



A Review of Rainfall-induced Landslide Early Warning Systems in the Context of Early Warnings for All Framework

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This review is timely in offering a comprehensive assessment of rainfall-induced landslide early warning systems through the perspective of the United Nations *Early Warnings for All* framework. Existing rainfall-induced early warning systems are operational in a limited number of settings and are unevenly distributed geographically. Across different implementation levels, locally based systems are frequently fragmented and operationally burdensome. Most functioning systems prioritise debris flows and shallow landslides and rely predominantly on rainfall-based thresholds. Although susceptibility mapping is commonly included, explicit risk mapping remains largely neglected. Real-time monitoring using instruments such as piezometers and inclinometers is present in some systems but is constrained by substantial maintenance demands, which restrict wider deployment. Persistent challenges include limited data availability, the absence of harmonised forecasting methodologies, insufficient forecast validation, and the underutilisation of artificial intelligence, all of which undermine overall system robustness. Engagement with communities and relevant stakeholders is generally weak, and consideration of multi-hazard environments is rare. This review highlights a range of critical areas requiring further development and underscores the importance of collaborative, context-sensitive, and geographically adaptable approaches to advance reliable and inclusive landslide early warning systems at a global scale. While the *Early Warnings for All* initiative offers a potentially transformative framework, its application to landslide early warning remains constrained by funding limitations, inadequate localisation, and enduring regional inequalities. Without prioritising regionally tailored strategies and securing sufficient resources, the universal establishment of effective landslide early warning systems is unlikely to be achieved.