Study of Mining Void Utilization Model as a Flood Control in Tropical Region

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Abstract

Flood is a major adverse event that commonly happens in the Indonesia region. Many factors might cause floods such as extreme weather, climate changes, and the effects of alteration in land cover. In Indonesia, mining is one of the largest industries that contribute to land cover change thus suggesting its part as the main cause of the flood in the disturbed area. However, this justification cannot be fully concluded due to the strong capability of the vast area from the mining to be used as flood control. Utilization of mining existing openings i.e. voids, as a temporary water flood storage, could reserve functions similar to a detention basin hence might control the peak flood discharge. This void may serves as a buffer for runoff in a certain time before the stream flows back into the natural stream, and supports to reduce the peak flood quantity depending on its volume capacity.

In this research, a study of the calculation model from flood discharge was carried out using the Nakayasu Synthetic Unit Hydrograph method. Comparative analysis of flood discharge was calculated for 2 scenarios, before and after utilization of void as a flood control. The model was simulated in 2 catchments with a different condition (catchment C1 and C2, consecutively).

Based on the analysis for void conditions that have a dead-depth storage of 0.7 times the maximum void depth, the peak flood discharge at catchment C1 with a 5-year return period rainfall decreases from 1028.24 m^3/s to 577.44 m^3/s (a decrease of 43.84% for daily rainfall), and 1440.32 m^3/s to 938.22 m^3/s (a decrease of 34.86% for bi-daily rainfall) after void utilization. Meanwhile, for void located in catchment C2, there was a decrease in peak flood discharge from 1015.07 m^3/s to 484.25 m^3/s (a decrease of 52.29% for daily rainfall) and 1386.84 m^3/s to 890.38 m^3/s (a decrease of 35.80% for bi-daily rainfall) after void utilization.

Above mentioned calculation and analysis suggests that the use of voids created by mining can reduce the peak flood discharge prior to being directed back into the natural stream, which can be used in flood control especially in tropical area.

Keywords: Mine Void, Flood Discharge, Storage, Nakayasu Hydrograph

Introduction

South Kalimantan is one of the provinces in Indonesia that often floods. In early 2021 of January, according to the BNPB of South Kalimantan, floods submerged 11 of the 13 districts/cities in this province. The leading cause is the occurrence of weather anomalies and high-intensity rainfall that occur in succession for some time, where the value of the bi-daily rainfall depth has exceeded the usual amount of monthly precipitation. However, in addition to the hydrometeorological conditions, the flood event can also be associated with changes in land cover, primarily related to the presence of mines.

There are two large sedimentary basins in South Kalimantan Province, namely Barito and Asam basins, which contain various rock formations, including several coal-bearing formations, hence numerous industries and mining activities are found in the area. One of the characteristics of coal mining activities is the alteration in land and the formation of void (Tuheteru, *et al*. 2021). However, naturally, the existence of a mine in an area can be used, including for flood control. Voids or pit lakes (for the mined-out area which has been filled with water) can be used to accommodate runoff and excess water flow to reduce the runoff and flood discharge that would otherwise go directly into the river.

This research aims to simulate a void model for use in flood control using the Nakayasu Synthetic Unit Hydrograph method. Comparative analysis of flood discharge was calculated for two scenarios, before and after utilization of void as a flood control.

Methods

Study Area

This study is conducted in an area within South Kalimantan Province, one of the provinces in Indonesia with the largest coal reserve and extensive coal mining operation. Mine voids were often left as legacies of coal mining, which extensively spread in the province. Furthermore, this province has high annual rainfall (more than 2000 mm/year) and is prone to flash-flooding events, especially in extreme and low-lying areas. The study area consists of 2 main catchments, catchment C1 and catchment C2. Mine voids are located near the outlet of each catchment, Void-1 and Void-2, respectively. The location of the study, catchment area, and voids is shown in Figure 1

Unit Hydrograph using Nakayasu

There are several methods of calculating peak flood discharge and runoff function over time for ungauged catchments (Sivapalan, *et al*, 2009), including the hydrograph unit method (Seibert and Beven, 2009). In this study, the Nakayasu unit hydrograph will be used since this method is suitable for estimating the runoff of areas ranging from 30 km^2 to 30,000 km^2. Nakayasu has investigated unit hydrographs in Japan and provided a set of equations to calculate the peak discharge of a unit hydrograph which is formulated as follows (Safarina, 2011):

$$Qp = \frac{C \times A \times R_0}{3{,}6(0.3T_P + T_{0.8})}$$

Where:

Qp : peak flood discharge (m^3/s)

C : runoff coefficient/watershed characteristic coefficient

R_0 : rainfall depth (mm)

A : catchment area (km^2)

Tp : time to peak (hour); T*p*= *tg* + 0,8 × *Tr*

Tg : time lag (hour), Tg = 0,4 + 0,058 × *L*

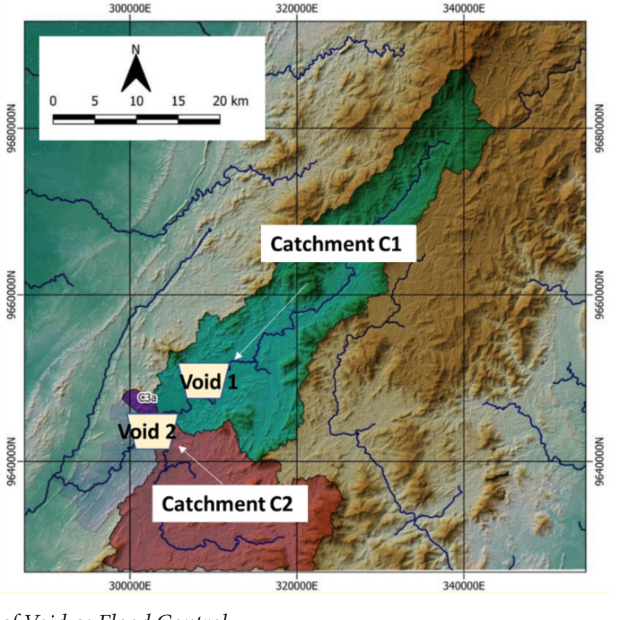

Figure 1 *Study Area of Void as Flood Control*

L : Length of stream (kilometers)

Tr : duration of effective rainfall (hour), Tr = 0.85×Tg

$T_{0,3}$: time for 30% peak (hour), $T_{0,3} = \alpha \times Tg$

α : alpha coefficient, ranging from 1.5 - 3.0 (in this study = 1.50)

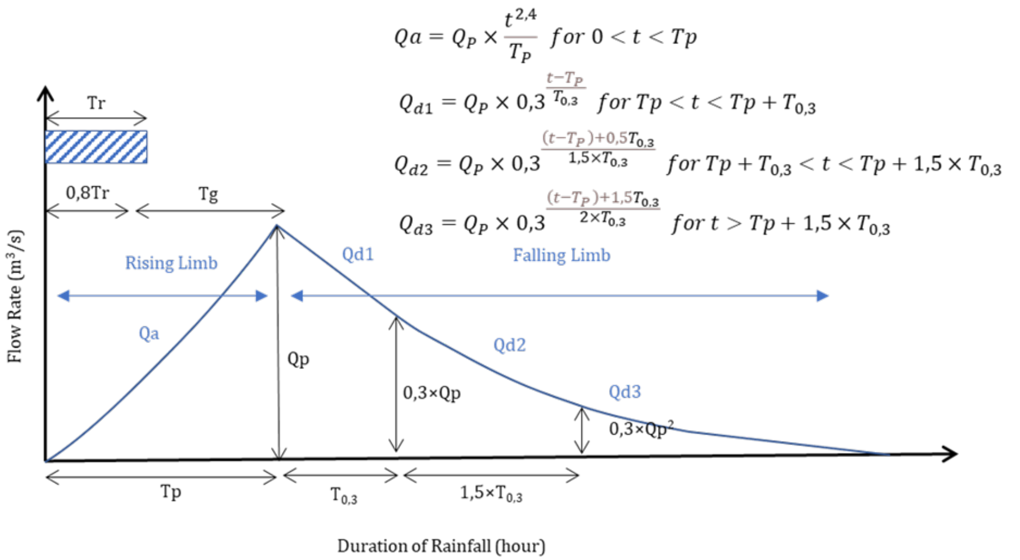

***Figure 2** Nakayasu Hydrograph and The Calculation Method*

Nakayasu also gives several equations to calculate the ordinates forming a hydrograph. The unit hydrograph of Nakayasu consists of 4 sections: rising limb (Qa), Falling Limb-1 (Qd1), Falling Limb-2 (Qd2), and Falling Limb-3 (Qd3). The equation can be written as follows:

Water Balance and Hydrograph

Water balance and flood hydrograph is used to evaluate the peak flood rate and possibility of void (for the mined-out area which has been filled with water) can be used to accommodate runoff and excess water flow to reduce the runoff and flood discharge that should go directly into the river. In this study, it is assumed that void will contain all runoff discharge from initial rainfall events up to its full capacity and thereafter all the discharge will be from runoff discharge.

Data and Analysis

Rainfall at Extreme Events

To simulate peak flow from runoff for each catchments, extreme rainfall events need to be calculated, as an input for hydograph calculation. Daily rainfall and bi-daily rainfall depth in milimeters and their associated return period and probability of exceedance is shown in Table 1.

***Table 1** Extreme Rainfall Events*

Return Period (year)	Probability of Exceedance	Daily Rainfall (mm)	Bi-Daily Rainfall (mm)
1.03	0.97	62.00	69.8
1.95	0.51	99.10	128.7
2.00	0.50	99.95	130.5
5.00	**0.20**	**118.04**	**161.4**
10.00	0.10	121.80	169.7
31.00	0.03	145.00	224.4

Daily rainfall and bi-daily rainfall are used in this study since most of extreme rainfall events are occurred within 1 day and 2 consencutive days. In this study, return period of 5 years (probability of exceedance 20%) will be used in subsequent analysis.

Table 2 Catchment Geometrical Parameter

Catchment ID	Area	Natural Stream Length	Highest Point Elevation	Lowest Point Elevation	Elevation Difference	Slope
	A	L	Z1	Z2	dZ	S
	km²	km	mdpl	mdpl	m	m/m
C1	544.20	72.04	305	46	259	0.36
C2	344.75	39.42	155	46	109	0.28

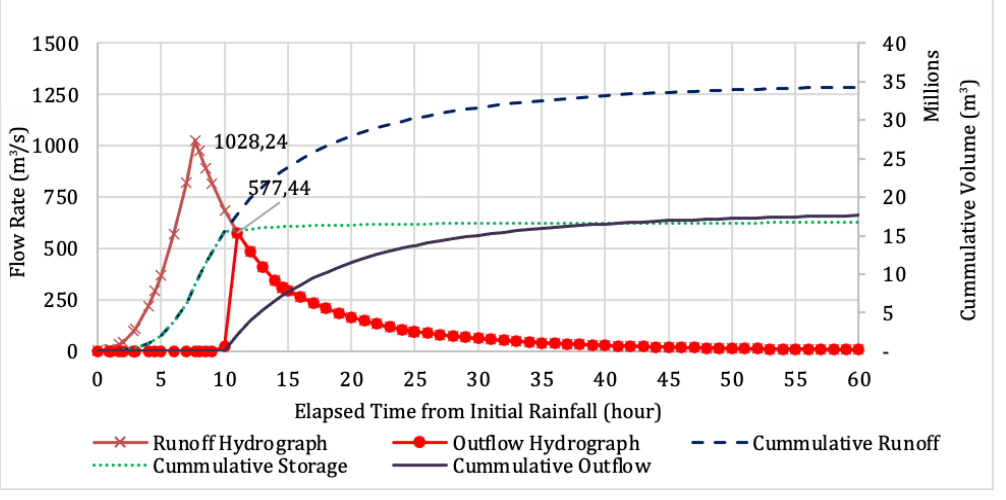

***Figure 3** Hydrograph of Void located in catchment C1 (Daily Rainfall, 5-year return period)*

Catchment Geometrical Parameter

Calculations of catchment areas (Catchment 1 and Catchment 2) and their geometrical parameter used in hydrograph calculationis shown in Table 2.

Void Storage

Two voids are used as research objects, voids V1 (located in C1) and V2 (located in C2). Each void has different storage volume of at least 17 000 000 cubic meters and 10 400 000 cubic meter, respectively. The voids storage volumes are calculated by assumption that 30% of total void volume is available for storage.

Hydrograph Calculation

Calculation and analysis of the flood hydrograph are taking place using two scenarios: 1. Runoff Hydrograph using Daily Rainfall, 5-year return period and 2. Runoff Hydrograph using Bi-daily Rainfall, 5-year return period. Both scenarios include a hydrograph of conditions without void utilization as flood control.

Hydrograph Results

The peak flood discharge at catchment C1 with a 5-year return period rainfall decreases from 1028.24 m^3/s to 577.44 m^3/s (a decrease of 43.84% for daily rain), and 1440.32 m^3/s to 938.22 m^3/s (a reduction of 34.86% for bi-daily rainfall) after void utilization as shown in Figure 3 and Figure 4. Meanwhile, for void located in catchment C2, there was a decrease in peak flood discharge from 1015.07 m^3/s to 484.25 m^3/s (a reduction of 52.29% for daily rainfall) and 1386.84 m^3/s to 890.38 m^3/s (a reduction of 35.80% for bi-daily rain) after void utilization as shown in Figure 5 and Figure 6.

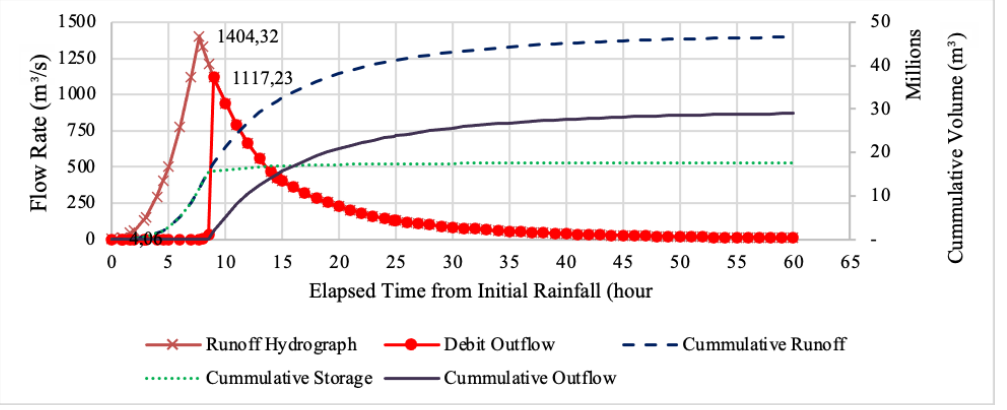

Figure 4 *Hydrograph of Void located in catchment C1 (Bi-daily Rainfall, 5-year return period)*

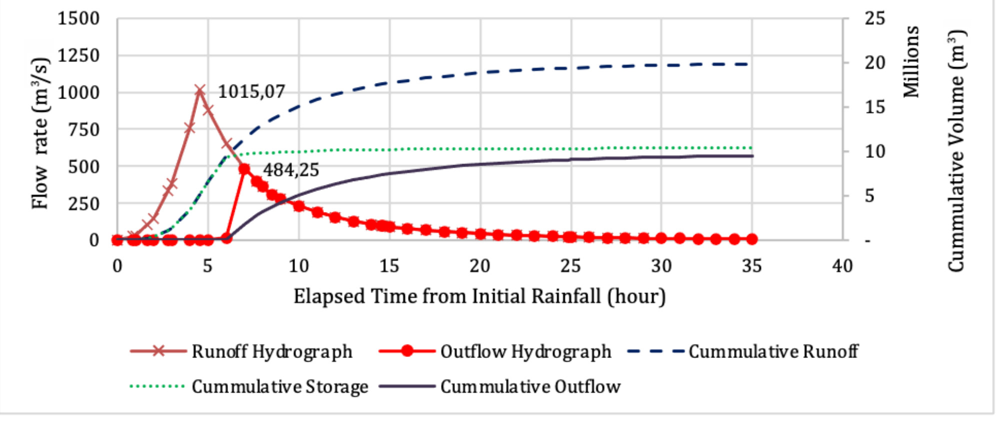

Figure 5 *Hydrograph of Void located in catchment C1 (Daily Rainfall, 5-year return period)*

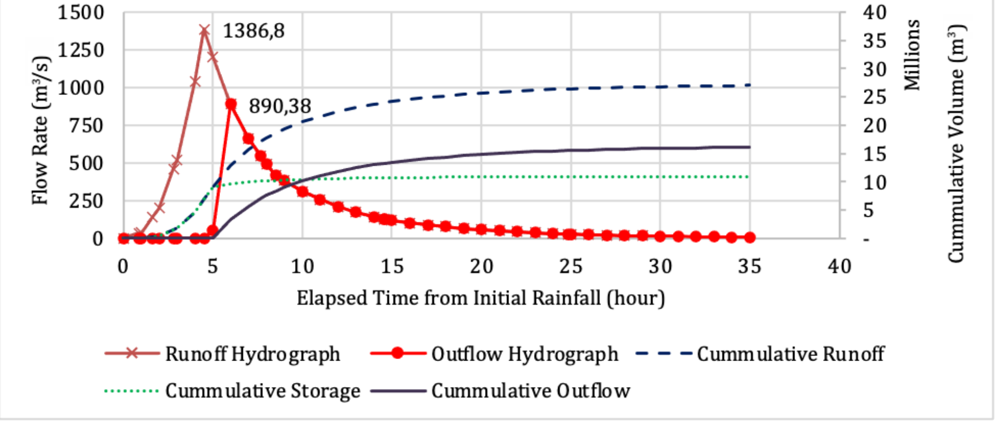

Figure 6 *Hydrograph of Void located in catchment C2 (Bi-daily Rainfall, 5-year return period)*

Conclusions

In addition to cutting and decreasing peak discharge, the use of voids in storing water will also shift the delay time of the hydrograph formed. This significant decrease in flood discharge occurs because all the initial inflow discharge will be accommodated directly in the void, and no discharge will come out until the water level in the void is still below the basic elevation of the open channel. The water will come back out of the void when the water level in the void has passed the runoff point and flows out through the drainage channel in the form of an open channel. The output discharge will have a value that is proportional to the water level as it passes through the open channel. However, if the discharge that enters the void is still of large value, then in this condition, the outflow that flows is the same value as the inflow discharge that enters the void.

Acknowledgements

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