Review on Co-factors Triggering Flash Flood Occurrences in Indonesian Small Catchments

A Zain1, D Legono1,*, A P Rahardjo1, R Jayadi1

1Civil and Environmental Engineering Department, Universitas Gadjah Mada, Yogyakarta, Indonesia

*Corresponding author: djokolegono@ugm.ac.id

Abstract. Flash flood is defined as "a flood of short duration with a relatively high peak discharge," which leaves little time to take action to reduce property damage and the risk to life. Flash floods occur not only because of heavy rainfall but some co-factors that can trigger it. This study aims to determine the co-factors that trigger the flash flood. Observations are carried out using a descriptive-qualitative approach of five small catchments in Indonesia, namely Bahorok Catchment (Langkat, North Sumatra), Kalijompo, and Kalipakis Catchment (Jember, East Java), Nasiri Catchment (Western Seram, Maluku), Wasior Catchment (Wondama Bay, West Papua). The dominant co-factors are related to rainfall IDF, morphological characteristics (slope, channel properties, flow pattern), geological conditions (rock, soil, structure, geohydrology), catchment conditions (vegetation, land use). Flash floods generally occur due to landslides in the upstream part of the river. Debris consisting of water, rock, and tree trunks can stem the river's flow and form natural dams. In five flash flood cases under investigation, the causes of a flash flood triggered by heavy rainfall and the morphological characteristics are 60% and 40%, respectively. The quantitative measure of each co-factor that triggers flash floods is essential for further research to identify flash flood symptoms.

Keywords: Co-factors, trigger, flash flood, small catchment

1. Introduction
Flash floods occur in various regions in Indonesia. The leading cause of flash floods in the hydrometeorological condition, which is heavy rainfall. Flash flood is defined as a flood event with a short duration and high discharge [1]. Flash floods have a high concentration suspended sediment flow type that causes the flow capacity to carry tree trunks, vegetation, and building parts. The great and fast release of water energy makes the flow highly destructive, causing much damage and loss of life. Flash flood has a socio-economic impact, namely massive and rapid damage, loss of property, especially to damaged infrastructure, and residential buildings requiring high rehabilitation costs. In addition, damage to infrastructure buildings can isolate a residential area. As a result, the costs for evacuation and delivery of aid are difficult and expensive. In the long term, the loss of their livelihoods causes economic paralysis of the communities affected by the flash flood. A small catchment is defined as a catchment size of <100,000 ha [2]. This study aims to determine the co-factors that trigger the flash flood for determining quantitative parameters that can be used as a reference in further discussions and identification. This research is conducted in five small catchments in Indonesia, namely Bahorok Catchment (Langkat,
North Sumatra), Kalijompo, and Kalipakis Catchment (Jember, East Java), Nasiri Catchment (Western Seram, Maluku), Wasior Catchment (Wondama Bay, West Papua) (Figure 1).

In 2003, a flash flood in the Bahorok Catchment killed 200 people and destroyed nearby buildings. This is estimated due to land use change, illegal logging, and the community's lack of understanding of the protection of flash flood hazards [3]. In 2006, a flash flood was followed by landslides in the Kalijompo and Kalipakis Catchment areas, resulting in hundreds of people being injured and damaging hundreds of houses [4]. Flash floods caused by the natural dam-break occurred in the Nasiri Catchment in 2012. It caused 19 people to die and disappeared, 37 people were injured, 163 houses were severely damaged, 4,438 houses were slightly damaged, and 105,768 people were suffered and displaced [5]. In 2010, a flash flood was like a tsunami that occurred in the Wasior Catchment, in which the mud was mixed with water due to the river's overflow. This flash flood claimed many lives and material losses [6]. The damage, losses, and deaths are so many, analyzing the co-factors that trigger flash flood needs to be done for mitigation and further research.

2. Materials and Methods

The research was conducted using a descriptive qualitative method of five small catchments in Indonesia. Descriptive-qualitative carried out based on literature reviews, comparative studies of reports, accredited publications. The visualization approach used to determine the catchment characteristics, namely area, slope, and 3D modeling, is made using Geographic Information System (GIS). The flash flood events that became the focus of this research was in the Bahorok Catchment (November 2, 2003), the Kalijompo and Kalipakis Catchment (January 1, 2006), the Nasiri Catchment (August 1, 2012), and the Wasior Catchment (October 4, 2010).

3. Results and Discussion

3.1. Flash Flood in Bahorok Catchment

On November 2, 2003 there was a flash flood in Bahorok covering Bukit Lawang Village, Timbang Lawan Village, and Samperaya Village, Bahorok District, Langkat Regency, North Sumatra (Figure 2). The Bahorok Catchment has an area of 15,705 ha. Flash flood in the Bahorok Catchment is caused by heavy rainfall, topographic conditions, soil, and rock structure characteristics. Precipitation before the flash flood was 200-300 mm for three consecutive days. The topography of the Bahorok Catchment has
a very steep slope with a slope of >40°. Many logs found in the flood flow occurred due to landslides in the upstream area.

The Baharok Catchment area is a fractured zone where extreme and active tectonic activities affect fracture and joint structures, thus forming steep slopes with weathered rock conditions (easily landslides occur). The fractured structure is dense, generally trending northwest-southeast, part of the Semangko Fault system along the Bukit Barisan Mountains. The fault structure is very active. It occurs a shift that is evident from the occurrence of weak earthquakes periodically (on average 1-2 times every year). Evidence of a fault can be seen around the Bukit Lawang tourism area, and there are fault fields and the Bahorok river, which bends sharply to the south. The cohesion or strength of brittle rock (crushed) to resist movement on steep slopes is naturally very weak, so soil or rock movements (landslides) can easily occur, especially if the slope is disturbed. Crushed and brittle rock will naturally slide so that the vegetation above it will be dragged away by the movement [3][7].

![Figure 2. Visualization of Bahorok Catchment](image)

3.2. Flash Flood in Kalijompo and Kalipakis Catchment

Jember Regency is one of the regencies in East Java that has the potential for soil movement and heavy rainfall. On January 1, 2006, there was heavy rainfall in the Kalipakis Catchment (107 mm/day) and the Kalijompo Catchment (216 mm/day), which caused the ground movement to develop into a flash flood (Figure 3). These two catchments are Kalipakis Catchment (8,728 ha) and the Kalijompo Catchment (4,633 ha). As a result of this incident, 264 houses were washed away and damaged, 98 people died, dozens were injured, hundreds of hectares of rice fields were damaged, hundreds of houses were destroyed, six bridges were destroyed, nine check-dams were destroyed, other facilities, and infrastructure [8]. The worst areas were the Suci Village, Panti Village, and Kemiri Village, Panti District. Other areas that occurred landslides were Kemuning Lor Village (Arjasa District), Klungkung Village (Sukorambi District), and Panti Village (Panti District).

The soil movement in the study area is caused by the high level of rock weathering, heavy rainfall, steep slopes (>45°), vegetation factors, land use, and the presence of impermeable bedrock. It serves as a slip plane [4]. In hilly areas and steep river cliffs in the Arjasa area and surroundings, ground motion can occur. The ground movement causes the blockage of the river in the upstream area as a natural dam, resulting in a significant accumulation of water, then the natural dam break and becomes a flash flood.
3.3. Flash Flood in Nasiri Catchment

One of the flash flood cases in the Maluku islands was in Nasiri Hamlet. This hamlet is located on the coast flanked by two hills with a height of 260 meters and 370 meters. This hamlet was the area most severely affected by the flash flood on August 1, 2012, due to the collapse of the natural dam. The Nasiri River has a width of 8 meters and a catchment area of 1,052 ha (Figure 4). The impact caused by the flood was the collapse of almost all Nasiri Elementary School buildings and several houses. On that date, the Lohiatala Rain Station recorded rainfall of 225.2 mm/day. The results showed that the flash flood in the Nasiri was caused by two natural dams that collapsed at two different times. The first natural dam has a height of 7.55 meters collapsed at 09:52 AM with a peak flow of 83.58 m$^3$/s, while the second natural dam has a height of 8.91 meters collapsed at 02:24 PM with a peak flow of 54.16 m$^3$/s [5].

Figure 3. Visualization of Kalijompo and Kalipakis Catchment

Figure 4. Visualization of Nasiri Catchment
3.4. Flash Flood in Wasior Catchment

On Monday, October 4, 2010, the flash flood disaster in Wasior District, Wondama Bay Regency, West Papua Province, has caused many casualties and infrastructure damage. The disaster location was precisely in Rado Village, Sanduai, Wasior City, Mangurai, and Wondonawi, which are included in the Wasior District Area, Wondama Bay Regency, West Papua Province. The morphology of the Wondiboy Mountains has steep slopes with deep valleys. Materials flash flood swept through the District of Wasior, located in plain areas in the lower reaches of the mountains Wondiboy that destroyed human settlements and infrastructure in its path [6].

The morphology around the disaster site is the Wondiboy Mountains, which has a slope of 5–75°, an altitude of 1–2,150 masl, on the coast an alluvial plain with a slope of 0–5° and an altitude of 1–25 masl. The area of the Wasior Catchment is 1,157 ha. In an east-west direction, several rivers flow in a relatively parallel pattern in these mountain channels (Figure 5). The causes of soil movement are heavy rainfall of 179 mm/10 hours, fractured and easily crushed rocks, weathered soil that is thin and sandy with steep slopes, causing the material to move easily.

3.5. Analysis of Intensity Duration Frequency (IDF)

IDF analysis is carried out to determine how much time concentration, peak discharge, and rainfall intensity are in a certain return period. The calculation of rainfall intensity in the five catchments have been carried out using 5, 20, and 50 years return periods. Rainfall intensity (I) is the average rainfall (mm/hour) on a certain rainfall duration and with a chosen frequency. The general shape of the intensity – duration – rainfall curve is described in (Figure 6). From the calculations that have been made, the Bahorok Catchment has a time concentration of 171.5 minutes, and the peak discharge value of $Q_{5} = 757.8$ m$^3$/s, $Q_{20} = 902.1$ m$^3$/s, $Q_{50} = 924.6$ m$^3$/s. The maximum daily rainfall data in the Bahorok Catchment is obtained from [7]. The Kalipakis Catchment has time concentration of 90.63 minutes, and the peak discharge value of $Q_{5} = 371$ m$^3$/s, $Q_{20} = 409.7$ m$^3$/s, $Q_{50} = 429.4$ m$^3$/s. The Kalijompo Catchment has time concentration of 80.53 minutes, and the peak discharge value of $Q_{5} = 213.1$ m$^3$/s, $Q_{20} = 235.4$ m$^3$/s, $Q_{50} = 246.7$ m$^3$/s. The maximum daily rainfall data in the Kalipakis and Kalijompo Catchment is obtained from [9]. The Nasiri Catchment has time concentration of 49.88 minutes, and the peak discharge value of $Q_{5} = 93.9$ m$^3$/s, $Q_{20} = 127.1$ m$^3$/s, $Q_{50} = 148.1$ m$^3$/s. The maximum daily rainfall data
in the Nasiri Catchment is obtained from [10]. The Wasior Catchment has time concentration of 37.65 minutes, and the peak discharge value of $Q_5 = 152\ m^3/s$, $Q_{20} = 177.3\ m^3/s$, $Q_{50} = 191.7\ m^3/s$. The maximum daily rainfall data in the Wasior Catchment is obtained from [11].

![Typical Rainfall of Intensity Duration Frequency (IDF) Curve at Bahorok Catchment (a), Kalipakis and Kalijompo Catchment (b), Nasiri Catchment (c), Wasior Catchment (d)](image)

**Figure 6.** Typical Rainfall of Intensity Duration Frequency (IDF) Curve at Bahorok Catchment (a), Kalipakis and Kalijompo Catchment (b), Nasiri Catchment (c), Wasior Catchment (d)

### 3.6. Flash Flood Mechanism

Based on the review of flash floods in the five catchments, it can be seen that the mechanism for flash flooding is extreme rainfall that triggers landslides on steep slopes and drags trees, then this debris is blocked, and damming occurs (Figure 7). Debris consisting of water, rock, and tree trunks can stem the river's flow in some parts. Small catchments cause water to accumulate quickly in natural dams. Then the heavy rainfall causes the formed dam not to be strong enough to withstand the load and collapse. On the way, the material that flows downwards erodes and drags the rocks and trees in its path because it has a high volume and discharge. In the end, the volume of debris flow increases, causing a flash flood. The flow of debris in steep areas moves very quickly and has great erosion power, while in flat areas, the flow slows down and spreads widely. The energy or momentum of the debris flow in the plains is very large even though the speed is slowing because it involves a very large mass of material. Furthermore, anything in its path will be dragged downstream or to the coast.

The flash flood formation can be explained in (Figure 8) [12]. The sketch shows that the flash flood has a discharge above the dominant discharge with a short time duration. The flash flood formation is divided into three segments, namely: production channel, transportation channel, and alluvial or sedimentation channel. The Production channel is an area where flash flood material is still at the place where it was formed. The transportation channel is a flash flood flow displacement with a steep hydrograph and a short time. The alluvial or sediment channel is sedimentary material left by flash floods when discharge returns to normal.
Figure 7. Flash Flood Mechanism, River in Normal Condition (a),
Natural DAM Formed (b),
Natural DAM Break (c)
4. Conclusion

Flash floods are very destructive and cause many casualties due to not having time to evacuate at the incident. In addition, the flash flood that carries the material causes the damage to the building to get worse. The dominant co-factors that trigger flash floods in the research area are related to IDF of rainfall, morphological characteristics (slope, channel properties, flow pattern), geological condition (rock, soil, structure, geohydrology), catchment conditions (vegetation, land use). So far, only two co-factors have been considered as co-factors triggering the flash flood occurrence, i.e., the rainfall and the river characteristics. Other co-factors should accompany the flash flood occurrence and therefore still subject of interest. In five flash flood cases under investigation, the causes of a flash flood triggered by heavy rainfall and the morphological characteristics are 60% and 40%, respectively. The quantitative measure of each co-factor that triggers flash floods is essential for further research to identify flash flood symptoms.

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