Post-Earthquake Unstable Sediment Hazards in Mountain Watersheds: Case Study from the 2024 M_L 7.2 Hualien Earthquake, Taiwan

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Abstract: On 3 April 2024, an M_L 7.2 earthquake struck eastern Taiwan, triggering 18.2 ha of new landslides in the DF174 watershed (292 ha). Roughly 270,000 m^3 of unstable sediment stored on upstream. Loose slope material transformed into debris flows that endangered downstream villages and the culvert bridge. This study integrated field surveys with remote sensing: SAR-based change detection and InSAR track sub-centimeter slope deformation, while repeating UAV survey. UAV-derived DTM differencing indicates ~188,000 m^3 (≈70%) of the unstable sediment was deposited downstream, causing channel aggradation, overflow and confluence siltation. Using RAMMS, debris flow simulations under design rainfall scenario show that the 50-year event would rapidly aggrade the riverbed, inundate the culvert, bury the bridge, and potentially block the mainstream—posing extreme threats to downstream school. Mitigation scenarios suggest that lowering the spillway crest of the check dam and constructing additional dams substantially reduce debris-flow risk. Medium- to long-term resilience measures include installing solar-powered CCTV and radar-based, non-contact water-level gauges; conducting periodic dredging paired with UAV photogrammetric surveys to support early warning and community protection; and maintaining InSAR/satellite surveillance of residual unstable sediments upstream.

Keywords: ***Unstable sediment hazards, Co-seismic landslide, RAMMS, InSAR, Watershed management plan.***

Introduction

On 3 April 2024, an ML 7.2 earthquake struck eastern Taiwan, triggering more than 3,000 coseismic landslides in the mountain area. In the Sanzhan South River watershed, Debris flow SN: Hualien DF174, the PGA reached 400 gal and PGV 50~60 cm/s (Yang et al., 2025). Post-event satellite imagery mapped 18.2 ha of new slope failures and an estimated ~0.27 Mm^3 of unstable sediment stored on upstream headwater slopes.

The subsequent flood season exacerbate hazard conditions: rainfall-runoff mobilized the unstable sediment, generating debris flows to impact downstream, putting great risk to villages and an undersized culvert bridge (Figure 1).

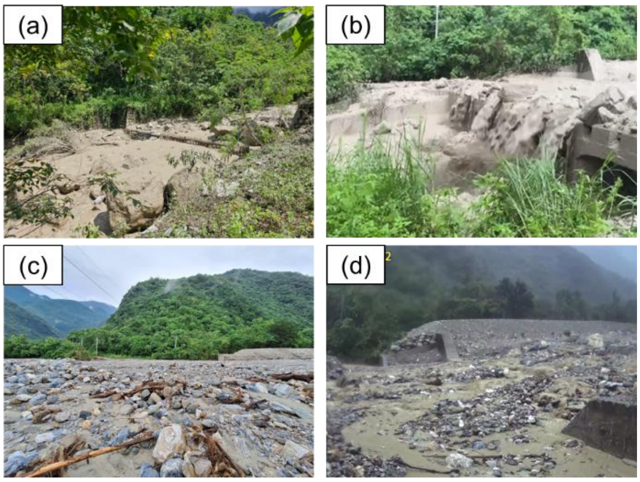

Figure 1, Debris flow events in the Sanzhan South River. (a) June 20, (b) June 29, (c) July 25 during Typhoon Gaemi and (d) Dec 31during Typhoon Kong-rey.

Methodology

Post-quake Field Survey

The Sanzhan South Creek watershed is underlain mainly by marble and gneiss. Prior to the earthquake, the competent rock mass meant few documented landslides. However, strong ground motion, amplified by local topography, triggered shallow failures near ridge crests.

UAV-derived DTM indicates that, before the Typhoon Gaemi, the sediment storage zone of the check dam had already accumulated roughly 75000 m^3 of sediment. After Typhoon Gaemi and Typhoon Kong-rey, DTM show roughly 188,000m^3 sediments stored in the downstream (Figure 2).

Solar-powered CCTV provided real-time monitoring and captured invaluable debris-flow footage. The culvert bridge, situated by the downstream of the check-dam spillway, was repeatedly buried during debris-flow events. Despite times emergency dredging campaigns, channel conveyance remained inadequate to withstand large unstable sediment.

Unstable sediments not only infilled the check-dam storage zone but also blocked the confluence, diverting the main channel toward the opposite bank and threatening the levee adjacent to Sanzhan Elementary School.

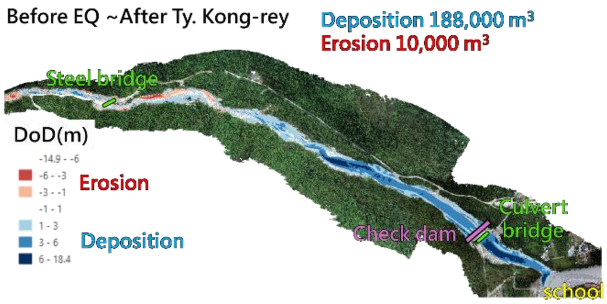

Figure 2, The erosion and deposition changes in the downstream area.

SAR Analysis

To rapidly map co-seismic landslides after the earthquake, this study applied SAR backscatter change detection between pre- and post-event SAR signal to delineate likely landslide area (Jung and Yun, 2020).

Post-earthquake analysis shows an increase in the number of coherent InSAR observation points, attributable to the exposure of freshly denuded landslide surfaces. InSAR time-series analysis further delineates clusters in the upstream and along the midstream that exhibit line-of-sight velocities greater than 3 cm/yr, highlighting ongoing erosion and sediment mobilization in the mid- to downstream.

RAMMS Simulation

In view of the high mobility of the unstable sediment in the Sanzhan watershed. RAMMS (2024): Debris Flows are conducted to quantify potential debris flow impacts. Under design rainfall scenarios, the 50-year event simulation predicts rapid aggradation that inundates the undersized culvert, buries the bridge, and blocks the main stem (Figure 3).

Figure 3, Max flow height during debris flow simulation in Q50 scenario.

Extreme scenarios further indicate that debris flow could threaten Sanzhan Elementary School. In the mitigation scenarios, lowering the check dam's spillway crest and constructing additional check dam could substantially reduce debris flow risk and the culvert bridge can be preserved.

Mitigation and Adaption

As the debris flow threatens the downstream village, the authorities have installed solar-powered CCTV and radar wave water-level gauges for real-time river monitoring. A long-term flood control project, validated through RAMMS simulation, is now at design stage. During reconstruction, medium-term resilience measures are strongly recommended includes periodic river-bed dredging paired with UAV surveys and continued InSAR/satellite surveillance of residual unstable sediments.

Conclusion

The April 3 earthquake in eastern Taiwan triggered extensive landslides in the DF174 watershed, depositing approximately 270,000 m^3 of unstable sediment. About 70% of colluvium material had been transferred downstream in the following flood season, causing significant aggradation. SAR analysis delights the rapid change in watershed.

Numerical simulations predict that a 50-year rainfall event would trigger a debris flow, posing an extreme threat to a downstream village. To mitigate this risk, the study recommends immediate engineering solutions, coupled with resilience measures including an early warning system, periodic dredging, and continuous satellite surveillance of the unstable sediment.

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