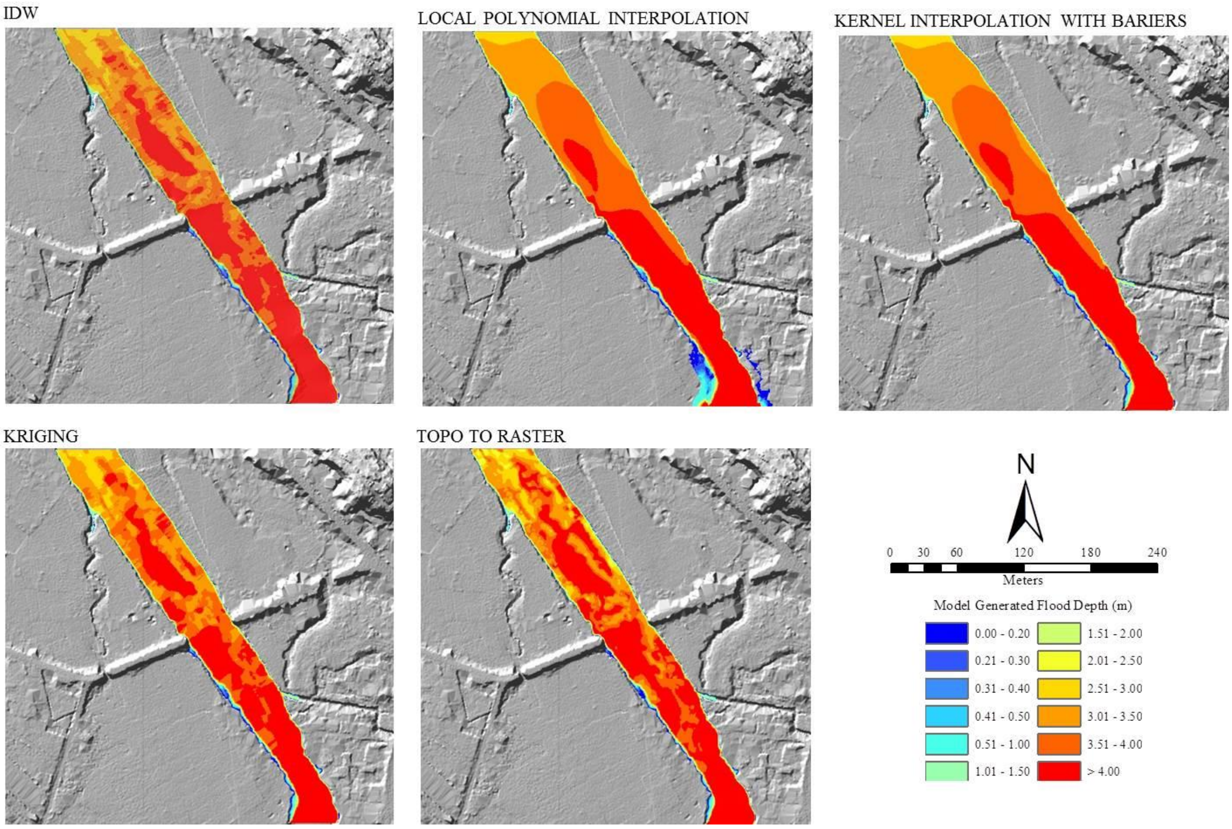


Figure12. Maximum flood depths simulated by the 2D hydraulic model using the 5 bed-integrated DTM.

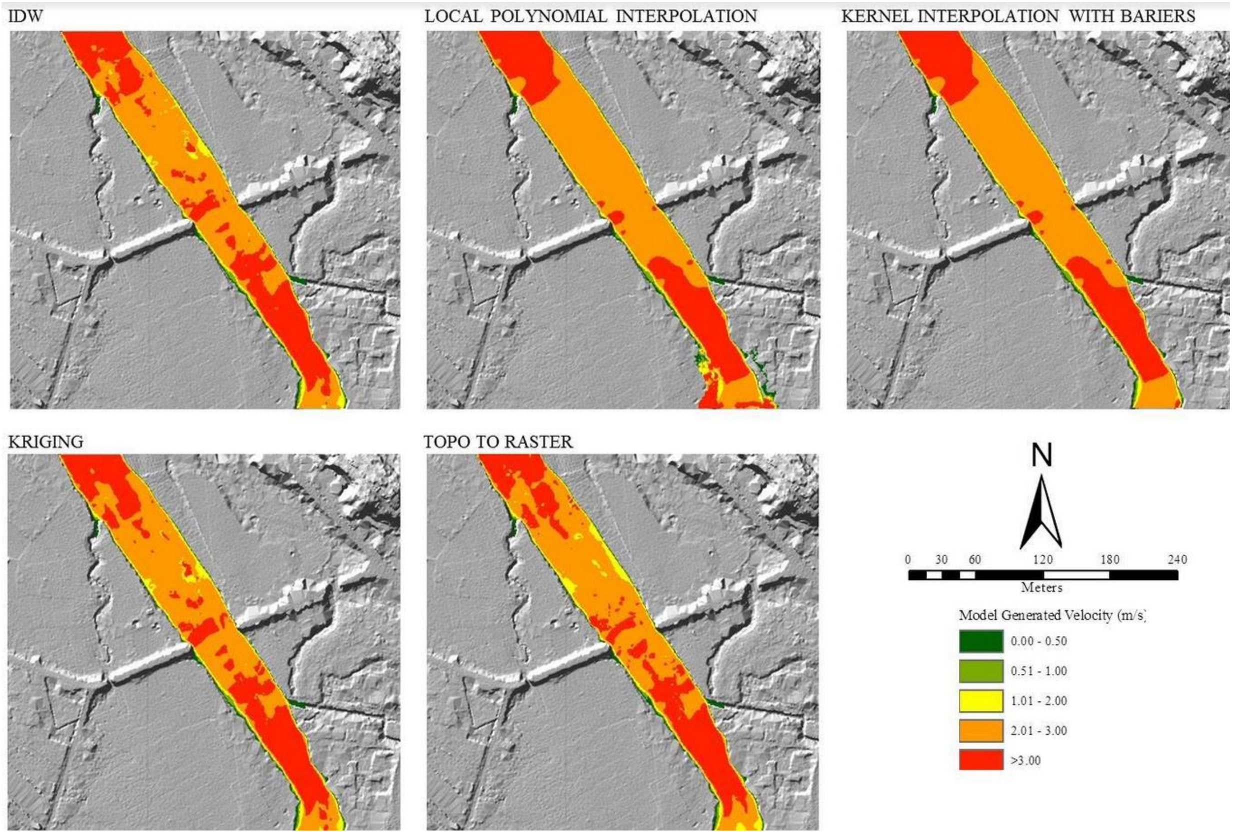


Figure13. Maximum flood velocities simulated by the 2D hydraulic model using the 5 bed-integrated DTM.

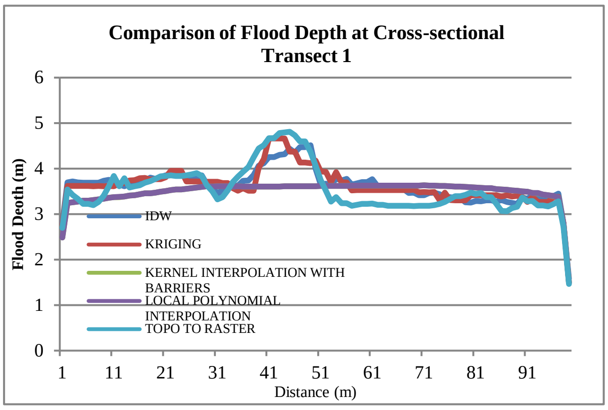


Figure 14. Comparison of model generated flood depth at cross-sectional transect 1.

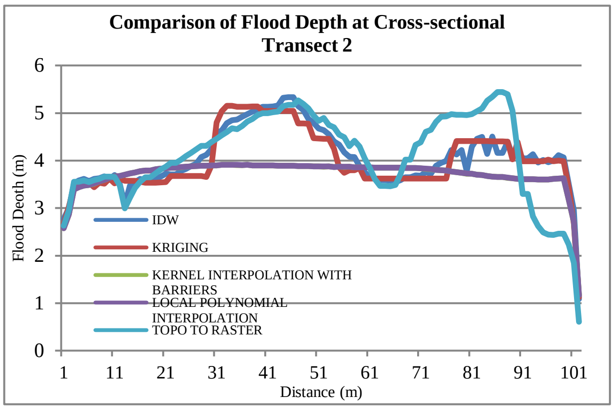


Figure 15. Comparison of model generated flood depth at cross-sectional transect 2

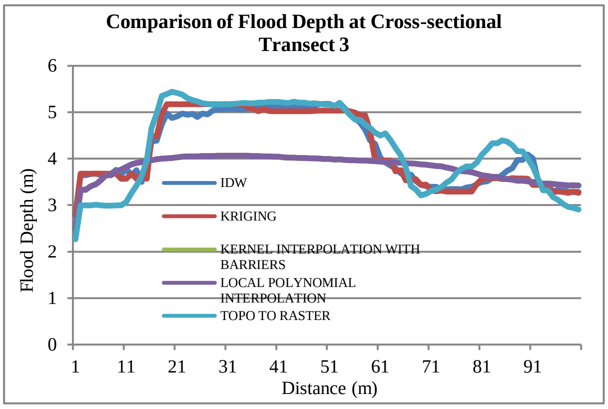


Figure 16. Comparison of model generated flood depth at cross-sectional transect 3.

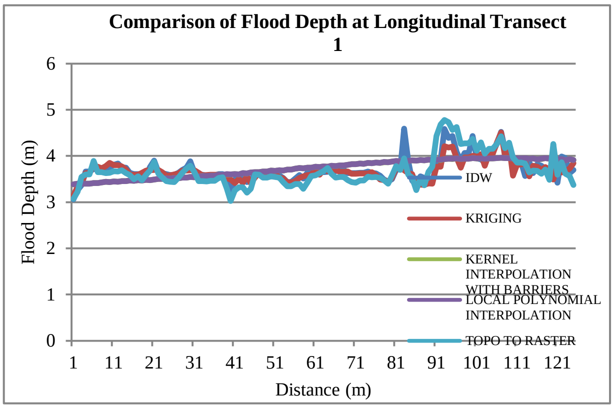


Figure 17. Comparison of model generated flood depth at longitudinal transect 1.

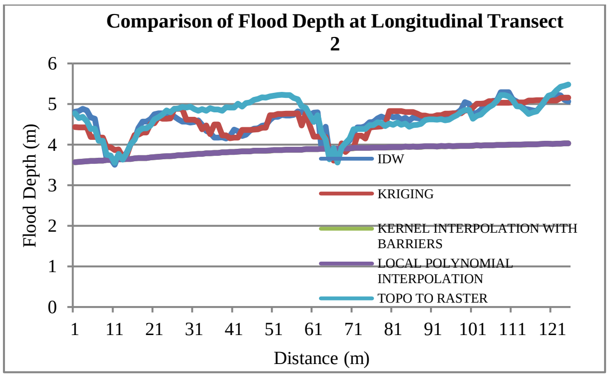


Figure 18. Comparison of model generated flood depth at longitudinal transect 2.

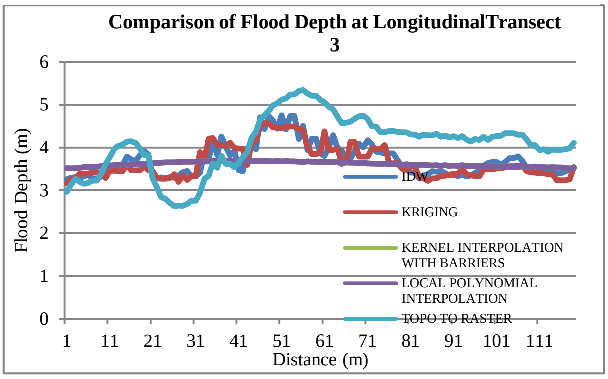
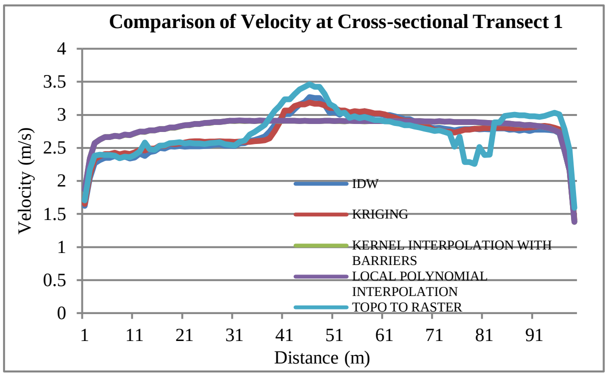


Figure 19. Comparison of model generated flood depth at longitudinal transect 3.



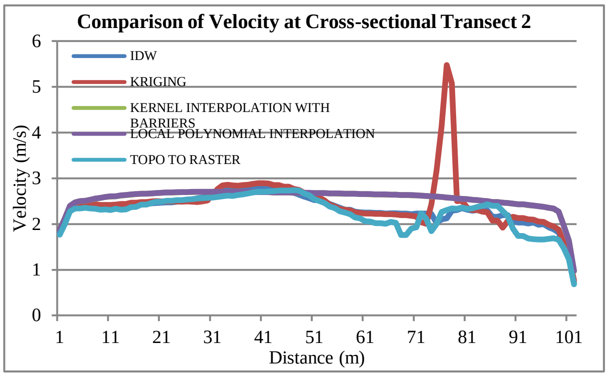
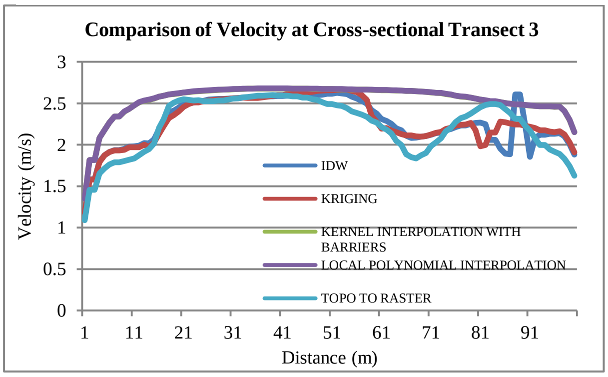


Figure 20. Comparison of model generated flood velocity at cross-sectional transect 1.

Figure 21. Comparison of model generated flood velocity at cross-sectional transect 2.



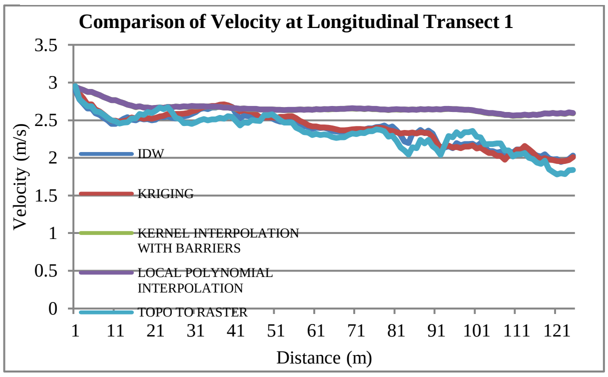
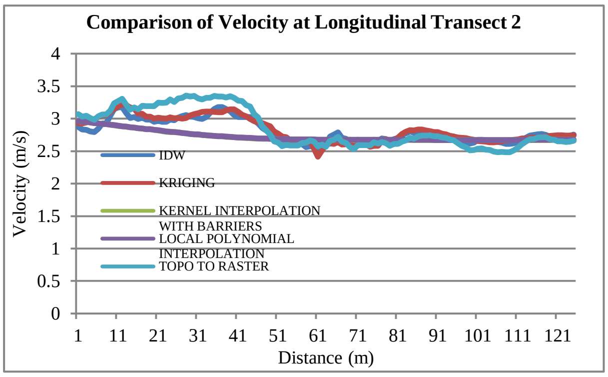


Figure 22. Comparison of model generated flood velocity at cross-sectional transect 3.

Figure 23. Comparison of model generated flood velocity at longitudinal transect 1.



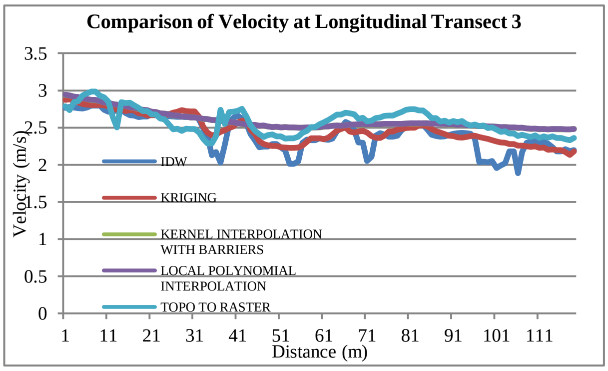


Figure 24. Comparison of model generated flood velocity at longitudinal transect 2.

Figure 25. Comparison of model generated flood velocity at longitudinal transect 3.

CONCLUSION

In this paper, we determined the accuracy of different spatial interpolation techniques and the result of the 2D hydraulic model utilized the different bed-integrated DTMs. The results show that IDW is the suitable and accurate interpolation technique for generating the river bed topography of our study area. It also concluded that generated river bathymetry from different interpolation techniques and integrated with LiDAR DTM also produced different 2D model simulation results in terms of depth, velocity, and extent of inundation.

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