The application of Rainfall-Runoff-Inundation (RRI) model for inundation case in upper Citarum Watershed, West Java-Indonesia

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Abstract

The upper Citarum River watershed which located in West Java-Indonesia, has been suffered from flood occurrence every year during the rainy season because it is a plateau area surrounded by the mountain. In order to prevent and mitigate flood damage, it is necessary to understand the characteristic of the flood, however, the local areas often suffer from a lack of the hydrological data. Therefore, an approach to estimate the flood inundation area using satellite-based rainfall instead of the limited hydrological data is proposed. To reproduce the largest 2010 flood in the upper Citarum River Watershed, Rainfall-Runoff-Inundation (RRI) Model, which consists of tightly coupled a two dimensional rainfall-runoff and inundation model, was utilized. As an input data, 15 arc-second HydroSHEDS Digital Elevation Model (DEM) and satellite-based hourly rainfall data (GSMaP), which is validated by comparing with the daily observation data, are used. Simulation results are compared with the observed water discharge at the outlet, Nanjung water stage gauging station, and observed inundation area provided by Upper Citarum Basin Flood Management (UCBFM) Team in the year 2010. Although the simulated inundation area showed a good agreements with the observed one, the simulated discharge showed some discrepancy because of the uncertainties involved in the observed discharge and the deficit of the input data for simulations.

Keywords: Rainfall-Runoff-Inundation model, Citarum, flood, GSMaP, HydroSHEDS

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1. Introduction

Flood disaster is one of the most harmful disasters in the world. As the occurrence of flood event has become common, the awareness of flood risk and flood prevention is increasing. The climate which extremely change also impacts on floods, such as increasing the heavy rainfall which generate the floods. Flooding will occur when the watershed system receives the unusual high rainfall intensity or the prolonged rainfall event so that the streamflow rate exceeds the channel capacity [3]. In upper Citarum watershed case, the channel capacity is not accommodating the high discharge of surface flow [6]. Hence, it happens the flood in every year.

To prevent and mitigate flood damage, it is necessary to establish the countermeasures. Techniques for preventing flood damage can be classified as structural and non-structural countermeasures. There is a growing realization about the importance of non-structural measures in flood management, including flood forecasting and early warning. Establishing a flood forecasting system would enhance the effectiveness of all other mitigation measures by providing time for appropriate actions. This has increased the importance of flood modeling for flood forecasts to issue advance warning in severe situations to reduce the property damage and any other losses [5]. But the accuracy of operational hydrological models primarily rely on a good rainfall data input in terms of temporal and spatial resolution [9].

Upper Citarum watershed is a plateau area surrounded by mountain range forming a basin [1]. There are several issues in application of hydrological models in the mountainous area. One of the major issues is a lack of high-quality local data since observation stations to collect climatic and hydrologic data, which is primarily used as an input for hydrological analysis, is relatively limited [8]. It is very difficult to establish the countermeasures without understanding the characteristic of the flood which correlated with the hydrologic data. Therefore, an approach to estimate the flood inundation area using satellite-based rainfall instead of the limited hydrological data is proposed.

Non-structural countermeasure to prevent and mitigate the flood damage is possible to be done with rainfall runoff modeling and inundation analysis. The inundation simulation usually performed by two models, which are the rainfall-runoff model for predicting river discharge and the hydraulic model for propagation of water. However, the conventional separate modeling approach is not appropriate for flood with flat watershed and large inundation area because of significant interaction between river and flooding water. Furthermore, the parameter estimation for separate two models is difficult because of the deficiency of data. Therefore, in this study, Rainfall-Runoff-Inundation (RRI) model [10], which is a fully coupled model of rainfall-runoff model and hydraulic inundation model, is applied for upper Citarum watershed of West Java, Indonesia.

2. Description of Methodology

RRI model is a two-dimensional model capable of simulating rainfall-runoff and flood inundation simultaneously. Fig. 1 shows the schematic diagram of RRI model [11]. The flow on the slope grid cells is calculated with the 2D diffusive wave model, while the channel flow is calculated with the 1D diffusive wave model. For better representations of the rainfall-runoff-inundation processes, the RRI model simulates also lateral subsurface flow, vertical infiltration flow, and surface flow. The flow interaction between the river channel and slope is estimated based on different overflowing formulae, depending on water level and levee height conditions [11]. The methodology flowchart of this study can be seen in Fig.2.

3. Model Application with Insufficient Hydrological Data

Rainfall distribution is an important input for RRI Model. Due to the limited observation data of the rainfall, the satellite-based rainfall, namely GSMaP has been used. Distributed rainfall in hourly from GSMaP was corrected with a simple bias correction method based on ground-gauged rainfall. First, the ratio of total rainfall observed by six rain gauges and GSMaP were calculated. The observed rainfalls from six rain gauges were spatially interpolated over the upper Citarum watershed using the Inverse Distance Square (IDWS) Method. The ratio between GSMaP and IDWS method was then multiplied to the original GSMaP for each grid to adjust the GSMaP distribution with
equal total rainfall at the rain gauge stations. The rainfall distribution between GSMaP, IDWS, and the adjusted GSMaP with IDWS Method can be seen in Fig. 3.

Fig. 1. Schematic diagram of RRI Model (Sayama, T., 2013).

Fig. 2. Methodology Flowchart.

Fig. 3. The Estimation of Rainfall Distribution over Upper Citarum Watershed
Digital Elevation Model (DEM), flow accumulation (ACC), and flow direction (DIR) were the topography input for RRI Model. DEM, ACC, and DIR were obtained from Hydrological data and maps based on Shuttle elevation Derivatives at multiple scale (HydroSHEDS). To reduce the computational cost, the 15-arc second resolution (approximately 450 m) was used.

River cross section confirmed to be the sensitive parameter for the RRI Model. As the reliable surveyed data for the river cross section could not be obtained, the following regression was used which were estimated at several location in upper Citarum watershed:

\[
Width(m) = 5A^{0.34} \tag{1}
\]

\[
Depth(m) = 0.5A^{0.367} \tag{2}
\]

where, A (km\(^2\)) is the flow accumulation area.
The other parameters used in this study were: the river roughness which was assumed refer to [2] for the big channel with un-uniform channel and rough which the value range is 0.035-0.100 m-1/3 s; the slope roughness, as there was no land use data used for this study input, it was assumed to refer the percentage of rice field and the settlement area in the period of the simulation. RRI Model can simulate several condition which only overland flow, consider the vertical infiltration and consider the saturated subsurface. However, for this study only for the overland flow, which did not consider any infiltration and saturated subsurface, were simulated.

4. Result and Discussions

Citarum River is one of the important rivers in West Java, Indonesia. During the rainy season, flood disaster also often occurs almost every year which flows through Bandung Regency located in upper Citarum watershed. Some of the area in upper Citarum is a flat area which surrounded by the mountain which forms a basin (Fig.3b). The area of upper Citarum watershed is approximately 1,800 km2. Big scale of flood happened on 1931, 1945, 1977, 1982, 1984, 1986, 1998, 2005, 2010 [7]. Every year, outflow from Citarum River cause the flood in most of upper part of Citarum.

There were three outputs from RRI Model which include the water depth on the slope (m), river discharge (m3/s), and the inundation area. In this study two value of river threshold were considered, there were 1000 and 1500. The grid cells with more than the defined threshold value were confirmed to have a river channel. Simulated hydrographs at Nanjung and Dayeuh Kolot with the threshold 1000 can be seen in Fig. 6 and simulated hydrographs with the threshold 1500 can be seen in Fig. 7.

From Fig. 6 and Fig. 7, it can be seen that the river geometric parameters which include the width, the depth, levee, and threshold of the channel can be considered as the sensitive parameter for RRI Model. These parameters indicate the importance of representing a reasonable flow capacity in the river. The overestimate of a river channel capacity should be avoided, since it cause the underestimate of the flooded area [11]. The uncertainty of the channel
cross section parameter and the observed discharge caused the disagreement between the simulated discharge and the observed discharge. However, it perfectly fit in some parts.

Fig. 8. shows the comparison between the simulated inundation area with the flood extent provided by UCBFM Team in 2010. From the figure, the brown colored part shows the inundation area from UCBFM while the green and blue colored part are the inundation area simulated by RRI Model. The inundation area from the observed data was approximately 151.62 km², while the simulated area with threshold 1000 was approximately 83.76 km² and with the threshold 1500 was approximately 141.70 km². Hence, the inundation area with the threshold 1500 shows a better agreement rather than the simulation with the threshold 1000. However, from this figure it can be seen that the RRI Model is capable to simulate the inundation area.

![Threshold 1000](image1)

![Threshold 1500](image2)

Fig. 8. Comparison of Simulated Inundation Area with the Flood Extent Provided by Upper Citarum Basin Flood Management (UCBFM) Team in 2010 (JICA,2010).

5. Conclusions

In every year, outflow from Citarum River causes the flood in most area of upper part of Citarum watershed. This study focused on Nanjung and Dayeuh Kolot as the representative of the upper Citarum region. In this study, a RRI Model was applied to simulate the rainfall-runoff and the inundation area simultaneously. The objective of this study was to construct the optimized RRI Model with the limited data and focused on how well the simulated inundation area agrees with the observed inundation map.

The interaction between slope and the river using diffusion wave model caused the simulated inundation area shows a good agreement with the observed inundation map provided by UCBFM Team in 2010 [4]. In this simulation involved a lot of uncertainties include the observed discharge and the river cross section parameter. Hence, it caused the disagreement between simulated discharge and observation discharge. However, the simulation should be improved if the specific land use for the whole region and the infiltration data are used. The infiltration and the saturation will be considered for further study.

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