Beam-Type Sabo Dam Performance in Trapping Woody Debris and Boulders in Debris Flows

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Abstract

The aftermath of the March 26, 2004 landslide that occurred within the upper Jeneberang River led to the accumulation of 300 million m3 of caldera wall debris. According to the South Sulawesi Pompengan River Basin Center (BBWS), approximately 80 million m3 of this material had entered the Bili-Bili reservoir by 2019. The hydrometeorological disaster on January 22, 2019, was caused by heavy rainfall of 300 mm/day, leading to a debris flow carrying boulders and wood debris. The investigation revealed that the sand pocket, originally designed to hold sediment of sand grains, has now surpassed its capacity due to the influx of boulders. Sabo dams constructed upstream have struggled to contain significant quantities of boulders, resulting in some of them being carried downstream as debris towards other structures. Not only have some sabo dams reached their maximum capacity, but several have also sustained damage from boulders measuring 1-2 meters in diameter. One potential solution to prevent the flow of boulders and wood debris downstream is the construction of beam sabo dams. These structures are designed to effectively retain such debris, thereby safeguarding the structures located further downstream. To assess the effectiveness of beam sabo dams in capturing a combination of boulders and wood debris, a comprehensive study is essential. This research aims to identify the debris flow parameters that influence the performance of beam sabo dams, establish the interrelationships between these parameters, and determine the optimal gap distance between beams to effectively trap debris flow carrying boulders and wood debris. The proposed research methodology will involve experiments with a physical model in a laboratory setting by utilizing a flume.

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1 Introduction

Sabo dams serve as critical sediment management systems that significantly contribute to the mitigation of debris flow hazards. These open-type dams are designed to permit the passage of water and specific sediment types to flow, while effectively trapping larger debris materials, thereby minimizing the potential damage from debris flows. The debris flow poses threats to infrastructure, the environment, and human safety. Notably, debris flows can transport not only substantial boulders but also driftwood, further complicating the risks they present. The present literature review aims to present a comprehensive analysis of the effectiveness of open-type dams in managing debris flows, drawing upon the findings of current studies.

The upper Jeneberang River contains about 300 million cubic meters of material from the caldera wall collapse due to a landslide on March 26, 2004. By 2019, the Pompengan-Jeneberang River Basin Center reported that 80 million cubic meters had been displaced into the Bili-bili reservoir, leaving a significant volume of debris upstream that poses a risk of mobilization and could threaten downstream water infrastructure.

To manage sediment flow from the Jeneberang River to the Bili-bili reservoir, 24 sediment control structures, including sand pockets, consolidation dams, and sabo dams, have been built. Seven closed-type sabo dams are used for upstream debris flow management. However, the sand pocket, which is intended to capture sand grains, has exceeded its capacity due to larger boulders, rendering the upstream sabo dams ineffective at retaining significant boulder quantities.

Previous studies on the upper Jeneberang River assessed sediment management and energy mitigation using a slit-type sabo dam (Haeruddin C.M., et al, 2018), focusing on debris flows of water and boulders. However, the river's upper now has many boulders 3 to 4 meters in diameter, and flooding often carries wooden debris with sediment. Therefore, further research is needed to evaluate the effectiveness of alternative open-type sabo dams in capturing larger boulders mixed with wood.

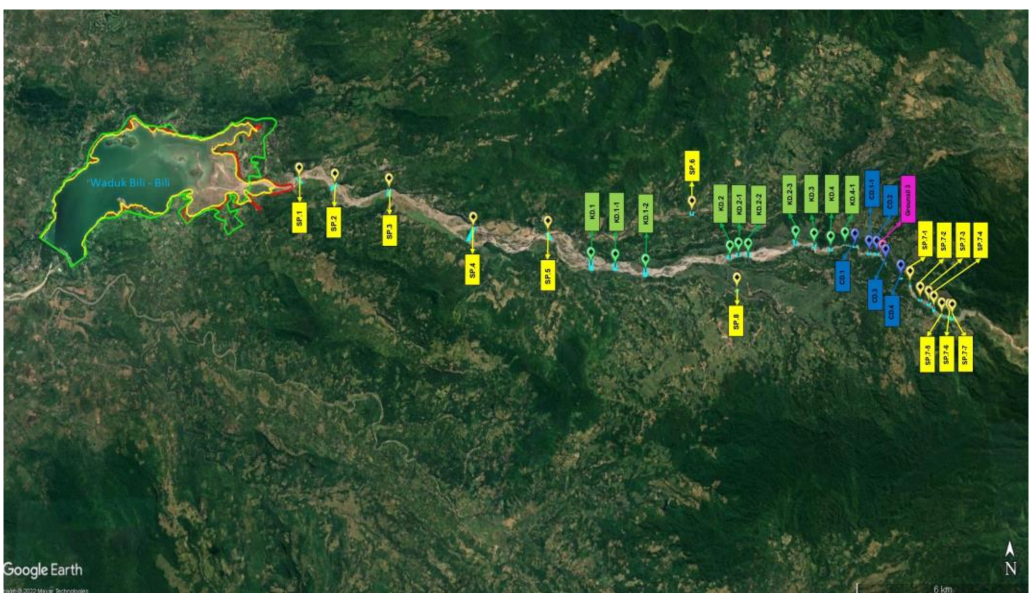

Figure 1: Location of Pompengan-Jeneberang River Basin Center waterworks construction

2 Research Method

This study employed a literature review to systematically collect and analyze existing research on debris and sabo dams. The study aims to enhance understanding of river dynamics and to identify prevailing theories and methodologies in prior works.

3 Characteristics of Debris Flow

A debris flow is a rapid movement of a mass composed of water, soil, rocks, and organic matter that travels quickly down slopes or river channels, often carrying large materials (Hungr, Morgan, and Kellerhals, 1984). The Jeneberang River has experienced multiple debris flows, damaging several nearby rice fields, according to the data of the Pompengan River Basin Center (BBWS). This has also resulted in significant sediment influx in the Bili-bili reservoir, accelerating its storage capacity reduction.

Figure 2: Sabo Dam 7.1 Jeneberang River

Debris flows are defined by their rapid and chaotic descent down slopes, moving large amounts of soil and rock while having the ability to transport considerable materials (Takahashi, 2007). The velocity can reach tens of kilometers per hour with the volume of transported material varying based on the influencing topography and rainfall. The Pompengan-Jeneberang River Basin Center in 2009 noted about 82,700,000 m³ of unstable sediment in the caldera, posing a risk for debris flows. Additionally, the caldera wall, 35 kilometers upstream from the Bili-bili reservoir, could collapse, with an estimated 72,500,000 m³ at risk.

4 Open-type Sabo Dam

Open sabo dams differ from closed ones by having openings or grates that allow water and fine sediments to pass while trapping larger debris like rocks and timber (Mizuyama, 2008). This design helps reduce stress on the dam and lowers the risk of failure during debris flows. Open sabo dams come in various types, including slit, grid, and beam types.

Okano et al. (2009) conducted modeling experiments to explore how different designs of sabo dams affect their effectiveness in managing various debris-flow scenarios, while Furuichi et al. (2008) assessed the performance of various sabo dam types, including open and closed types, in mitigating disaster risks in regions susceptible to debris flows. Both studies found that open-type sabo dams are particularly effective at controlling debris flows, as they effectively capture larger materials such as rocks and coarse soil while allowing water and finer particles to pass downstream, thereby reducing material accumulation behind the dam.

The velocity of debris flow is crucial for dam effectiveness. Mizuyama (2008) notes that grid-type sabo dams effectively reduce debris flow velocity and retain larger materials while allowing water to pass. Takahashi (2007) adds that the success of these structures depends on optimizing their design for the specific flow characteristics, topography, and debris size. Typically, these dams utilize metal or concrete grids of bars arranged vertically and horizontally to capture larger debris.

5 The behavior of Woody Debris and Boulder Mixture Carried by Flow through Sabo Dam

Debris flow, consisting of woody debris and boulders mixture, can significantly stress sabo dams, risking structural if not properly designed. Research by Maricar F. et al. (2011) has examined the behavior of these mixtures, focusing on the ability of sabo dams to effectively capture driftwood and sediment during debris flow events. In controlled lab tests, the dams retained about 70-80% of the driftwood and sediment mixture carried by the flow.

Maricar studied a beam-type sabo dam for debris flow management, whereas Xie et al. (2023) investigated a slit-type design. Xie's laboratory-scale study employed a flume to simulate the behavior of a mixture of wood, sediment, and water. Their findings showed that the slit-type dam effectively captured wood debris, regulated sediment flow, reduced flow velocity, and filtered out large woody debris. Additionally, Schalko and Weitbrecht (2021) examined beam-type sabo dams with oblique beams, finding that when large wood blocked 20% of the flow cross-section, then sediment transport decreased by 50%.

6 Conclusion

Research on debris flow in the Jeneberang River remains limited. The river's upper reaches have substantial caldera debris that could be mobilized downstream at any moment. Previous studies show that open sabo dams, such as grid and slit types, effectively capture driftwood and large materials, reducing downstream damage. Nevertheless, their effectiveness depends on proper design, placement, and maintenance. Further studies are needed to explore the interactions between wood and boulders during large-scale debris flows. Additionally, analyzing various beam gap performances in beam-type sabo dams could enhance their effectiveness in retaining mixed wood and boulder debris could also be studied.

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