Rainfall Threshold of Citarum River Flood for Early Warning on Urban Area

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Abstract. Floods in Bandung basin located in the upper Citarum river resulted in huge losses because they occurred in industrial areas and densely populated settlements. Disaster risk reduction can be done with flood early warning in residential areas. The purpose of this study is to determine the rainfall threshold that causes inundation in residential areas in seven districts located on the floodplain of the Citarum river. The method used is the analysis of the rainfall-runoff model to obtain the Citarum river unit hydrograph. Flows in the rivers are assumed to be one-dimensional unsteady flow whereas overflow is assumed to be overland flow. Threshold rainfall is determined based on the deconvolution method, with the drainage coefficient calculated based on the land use map. The results of the study are the capacity discharge and the load discharge of the Citarum river in the seven sub-districts, which the most upstream is the Majalaya sub-district and the downstream is Katapang sub-district. The lowest threshold rainfall has occurred in the sub-district Bojongsoang that is 54.34 mm that produced the flood water level as high as 662 m MSL. and the evacuation time for early warning is 5.5 hours.

1. Introduction
The Citarum River Basin in West Java Province is a National Strategic Watershed that has very large potential water resources, including the potential of energy, those are water sources of 3 power plant reservoirs as the electricity suppliers for Java and Bali, food potential, those are water sources of the irrigation network, and potential raw water for the community and industry. The current problem is the destruction of the Citarum watershed because of the greater runoff causing flooding. Bandung Regency which is included in the Bandung Basin is an area that experiences Citarum River overflow every year. Floods in the Bandung Basin region occur because of reduced water infiltration into the ground so that each time the rain produces a large proportion of runoff water and accumulates into flooding and inundation [1].
Settlements along the Citarum River Basin are very vulnerable to flooding. In a short time, the floods soaked the settlement area and stopped and paralyzed the socio-economic activities of the surrounding area. Flooding continues even though local rains have subsided but rain in other regions continues to occur because the flow of rain in other locations still leads to the Citarum River through tributaries. Floods due to overflowing of the Citarum River are becoming more frequent, with areas inundated not only along settlements in river basins but already expanding into the surrounding areas along the
Citarum River Basin [2]. Changes in the extent of flooding in South Bandung are currently very severe, not only the increase in the area but also the increase in flood water level. The floodwater level at Cieunteung Village, Bale Endah Village, Bale Endah District, Bandung Regency is reported to exceed 4 meters. One reason is the change in land use in the upper reaches of the Citarum River and in the Bandung Basin, which is an urban and industrial area. In 2010, several textile industries stopped production due to storm rainfall which causes flooding [3].

Various efforts have been made by the government to prevent residents affected by flooding. Technically, the Bandung regency government supported by the West Java Provincial Government and the Central Government has normalized the Citarum river. The shallow riverbed is then dredged to restore the river's depth so that the surface of the river is expected not to overflow. Social handling has also been carried out, such as evacuation and relocation of permanent resettlement of residents to avoid overflowing river water. But these various efforts in their realization are not entirely optimal in preventing people from flooding. One of the main obstacles is believed to originate from the condition of the community itself. Increased population, overcrowding, and attitudes the community is believed to have relevance to the success of the flood disaster in the government programs to deal with the flood problem. One of the adaptation strategies to deal with floods is to form groups in the community, especially in flood-prone areas that aim to deal with flood disasters. The emergence of socially conscious communities indicates the application of survival values and overcoming problems that are based on the independence of the community itself [4].

The early warning system gives people time to avoid floods, tornadoes, or tsunamis so that local stakeholders can evacuate and protect many people. This system provides information about events that endanger public health so that the response to aid can be faster such as food needs and feelings of insecurity. Early warnings given can also provide an opportunity for the community to protect its property and infrastructure [5]. The parameter used as an input for a community-based flood warning system is the elevation of the river's water level which is monitored by people living near the river [6][7]. If the river water level reaches a certain elevation that has been designated as a flood elevation, then an early warning alarm will be reads then this information is disseminated to stakeholders through a decision-supporting system [8]. The flood early warning system can also use rainfall data as a threshold by reading rainfall data from the rain station [9]. Rainfall observation systems are also used in flood early warning systems in Kenya Africa [10].

2. Methods of the study

The method used is the analysis of the rainfall-runoff model to obtain the Citarum river unit hydrograph. Flows in the rivers are assumed to be one-dimensional unsteady flow whereas overflow is assumed to be overland flow [11]. Threshold rainfall is determined based on the deconvolution method, with the drainage coefficient calculated based on the land use map.

In the rainfall-runoff model analysis, the unit hydrograph is calculated based on measured data or the observation unit hydrograph. The observation unit hydrograph method used in this study is the convolution method.

An impulse, both a step and a pulse response function, is defined as having a continuous-time domain. If the time domain is discretized with a duration interval $\Delta t$, then there are two ways to describe the continuous-time function in the discrete-time domain, the pulse data system, and the sample data system. The pulse data system is used for precipitation and the sample data system is used for direct flow and runoff. The discrete convolution equation for a linear system is,

$$Q_n = \sum_{m=1}^{n} P_m U_{n-m+1}$$

(1)

where $Q$ is direct runoff discharge, $P$ is effective rainfall and $U$ is unit hydrograph ordinate. The basic flow is determined using the straight-line method of flow hydrograph. The synthetic unit hydrograph derived from Nakayasu method, while the observation unit hydrograph ($U$) is obtained by deconvolution calculation as follows,

$$U = \{(P^T) \cdot P \}^{-1} \cdot P^T \cdot Q$$

(2)
The equation for one-dimensional unsteady flow used in this study can be seen in the following equation,

$$\frac{\partial y}{\partial x} + \alpha \frac{V}{g} \frac{\partial V}{\partial x} + \frac{1}{g} \frac{\partial V}{\partial t} + \frac{\partial z}{\partial x} + S_f = 0$$

(3)

where \(y\) is the flow depth, \(V\) is velocity, \(z\) is the distance of the bed channel from the datum, and \(S_f\) is energy slope. Unsteady flow analysis can identify the maximum water surface elevation at various cross-sections during the propagation of the flood wave through a river reach. The unsteady flow in a river which meanders through a flood plain is complicated because of differences in hydraulic resistances of the main river channel and the flood plain and variation in the cross-sectional geometries of the channel [12].

The overflows from the river when it floods and flows to the land, in this study is assumed to be a turbulent overland flow with the direction from the river to the land [13]. The equation used to determine the inundation area is based on land elevation and the inundation height \((Y)\) equation for overland flow as follows,

$$Y = \left( \frac{\eta q_o}{S_o} \right)^{3/5}$$

(4)

where \(\eta\) is the roughness coefficient, \(q_o\) is the discharge per unit width and \(S_o\) is the bed slope. Determine the monthly flood discharge for each sub-district is done by analyzing the rainfall-runoff model in the sub-district for analysis of inundation in the respective sub-district. Overflow to the land is used to calculate flood elevation for each sub-district and threshold rainfall for each sub-district is calculated using the convolution method.

3. Results and discussion

3.1. Study area

The upstream Citarum river basin where the outlet is in Nanjung, Margaasih Sub-District at an elevation of 675 m MSL as shown in figure 1, is located at -6.75\(^{\circ}\) S to -7.24\(^{\circ}\) S and 107.37\(^{\circ}\) E to 107.94\(^{\circ}\) E with an area of about 1762 km\(^2\) and river length 82 km. The upstream of the Citarum river is in Kertasari Sub-District at an elevation of 1638 m MSL.

The flow of the Upper Citarum watershed crosses 4 cities including Bandung Regency, West Bandung Regency, Bandung City, and Cimahi City. In addition to being a source of raw water for drinking water, the Citarum River also being an irrigation water source for hundreds of thousands of hectares of rice fields and power plants for Java and Bali. In the Citarum river, there are three large reservoirs, namely Saguling, Cirata, and Jatiluhur. The map of Upper Citarum watershed is shown in figure 1.

The upstream area of the Citarum river starts from Majalaya Sub-district to Margaasih Sub-district, geographically shaped in a basin so it is often called the Bandung Basin. The Bandung Basin is a bowl-shaped at an elevation of 662.5 m MSL and in a hydrological model is a water parking area so it is prone to flooding. The Bandung Basin area is surrounded by mountains starting from Manglayang Mountain at an elevation of 1800 m MSL in Cilengkrang Sub-District, Geulis Mountain in Tanjungsari Sub-District at an elevation of 1200 m MSL, Kerenceng Mountain in Cimanggung Sub-District at an elevation of 1690 m MSL, Mandalawangi Mountain in Nagreg Sub-District at an elevation of 1600 m MSL, Artapela Mountain in P衡alengan Sub-District at an altitude of 1525 m MSL, Bumi Wangi Mountain in Ciparay Sub-District at an elevation of 1027 m MSL and Pasir Ipis Mountain in Cililin Sub-District at an elevation of 1050 m MSL.
Based on the land use map, the runoff coefficient of the Upper Citarum river basin is 0.57.

3.2. Citarum river unit hydrographs in each sub-district

Subdistricts on the banks of the upstream Citarum river that is often flooded areas analyzed in this study are Majalaya Sub-District, Solokan Jeruk Sub-District, Ciparay Sub-District, Bojongsoang Sub-District, Baleendah Sub-District, Dayeuhkolot Sub-District, and Katapang Sub-District. To analyze the overflow that occurred, the Citarum river unit hydrograph was derived in the river segments through these seven districts. To get the unit hydrograph, the characteristics of the river in the section are measured, namely the length of the main river and the area of the watershed. The unit hydrograph is calculated using the Nakayasu synthetic method. Peak discharge in the unit hydrograph if multiplied by convolution with effective rainfall shows the maximum discharge load on that cross-section, while peak time indicates the time of evacuation in disaster mitigation.

The monthly design rainfall is calculated based on a 50 year return period with the frequency analysis method from Gumbel. Based on this rainfall, the discharge load calculated for each sub-district is also a monthly discharge. This monthly analysis is done so that flood observations can be analyzed in more detail with the behavior of the seasons. Indonesia is a tropical country with two seasons. The peak wet
season generally occurs in November, December, and January, while the peak dry season in June, July, and August. The table 1 shows unit hydrograph parameters of the Citarum river in each sub-district,

Table 1. Unit Hydrograph Parameters of Citarum River in Each Sub-District

| Sub-District Number | Sub-District Name | Qp (m³/s) | Tp (hour) | Tb (hour) |
|---------------------|-------------------|-----------|-----------|-----------|
| 1                   | Majalaya          | 6.04      | 3.69      | 35.00     |
| 2                   | Solokan Jeruk     | 5.67      | 5.00      | 40.00     |
| 3                   | Ciparay           | 5.96      | 4.65      | 40.00     |
| 4                   | Bojongsoang       | 12.57     | 5.52      | 50.00     |
| 5                   | Baleendah         | 14.24     | 6.00      | 55.00     |
| 6                   | Dayeuhkolot       | 16.78     | 6.00      | 65.00     |
| 7                   | Katapang          | 19.23     | 7.60      | 75.00     |

Based on the table 1, the highest unit hydrograph parameter is at the farthest location from the upstream of the Citarum river, Katapang. This means that the discharge load from the Citarum river channel gets greater if the location is further away from the upstream. Figure 2 shows a map of sub-districts along the banks of the upper Citarum river which are the location of the study in this research.

Figure 2. Map of Sub-Districts Along the Banks of the Upper Citarum River

3.3. Inundation area in each sub-district

Determine the inundation area for each sub-district using the elevation of flood water levels obtained from the calculation of overland flow based on overflow discharge. One-dimensional unsteady river analysis was performed using the Hecras software. Inputs entered into the software are river cross-sections and flow hydrographs. Flow hydrographs are obtained by convolution multiplying between the effective rainfall and the unit hydrograph. Table of monthly calculation results for each sub-district is shown in table 2,
Based on Table 2 above, November and December are months that always occur flooding in each sub-district, while February is the month that does not experience. The highest inundation occurred in December in Solokan Jeruk and in March in Bojongsoang with a pool area of 92.2% of the subdistrict's area. Bojongsoang and Baleendah sub-districts always experience floods throughout the year, except in August. Katapang sub-district is the sub-district with the least frequency of flood events, those are only in March, November, and December.

3.4. Rainfall threshold in each sub-district

Threshold rainfall is calculated based on river discharge capacity in each district. This rainfall can be seen from the rainfall gauge that is published on the rainfall station display so that it is easily accessible both by the community and by stakeholders. The rainfall stations used for the analysis of each district differ according to station location. Representative rain stations are in the upstream sub-districts. The rain station which is located under the district certainly does not affect the discharge analyzed. Rainfall station for each sub-district is shown in table 3,
Table 3. Rainfall Threshold in Each Sub-District

| Sub-District Number | Sub-District Name   | $R_{ef}$ (mm) | Gauge Rainfall (mm) | Evacuation Time (hour) |
|---------------------|---------------------|---------------|---------------------|------------------------|
| 1                   | Majalaya            | 40.15         | 70.44               | 3.69                   |
| 2                   | Solokan Jeruk       | 40.69         | 71.38               | 5.00                   |
| 3                   | Ciparay             | 46.26         | 81.16               | 4.65                   |
| 4                   | Bojongsoang         | 30.97         | 54.34               | 5.52                   |
| 5                   | Baleendah           | 36.15         | 63.43               | 6.00                   |
| 6                   | Dayeuhkolot         | 36.30         | 63.68               | 6.00                   |
| 7                   | Katapang            | 31.67         | 55.57               | 7.60                   |

Based on Table 3, each sub-district has a different rainfall threshold and evacuation time. This difference shows that each sub-district has different characteristics in flood events [14]. This result can be detailed information for each sub-district for flood disaster mitigation. Overall, the threshold rainfall used was the lowest, so for the Bandung basin flooding the threshold rainfall is the threshold rainfall in Bojongsoang which is 54.34 mm and the evacuation time is 5.52 hours, with the water level elevation at 662 m MSL.

4. Conclusion
Urban flooding is different from river basin flooding because it requires a detailed analysis of overland flow in urban areas for controlling the flood. The overland flow analysis that is integrated with flood analysis in watersheds, becomes an integrated solution between watershed analysis and urban flood analysis. Threshold rainfall in each sub-district can provide flood alert information in more detail because floods that occur in the most vulnerable sub-districts will occur first so that a warning will be given at the earliest. In this study, Bojongsoang is the most vulnerable district with the lowest threshold rainfall of 54.34 mm.

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