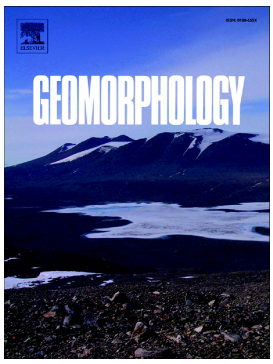


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# A progressive entrainment runout model for debris flow analysis and its application

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**Abstract:** A progressive entrainment model has been incorporated into an energy-based runout model to calculate the kinematic characteristics of debris flow. The progressive entrainment model considers both rolling and sliding motions of erodible material. To study the effect of the controlling parameters in the entrainment model, sensitivity analyses have been carried out by varying model parameters such as the internal friction angle of the debris, the basal friction angle of the channel, the turbulent flow coefficient, and the mean value of the probabilistic density function (PDF) for the resting angle. The results are evaluated by calculating the change of the maximum entrainment rate, the maximum frontal velocity, the final total volume, the longitudinal length of deposition, the maximum debris flow height, and the runout distance of the debris. The progressive entrainment runout model is sensitive to the characteristic particle size, basal friction angle and turbulent coefficient. Measurements from the 1990 Tsingshan debris flow, Hong Kong, China, are used to validate the model. Velocities at different channel sections estimated using the super-elevation method and entrainment depth are used to evaluate the simulation results. Comparing the results between simulated and observed maximum velocity and entrainment depth indicate that the progressive entrainment model together with the runout model can capture the erosion characteristics of the granular material. The results are also compared with that using a dynamic entrainment model. The results demonstrate that the progressive entrainment model provides a more realistic calculation of entrainment for this case compared with the dynamic entrainment model.

**Keywords**: debris flow; entrainment; Tsingshan debris flow; runout modeling; landslides, granular flow.