ASSESSMENT OF FLOOD RISK AND IMPACT BASED EARLY WARNING SYSTEM IN THE CIDURIAN RIVER BASIN, INDONESIA

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ABSTRACT

The Cidurian River Basin (CRB) in Indonesia experiences flooding almost every year and it has been a problem since it causes damage and interferes with daily life. Structural countermeasures such as embankment and diversion channels have been planned and implemented since 2016 at several locations for reducing the impact of flooding. However, non-structural countermeasures such as flood early warning systems in the CRB are not established yet. In order to reduce the flood risk, this study thus attempts to propose a framework for establishing early warning systems by combining the hydrological analysis using the rainfall-runoff-inundation (RRI) model and the impact-based forecast (IBF) from Agency for Meteorological, Climatological, and Geophysics (BMKG). Flood simulation for various flood scenarios based on frequency analysis with various rainfall patterns provides an idea of how the spatial-temporal distribution of rainfall influences flood extent and inundation depth. The results of this study show that combining the extent of flood area resulting from RRI modeling and the IBF can provide more specific and reasonable information of flood early warning.

Keywords: *Risk Assessment, Impact Based Forecast, Frequency Analysis, Early Warning Systems*

INTRODUCTION

Hydrometeorological disasters are the most frequent in Indonesia (BNPB, 2015). The data of disaster events from 2008–2021 in Indonesia show that 40% of the disasters were caused by flood event. The most frequently affected districts by floods disaster are Bogor and Tangerang. CRB is one of the strategic rivers, which flows between these District. In 2020 the flash flood in Cidurian and Ciujung River Basin, causing 1.000 houses damages, 9 people death and several infrastructure such as the bridge are destroyed. In 2021 flood also casued 500 houses inundated.

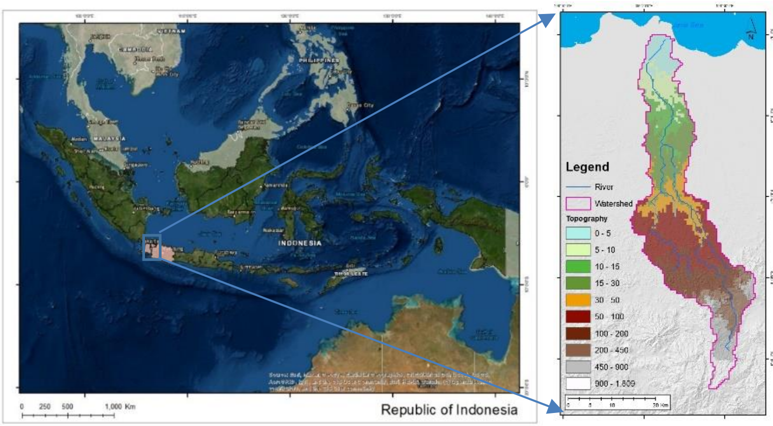

Figure 1. Location of Cidurian River Basin (CRB)

The location of the upstream of CRB is in Bogor District, the middle stream area is located between Lebak and Serang District, and the downstream area is located between Serang and Tangerang District. Figure 1 shows the location of CRB, with a total catchment area of 842.57 km^2, The CRB has an altitude of upstream area at an elevation of 559 to 1,785 meter above sea level (masl). The altitude of the middle stream is between 77 to 559 masl. In the down-stream, the altitude of the land are in the range of elevation 0 to 77 masl. The analysis of land cover data from the Directorate General of Planning Forestry and Environmental Management (KLHK) for 5 year from 2016 to 2020 shows the settlements are

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increased by 27%, and farmland decreased to 40%. The development of new settlements in flood-prone areas increased the vulnerability of people at floor risk in CRB.
Several structural countermeasure projects to reduce the flood in the CRB have been planned and implemented since 1996 by Japan International Cooperation Agency (JICA), and by the Ministry of Public Work of Indonesia (PUPR) in 2014. Unfortunately, the early warning systems in CRB have not been established to support the structural measurements. In 2020, National Agency for Disaster Management (BNPB) and BMKG started collaboration to develop the IBF platform named Signature BMKG. This platform gives an early warning by using the extreme weather forecast from BMKG combined with the risk maps from InaRisk by BNPB as the input. The weather forecast provides the areas (in polygon format) which are forecasted to experience extreme rainfall so-called extreme-rainfall regions. These polygons are then intersected with BNPB's risk maps to result in the estimated flooded area. This mechanism makes it possible to forecast which are to be inundated and then be used for preparedness measurements such as early warning systems. However, the maximum extent of the estimated flood are the boundary of the polygons. In fact, floods can expand to the larger areas beyond the polygons as water flow considering topography. As a result, there might be areas which possibly be flooded even though they are out of the extreme-rainfall regions. This research, therefore, aims to develop a framework to improve the flood risk assessment using the RRI modeling as the input for Impact-based forecasts to enhance the early warning systems in the CRB. To obtain a more precise number of the affected buildings, the building footprints data and RRI simulated model are used. The specific output hopefully can increase the reliability of early warning information.

THEORY AND METHODOLOGY

The work flow for this research consists of four main parts as shown in Figure 2.

Model Set Up

The RRI model is a two-dimensional model capable of simultaneously simulating rainfall runoff and flood inundation (Sayama, 2017). The model treats data on slopes and river channels differently. All model grid cells receive rainfall, and the model tracks the flow based on 2D diffusive wave equations regardless of topography (i.e. including hill slopes and flood plains). This 2D model also simulates vertical infiltration based on the Green-Ampt model and saturated subsurface flow in mountainous areas for better representations of rainfall-runoff processes. The data used in this study are, the Digital Elevation Model (DEM) from HydroSHED with horizontal resolution of 450 m x 450 m. Rainfall and discharge data for 25 years (1997–2021) of 6 rainfall stations, obtained from River Organization of Cidanau Ciujung and Cidurian (BBWS 3Ci).

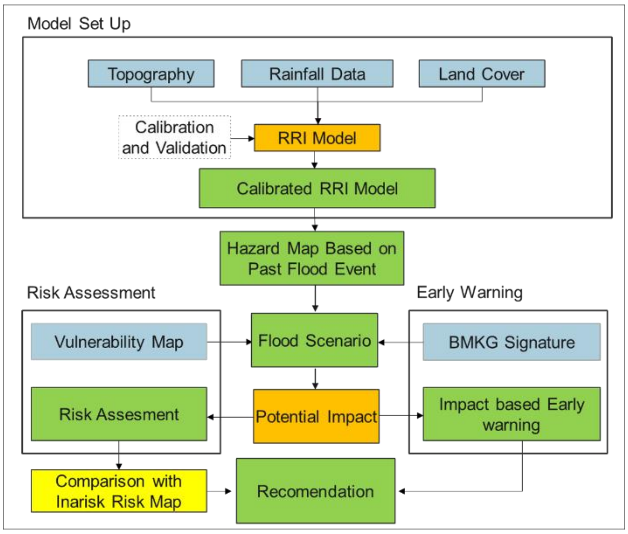


Figure 2. Work Flow

Flood Scenario

Flood scenario analysis is carried out to find out the spatial-temporal variation of flood inundation in CRB. The flood scenarios are divided into seven scenarios based on rainfall pattern. The flood scenario represents the combination of rainfall in mountainous area, plain and coastal areas of the river basin. Each scenario has been analyzed by using three return period of 10, 50, and 100 years. The return period are estimated based on frequency analysis.

Risk Assessment

In this study, the risk assessment is primarily based on exposed building units and population in the inundated area. Population density was distributed spatially using the building footprint from the Microsoft) and calibrated using Open Street Map data (Xiao Huang, 2020). Using the building footprint for population density analysis is expected to increase accuracy in quantifying the population affected by flood in the risk assessment. Referring to Regulation of BNPB No. 02/2012 about general regulation for risk assessment, the risk classes are define based on relationship between hazard, vulnerability and capacity. However, in this study the risk classification simplified refers to the inundation depth classification that affected the buildings, which is 0 to 0.75 meters (m) inundation depth for low class, 0.75 to 1.5 m for medium class and above 1.5 m for high class.

Impact Based Early Warning

To develop proper early warning systems, it needs a lot of time and cost. The proposed framework of the flood early warning system is shown in Figure 3. This framework proposed to fill the gap for the existing IBF. There is a limitation on the existing IBF which only gives a warning to areas in extreme-rainfall areas. In fact, Flooding can occur even outside the areas of heavy rain. For example, if heavy rainfalls in the upstream of the river, there is a chance that flooding will occur at the downstream. By integrating the RRI model simulation into the IBF framework, there is possibility we can get more specific inundation areas and improved the IBF to give more reliable information.

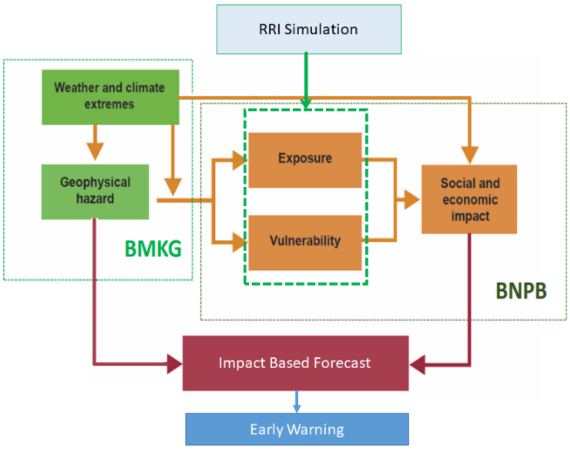


Figure 3. Proposed Impact Based Early Warning Framework

RESULTS AND DISCUSSION

Hydrological Modeling

Figure 4 compares the calculated result of discharges using RRI model with observed discharge for flood event in February 2021 (for Calibration) and flood event in January 2020 (for validation). The model efficiency criteria using the

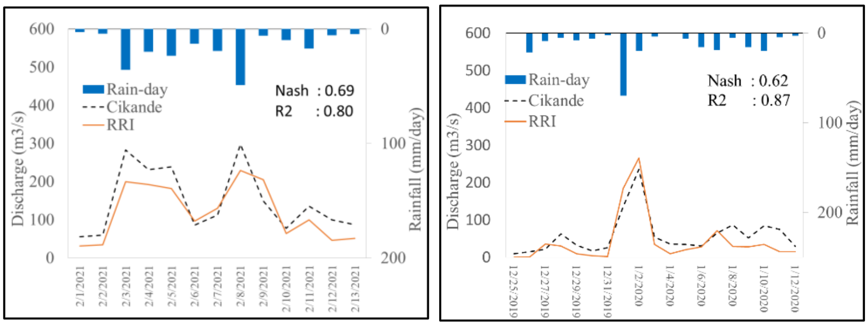


Figure 4. Model Calibration and Validation

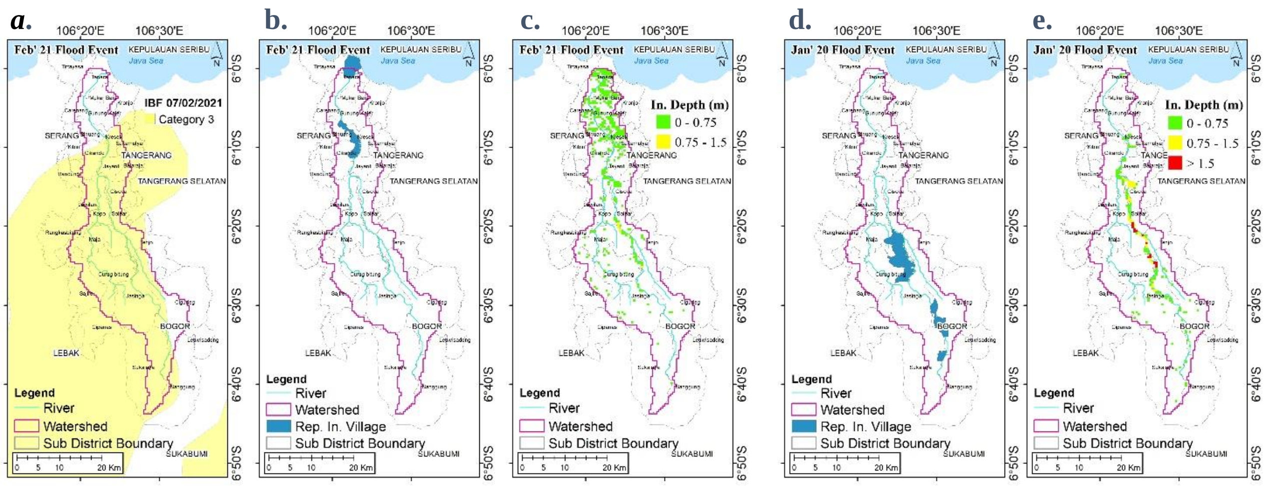
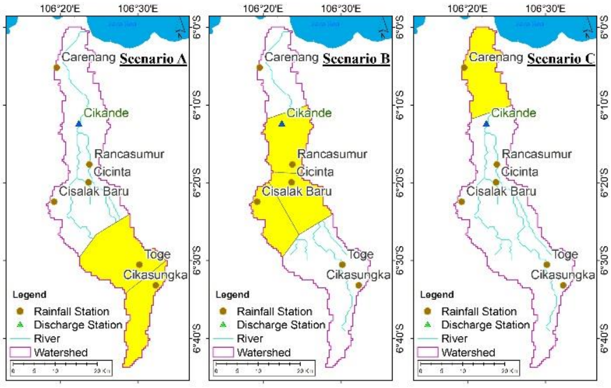


Figure 5. a. IBF (Feb 20201), b and c Reported Inundated Village and RRI model inundation map for (Feb 2021 flood event), d. and e. Reported Inundated Village and RRI model inundation map for (Jan 2020 flood event)



NASH value are within the acceptable range, which are 0.69 for calibration and 0.62 for validation. Figure 5*b* to 5*e* shows the inundation map resulting from the RRI model and the reported flooded villages in the CRB. There are no inundation extent data to validate the inundation model result, however the reported village data can show the approximate location of the flood event. We can also use satellite image data for validation, but the satellite data was obscured by clouds during this flood event.

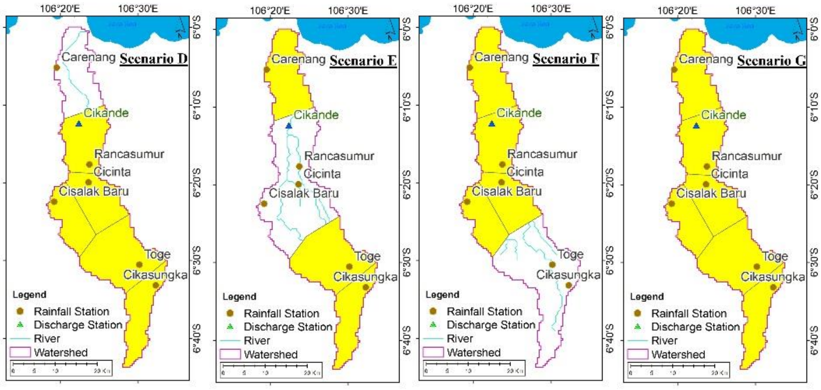


Figure 6 . Rainfall distribution Scenario

Frequency Analysis and Flood Scenario

The frequency analysis was performed in several scenarios based on rainfall pattern distribution as shown in Figure 6. This scenario aims to understand the effect of different spatial-temporal distributions of rainfall on flood inundation and extent. Table 1 shows the rainfall data of peak rainfall before the flood from the ground station. Table 2 shows the maximum basin average rainfall based on rainfall pattern distribution. And Table 3 shows the conversion factor for the rainfall based on the generated extreme value (GEV) maximum rainfall. The Flood Scenarios were applied in several rainfall patterns based on rainfall distribution. Scenario A was assumed rainfall occur in the upper stream region, Scenario B and C for rainfall in middle and downstream region. Scenario D assumed rainfall occur in upper and middle area, Scenario E assumed rainfall occur in upper and downstream area, and scenario F assumed rainfall middle and downstream region. In scenario G, it was assumed that the rainfall occur in all the basin area. The region represents the mountainous area, plain area and coastal area.

Table 1. Peak rainfall of January 2020 Flood Event and February 2021 Flood Event

Flood Event	Carenang	Rancasumur	Cicinta	Cisalak	Toge	Cikasungka	Basin Average
2/8/2021	16	48	17	58	41	107	48.8

Table 2. Maximum Basin Average Rainfall based on Rainfall Pattern Distribution

Flood Event	Maximum Basin Average						
	Scen. A	Scen. B	Scen. C	Scen. D	Scen. E	Scen. F	Scen. G
8/2/2021	78	42.4	8	52.2	38.1	58.5	48

Table 3. Conversion Factor

Return Period	Scenario A	Scenario B	Scenario C	Scenario D	Scenario E	Scenario F	Scenario G
	8/2/2021	8/2/2021	8/2/2021	8/2/2021	8/2/2021	8/2/2021	8/2/2021
10	1.8	3.4	19.7	1.4	2.2	1.8	1.4
50	2.7	4.9	28.1	2	2.6	2.3	1.9
100	3.1	5.77	32	2.3	2.8	2.6	2.1

From this analysis, we can see the effect of variability of spatial-temporal rainfall pattern in the inundation area and depth of flood. For example, In scenario C (see Figure 7) based on 100 year return period for 2021 flood event, inundation are occur in the downstream area and no inundation in the upper and middle stream area. Normally, rainfall in downstream area is rarely causing the flood, but it can happen when the rainfall is high, and the soil has already saturated enough. This flood scenario can be input for the flood forecasting to determine which area will be inundated by a certain rainfall intensity and pattern.

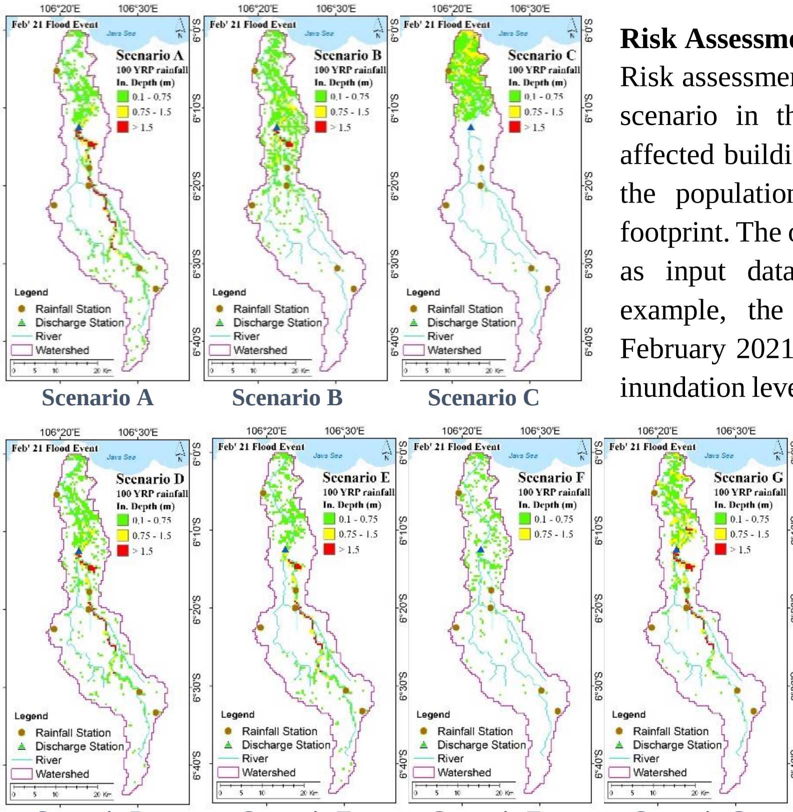


Figure 7. Flood Scenario Based on February 2021 Flood Event (100 Year Return Period)

Risk Assessment

Risk assessment will be performed for each flood scenario in this study with GIS analysis, the affected building and population quantified using the population distribution based on building footprint. The output of risk assessment is required as input data in the IBF classification. For example, the 100-year return period for the February 2021 flood event giving information of inundation level and affected building for different flood scenario. From table 4 we can see the areas categorized as high-risk area are Jasinga, Tenjo, Maja, Curug Bitung, Kopo, Cikande, Cisoka, Solear, Jayanti and Kresek with inundation depths above 1.5 m. Based on topographic condition, these areas such as Jayanti, Kresek and Cikande are identified as the lowland area. The areas categorized as medium risk, are the areas that often inundated by flood between 0.75–1.5 m depth and low - risk category area are the areas with potential flood between 0.1 -0.75 m. and there are 5 areas without flood risk. The distribution of the risk area shown in Figure 8. This classification then used to be input for the IBF about which areas have a high impact and which areas are safe from flooding.

Table 4. Sub District Risk Assessment

District	Sub District
BOGOR	NANGGUNG
BOGOR	LEUWISADENG
BOGOR	CIGUDEG
BOGOR	SUKAJAYA
BOGOR	JASINGA
BOGOR	TENJO
LEBAK	CIPANAS
LEBAK	SAJIRA
LEBAK	RANGKASBITUNG
LEBAK	MAJA
LEBAK	CURUG BITUNG
SERANG	BANDUNG
SERANG	JAWILAN
SERANG	KOPO
SERANG	CIKANDE
SERANG	KIBIN

District	Sub District
SERANG	CARENANG
SERANG	BINUANG
SERANG	TIRTAYASA
SERANG	TANARA
TANGERANG	CISOKA
TANGERANG	SOLEAR
TANGERANG	TIGARAKSA
TANGERANG	BALARAJA
TANGERANG	JAYANTI
TANGERANG	SUKAMULYA
TANGERANG	KRESEK
TANGERANG	GUNUNG KALER
TANGERANG	KRONJO
TANGERANG	MEKAR BARU
TANGERANG	KEMIRI

Risk Classe
Low
Medium
High

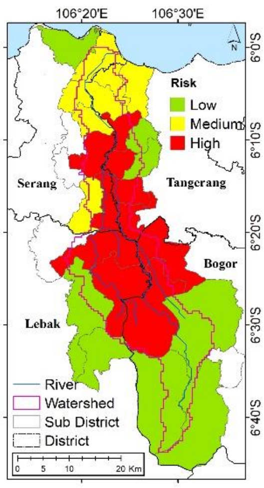


Figure 8 Risk Map (100 Year Return Period)

Impact-Based Early Warning

By using flood simulation result as the input for the impact-based forecast information, we can improve the accuracy of the alerted area and increase the lead time for early warning needs. Figure 9 shows the existing IBF, reported area and RRI flood simulation result.

From the image we can see the area inside the black box are outside the existing IBF area, which means this area not get warning information. Further, Table 5 shows the name of sub district gets a warning from existing IBF compared with reported inundated area and inundated based on RRI simulation result on February 2021 flood event. In this table the RRI simulation result coincide with all the reported inundated area. Hence, the proposed IBF system would specifies the area to be informed based on the simulation results potential inundation area, and the information could be including the potential inundation depth.

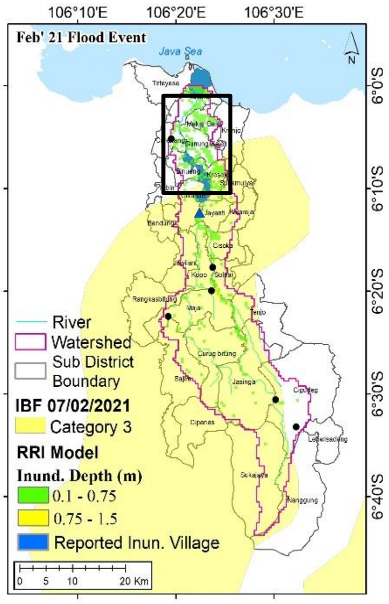


Figure 9. Impact Based Forecast and Reported Inundated Village RRI model Result

Table 5. Comparison of IBF, Reported Flood and RRI Model

SUB DISTRICT	IBF	Reported	RRI
CIGUDEG	v	-	-
JASINGA	v	-	v
LEUWISADENG	-	-	-
NANGGUNG	v	-	-
SUKAJAYA	v	-	-
TENJO	v	v	v
CIPANAS	v	-	-
CURUGBITUNG	v	-	v
MAJA	v	-	v
RANGKASBITUNG	v	-	-
SAJIRA	v	-	v
BANDUNG	-	-	-
BINUANG	v	v	v
CARENANG	-	-	v
CIKANDE	v	v	v
JAWILAN	v	-	-

SUB DISTRICT	IBF	Reported	RRI
KIBIN	v	-	-
KOPO	v	-	v
TANARA	-	v	v
TIRTAYASA	-	-	v
BALARAJA	v	-	-
CISOKA	v	-	v
GUNUNG KALER	v	-	v
JAYANTI	v	-	v
KEMIRI	v	-	-
KRESEK	v	-	v
KRONJO	v	-	-
MEKAR BARU	-	-	v
SOLEAR	v	-	v
SUKAMULYA	v	-	-
TIGARAKSA	v	-	-

CONCLUSSION AND RECOMMENDATION

In this study, the RRI model was applied to simultaneously simulate rainfall runoff and flood inundation with different flood scenarios. The RRI Model for the CRB was calibrated for February 2021 and validated for January 2020 flood events, by comparing calculated discharge with observed discharge data. The simulation results show that the flood inundation area was larger in 2021 flood than that in 2020 flood event. This is possibly due to saturation of the soil caused by rainfall occurred just before the main flood event, as some rainfalls in the CRB occurred before the February 2021 flood event for two days. Because of unavailability of satellite data to confirm the Inundation extent, validation of inundation extent is using the reported location from the news and disaster report. The simulation result is showing coincide with the report in some area. This simulation result was good enough to show specific location of inundated area due to certain rainfall pattern and intensity for early warning needs. Currently, the model set up of RRI model in this study does not consider the structural measurement operation, but as a next step in this research, the weir operations and diversion channel may be considered. More cross-sectional data and subsequently higher-resolution DEM data may provide a more accurate representation of the floodplain, which may then be used to improve the flood mapping.

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