An Integrated Approach to Analyze Concurrent Debris Flow-Induced Transport Network Failures

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Abstract

Disasters triggered by extreme precipitation events i.e., landslides, debris flows, and floods cause devastating damages to lives, infrastructure, and the economy. Under a warming climate, precipitation extremes and the occurrence of debris flows are further expected to intensify. Driven by extreme runoff, the triggering of debris flows can be simultaneous. Their concurrent occurrence multiplies complexity in decision-making during emergencies. Despite advancements in geotechnics and network science, a systematic framework to analyze the impact of debris flows on road networks is lacking. While network science-based approaches work on large-scale, geotechnics-based damage assessments are done solely on a site-to-site basis. Here we develop an integrated approach to analyze the impacts of simultaneous debris flows on road networks. The approach includes a novel infinite slope-based one-dimensional numerical model that simulates runoff-induced erosion and a network science-based mathematical model for road failures. This study covers multiple catastrophic events of debris flows that occurred in different geological and climate settings i.e., post-earthquake, post-volcanic, and post-wildfire environments. We perform spatio-temporal simulations of initiation and runout of debris flows and calculate the damage caused on individual road segments. We validate the model results using metadata. Our results show even remote local disturbances caused by successive debris flows upstream may lead to complete cascading disruption of the network downstream. Our unified strategy opens avenues to understand the resilience of critical infrastructure networks against catastrophic debris flows.

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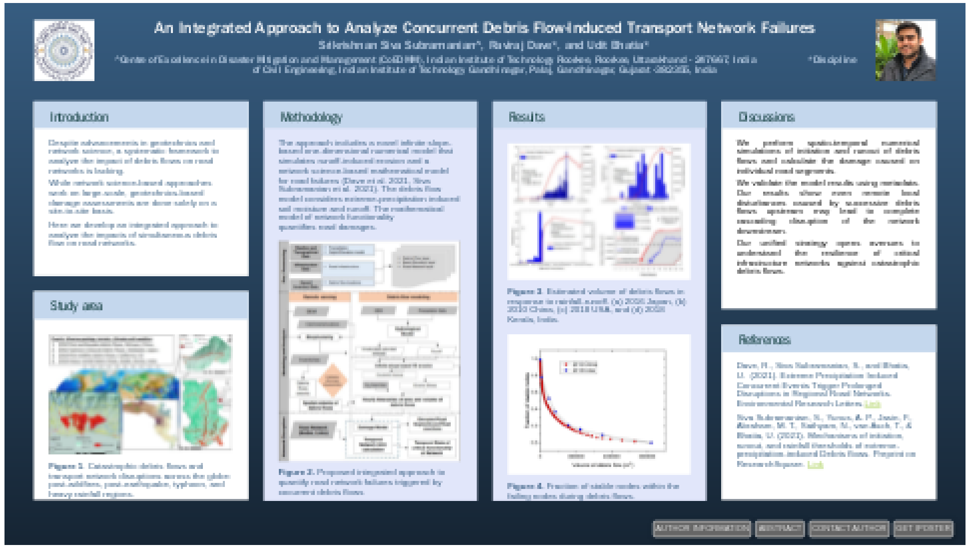

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INTRODUCTION

Despite advancements in geotechnics and network science, a systematic framework to analyze the impact of debris flows on road networks is lacking.

While network science-based approaches work on large-scale, geotechnics-based damage assessments are done solely on a site-to-site basis.

Here we develop an integrated approach to analyze the impacts of simultaneous debris flow on road networks.

STUDY AREA

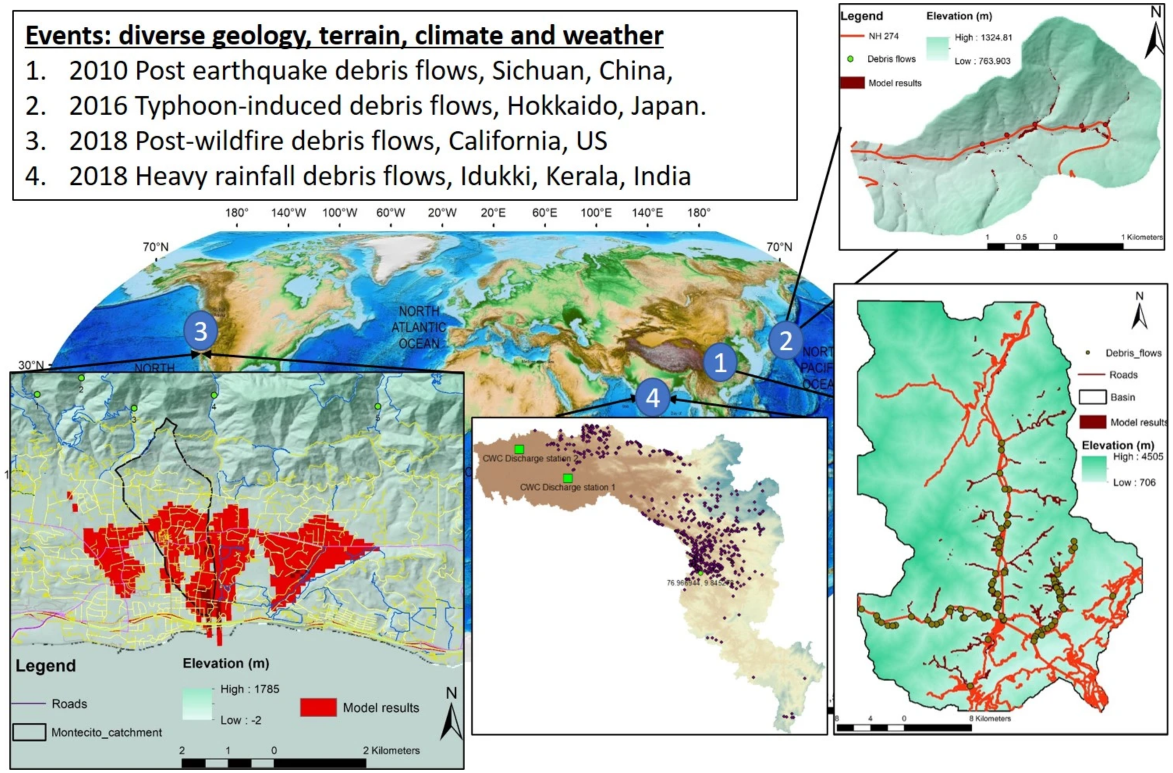

Figure 1. Catastrophic debris flows and transport network disruptions across the globe: post-wildfires, post-earthquake, typhoon, and heavy rainfall regions.

METHODOLOGY

The approach includes a novel infinite slope-based one-dimensional numerical model that simulates runoff-induced erosion and a network science-based mathematical model for road failures (Dave et al. 2021, Siva Subramanian et al. 2021). The debris flow model considers extreme-precipitation induced soil moisture and runoff. The mathematical model of network functionality quantifies road damages.

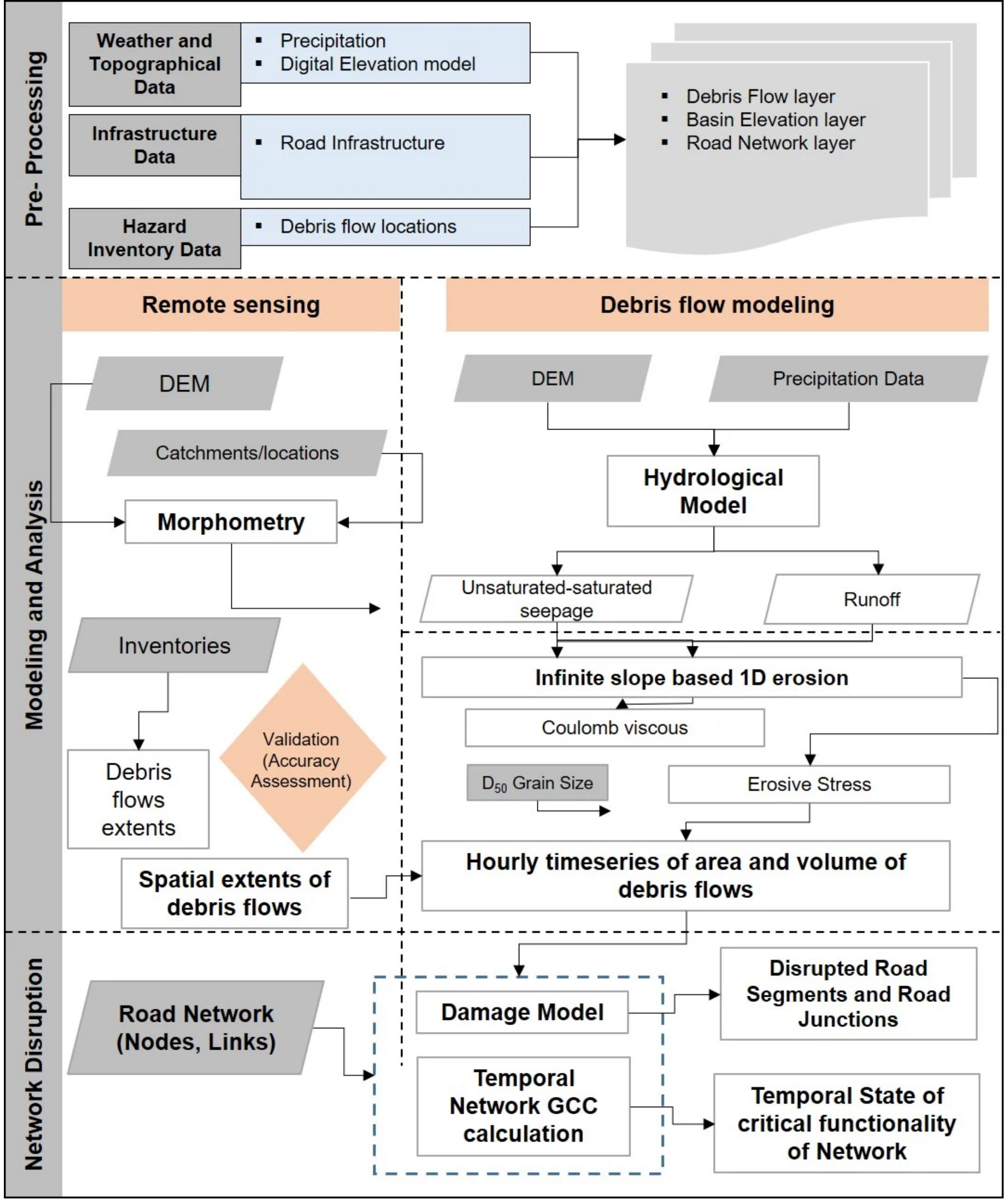

Figure 2. Proposed integrated approach to quantify road network failures triggered by cocurrent debris flows

RESULTS

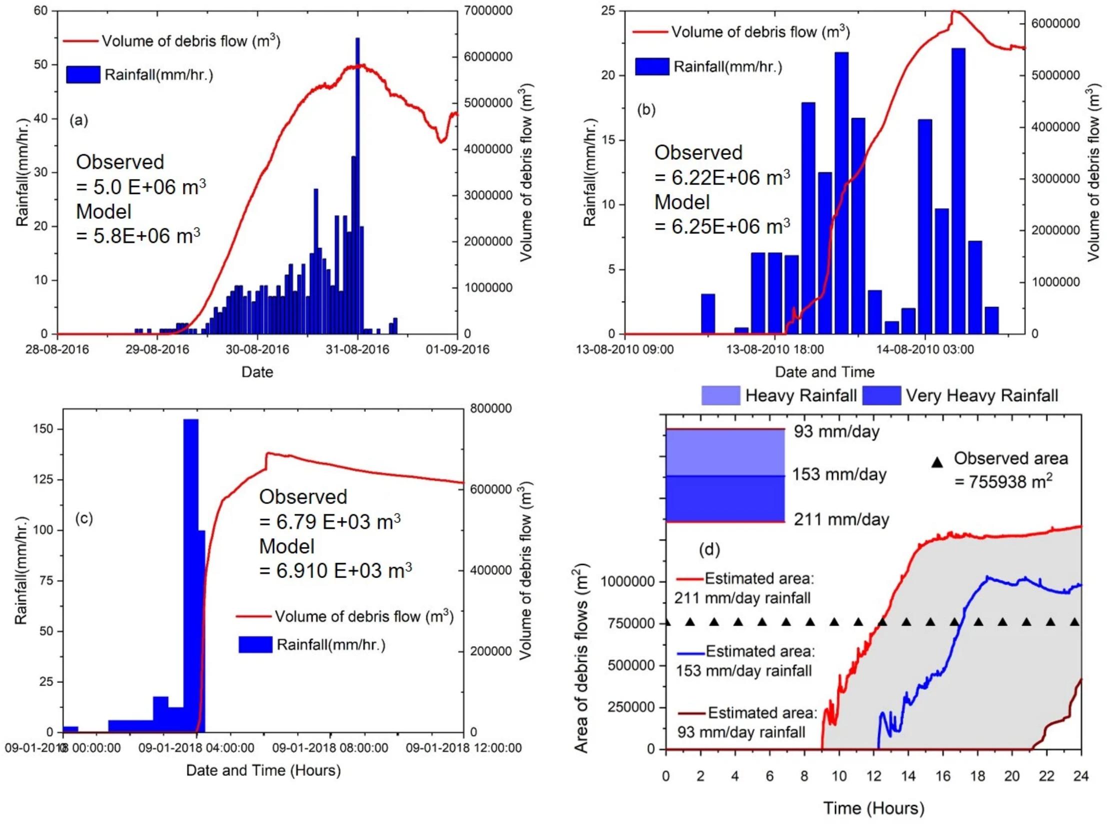

Figure 3. Estimated volume of debris flows in response to rainfall-runoff. (a) 2016 Japan, (b) 2010 China, (c) 2018 USA, and (d) 2018 Kerala, India.

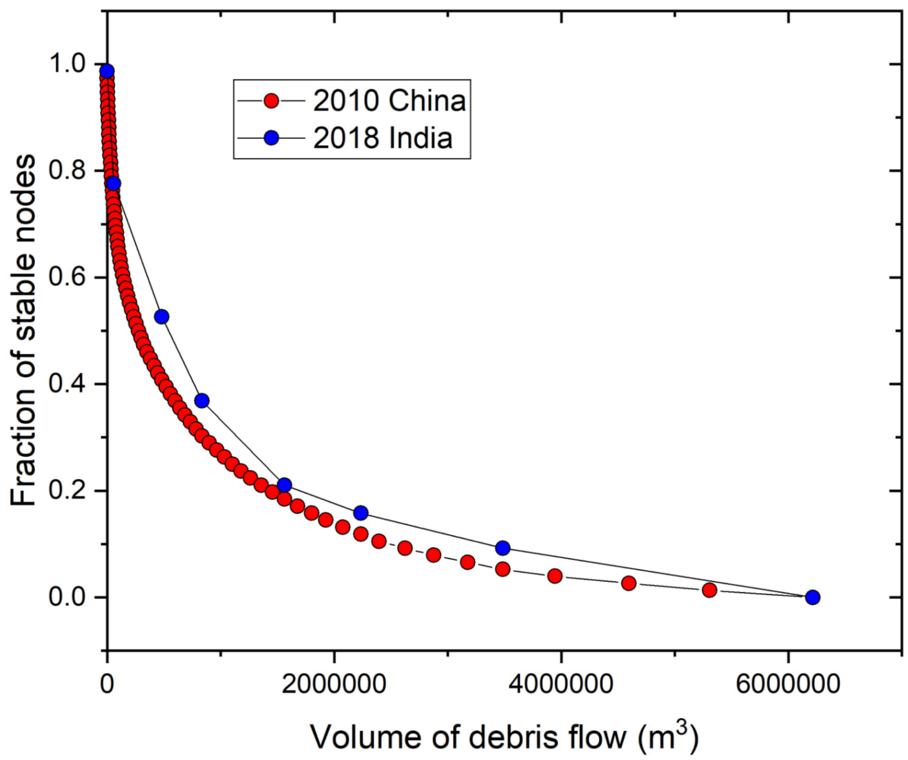

Figure 4. Fraction of stable nodes within the failing nodes during debris flows.

DISCUSSIONS

We perform spatio-temporal numerical simulations of initiation and runout of debris flows and calculate the damage caused on individual road segments.

We validate the model results using metadata. Our results show even remote local disturbances caused by successive debris flows upstream may lead to complete cascading disruption of the network downstream.

Our unified strategy opens avenues to understand the resilience of critical infrastructure networks against catastrophic debris flows.

REFERENCES

Dave, R., Siva Subramanian, S., and Bhatia, U. (2021). Extreme Precipitation Induced Concurrent Events Trigger Prolonged Disruptions in Regional Road Networks. Environmental Research Letters.Link (https://doi.org/10.1088/1748-9326/ac2d67)

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AUTHOR INFORMATION

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ABSTRACT

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