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Prediction of Flooding Area in Batang Sinamar River Basin based on Design Return Period Simulation by Using Rainfall Runoff Inundation Model

Angga Putra Arlis [1], Mohammad Farid [2,3], Ahmad Nur Wahid [2,3,*], Yadi Suryadi [2] and Arno Adi Kuntoro [2,3]

1 Master Program in Water Resources Management, Institut Teknologi Bandung, Jalan Ganesha 10, Bandung 40132, Indonesia; email@address.com (A.P.A.)
2 Water Resources Engineering Research Group, Institut Teknologi Bandung, Jalan Ganesha 10, Bandung 40132, Indonesia; email@address.com (M.F.); email@address.com (Y.S.); email@address.com (A.A.K.)
3 Center for Water Resources Development, Institut Teknologi Bandung, Jalan Ganesha 10, Bandung 40132, Indonesia
* Correspondence: ahmdnrwhd@gmail.com; Tel: +62-82271396357
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Abstract: Lima Puluh Kota Regency in West Sumatera Province is one of regencies in Indonesia that often has flood problem every year since last decade. In case of such large-scale flooding, it is important to classify the hazard zone for efficiency of the flood mitigation. In this paper, rainfall-runoff inundation (RRI) model is applied to the Batang Sinamar River Basin in order to predict the widespread inundation, where both rainfall-runoff from surrounding mountain and rainfall on floodplain contributed to the flood event. Flood simulation was conducted by using nationally available dataset including high resolution digital surface model and rainfall ground station data. The simulation was calibrated with discharge observation data in Batang Sinamar and gave a good result with Nash Sutcliffe Efficiency index and correlation value 0.768 and 0.908 consecutively. The result of simulation using 10-year and 25-year return showed the increasing discharge by 15.72 percent from 406.77 m^3/s to 470.74 m^3/s. Furthermore, the average of peak inundation water level had increased from less than 1.5 meters to more than 1.5 meters. Based on these results, it can be concluded that the model can predict the potential inundation area in Batang Sinamar River Basin in Lima Puluh Kota Regency.

Keywords: Rainfall Runoff Inundation Model; Batang Sinamar River; Flood Hazard

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1. Introduction

Flood has become an annual disaster that probably be the most destructive, boundless and give significant losses in many countries [1]. This Inundation phenomena usually inundates area which normally dry and gives a significant lose in physical, social and environment [2].

Lima Puluh Kota Regency is one of the regencies in West Sumatera Province Indonesia that located in sub-catchment Batang Sinamar River and part of the upstream of Indragiri catchment area with total area about 1,330.65 km^2. This regency located at hillside of the Sago Mountain that has experienced flood from Batang Sinamar River for every year since last decade from 2010 to 2019. The annual floods give significant losses in agriculture and public facilities. For this concern, flood prediction model is needed to evaluate this phenomenon.

Hydrodynamic and hydrological models are widely applied to represent flood assessment. Hydrological models such as HEC-HMS, SWAT, MIKE 11 are usually applied to reproduce the precipitation-runoff process. While Hydrodynamic models such as MIKE 21, HECRAS, DELFT 2D can simulate flow along river and floodplains [3,4]. The selection of model is considered on the purpose of the model and availability of time, funds, and data.

Availability and quality of hydrometeorological data is a main problem in developing countries. Lack of long-term hydro-meteorological observation data and river's topography gives significant effect for the result of hydraulic and hydrological model. However, over the last decades a large number of satellites have been developed by international agencies. Even though, the qualities and resolution of these data is not as detail and accurate as observation data, but they give a sufficiently result for this phenomenon [5,6].

Commonly model practitioner run their flood model in two different models, one for hydrological process for the input in the upstream boundary condition and another for hydrodynamics for the flood inundation. These method is quite difficult to identify in larger basin if many floods happen. Therefore, Rainfall-Runoff-Inundation (RRI) model have been developed with a fully two-dimensional distributed rainfall-runoff inundation [7]. This model has widely applied in flood risk mapping [8,9] and flood damage assessment and management [10–12].

In this paper, will be presented flood inundation model using Rainfall-Runoff-Inundation model. The model will be calibrated with 2019 flood event and simulate with 10- and 25-years' time return to see the performance and the maximum inundation area.

2. Methods and Materials

2.1 Rainfall-Runoff-Inundation Model

Rainfall-Runoff-Inundation Model is a two dimensional based model that can simulate Rainfall runoff and Inundation process simultaneously [7,13,14]. This model is able to simulate the water that flow on slope using 2D diffusion wave equations, while the discharge in river using 1D diffusion wave equations. For more realistic result from rainfall-runoff simulation processes, this model also takes consideration about lateral subsurface flow, vertical infiltration, and surface flow. The infiltration process is calculated using Green-Ampt method [13] with parameter includes saturated hydraulic conductivity (K) [mm/hour], soil surface porosity (ϕ), suction head (Sf) [mm] and depth of saturated soil (d) [mm]. The river geometry parameter that will be input of the model, can be obtained using equations (1) and (2) as a function of catchment area A [km^2]. The river geometry is considered as a rectangular with W [m] as width of the river and D [m] as depth of the river.

$$\mathrm{W} = C_w A^{S_w} \tag{1}$$

$$D = C_d A^{S_d} \tag{2}$$

2.2. Target Flood Event

Batang Sinamar River is a sub-catchment of Indragiri River's catchment area. The area of Batang Sinamar River catchment is 1330.65 km^2. This river has been used to irrigate 7766 Ha agriculture areas. It is on the average 1246 meters at the upstream and 486 meters at the downstream above mean sea level.

In December 2019, there was uncommon flood events that happen in two adjacent times. The rainfall high is still in average, but the volume has increased because the length of rain event. It affected six districts and damage residents, public facilities, and agricultures. Besides the flood event in 2019, the model will be performed for the flood event in 2013.

2.3. Data Used dan Preparation

The general workflow of this study is shown in Figure 1 and the required input data have been gathered for this study includes high daily rainfall in Suliki and Tanjung Pati Station for ten years and Batang Sinamar Water Surface Elevation Station by Water Resources Agency of West Sumatera, digital elevation model (dem) by DEMNAS Indonesia (you can access it here: DEMNAS (indonesia.go.id)), Land use and soil type by Indonesia Geospatial Agency as shown in Figure 2. Rainfall data are processed using polygon thiessen method to get high rainfall design with 10- and 25-years as shown in Figure 5. The surface raster is processed to obtain the flow characteristic raster data of the area as shown in Figure 3. River's geometry, which is a scarce data, is digitalize measured using satellite images and dem shown in Figure 4. Digital measurements are applied in several cross section along the river to obtain geometries coefficients C_w, S_w, C_d and S_d with the result values are 1.8931, 0.3772, 0.162, and 0.4772, respectively.

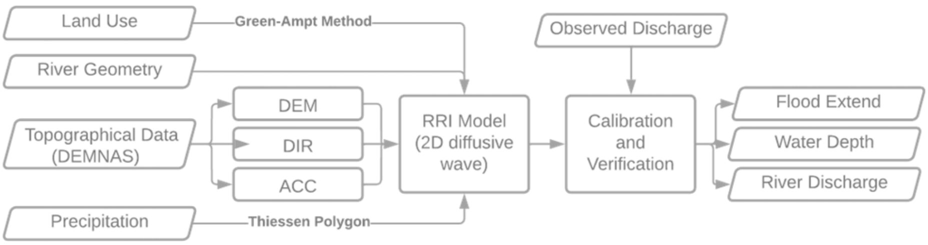
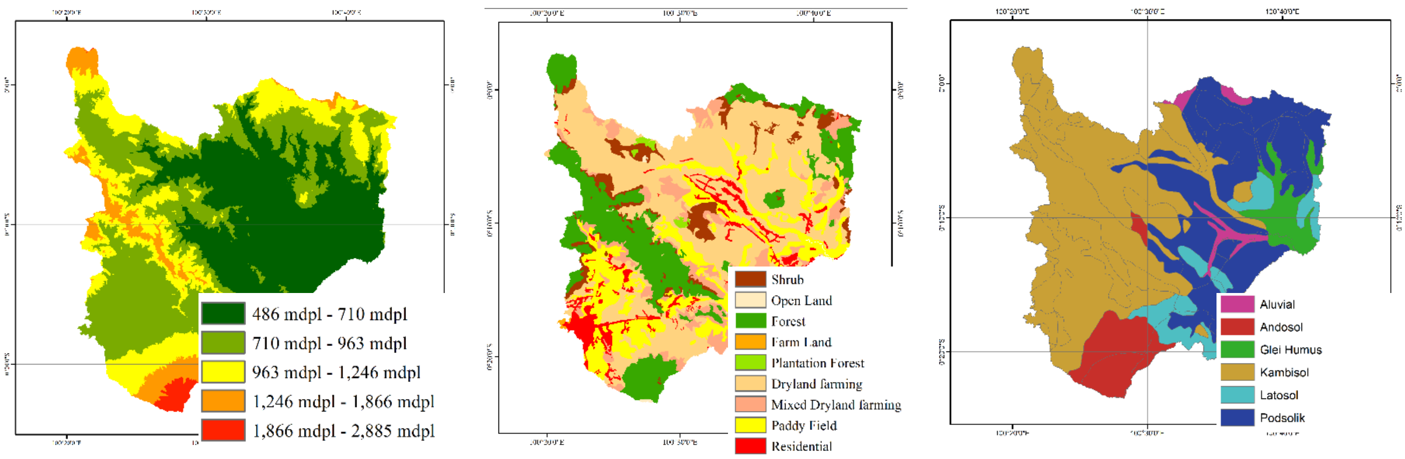


Figure 1. Workframe of the study.



(**a**) (**b**) (**c**)

Figure 2. General Information of study area: (**a**) Focus area elevation map; (**b**) Land use classification map.

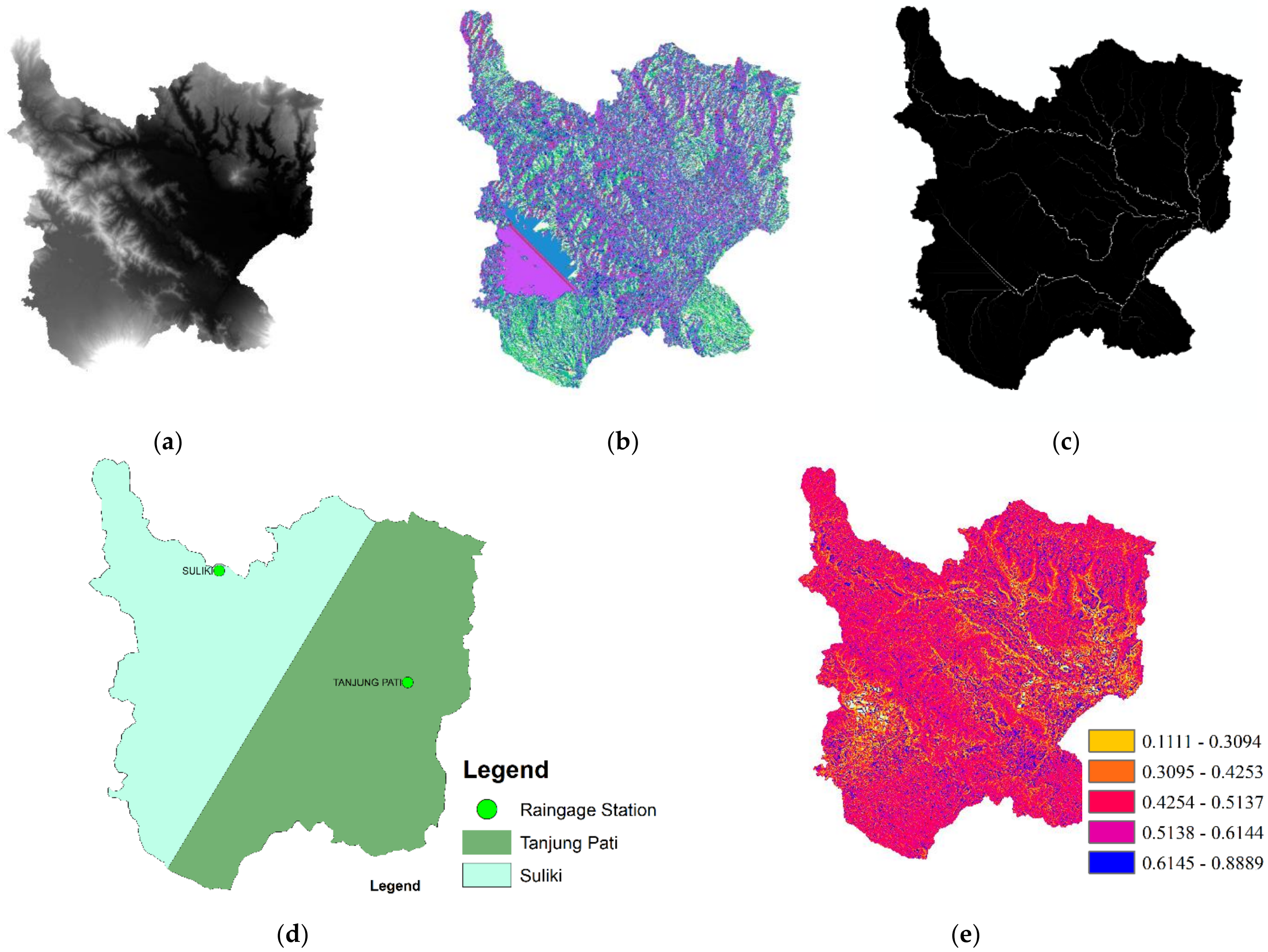


Figure 3. Topographic information as input RRI Model: (**a**) dem; (**b**) flow direction raster; (**c**) flow accumulation raster; (**d**) thiessen polygon area; (**e**) roughness coefficient

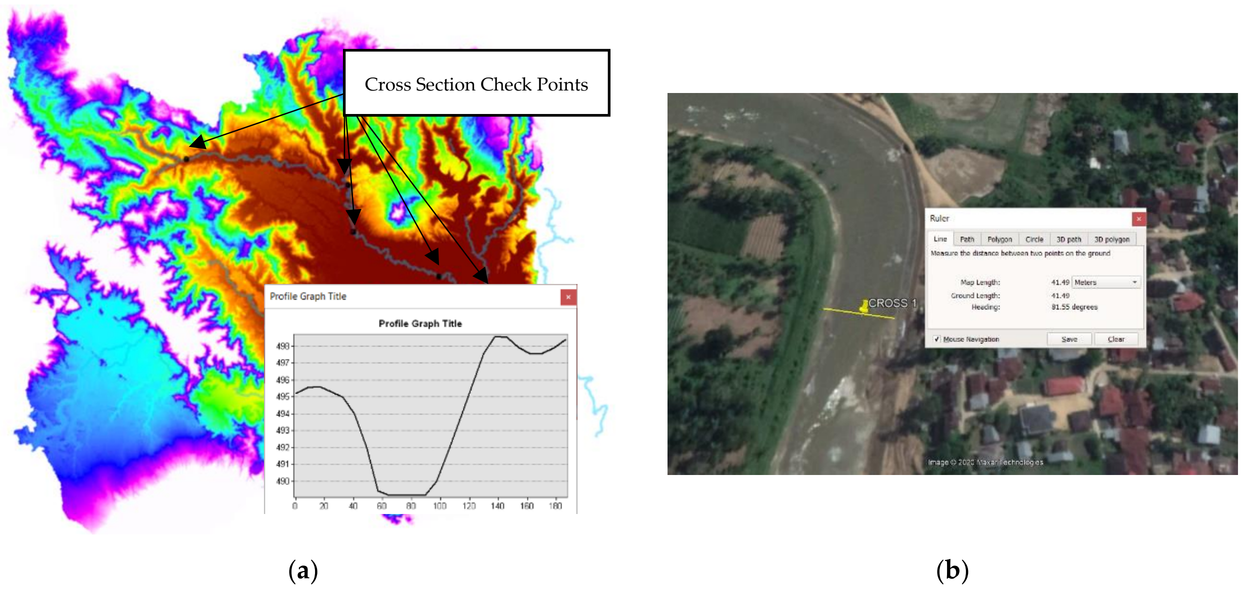
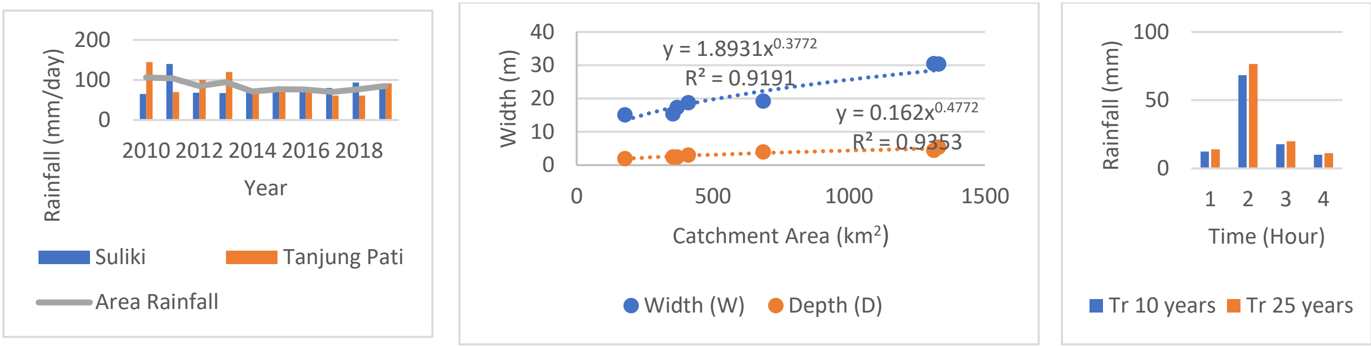


Figure 4. River geometry input for model RRI: (**a**) cross-section checking using dem; (**b**) river width checking using satellite images (source : Google Earth).



(**a**) (**b**) (c)

Figure 5. (**a**) Annual rainfall data, (**b**) river geometry parameter analysis, (**c**) Rainfall distribution in time recurrence.

2.4 Performance Assesment

The RRI model input parameter is sensitive especially for roughness and infiltration which need a calibration for approach real events [14]. The model is compared and calibrated with real discharge observation data. Furthermore, the performance of the model will be evaluated using Nash-Sutcliffe Efficiency (NSE) [15] and checked its correlation value with this following equation. Where Q_t^{obs} is observed discharge at time t, Q_t^{sim} is simulated discharge value at time t, and n is number of available discharge value.

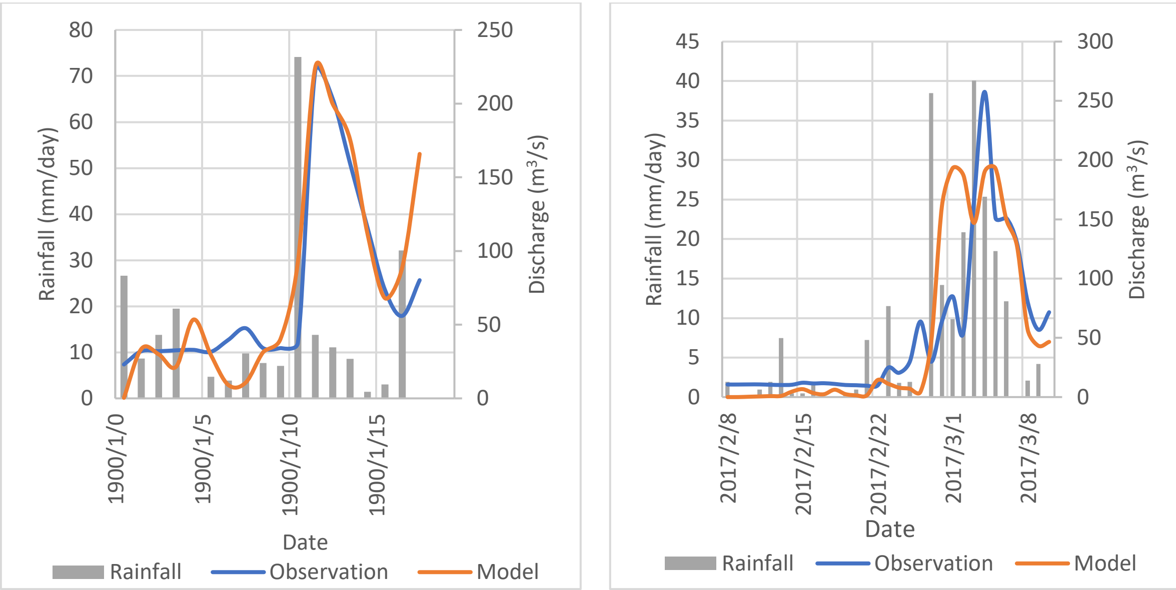
$$NSE = 1 - \frac{\sum_1^n \left(Q_t^{obs} - Q_t^{sim}\right)^2}{\sum_1^n \left(Q_t^{obs} - \overline{Q^{obs}}\right)^2} \quad (3)$$

$$R = \frac{n \sum_1^n Q_t^{obs} Q_t^{sim} - \sum_1^n Q_t^{obs} \sum_1^n Q_t^{sim}}{\sqrt{n \sum_1^n {Q_t^{obs}}^2 - n \sum_1^n (Q_t^{obs})^2}\sqrt{n \sum_1^n {Q_t^{sim}}^2 - n \sum_1^n (Q_t^{sim})^2}} \quad (4)$$

4. Result and Discussion

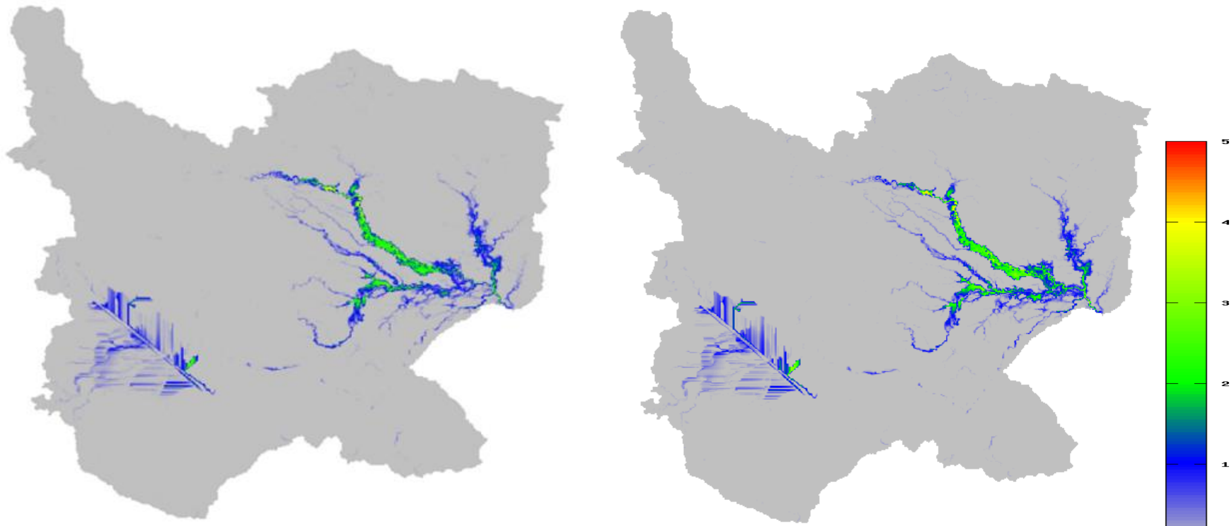
The RRI model is applied to simulate two scenarios in Batang Sinamar river in two scenarios. The first scenario is flood event on 20 December 2019 and the second is 3 March 2017. The results of the model will be calibrated with flow observation station data and will be checked the NSE and correlation value. The simulation for the first scenario was using rainfall for 17 days from 9 to 26 December 2019 with the peak on 20 December 2019. Meanwhile the second will be simulated for 31 days from 8 February to 10 March 2017. Based on observed and simulated result, highest discharge of the hydrograph on 20 December are 222.20 m^3/s and 224.65 m^3/s respectively and on 3 March are 257.50 m^3/s and 190.48 m^3/s. The model gives satisfactory results with NSE and Correlation value for the first scenario are 0.768 and 0.908 and for the second scenario are 0.531 and 0.828, respectively.

The evaluation of flood inundation is using 10 years and 25 years design rainfall. These threshold rainfalls are used in Indonesia standard flood modelling. The result gives similar pattern between designs rainfall. The flooding area is increase about 12.6% from 59.963 km^2 using 10 years design rainfall to be 68.592 km^2 using 25 years design. Highest hydrograph discharge from the simulation is also increase about 13.6% from 406.72 m^3/s using 10 years design to be 470.74 m^3/s.



(**a**) (**b**)

Figure 6. The hydrograph results of rainfall-runoff inundation modelling compare with daily observation discharge data (**a**) flood scenario 9 to 26 December 2019; (**b**) flood scenario 8 February to 10 March 2017



(**a**) (**b**)

Figure 7. Simulation result for time return design rainfall : (**a**) 10 years return; (**b**) 25 years return

5. Conclusions

In this study, application of rainfall-runoff and inundation model in Batang Sinamar River. Lacks of river's geometry survey data, which the main input for the model, can be replaced by digital measurement using satellite's images. Surprisingly, it gives a good agreement result when its compare with discharge observation data in two flood events. In the first scenario the model is able to catch the peak of the flow, even though in the second scenario the model is underestimate. It is proven with the NSE values for the scenarios are 0.768 and 0.531, and the correlation about 0.908 and 0.828, respectively for both scenarios. The result of flood with 10 years return period has 59.963 km^2 inundated area and 406.72 m^3/s as the highest discharge. Furthermore, in 25 years return period, the inundated area increases about 13% or become 68.592 km^2 and the peak flow grows to 470.74 m^3/s.

This application can be a good alternative when money and time is a limited resource in the process. However, in higher decision making, survey and field observation must be held for the exact result.

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