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Assessment of Parameter Sensitivity in Rainfall-Runoff Modelling for Peninsular Malaysia

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Abstract. The parameter sensitivity is identified in the usage of the Rainfall-Runoff-Inundation model, also known as RRI for Peninsular Malaysia. The data used in the analysis were obtained from 518 rainfall and 5 evaporation stations from 2017 to 2020 with topography resolution of 1 km. Subjected to overland flow behaviour condition, six model parameters were individually tested to observe the significance of the changes in the runoff outputs from the model default values. The comparisons were conducted in terms of average, maximum, and minimum discharge throughout the period. The results showed land roughness is the most sensitive parameter, followed by parameters of river width, river depth, and river roughness. The study helps researchers in calibrating RRI model for the application in Peninsular Malaysia.

1 Introduction

Peninsular Malaysia has an abundance of rainfall and a consistent temperature with high humidity due to the light wind intensity. However, different regions on the peninsula experience different climate patterns that are influenced by the monsoons, locally termed as southwest and northeast monsoons [1]. The different rainy and dry seasons are explained by these monsoon seasons and the inter-monsoon seasons that occur between them. Peninsular Malaysia therefore has both the dry and hazy seasons and the flood seasons, which include flash floods. Due to its proximity to these seasons, hydrological modelling plays an important role to determine the relationship between water, land and climate change besides to assist in water resources planning.

The application of physically-based distributed model is still limited due to the complexity and large number of datasets required [2]. However, as the technology evolve, the application of the model no longer looks as an impossible approach especially with the existence of better computing specification and large availability of open datasets. Rainfall-Runoff-Inundation (RRI) model application had shown its capability in simulating large area considering the interaction between land and river simultaneously [3]. This non-commercial software had established on 2010, capable in simulated the river channel and lateral flows

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based on the basis of 1-dimensional and 2-dimensional. No requirement for meshing preparation has made RRI easier to use compare to others. The tool was famously applied in Japan, and its usage is currently spreading to other countries in Asia. Hence, RRI is selected as a tool to conduct the analysis of the study area. Nevertheless, the parameter estimation during model calibration remains a significant challenge when there is uncertainty in the model parameters. This is especially when the parameters interact and the model output is determined in a non-linear way [4]. A previous study conducted in Pakistan using RRI showed river-related parameters inherited higher sensitivity to the discharge [5].

This study suggests an approach to assess the relevance of the output changes in relation to the parameter values assigned in the RRI model. The objective of the study was to set up a 2D physically-based distributed model of Peninsular Malaysia and analyse the impact of model parameters on the simulated discharge. This is particularly significant since the application of RRI in hydrological studies in Malaysia is still relatively new [6-12].

2 Methods and Materials

2.1 Peninsular Malaysia

Peninsular Malaysia, or West Malaysia, is a region of Malaysia, a country in Southeast Asia. With an area of about 131,206 km^2, Figure 1 illustrates the study area which consisted of 11 states with 74 main river basins [13]. The estimated population as of 2021 is reported about 26,470,800, which covered 81.6% from the country total population [14]. Geographically, the study area is separated into two distinct parts: the east and west coast, which are divided by the Titiwangsa Range's high topography features. The average annual rainfall is about 2,500mm, while the average annual evaporation is approximately 1,300mm, generally occurs throughout the year [15].

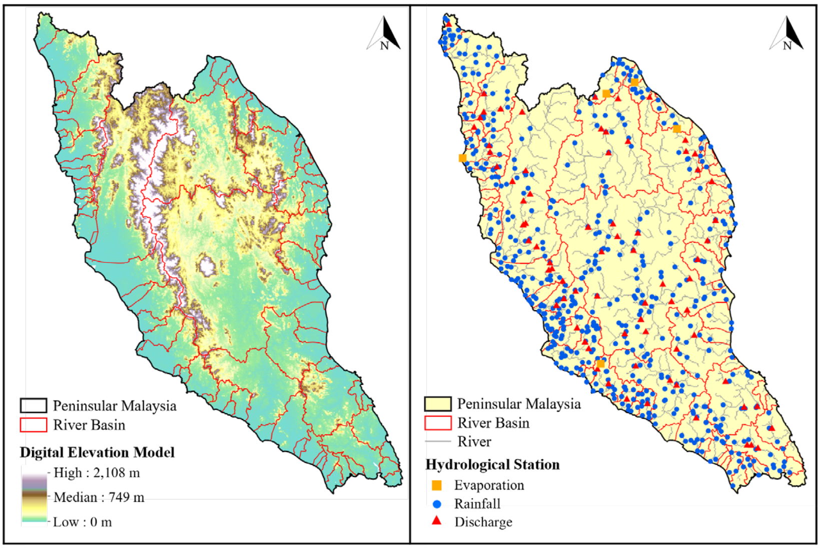

Fig. 1. Background of study area. Left: Digital Elevation Model. Right: Hydrological station.

Peninsular Malaysia has seen a succession of drought events throughout its history, which were caused by the El-Nino phenomenon. The three most recent occurrences took place in 1992, 1998, and 2014. Not only that, the occurrence of intense rainfall-induced floods, especially in the northeast monsoon season, significantly contributes to the natural hazard in the peninsula region [16]. The worst flood disaster in history was recorded in 2021, resulting in estimated total losses of USD 1.2 billion [17].

2.2 Study Framework

The study framework is illustrated in Figure 2. Based on overland flow behaviour condition, RRI essentially relies on two data types to set up the model: (1) geospatial data: digital elevation model (DEM), and (2) climate data: rainfall and evaporation records.

The DEM of 1 km resolution from MERIT Hydro, which has a good representation in the river network [18], was obtained from http://hydro.iis.u-tokyo.ac.jp/~yamadai/MERIT_Hydro/ and adopted into the RRI model. For the climate datasets, the records from 2016 to 2020 of rainfall and evaporation from the Department of Irrigation and Drainage Malaysia (DID) were referred. The absolute homogeneity assessment introduced by Wijngaard et al. [19] was conducted prior to select 518 rainfall and 5 evaporation stations throughout Peninsular Malaysia. The model was then setup, where we reserved all default values in the RRI parameter settings. The parameter settings were changed to execute the model scenarios, and the parameter sensitivity were assessed.

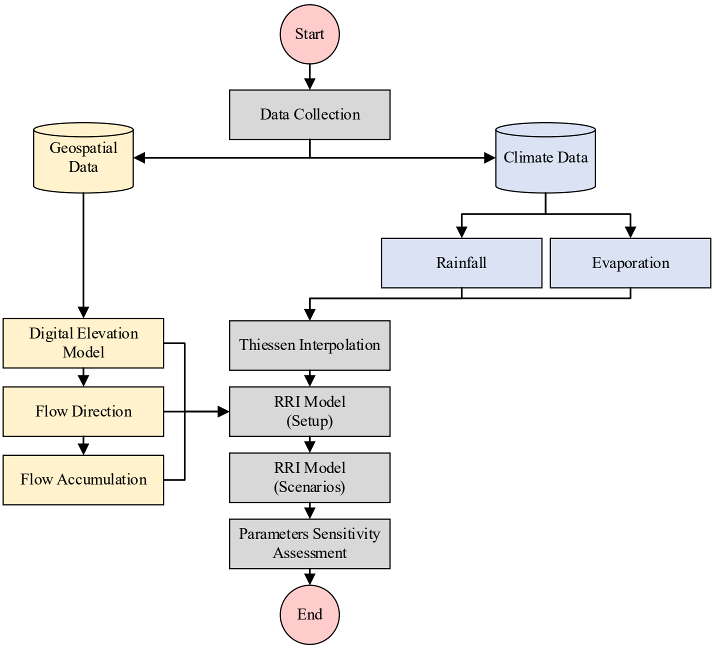

Fig. 2. Framework of parameter sensitivity assessment using RRI

2.3 Rainfall-Runoff-Inundation Model

The RRI model, a physically based distributed hydrological model, addresses slopes and river channels separately while simulating rainfall-runoff, and flood inundation simultaneously. The model is flexible for macroscale simulation and suitable for large-scale flood inundation, besides has a shorter computation time to execute the model [3]. It incorporates hydrologic procedures besides able to estimate river channel geometry with regards to the unavailability of river cross-section information. The software is available in two interface type, which are graphical user interface (GUI) and command user interface (CUI). The theoretical information is described in the model manual [20]. In this study, the model was simulated via CUI for 4 years, covering 2017 to 2020 excluding the first year of 2016 to undergo warm-up stage with hourly time-step.

2.4 Sensitivity Assessment

The assessment on parameter sensitivity is important to identify how significant the model reacted to the changes made on input parameters. Six parameters were chosen in the study considering the basic requirement to execute RRI. The model scenarios to measure the sensitivity were divided into four where the parameters were adjusted based on: (1) reduction by 10%, (2) reduction by 20%, (3) increase by 10%, and (4) increase by 20% from the RRI default values. These parameters were individually adjusted, as tabulated in Table 1, one by one with maintaining other values to default. Overall, 25 simulations, which are the default case and 4 cases by 6 parameters, were executed. For the simplification in the analysis, the relative percent change in hourly discharge at 77 selected locations for each simulation was calculated to define the sensitivity trendline where the sensitivity magnitude was determined based on the linear regression slope [21]. Based on the generated temporal discharge outputs of 2017 to 2020, the changes were analysed and compared in terms of average, maximum and minimum.

Table 1. Applied parameter values for RRI model scenarios.

	River Roughness	**River Geometry (Width): C_W***	**River Geometry (Width): S_W***	**River Geometry (Depth): C_D***	**River Geometry (Depth): S_D***	**Land Roughness**
Default	0.030	5.000	0.350	0.950	0.200	0.400
Case A Reduction by 20%	0.024	4.000	0.280	0.760	0.160	0.320
Case B Reduction by 10%	0.027	4.500	0.320	0.855	0.180	0.360
Case C Increase by 10%	0.033	5.500	0.390	1.045	0.220	0.440
Case D Increase by 20%	0.036	6.000	0.420	1.140	0.240	0.480

* Based on the river geometry equations applied in the RRI: (1) river width, $W = C_w A^{S_w}$ and (2) river depth, $D = C_D A^{S_D}$ where A is the upstream contributing area.

3 Results and Discussions

3.1 Relative Changes of River Discharge

RRI model allows the simulated river discharge to be obtained in a spatiotemporal profile. In the study, hourly discharge of 2017 to 2020 at 77 points across Peninsular Malaysia for all simulations was extracted, and the mean from each temporal variation was determined. We selected these points following to the DID river discharge locations, as shown in Figure 1.

Figure 3 presents the relative change distribution between default model and model scenarios in term of average discharge across all selected points. Based on the median of the boxplot, which is overall ranging from -1% to 1%, an increment in the river geometry parameters values of C_W, S_W, C_D, and S_D demonstrate an increase in average discharge, while an increment in the river and land roughness parameters leads to a reduction. There are no significant differences in the distribution of relative values throughout the area, revealing that this factor inherited monotonic pattern. Hence, the comparisons on maximum and minimum discharges between default model and model scenarios were then conducted to further analyse the parameter effects.

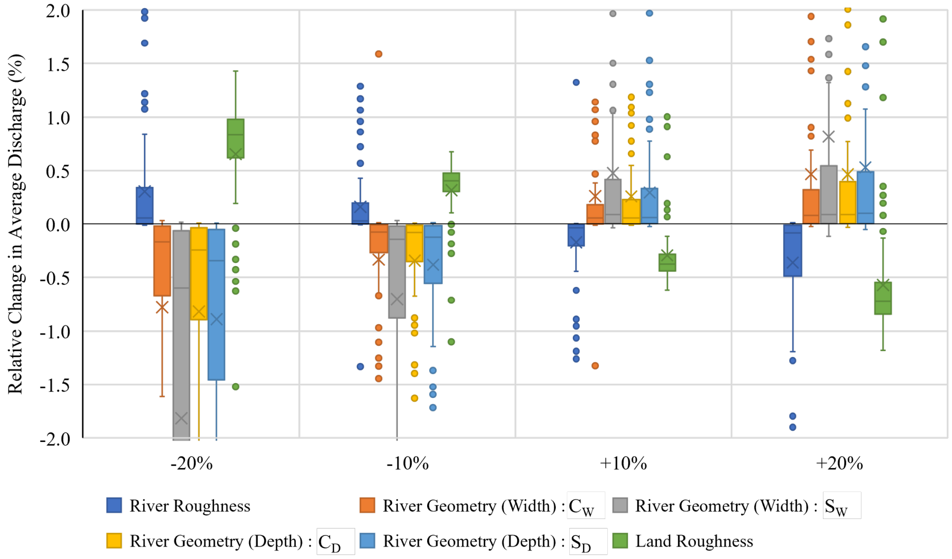

Fig. 3. Boxplot of relative change in average discharge for model scenarios compared to the default model.

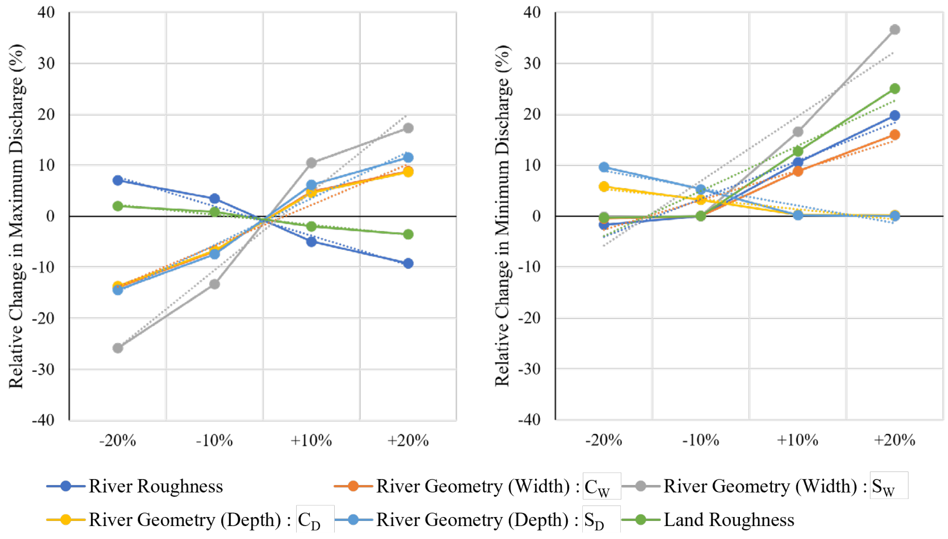

Fig. 4. Relative changes in maximum discharge (left) and minimum discharge (right).

Maximum and minimum river discharges are closely related to the wet and dry basin conditions. By individually adjusting the value of RRI model parameters, significant relative changes in these discharges to the model parameters were identified, as graphically depicted in Figure 4. Under maximum discharge, the reduction in parameter values resulted in a larger rate of relative change than in the scenario of increment. The differences varied approximately by -25% to 20%, where an increase in the river geometry and river and land roughness parameters resulted in an increase and decrease in the hourly maximum discharge. Meanwhile, for minimum discharge, the relative changes for all the model parameters typically range from 0% to 40%, which dominantly indicates the increment in discharge magnitude from the default model. This shows that parameter adjustments under overland flow conditions are unable to significantly shift down the pattern of minimum discharge compared to maximum discharge.

3.2 Parameters Sensitivity

The sensitivity rank for every parameter is summarised and listed in Table 2 based on the absolute values of the linear trendline slope, which correspond to the changes in the parameter values. The slopes were identified according to the profiles of average, maximum, and minimum discharges throughout 2017 to 2020. While land roughness appears to contribute the most significant effect to the average discharge, S_W, a component of the river width parameter, indicates that it significantly affects maximum and minimum discharge compared to others. Based on the ranks regarding the average, maximum, and minimum discharges, the overall rank was then determined.

Table 2. Sensitivity rank of RRI model parameters in Peninsular Malaysia hydrological modelling for 2017-2020.

Parameter	**Average**		**Maximum**		**Minimum**		**Overall Rank**
	Slope	**Rank**	**Slope**	**Rank**	**Slope**	**Rank**	
River Roughness	(0.0485)	6	(5.7324)	5	7.4953	3	5
River Geometry (Width): C_W	0.0972	5	7.9910	3	5.8132	4	4
River Geometry (Width): S_W	0.2360	2	15.3100	1	12.6800	1	1
River Geometry (Depth): C_D	0.1163	4	7.8657	4	(1.9711)	6	6
River Geometry (Depth): S_D	0.1550	3	9.1452	2	(3.3977)	5	3
Land Roughness	(0.5470)	1	(1.9466)	6	8.8680	2	2

** Parentheses indicate negative values

The overall rank can summarise that land parameter have a larger effect on the output compared to river parameters, where a slight change could have a large effect on model results. While the river-related parameters are highly sensitive in indicating the open channel capacity for flood modelling [5], the land roughness parameter is found to be particularly influenced the average and minimum discharge profiles. These will substantially affect the accuracy of the long-term simulation. The study was conducted by only taking into account overland flow condition throughout Peninsular Malaysia without taking into account infiltration loss and subsurface flow. Thus, a more in-depth analysis of the influence of soil depth, land porosity, and hydraulic conductivity on river runoff is recommended in the future using RRI.

4 Conclusions

This research set up and modelled the Peninsular Malaysia rainfall-runoff of overland flow condition that consist of 74 main river basins utilising the 1 km MERIT Hydro topography resolution and DID hydrological stations. Including the first year of model simulation to undergo the warm-up period, the model was executed for 2016 to 2020 based on the default values. Then, the parameters were adjusted individually, reducing and adding 10% and 20% from the defaults. From the spatiotemporal discharge results that were obtained from the RRI model, 77 locations were selected where the discharge time series were compared to the default case. The assessment identified land roughness as the most sensitive parameter compared to the other five tested in the study, indicating land-related parameter is more sensitive in terms of simulated runoff than river-related parameters. This finding may contribute to RRI model refinement, besides enhance its application for hydrological analysis in the targeted region.

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