ASEAN Engineering Journal

Full Paper

A Proposed Technique for Improving the Accuracy of Tidal Modeling of River Networks Connecting to The Dadahup Irrigation Area

Article history
Received
19 October 2022
Received in revised form
25 January 2023
Accepted
12 March 2023
Published online
31 August 2023

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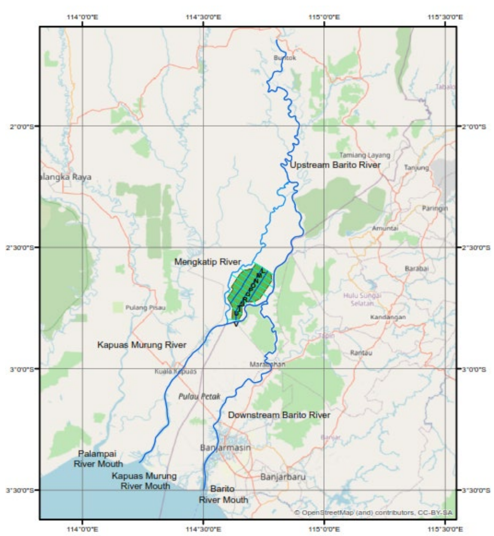
Graphical abstract



Abstract

Optimizing the operational management of tidal irrigation networks is a significant factor in the reactivation program of the swamp irrigation areas in Central Kalimantan Province. Appropriate water level and flow rate control in a tidal environment would provide a better solution for this effort. Monitoring water parameters and hydraulic modeling is an intelligent technique for evaluating irrigation canals' gate system operations. This paper focuses on providing more accurate hydraulic modeling that requires proper boundary conditions and calibration of the canal roughness coefficient. This study aims to obtain a more precise downstream boundary condition data calibration method with an appropriate river cross-sectional roughness coefficient value to improve the overall hydraulic modeling accuracy of the river network connecting to the Dadahup Irrigation Area. The hydraulic modeling utilized the HEC-RAS Software, where input data preparation used geometric data derived from the National Geospatial Agency's DEM in the form of river channel network chain, cross-section, and long-section data. Boundary condition data evaluation compared and selected data generated from references and the Tides Application Software. The results show that the tide prediction from the Tides Application Software provides the slightest difference between the predicted tide and the measured ones. The river network's channel roughness coefficient calibration utilized the generated boundary condition tide and simultaneously measured water level data at several locations. The results show that the most minor Root Mean Squared Error (RMSE) of the Manning roughness coefficient differences of the river channel network can reach 0.04 with a minimum RMSE value of 0.027.

Keywords: Hydraulic modeling, HEC-RAS, River channel network chains, Manning roughness coefficient, Dadahup irrigation

1.0 INTRODUCTION

The Barito River Basin is one of the surface water sources used to develop tidal irrigation canal networks in the Central and South Kalimantan Provinces [1],[2]. Optimizing the operational management of the tidal irrigation canal network is a significant factor in the reactivation program of swamp irrigation areas by utilizing the tidal water level and flow rate control [3]. Tidal water level changes that are pretty strong occur along the river up to hundreds of kilometers upstream, determining water quantity and quality in this area [4]. One technological innovation effort developed to optimize the operational management of the tidal canal network in the irrigation area is the water parameter monitoring and numerical simulations of water level dynamics based on hydrological and river hydraulic data records [5],[6].

Developing water management technology that uses reliable numerical modeling is essential to support research related to water resource issues [7]. River hydrodynamic modeling is vital for estimating flow discharge, velocity, and water level dynamics and predicting probable inundation [8]. Hydrodynamic modeling requires a geometric profile of longitudinal and transversal river views with a roughness coefficient [9]. The accuracy of the river geometry profile is a challenge often faced in obtaining simulation results close to the field conditions.

One of the standard approaches to improve model parameters is parameter calibration and model validation to reduce the uncertainty of the modeling results. Setting proper model parameters can increase the accuracy of the hydrodynamic model output by comparing the simulation results and the measurement data of a particular case [10]. River hydrodynamic modeling can convey the understanding of relationships between water level and flow velocity at the same and different places. The data sets of simulated and measured data pairs are reliable sources for parameter calibrating and validating hydrodynamic models [11]. This study aims to obtain more precise downstream boundary condition data for calibration processes and to obtain the appropriate river cross-sectional Manning n roughness coefficient values to achieve the overall hydraulic modeling accuracy of the Barito, Kapuas Murung, and Mengkatip river network connecting to the Dadahup Irrigation Area. Having the calibrated parameter values and appropriate boundary conditions would increase the reliability of further predictive simulation results in the evaluation of development schemes and operational scenarios of the Dadahup swam irrigation channel networks. The resulting methods may also be applied in any location with similar problems.

2.0 METHODOLOGY

2.1 Study Area

The study area is in the Barito River Basin, with rivers comprising the Barito River, the Kapuas Murung River, and the Mengkatip River. The Barito River Basin includes a tidal irrigation area with a total length of the river reaching 157 Km from the Barito River mouth. Geographically, the river basin area of this study spans from 2°15'0''S to 3°30'0''S and 114°15'0''E to 115°0'0 ''E, as shown in Figure 1.

Dadahup swamp irrigation area is located between the Mengkatip River in the West and the Barito River and Kapuas Murung River in the East. Several primary channels connect those two rivers. The junction of the Barito River and the Kapuas Murung River is on the East side of the Dadahup swamp irrigation area and from the junction the water flows to the sea through the downstream part of the Barito River connect to the sea. The downstream end of the Mengkatip River connects to the Kapuas Murung River at the South side of the Dadahup swamp irrigation area. The downstream end of Kapuas Murung River connects to the sea. The upstream end of the Mengkatip River connects to the upstream reach of the Barito River.

2.2 Tidal Modeling

The modeling of tide propagation or flows within the above tidal river networks uses the HEC-RAS software which can model the river network topology by several reaches connected by junctions. In the river networks, the tide waves propagate from Kapuas Murung and Barito River mouths to the upstream parts of the river networks and then interact with each other providing complex tidal patterns. This tide hydrodynamic model uses the Saint-Venant equation whose approximate solutions are obtained by finite difference numerical schemes [12]. The model results depend on the geometry data of the river networks and the applied boundary conditions in the form of tide data at the Kapuas Murung and Barito River mouths and discharge data at the upstream end of the Barito River.

For obtaining appropriate adjustable model parameter values of the above river network it is necessary to have measured water level data at the different places in the channel river networks including at all river network boundaries of the same period. However, in this case, those data are not available. Therefore, before parameter adjustment can be done, a tidal prediction procedure was conducted to provide the necessary sea boundary condition. In such above limited data condition, therefore, this study was conducted in two consecutive steps.

The first step was collecting the available records of simultaneous water level data within river networks, measuring the tide at three intake locations of the Dadahup swamp irrigation area, collecting tidal water surface elevation data at the Palampai River mouth which is close to the Barito River mouth, collecting tidal component data close to the Barito River mouth, and conducting tide prediction. The simultaneous tide records within the river network were obtained at the intake locations of the Dadahup swamp irrigation area along the Barito (2°36'42.32"S; 114°47'38.95"E), Kapuas Murung (2°44'26.72"S; 114°40'55.10"E), and Mengkatip River (2°39'37.44"S; 114°35'59.97"E) sides. The water level elevation measurements were carried out by reading the previously installed measuring signs at the intake of the Dadahup irrigation canal network namely at the point L Barito River, point S Kapuas Murung River, and point S2 Mengkatip River as shown in Figure 1. The measurement period started on March 18, 2022, and finished on March 31, 2002 (15 days).

The available tide data at the Palampai River mouth are not in the same period as the simultaneous tide records. Therefore, it is necessary to use a tide prediction tool to approximate the tide data of the same period. In this research, the Tides application was used. The available tide data at the Palampai River Mouth, beginning on October 04, 2021, and ending on October 19, 2021 [13]. This selected measurement period aimed to know the water surface elevation fluctuations during low (neap) and high tide conditions (spring), as suggested by [14]. Evaluation of conformity between this measured water level data and the generated water level data representing the tide of Barito River mouth is based on tidal component data at Belitung Traditional Boat Port, Banjarmasin, approximately 5 km from the sea [15] and the ones generated based on the Tides application.

The second step was numerical simulations of tide propagation within the river network using the HEC-RAS Software. The simulation used the long-sections and cross-section data derived from the National Digital Elevation Model (DEM), estimated river bed roughness coefficients as the first trial values, tide data at the river mouth, and flow discharge data as the upstream boundary condition. The similarity between the modeling results and the measured ones is indicated by obtaining the minimum value of differences (RMSE) by adjusting the value of the hydraulic parameters, namely the Manning roughness coefficient (n) on the cross-sections [16].

The Manning n roughness coefficient was calibrated by referring to the difference between the simulated water levels and the measured ones at the intake location. The difference between simulation results and measurement results needs to be minimized and uses the Root Mean Square (RMSE) formula described in Equation 1 as the indicator [17].

$$RMSE = \sqrt{\sum_{i=1}^{n} \frac{(yo-yp)^2}{n}} \quad (1)$$

Where *yo* is the measured water level data, *yp* is simulated data, and n is the number of data pairs. When the RMSE value is close to 0 (tolerable small) explains that the simulation results and measured results are said to meet the requirements for modeling development.

The tide data at Belitung Traditional Boat Port Banjarmasin have already tidal constituent values that can be used for tidal data generation as shown in Table 1 [18].

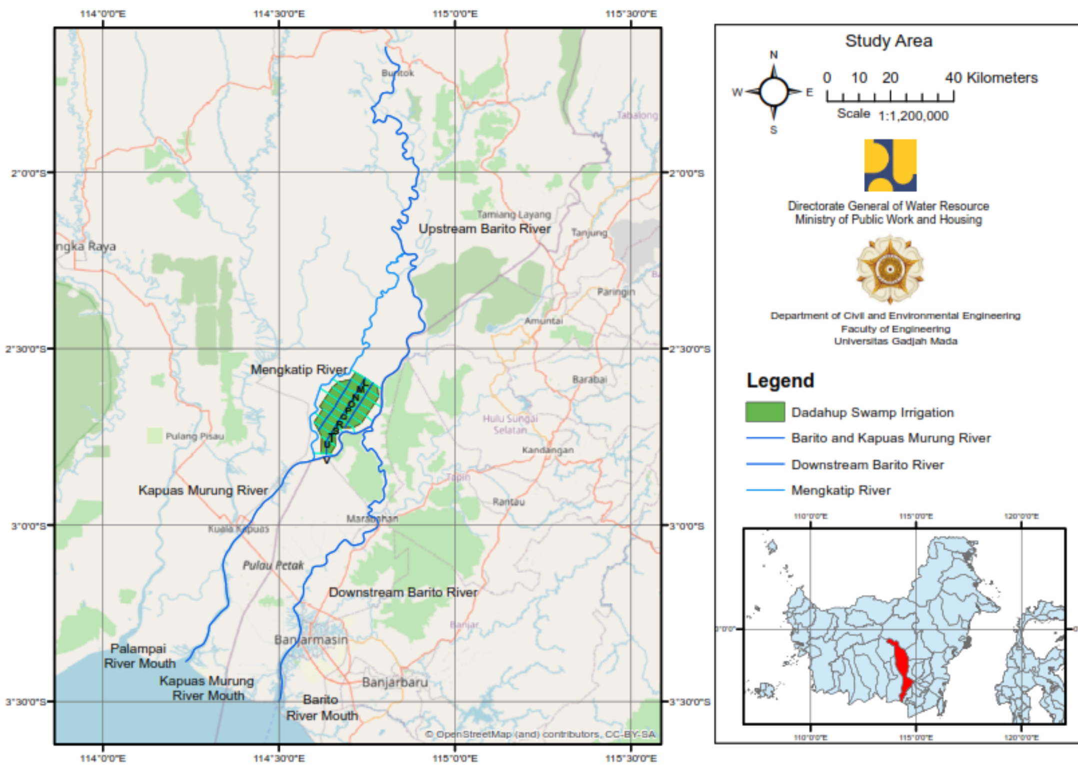


Figure 1 Location of study area **(**Base map from Google Maps**)**

3.0 RESULTS AND DISCUSSION

3.1 Evaluation of the Suitability Of The Tidal Boundary Conditions

Prediction of tidal data at the mouths of the rivers as boundary conditions uses two methods, namely generating water elevations based on the available tidal components and generating the water elevation data using the Tidal Application [19]. There are available tidal data that were collected at two locations. The first is at the Palampai river mouth. The tide was measured for 15 days from October 4th, 2021 to October 15th, 2021 [13]. The second is at Belitung Traditional Boat Port near Banjarmasin City in the Barito River, which is approximately 30 kilometers inland from the coast. The tide was measured for 30 days from October 01st 2012 to October 30th, 2012 [15].

Table 1 Tidal Constituents of Barito River Mouth at Belitung Traditional Boat Port Banjarmasin (Source: [19])

No	Constituents	Amplitude A (cm)	Epoch g (°)
1	M2	25	271
2	S2	8	195
3	N2	4	243
4	K2	1	311
5	K1	65	219
6	O1	32	170
7	P1	7	247
8	M4	0	68

Epoch is a phase shift from tide-producing force to high tide from a starting time.

Tide data that was generated using the available tidal components during the tidal observation period at Palampai were compared with the measured water level data at that location as shown in Figure 2. The result of this comparison did not show similarity both in magnitude and wave shape. A comparison between the tide data generated using the Tides Application at the Barito River mouth during the tidal observation period at Palampai and the measured tidal level at Palampai is shown in Figure 3. The result shows that similarity in shape and magnitude appears. A quantitative analysis of their similarity using the RMSE indicator also shows that the comparison between Tides Application data and measured data gives a smaller RMSE value than the other one as shown in Table 2.

Table 2 RMSE values of comparison between generated data results and measured data at the Barito River mouth from 04 Oct 2021 to 19 Oct 2021

No	Comparison between measured data and	RMSE
1	Tides Application	0.201
2	Tidal Components	0.575

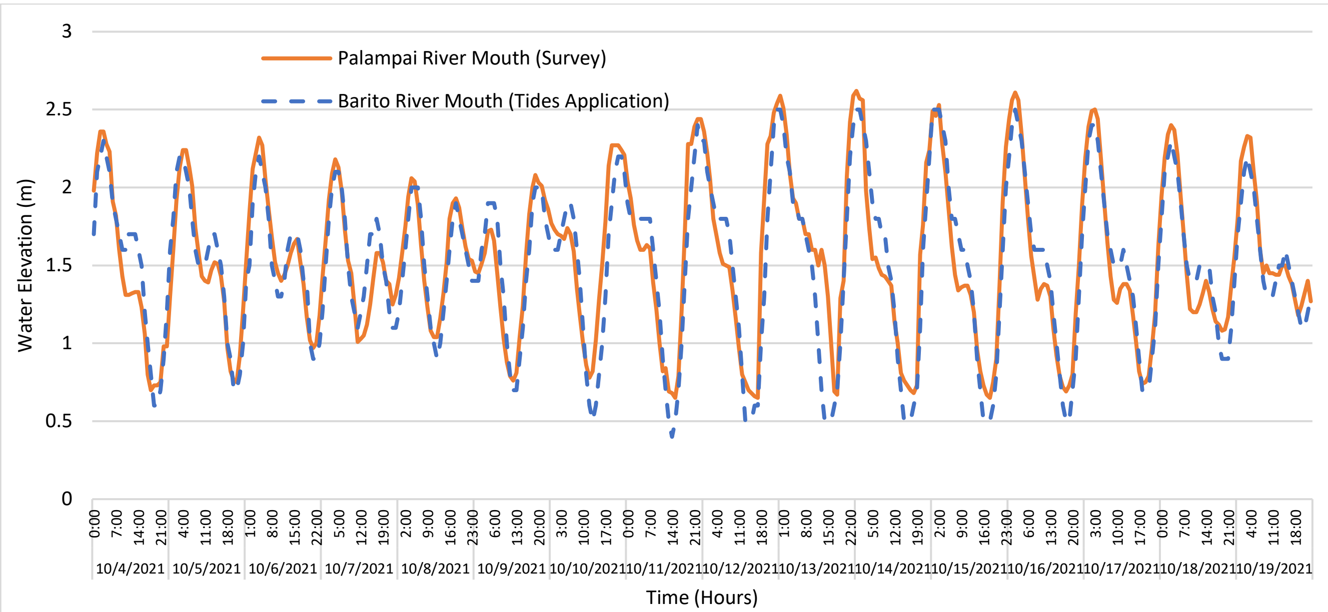


Figure 2 Comparison of measured tide data at Palampai with generated tide data based on Barito River Mouth tidal component

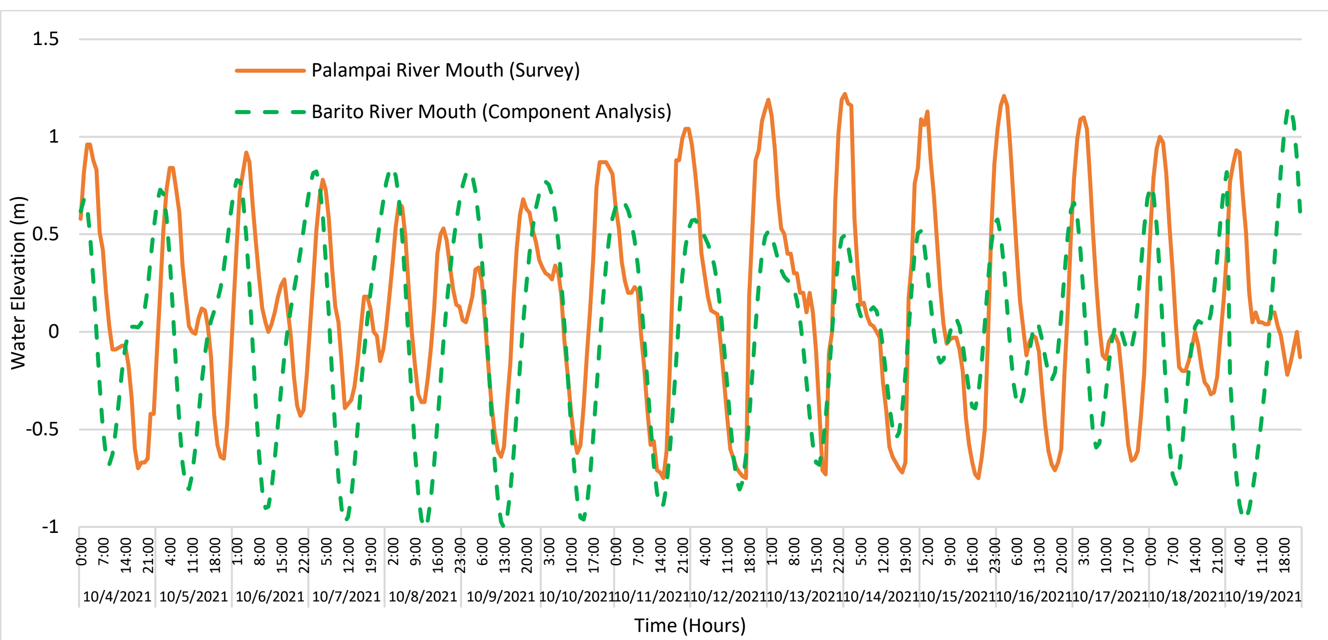


Figure 3 Comparison of measured tide data at Palampai with generated tide data based on Barito River Mouth tidal component

3.2 Tide Propagation Modeling in the River Network

Tide propagation modeling was carried out based on geometric data and boundary condition data of the river networks. The geometry data of the river network were built using measured cross-section data for several sections and approximated using the Digital Elevation Method (DEM) data for the other cross-sections. The geometry data are shown in Figure 4 [20].

The downstream boundary conditions used tidal data of the Barito River Mouth generated by the Tidal Application from March 18th, 2022 to March 31st, 2022, and the upstream boundary condition data were the flow rates obtained from the estimated monthly mean discharges in March [21].

The main physical forces controlling the flow in rivers are inertia, pressure, gravity, and friction. The friction parameter is directly influenced by the geometry and roughness of the river which can have a significant impact on changes in flow and water level [22]. The roughness coefficient has its value influenced by numerous factors such as the surface roughness, channel irregularities, and alignment, vegetation effects, changes in the channel bed geomorphology due to the deposit or degradation of bed materials, and the sediment transport of suspended and/or on the river bed [23].

The approximate value of the Manning roughness coefficient can be obtained based on the type of riverbed material that affects the roughness of the flow [24]. However, the trial of the Manning roughness coefficient value which aims to achieve water level simulation results as close as possible to the measurement results in the field [25], [26] is needed. It appears that, from the simulation results, the dynamics of water level changes are strongly influenced by the value of the Manning roughness coefficient, especially around the intakes of the Dadahup tidal irrigation networks as shown in Figures 4 and 5.

3.3 Calibration Process and Results

The simulation results were calibrated with measurement data obtained directly at the intakes of the Dadahup tidal irrigation network of the Barito River, Kapuas Murung River, and Mengkatip River. The calibration process used the result of the 15 days of water level measurements, from March 18th, 2022, to March 31st, 2022. The results of the calibration process based on the comparison between the simulated and measured water levels at the intakes of tidal irrigation networks with different Manning coefficient values are shown in Figure 5.

The calibration process used the RMSE to represent the similarity between the simulation result data series and the observed ones [27], as described in Equation 1. The analysis results with five n manning roughness coefficient values have RMSE differences from the water level data series between the simulation results and measurements, as shown in Figure 6. The calibration results show that the Manning n value of 0.04 gives a simulated water level pattern almost the same as the measured ones.

The minimum RMSE values of the comparison results for Manning n value of 0.04 are 0.030, 0.027, and 0.028 for L, S, and S2 points respectively, as shown in Table 3 and Figure 6. These minimum RMSE values indicate that the Manning n value of 0.04 is suitable for further numerical simulations in the evaluation of the alternative development and operation schemes of the Dadahup tidal irrigation channel networks which are connected to the Barito, Kapuas Murung, and Mengkatip River networks [28][29][30].

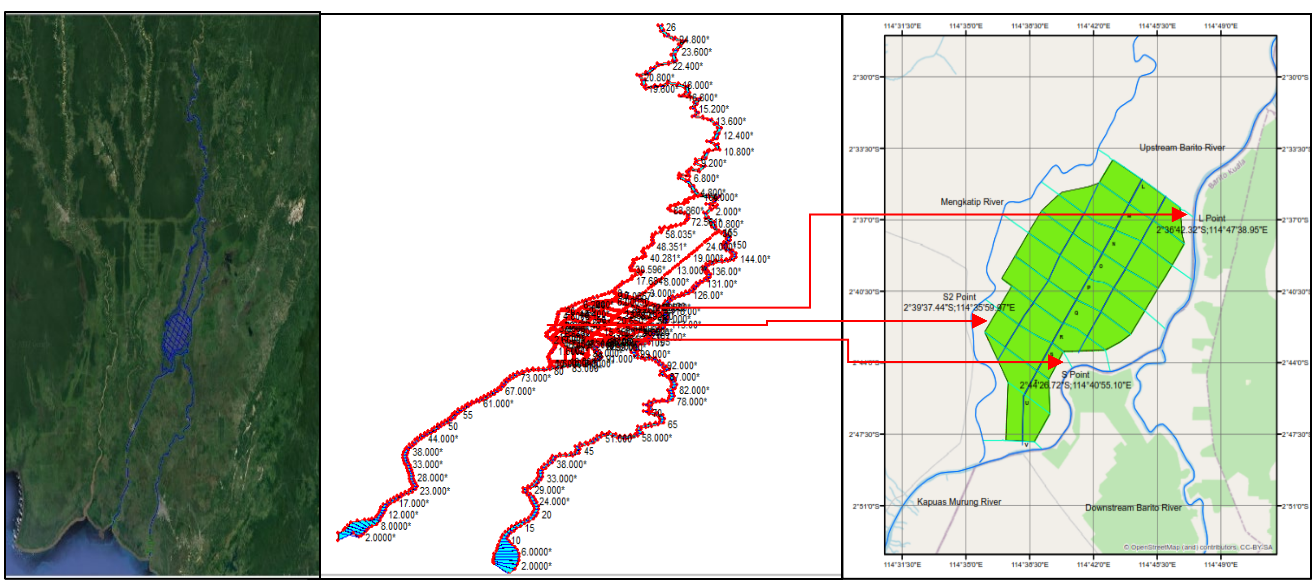
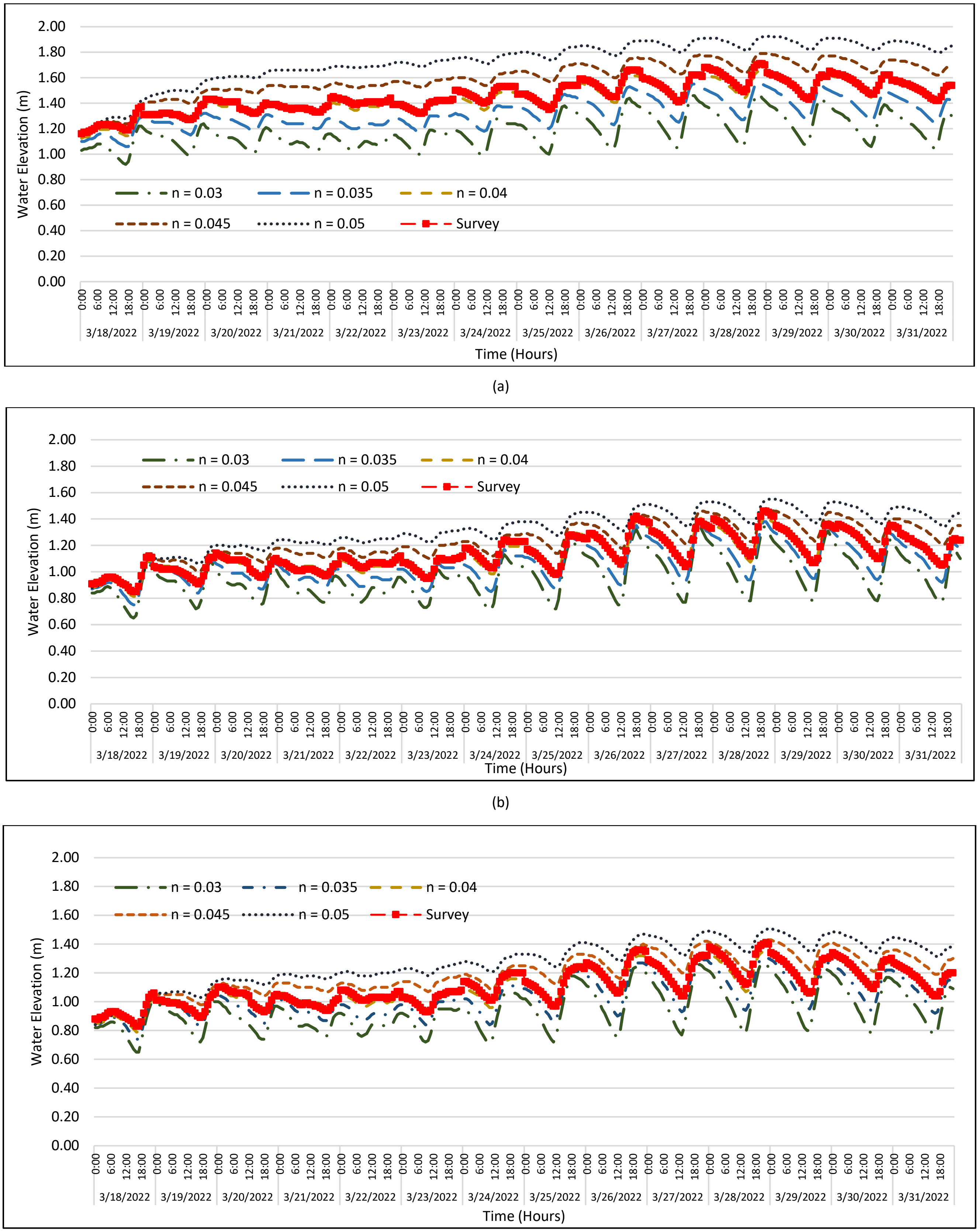


Figure 4 River network geometry (Source: HEC-RAS display and Google Earth Map)



(a)

(b)

(c)

Figure 5 Comparison between simulated water level series based on variations in Manning's n value and the measured ones at Point L Barito River (a), Point S Kapuas Murung River (b), and Point S2 Mengkatip River (c)

Table 3 RMSE between the simulation results and the measured data at the measurement stations of the Barito River, Kapuas Murung River, and Mengkatip River networks

No	Location	n	RMSE
1	Point L Barito River	0.03	0.259
		0.035	0.143
		0.04	0.030
		0.045	0.145
		0.05	0.245
2	Point S Kapuas Murung River	0.04	0.192
		0.035	0.097
		0.04	0.027
		0.045	0.099
		0.05	0.190
3	Point S2 Mengkatip River	0.03	0.180
		0.035	0.091
		0.04	0.028
		0.045	0.092
		0.05	0.176

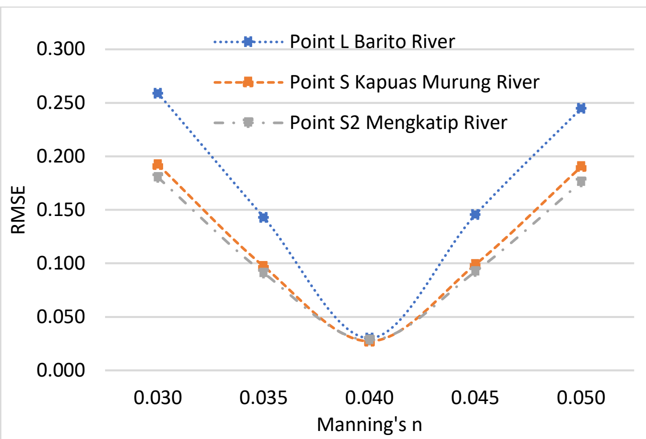


Figure 6 Relationship between RMSE and Manning's n value

4.0 CONCLUSION

This study concludes that in case there is no tide data for boundary conditions for a tide propagation simulation in a river network, the tide data generated by Tides Application can be used and give sufficient accuracy. It also concludes that the locations of tide measurement stations for the tide boundary conditions must be as close as possible to the coast. Tide data boundary conditions generated from tidal component values of measured data at 30 kilometers from the Barito river mouth have significant differences compared with the measured data at another nearby Palampai river mouth 1 kilometer from the coast. Tide data generated by Tides Application at the Barito river mouth are similar to the measured data at Palampai with an RMSE value of 0.201.

The calibration results conclude that the Manning n roughness coefficient of 0.04 s/m$^{1/3}$ gives the minimum RMSEs. This value is suggested to be used for tide propagation modeling in further analysis of the hydraulic performance of the tidal irrigation channel networks and their operation scenarios which are connected to the Barito, Kapuas Murung, and Mengkatip river networks.

Acknowledgment

The author would like to thank the Ministry of Public Works and Public Housing for supporting financial assistance through a scholarship program with the Department of Civil and Environmental Engineering, Universitas Gadjah Mada.

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