Proceeding Paper

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

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Abstract: Lima Puluh Kota Regency in West Sumatera Province is one of the regencies in Indonesia that has had a flood problem every year in the last decade. In the case of such large-scale flooding, it is important to classify the hazard zone for efficiency of the flood mitigation. In this paper, the 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 flood plain contributes to the flood event. Flood simulation was conducted by using a nationally available dataset, high resolution digital surface model, and rainfall ground station data. The simulation was calibrated with discharge observation data in Batang Sinamar, and provides a good result with the Nash–Sutcliffe Efficiency index and correlation value of 0.768 and 0.908, respectively. The result of the simulation using 10-year and 25-year return, showed the increasing discharge by 15.72% from 406.77 m^3/s to 470.74 m^3/s. Furthermore, the average peak of inundation water level increased from less than 1.5 m to more than 1.5 m. Based on these results, it can be concluded that the model can predict the potential inundation area in the Batang Sinamar River Basin in Lima Puluh Kota Regency.

Keywords: rainfall runoff inundation model; Batang Sinamar River Basin; flood hazard

1. Introduction

Flood has become an annual disaster that is probably the most destructive, boundless, and causes significant losses in many countries [1]. This inundation phenomenon usually inundates areas which are normally dry, and causes significant losses physically, socially, and environmentally [2].

Lima Puluh Kota Regency is a regency in West Sumatera Province Indonesia that is located in sub-catchment Batang Sinamar River Basin, and is part of the upstream of Indragiri catchment area with a total area about 1330.65 km^2. This regency is located on the hillside of the Sago Mountain that has experienced floods from Batang Sinamar River Basin every year in the last decade, from 2010 to 2019. The annual floods cause significant losses in agriculture and public facilities; therefore, a 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, and MIKE 11 are usually applied to reproduce the precipitation-runoff process. Hydrodynamic models such as MIKE 21, HECRAS, and DELFT 2D can simulate flow along rivers and floodplains [3,4]. The selection

of the model is considered on the purpose of the model and availability of time, funds, and data.

Availability and quality of hydrometeorological data are the main problems in developing countries. The lack of long-term hydro-meteorological observation data and river's topography affects the result of the 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 are not as detailed and accurate as observation data, they provide sufficient results for this phenomenon [5,6].

Common model practitioners 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 methods are quite difficult to identify in larger basins if many floods happen. Therefore, the Rainfall-Runoff-Inundation (RRI) model was developed with fully two-dimensional distributed rainfall-runoff inundation [7]. This model is widely applied in flood risk mapping [8,9] and flood damage assessment and management [10–12].

In this paper, the flood inundation model using the Rainfall-Runoff-Inundation model is presented. The model is calibrated with a 2019 flood event and simulated 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

The Rainfall-Runoff-Inundation model is a two-dimensional-based model that can simulate rainfall runoff and inundation processes simultaneously [7,13,14]. This model is able to simulate the water that flows on slopes using 2D diffusion wave equations, and the discharge in rivers using 1D diffusion wave equations. For more realistic results from rainfall-runoff simulation processes, this model also takes consideration of lateral subsurface flow, vertical infiltration, and surface flow. The infiltration process is calculated using the Green-Ampt method [13] with parameters including 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 is the 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 rectangle with W [m] as the width of the river and D [m] as the depth of the river.

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

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

2.2. Target Flood Event

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

In December 2019, there uncommon flood events happened at two adjacent times. The rainfall high is within the average, but the volume increased because of the length of the rain event. It affected six districts and damaged residents, public facilities, and agriculture. Besides the flood event in 2019, the model is performed for the flood event in 2013.

2.3. Data Used and Preparation

The general workflow of this study is shown in Figure 1, and the required input data gathered for this study include 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)), and land use and soil type by Indonesia Geospatial Agency as shown in Figure 2. The surface raster is processed to obtain the flow

characteristic raster data of the area as shown in Figure 3. The river's geometry, which are scarce data, is digitally measured using satellite images and dem shown in Figure 4. Digital measurements are applied in several cross sections along the river to obtain geometry coefficients C_w, S_w, C_d, and S_d with the result values of 1.8931, 0.3772, 0.162, and 0.4772, respectively. Rainfall data are processed using the polygon Thiessen method to obtain high rainfall design with 10- and 25-years as shown in Figure 5.

2.4. Performance Assessment

The RRI model input parameter is sensitive especially for the 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 is evaluated using Nash–Sutcliffe Efficiency (NSE) [15] and its correlation value is checked with the following equation.

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

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

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.
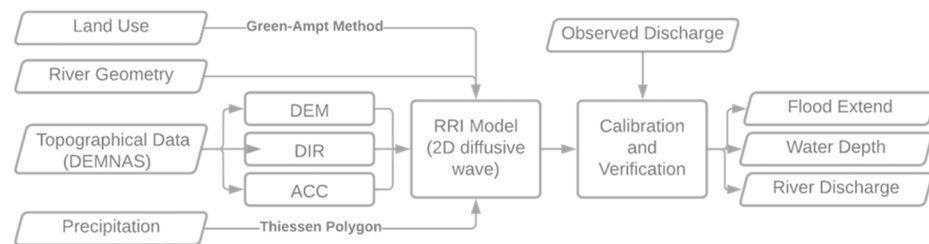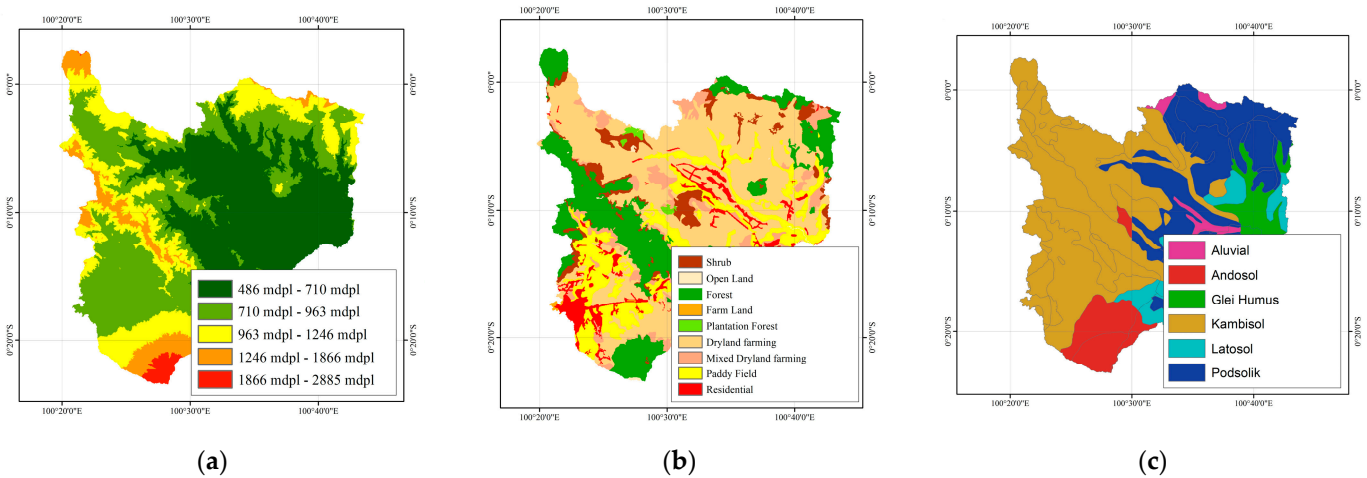

Figure 1. Workframe of the study.

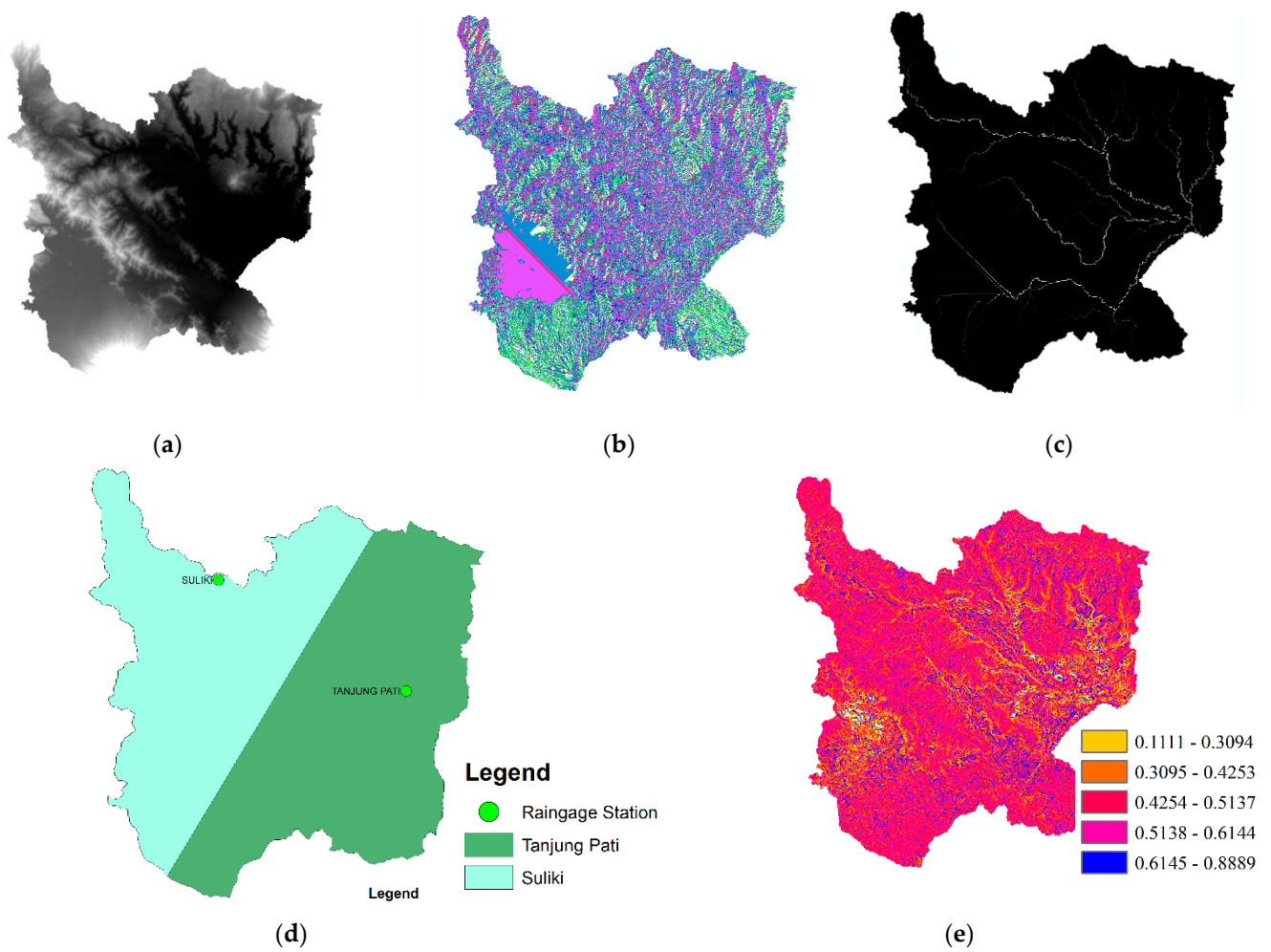**Figure 2.** General information of the study area: (**a**) focus area elevation map; (**b**) land use classification map; (**c**) Soil type map.

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.
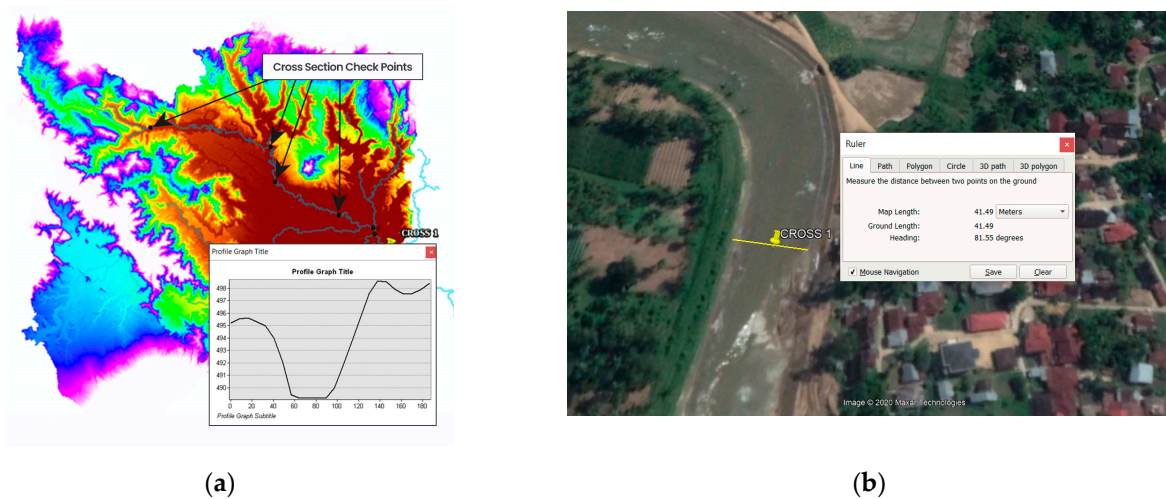

Figure 4. River geometry input for model RRI: (**a**) cross-section checking using dem; (**b**) river width checking using satellite images (source: Google Earth).
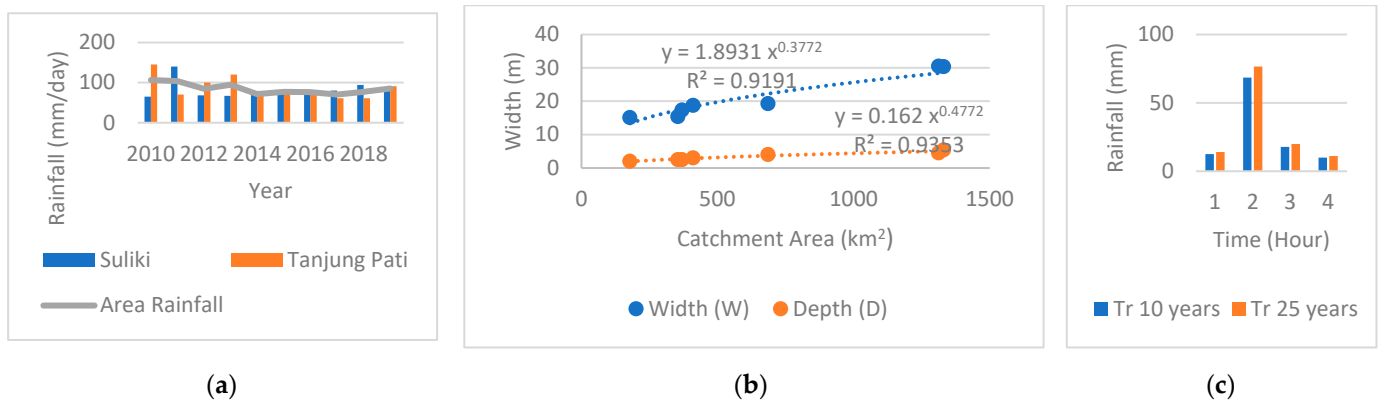
(**a**) (**b**) (**c**)

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

3. Result and Discussion

The RRI model is applied to simulate two scenarios in the Batang Sinamar River Basin in two scenarios; the first scenario is the flood event on 20 December 2019 and the second is 3 March 2017 as shown in Figure 6. The results of the model were calibrated with flow observation station data and the NSE and correlation value were checked. The simulation for the first scenario used rainfall for 17 days from 9 to 26 December 2019, with the peak on 20 December 2019. Meanwhile the second was simulated for 31 days from 8 February to 10 March 2017. Based on observed and simulated result, the highest discharges 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, respectively. The model provides satisfactory results with the NSE and correlation value for the first scenario as 0.768 and 0.908, respectively, and for the second scenario, 0.531 and 0.828, respectively.
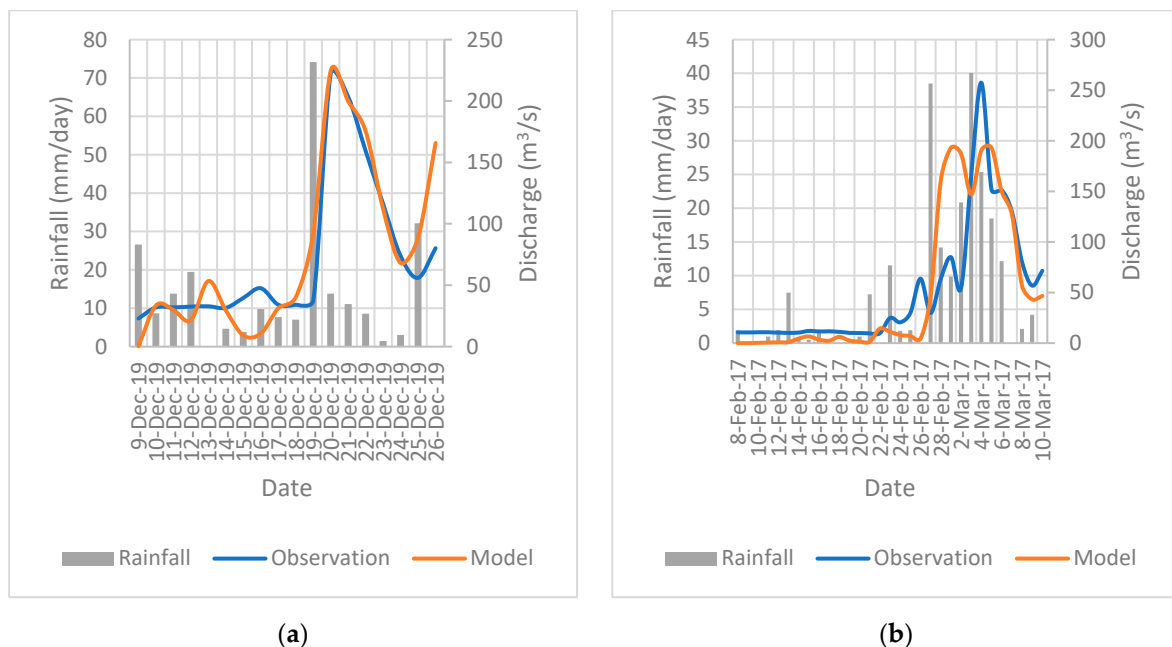

(**a**) (**b**)

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

The evaluation of flood inundation used 10-year and 25-year design rainfall. These threshold rainfalls are used in the Indonesia standard flood modelling. The result provides

a similar pattern between design rainfall as shown in Figure 7. The flooding area increase by about 12.6% from 59.963 km^2 using 10-year design rainfall, and 68.592 km^2 using 25-year design. The highest hydrograph discharge from the simulation is also increased by about 13.6% from 406.72 m^3/s using 10-year design to be 470.74 m^3/s.
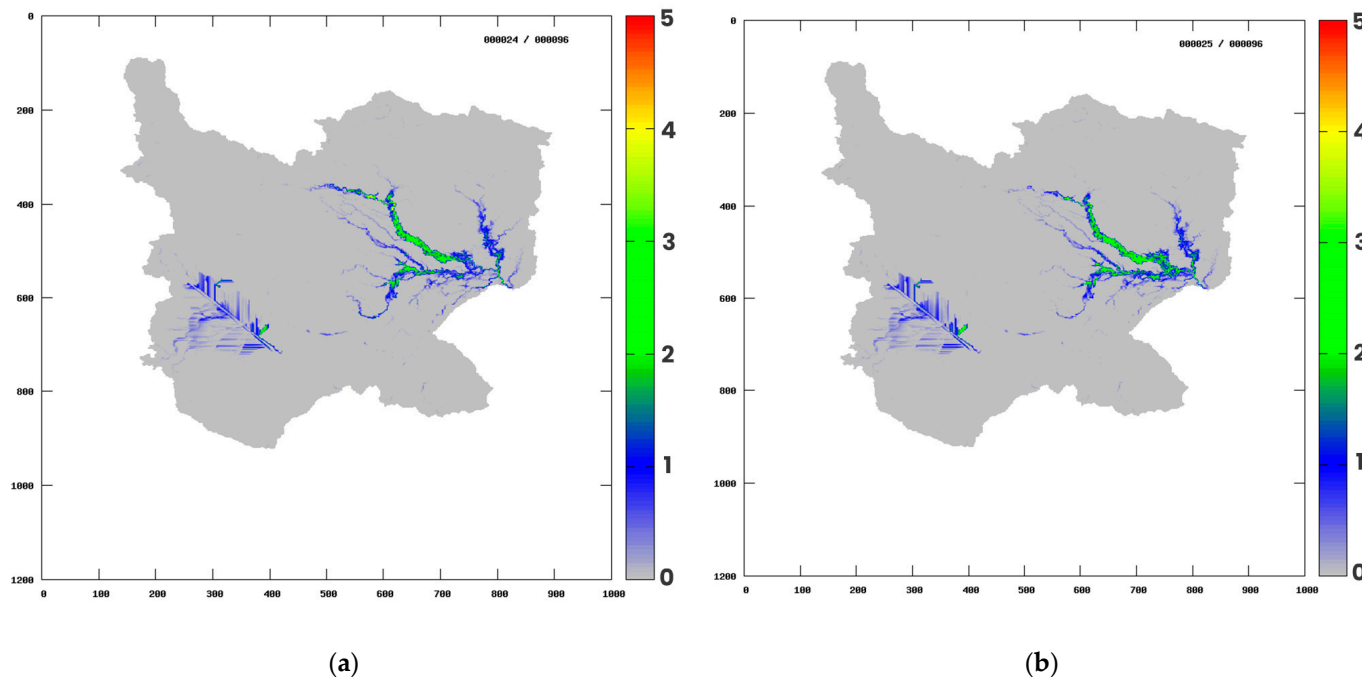

Figure 7. Simulation result for time return design rainfall: (**a**) 10-year return; (**b**) 25-year return.

4. Conclusions

In this study is observed the application of rainfall-runoff and the inundation model in Batang Sinamar River Basin. The lack of the river's geometry survey data, which are the main input for the model, can be replaced by digital measurement using satellite images. Surprisingly, this provides a good agreement result when it is compared 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 underestimated. It is proven that the NSE values for both scenarios are 0.768 and 0.531, respectively, and the correlation about 0.908 and 0.828, respectively. The result of flooding with 10-year return period has 59.963 km^2 inundated area and 406.72 m^3/s as the highest discharge. Furthermore, in 25-year return period, the inundated area increases by about 13% or becomes 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 are a limited resource in the process. However, in higher decision making, surveys and field observation must be performed for the exact result.

Informed Consent Statement: Not applicable.

Data Availability Statement: Digital elevation model, soil type and land use classification data downloaded freely from Indonesia Geospatial Information Agency site in Indonesia Geospatial Portal. Rainfall and discharge observation data received from West Sumatera Water Resources Agency.

Conflicts of Interest: The authors declare no conflict of interest.

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