Scenarios based debris flow hazard and risk evaluation in the Hindukush Mountain ranges, north Pakistan

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In mountainous regions worldwide, the occurrence of debris flows poses significant threats due to their intense velocity and forces, massive volumes of material, viscous flow, and long travel distance, resulting in causalities, infrastructure destruction, and destruction of ecosystems. Like other mountainous regions of the world, northern Pakistan is prone to debris flows because of its unique geomorphology, complex terrain, glaciers, rainfall pattern, deforestation, climatic variations, strong seismic activity, and human activities. Consequently, debris flows pose a serious hazard to human settlements and the environment in this region, where they could have catastrophic effects. As a result, anticipating the possible deposition regions of future debris-flow events in this region is crucial for risk reduction, emergency response, urban planning, and the protection of human and environmental assets. The current study involves a comprehensive assessment of debris flow hazard, vulnerability, and risk at a local scale in the village of Khalti in Ghizer district, located within the Hindukush Mountain ranges of northern Pakistan. The analysis involved employing Rapid Mass Movement Simulation (RAMMS), a 3D numerical simulation based on the Voellmy model, to model runout behavior. This allowed the estimation of crucial flow intensity parameters such as runout distance, velocity, elevation, and pressure along the path of propagation. For runout simulation, a very high-resolution DEM (digital elevation model) is used, which is a mosaic of UAV (unmanned aerial vehicle) generated and ALOS PALSAR DEM. Utilizing optimized frictional parameter values, a hazard assessment was carried out for two different potential release areas, each characterized by varying initial volumes. A hazard evaluation was

conducted using optimum frictional parameter values for two definite triggering blocks, each with different initial volumes. Moreover, a consolidated analysis was conducted to ascertain the likely runout distance and other flow intensity parameters for a range of potential scenarios that could emerge in the future. These results were exported to ESRI shape files for computing hazard maps. To evaluate vulnerability, the analysis incorporates data on elements at risk within the accompanying fan, encompassing factors such as the number of individuals, buildings, roadways, bridges, and agricultural and orchard lands. Multi-criteria analysis techniques were employed to ascertain the relative importance of each parameter in evaluating the vulnerability of each element to the debris flow. Risk maps are generated through the integration of potential hazard and vulnerability maps. The findings conclude that the debris flow scenario, which combines two release areas, exhibits the highest flow volume, vulnerability, and risk to exposed elements compared to the other scenarios.