

Independent Sentinel-2 mapping and mobility context of the 10 September 2024 Lang Nu debris avalanche (Lao Cai, Vietnam): a reproducible open-data workflow

Hoa Thanh Thi Nguyen

ntthoa@hcmunre.edu.vn

Ho Chi Minh City University of Natural and Resources Environment: Truong Dai hoc Tai nguyen va Moi truong Thanh pho Ho Chi Minh <https://orcid.org/0009-0008-2630-3794>

Tran Thi My Hong

HCMUT: VNUHCM-Ho Chi Minh City University of Technology

Le Song Giang

HCMUT: VNUHCM-Ho Chi Minh City University of Technology

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Abstract

The 10 September 2024 Lang Nu debris avalanche, triggered by Typhoon Yagi, killed 67 people and is the deadliest landslide in Vietnam's recorded history. It has been described from field and UAV survey by Van Tien et al. (2025); our aim is complementary – to map the failure rapidly from open satellite data, measure its extent independently, and place its mobility in a global context. From cloud-free Sentinel-2 composites we computed the pre- to post-event NDVI difference, which delineates the landslide as a coherent vegetation-loss feature covering $0.66 \pm 0.04 \text{ km}^2$ and extending about 3.6 km (3.2–3.6 km across NDVI-difference thresholds of 0.25–0.40), about 86% of the 4,220 m runout reported by Van Tien et al. (2025). A multi-temporal Sentinel-1 analysis (three pre- and three post-event scenes on one orbit) independently detected the failure as a co-located VV-backscatter decrease averaging -1.5 dB within the mapped footprint (Appendix A). Using the reported volume and reach angle, the event is about 2.3 times more mobile than the global volume–reach mean of Scheidegger (1973), a ratio that stays above about 2 across volumes of $0.66\text{--}1.6 \times 10^6 \text{ m}^3$ and reach angles of $11.6^\circ \pm 2^\circ$. This high mobility is consistent with the mechanism reported by Van Tien et al. (2025) - entrainment of saturated older deposits - and with velocity-weakening friction (Lucas et al. 2014; Iverson et al. 2011). The workflow and its Earth Engine code are provided (Appendix B). Throughout, quantities we measured are kept distinct from those taken from the literature.

1 Introduction

Rainfall-induced landslides cause tens of thousands of deaths each decade, concentrated in monsoonal Asia (Froude and Petley 2018). Typhoon Yagi, which made landfall in northern Vietnam on 7 September 2024, produced several days of intense rainfall; the national multi-sector assessment records 320 deaths and 25 people missing across 26 provinces (MARD and UNDP 2024). Its most lethal single failure was the Lang Nu debris avalanche in Lao Cai province, which destroyed a hamlet and killed 67 people (Van Tien et al. 2025; ICL 2025).

Van Tien et al. (2025) described this event in detail from field and UAV survey, reporting its volume, runout, reach angle, geological setting and failure mechanism; the International Consortium on Landslides (ICL 2025) and a December 2024 field survey (Sato et al. 2025) add further observations. We do not repeat that work. Our purpose is to ask a different question: can such a failure be mapped rapidly and independently from freely available satellite imagery, and how does its behaviour compare with global mobility and rainfall benchmarks? The contribution of this paper is therefore threefold: (i) an independent map of the landslide from Sentinel-2, with an explicit uncertainty estimate; (ii) a reproducible open-data workflow, with the processing code provided, that can be applied to future events in the region; and (iii) a quantitative placement of the event's mobility against global relations, together with a practical suggestion that mapping stored older-landslide deposits could improve run-out risk assessment. Quantities that we measured are stated as such and are kept distinct from values reported in the cited literature, which are used only as reference context.

2 Study Area and Event

Lang Nu hamlet lies in Phuc Khanh commune, Bao Yen district, Lao Cai province, on the floor of a steep valley draining the north-eastern flank of Con Voi Mountain (22.11888°N, 104.52616°E; Fig. 1). The bedrock belongs to the metamorphic complex of the Con Voi range — foliated gneiss and schist parallel to the regional structural grain and the nearby Red River shear zone — mantled by a thick, clay-rich regolith, with the foliation dipping broadly with the north-eastern slope (Sato et al. 2025). The climate is monsoonal and typhoon-influenced. The failure began below a scarp on the north-eastern slope and travelled to the valley floor at about 05:55 local time on 10 September 2024, during rainfall that a nearby gauge recorded as 356.6 mm over 55 h (ICL 2025). All of these descriptive quantities are from the cited sources; they are summarised in Table 2 and used here as context, not as results of the present study.

Table 2

Reference data for the event taken from the literature. All values below are from the cited published sources (Van Tien et al. 2025; ICL 2025; Sato et al. 2025) and are used here as context; they are NOT results of the present study.

Quantity	Value	Source
Total / entrained volume	~ 1.1×10 ⁶ m ³ / ~0.3×10 ⁶ m ³	Van Tien et al. 2025
Runout / reach angle	4,220 m / 11.6° (H/L = 0.205)	Van Tien et al. 2025; ICL 2025
Scarp / valley-floor elevation	~ 800 m / ~150–200 m	Sato et al. 2025
Event rainfall	356.6 mm over 55 h	ICL 2025
Impact	67 fatalities; 37 houses destroyed	Van Tien et al. 2025
Failure mechanism / entrainment	rockslide → debris flow; entrained saturated old deposits	Van Tien et al. 2025; Sato et al. 2025

3 Data and Methods

3.1 Satellite data and processing

Two open sources were used (Table 1). Sentinel-2 Level-2A surface-reflectance imagery (Drusch et al. 2012) was processed by the authors in Google Earth Engine (Gorelick et al. 2017): cloud- and shadow-masked median composites were formed for a pre-event window (January–August 2024) and a post-event window (September–December 2024) at 10 m. Sentinel-1 C-band SAR (Torres et al. 2012) was analysed by the authors in Earth Engine using the analysis-ready GRD collection (calibrated, terrain-corrected VV backscatter in decibels). Over the site the usable scenes belong to relative orbit 128; we formed the temporal mean of three pre-event scenes (10, 22 August and 3 September 2024) and three post-event scenes (15, 27 September and 9 October 2024) on this single orbit, and computed the post-minus-pre backscatter change. Averaging three scenes per window suppresses speckle. Details and

results are given in Appendix A. The Copernicus DEM GLO-30 (European Space Agency 2021) provided topographic context; the along-path profile of Section 4.5 was sampled from the 30 m SRTM DEM (Farr et al. 2007).

Table 1
Satellite data processed by the authors.

Dataset	Acquisition / composite	Processing	Use
Sentinel-2 L2A	pre: Jan–Aug 2024; post: Sep–Dec 2024	GEE: cloud/shadow mask, median composite, NDVI	Δ NDVI mapping (Fig. 2) – this study
Sentinel-1 GRD (VV), orbit 128	pre: 10,22 Aug, 3 Sep; post: 15,27 Sep, 9 Oct 2024	GEE analysis-ready (calibrated, terrain-corrected dB); 3 + 3 temporal mean, change	Independent SAR change (Appendix A) - this study
Copernicus DEM GLO-30	static	terrain correction; profile	Context

3.2 Optical mapping of the landslide

A landslide strips vegetation, which appears as a drop in NDVI between the pre- and post-event composites. We computed Δ NDVI = NDVI_pre – NDVI_post; positive values indicate vegetation loss. Pixels above a threshold were retained, connected components were labelled with eight-connectivity, and the component containing the deposit was taken as the landslide. Its area was obtained by summing pixel areas (about 92 m² per pixel at this latitude) and its length as the major-axis extent of a principal-component analysis of the component's coordinates. To quantify the sensitivity of these measurements to the (arbitrary) threshold, the mapping was repeated for Δ NDVI thresholds of 0.25, 0.30, 0.35 and 0.40, and the spread was taken as the uncertainty. These are the authors' own measurements.

3.3 Mobility and rainfall context

To place the event in context we used the volume and reach angle reported by Van Tien et al. (2025) and ICL (2025) – not our own measurements – and compared the apparent friction coefficient H/L (the tangent of the reach angle; Corominas 1996) with the global volume–reach relation of Scheidegger (1973). Because that relation is more than fifty years old and based on a small dataset, we also refer to more recent compilations (Corominas 1996; Dade and Huppert 1998; Legros 2002; Lucas et al. 2014). A sensitivity analysis was carried out over volumes of 0.66–1.6×10⁶ m³ (the range implied by the reported ± 40% volume uncertainty and by a higher figure of 1.6×10⁶ m³ quoted in some reports) and over reach angles of 11.6°±2°. The triggering rainfall was compared with the global threshold of Guzzetti et al. (2008), following Caine (1980), and with regional (Lu et al. 2024) and Vietnamese province-scale (Tien Bui et al. 2013) thresholds.

4 Results

4.1 Optical map of the landslide (this study)

The pre- to post-event NDVI difference delineates the landslide clearly as a coherent, elongated vegetation-loss feature extending from the source area on Con Voi Mountain down to the hamlet (Fig. 2). The connected Δ NDVI-loss component containing the deposit covers $0.66 \pm 0.04 \text{ km}^2$ ($0.59\text{--}0.68 \text{ km}^2$ across the 0.25–0.40 thresholds) and extends about 3.6 km along its major axis (3.2–3.6 km over the same thresholds), several hundred metres wide and broadening toward the deposit. The mapped feature stays a single connected component across all thresholds from 0.25 to 0.40, with no fragmentation. Raising the threshold from 0.25 to 0.40 reduces the component area by about 14% (from $\sim 7,400$ to $\sim 6,400$ pixels, i.e. 0.68 to 0.59 km^2), consistent with the uncertainty range reported in Table 3; the main effect is to shorten the distal tip and narrow the track rather than to change the overall morphology. Scattered vegetation loss elsewhere in the scene corresponds to agriculture and minor changes and is excluded by the connected-component selection. The post-event composite contained abundant cloud-free pixels over Lang Nu, so optical mapping was feasible despite the cloudy storm period. These are our own measurements; to our knowledge no equivalent satellite-derived planimetric map of this failure has been published.

Table 3

Measurements of this study (from Sentinel-2 Δ NDVI) compared with the reported runout.

Measure (this study)	Value $\pm$ uncertainty	Reported (literature)	Note
Planimetric length (2-D NDVI map)	$\sim 3.6 \text{ km}$ (3.2–3.6)	4.22 km runout (Van Tien et al. 2025)	planimetric length of the vegetated track; not the total travel distance; along-slope DEM length $\sim 4.1 \text{ km}$ (§ 4.5)
Planimetric area (veg-loss)	$0.66 \pm 0.04 \text{ km}^2$ (0.59–0.68)	not reported	new; threshold 0.25–0.40
Feature form	elongated source-to-deposit track	rockslide $\rightarrow$ debris flow	consistent
<i>Note: the length in the first row is the planimetric (map-view) extent of the vegetation-loss feature, not the along-slope travel distance; the independent along-slope path length from the DEM is about 4.1 km (Section 4.5, Fig. 6), consistent with the reported 4,220 m runout.</i>			

4.2 Comparison with the reported runout, and its limitation

Our mapped length (about 3.6 km) is shorter than the 4,220 m runout reported from field and UAV survey by Van Tien et al. (2025), reaching about 86% of it. A plausible reason is that the distal part of the path lies over the settlement and bare deposit, where little vegetation remained to be lost; however, we were not able to verify this independently, because we did not have access to the Planet or UAV imagery used in the field studies. We therefore treat the 3.6 km as a lower bound on the disturbed length and report it with the threshold-based uncertainty above (Table 3). In the absence of independent high-resolution validation, this 3.6 km should be read as a conservative measure of the vegetated disturbed track, not as the total runout; the shortfall relative to the 4,220 m field runout is within the underestimation expected where the distal bare deposit and settlement carry no vegetation signal, and it is independently

bracketed by the 4.1 km DEM-based path length of Section 4.5. Independent validation against high-resolution imagery remains a limitation of this work.

4.3 Mobility context

Using the reported volume (about $1.1 \times 10^6 \text{ m}^3$) and reach angle (11.6° , giving $H/L = 0.205$), the Scheidegger (1973) relation predicts $H/L \approx 0.48$; the observed value is about 2.3 times lower, i.e. more mobile than the mean expectation for its size (Fig. 3). The result is stable under realistic uncertainties (Fig. 4): the ratio stays between 2.2 and 2.5 as the volume varies over $0.66\text{--}1.6 \times 10^6 \text{ m}^3$, and between about 2.0 and 2.8 as the reach angle varies by $\pm 2^\circ$; in every case it remains well above 1. This departure of about 0.37 in $\log_{10}(H/L)$ is large: it places the event well outside the typical scatter of such empirical volume–reach relations. We deliberately do not attach a formal probability (z-score) to it, because the residual statistics of Scheidegger (1973) are not published and any assumed scatter would be arbitrary; the claim of unusually high mobility therefore rests on the robust factor of about 2.3 and its sensitivity analysis (Fig. 4). The Corominas (1996) envelope gives a smaller factor of about 1.7–2. These comparisons should be read as indicative, and we stress that the volume and reach angle are reported values, not our measurements. More recent analyses attribute the excess mobility of large, water-charged flows to velocity-weakening friction and fluidisation (Legros 2002; Lucas et al. 2014), which is consistent with the mechanism reported for Lang Nu (Section 5).

4.4 Rainfall trigger

The reported rainfall of 356.6 mm over 55 h (mean intensity 6.5 mm h^{-1}) is far above the Guzzetti et al. (2008) global minimum intensity–duration threshold (about 0.4 mm h^{-1} at 55 h; Fig. 5). Regional thresholds for ASEAN countries (Lu et al. 2024) and province-scale thresholds for Vietnam (Tien Bui et al. 2013) are higher, but the event exceeded these as well. The plotted value is a cumulative-derived mean rather than a short-duration peak, so the comparison is indicative; on every reference the rainfall was extreme.

4.5 Along-path topographic profile (this study)

Sampling the 30 m SRTM DEM (Farr et al. 2007) along the centreline of the mapped feature - traced to the distal end of the deposit - the path descends about 616 m over roughly 4.1 km (Fig. 6). This 4.1 km DEM-based length is longer than the 3.6 km vegetation-loss length of Section 4.1 because the distal deposit and the settlement are bare and produce no NDVI signal; the DEM length is therefore an independent estimate of the full travel distance and agrees closely with the 4,220 m runout reported by Van Tien et al. (2025), whereas the 3.6 km NDVI length measures only the vegetated part of the track. The gradient is markedly non-uniform: the upper $\sim 1.8 \text{ km}$ is steep, locally exceeding 20 degrees and staying above the 11.6° degree reach angle of the event, whereas beyond about 1.8 km the bed flattens progressively to below 5 degrees, and to below 2 degrees along the distal kilometre. That a flow travelled across this long, very low-gradient reach - well below the slope at which dry debris would normally arrest

- is itself an independent, topography-based indication of unusually efficient momentum transport (Section 5).

5 Discussion

Our satellite mapping and the published morphometry together describe a rainfall-triggered failure that was unusually mobile for its size. We did not measure the mechanism ourselves; the explanation comes from the field studies. Van Tien et al. (2025) and Sato et al. (2025) report that, at a valley bottleneck, the flow eroded and entrained saturated deposits of older landslides, on the order of $0.3 \times 10^6 \text{ m}^3$. Such entrainment of wet bed material is a recognised cause of enhanced runout: overriding saturated sediment generates positive pore pressures that lower basal friction and drive a feedback in which mass, speed and momentum grow (Iverson et al. 2011; Iverson 2012), and, more generally, effective friction decreases with volume and velocity (Legros 2002; Lucas et al. 2014). The elongated, vegetation-stripped track we mapped, terminating at the valley-floor settlement, is consistent with this mechanism, although our data do not by themselves prove it; the along-path gradient we extracted from the DEM (Fig. 6) supports this picture - a steep, erosive upper zone feeding an anomalously long, low-gradient depositional reach - although full numerical run-out modelling would be needed to test the entrainment feedback quantitatively and is left for future work.

The value of the present study lies less in any single number than in the demonstration and documentation of a rapid, open-data mapping procedure. Optical NDVI differencing is a standard technique, and we make no claim of methodological novelty; what we provide is an independent map of a specific, high-profile failure, an uncertainty estimate for it, and a complete, runnable workflow (Appendix B) that others can apply immediately to the next event in the Vietnamese uplands, where cloud-free optical scenes are often available within weeks of a storm. The Sentinel-1 analysis (Appendix A) provides an independent confirmation from an active sensor: the multi-temporal VV backscatter decreases within the optically mapped landslide footprint (mean -1.5 dB , against a scene-wide mean of -0.3 dB), so the optical and radar signals coincide spatially despite the residual speckle of C-band amplitude in steep, vegetated terrain. This convergence of two independent sensors strengthens confidence in the mapped feature. Interferometric coherence, which we were not able to compute from the amplitude product used here, would sharpen the delineation further and is a natural next step.

Placed in a regional context, Lang Nu is severe but not unique: the mountainous provinces of Vietnam have repeatedly produced large rainfall-triggered failures during typhoons, including widespread landsliding during Ketsana (2009) and Molave (2020) in the central region (MARD and UNDP 2024) and documented events in Hoa Binh province (Tien Bui et al. 2013). What distinguishes Lang Nu is its mobility, which the field survey attributes to the stored, saturated valley fill. This suggests a practical addition to hazard assessment: susceptibility maps indicate where a slope may fail, but not how far the resulting flow may travel; identifying and mapping thick, saturated palaeo-landslide deposits – recognisable in the field and in high-resolution imagery – would improve run-out and exposure estimates for settlements on valley floors below steep, deeply weathered slopes.

The main limitations are the absence of independent high-resolution validation of the mapped extent, the residual noise in the C-band amplitude change (even after multi-temporal averaging), which limits the precision of the SAR delineation, and the reliance on reported (not measured) volume and reach angle for the mobility comparison. Each is stated where it arises, and each defines a clear next step.

6 Conclusions

We mapped the 10 September 2024 Lang Nu debris avalanche independently from open Sentinel-2 imagery. The pre- to post-event NDVI difference delineates a coherent vegetation-loss feature of 0.66 ± 0.04 km² extending about 3.6 km (3.2–3.6 km across thresholds), about 86% of the runout reported from field survey; an independent Sentinel-1 multi-temporal backscatter analysis detected the same feature as a co-located decrease in VV backscatter (mean – 1.5 dB within the mapped footprint). Using published volume and reach angle, the event is about twice as mobile as the global average for its size, a result stable under realistic uncertainties and consistent with the field-reported entrainment of saturated older deposits. These results do not replace the detailed field description of Van Tien et al. (2025); they show that open satellite data can map such a failure rapidly, they quantify its extent with an uncertainty estimate, and they provide a documented, runnable workflow for future events. Mapping stored older-landslide deposits, which controlled the runout here, is suggested as a practical addition to run-out risk assessment in the Vietnamese uplands.

Declarations

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Competing interests. The authors have no relevant financial or non-financial interests to disclose.

Author contributions. Nguyen Thi Thanh Hoa: conceptualization, methodology, software (Google Earth Engine processing), formal analysis, data curation, visualization, writing – original draft. Tran Thi My Hong: investigation, validation, data curation, writing – review and editing. Le Song Giang: methodology, supervision, resources, writing – review and editing. All authors read and approved the final manuscript.

Data availability. Sentinel-1, Sentinel-2 and Copernicus DEM data are openly available from the Copernicus programme. The complete Google Earth Engine scripts used to produce the NDVI-difference map and the Sentinel-1 backscatter-change map, together with the DEM-profile sampling code, are given in Appendix B and have been placed in a GitHub repository that will be made public and archived on Zenodo with a citable DOI upon acceptance; the derived maps are available from the corresponding author.

Ethics approval. Not applicable; the study used only open satellite data and previously published information, with no human participants or animals.

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Figures

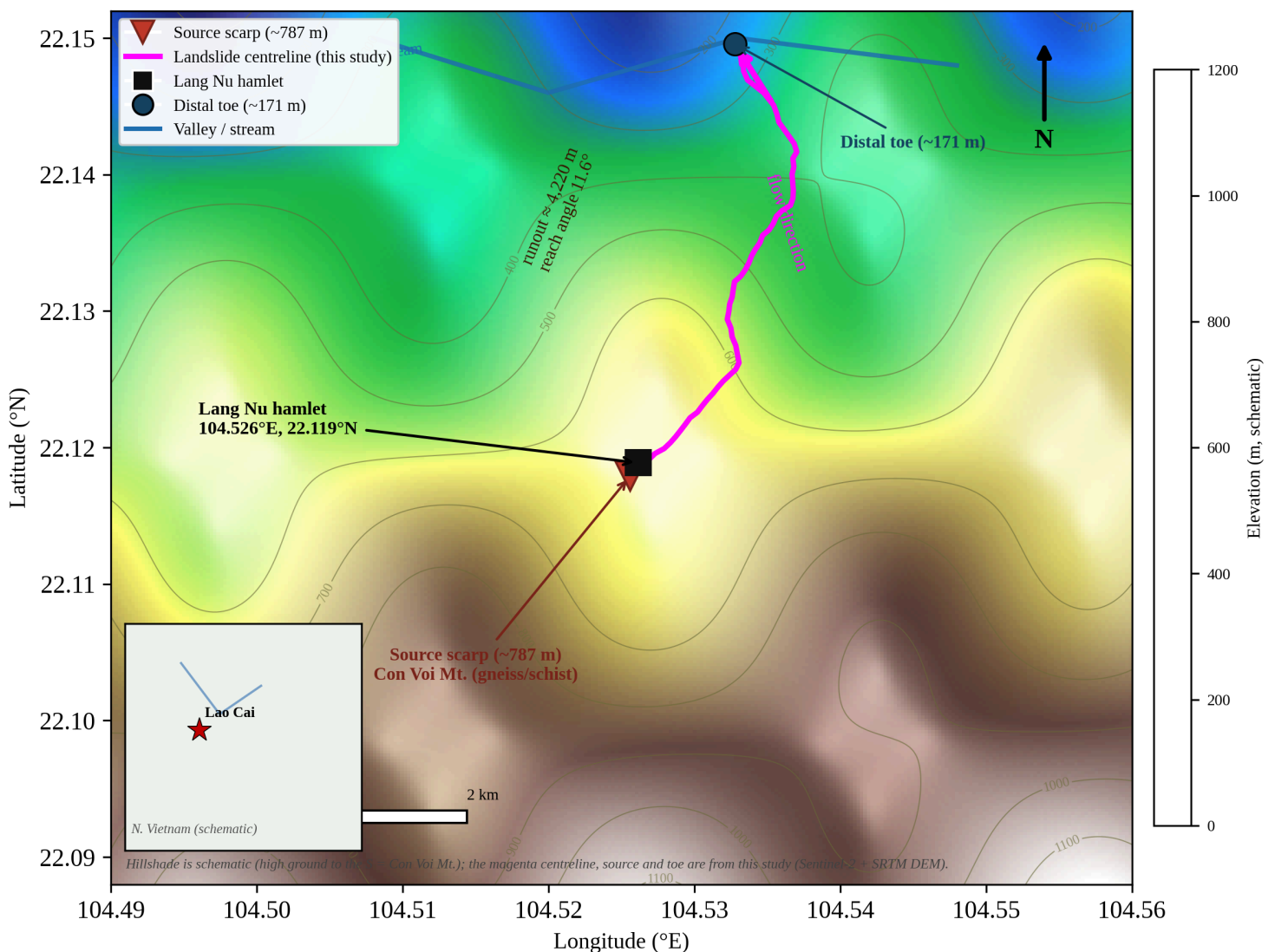


Figure 1

Site map of the Lang Nu landslide. The magenta line is the landslide centreline mapped in this study (from the Sentinel-2 NDVI-difference feature); the arrow gives the flow direction, from the source scarp (~787 m, Con Voi Mountain, gneiss/schist; red triangle, immediately above Lang Nu hamlet) down to the distal toe in the valley (~171 m; dark circle). The shaded relief is schematic, with high ground to the south; a scale bar, north arrow and a locator inset are shown. The centreline, source and toe are from this study (Sentinel-2 + SRTM DEM).

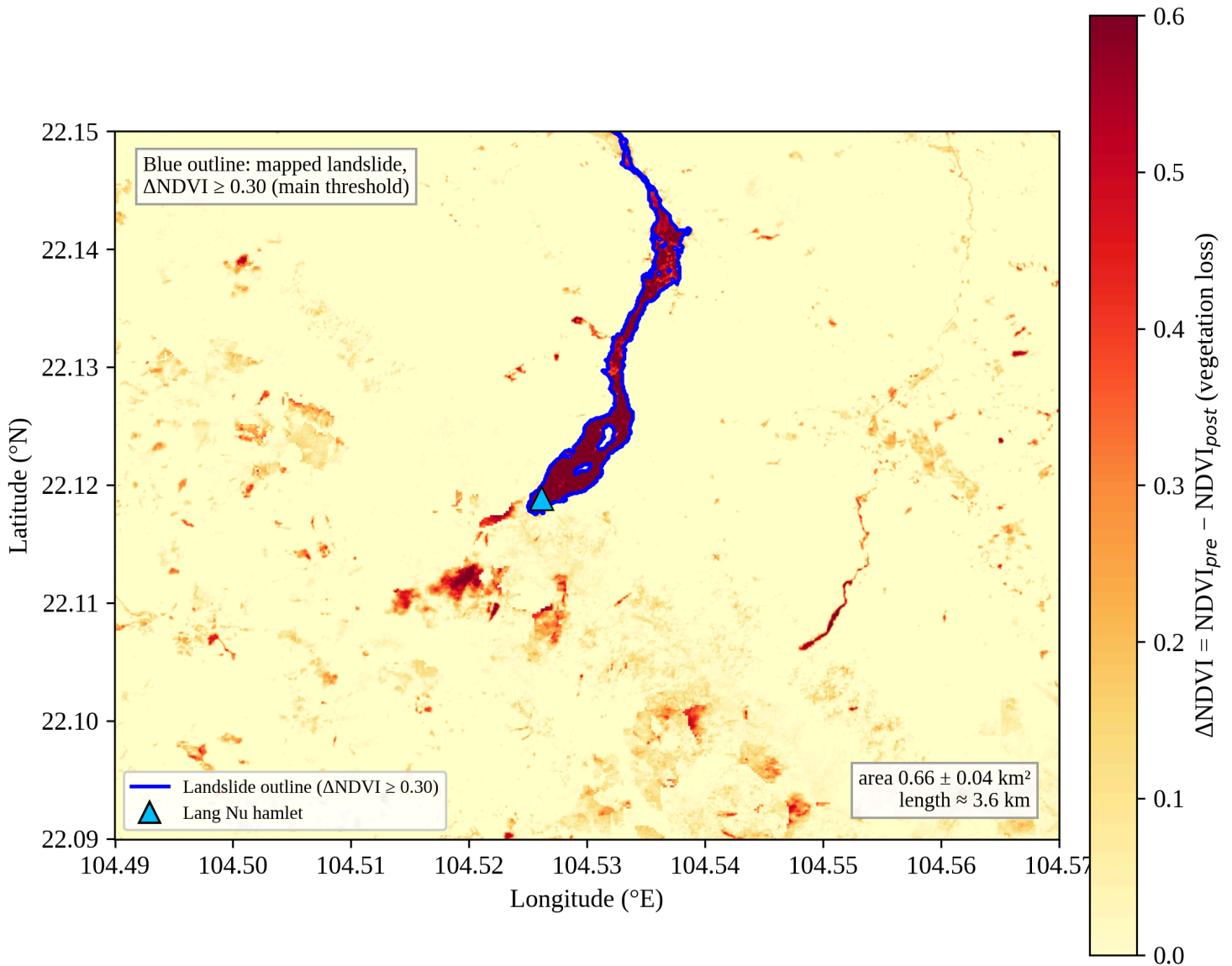


Figure 2

Sentinel-2 pre- to post-event NDVI difference ($\Delta\text{NDVI} = \text{NDVI}_{\text{pre}} - \text{NDVI}_{\text{post}}$; this study). The blue outline is the connected vegetation-loss component containing the deposit (the mapped landslide: $0.66 \pm 0.04 \text{ km}^2$; length about 3.6 km). Pre-event composite January–August 2024; post-event September–December 2024, cloud-free.

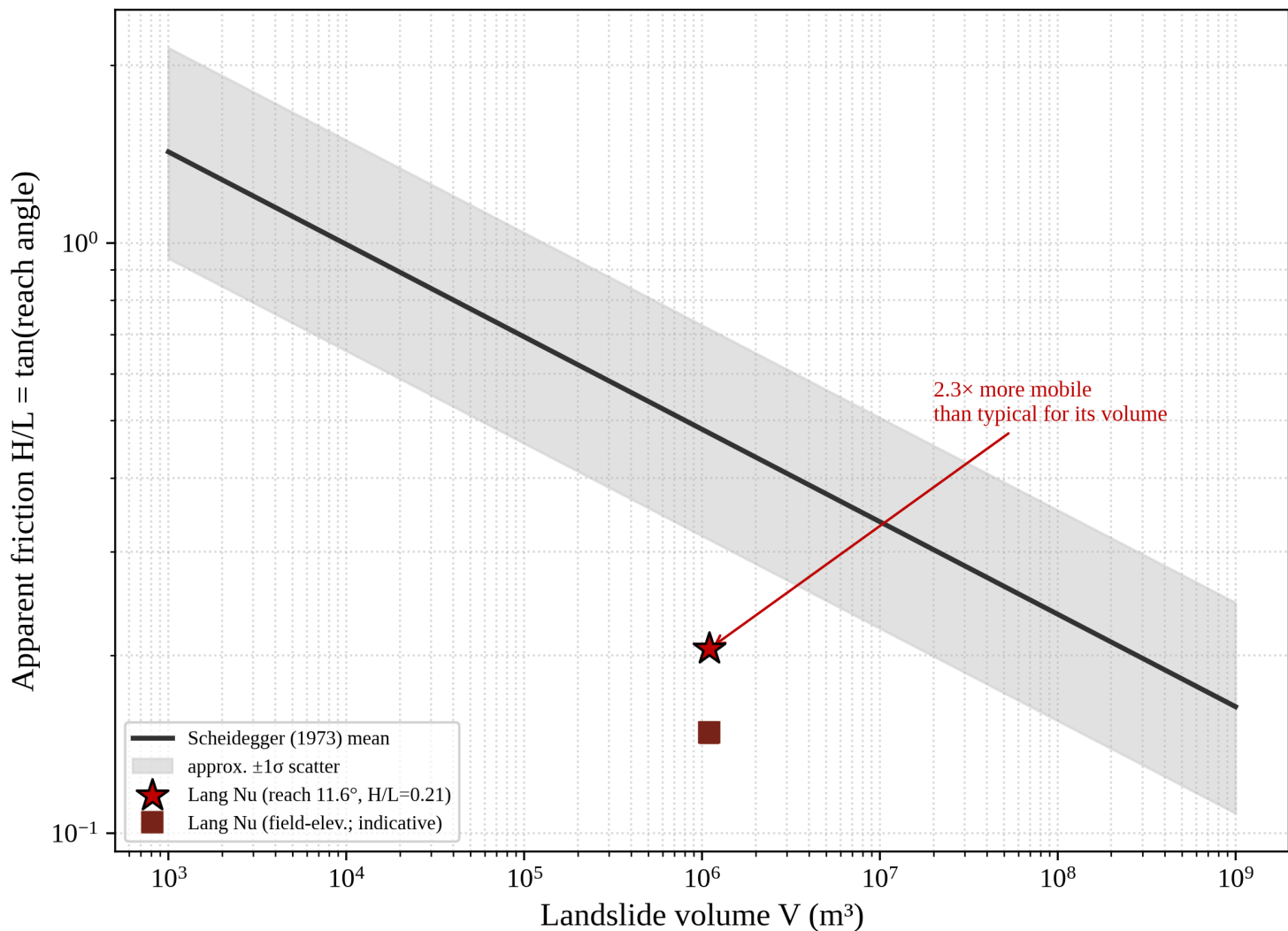


Figure 3

Apparent friction (H/L) versus volume for the Lang Nu event (using the reported volume and reach angle) against the global relation of Scheidegger (1973). The event plots about 2.3× below the mean trend. Square: less precise field-elevation estimate, shown for comparison only.

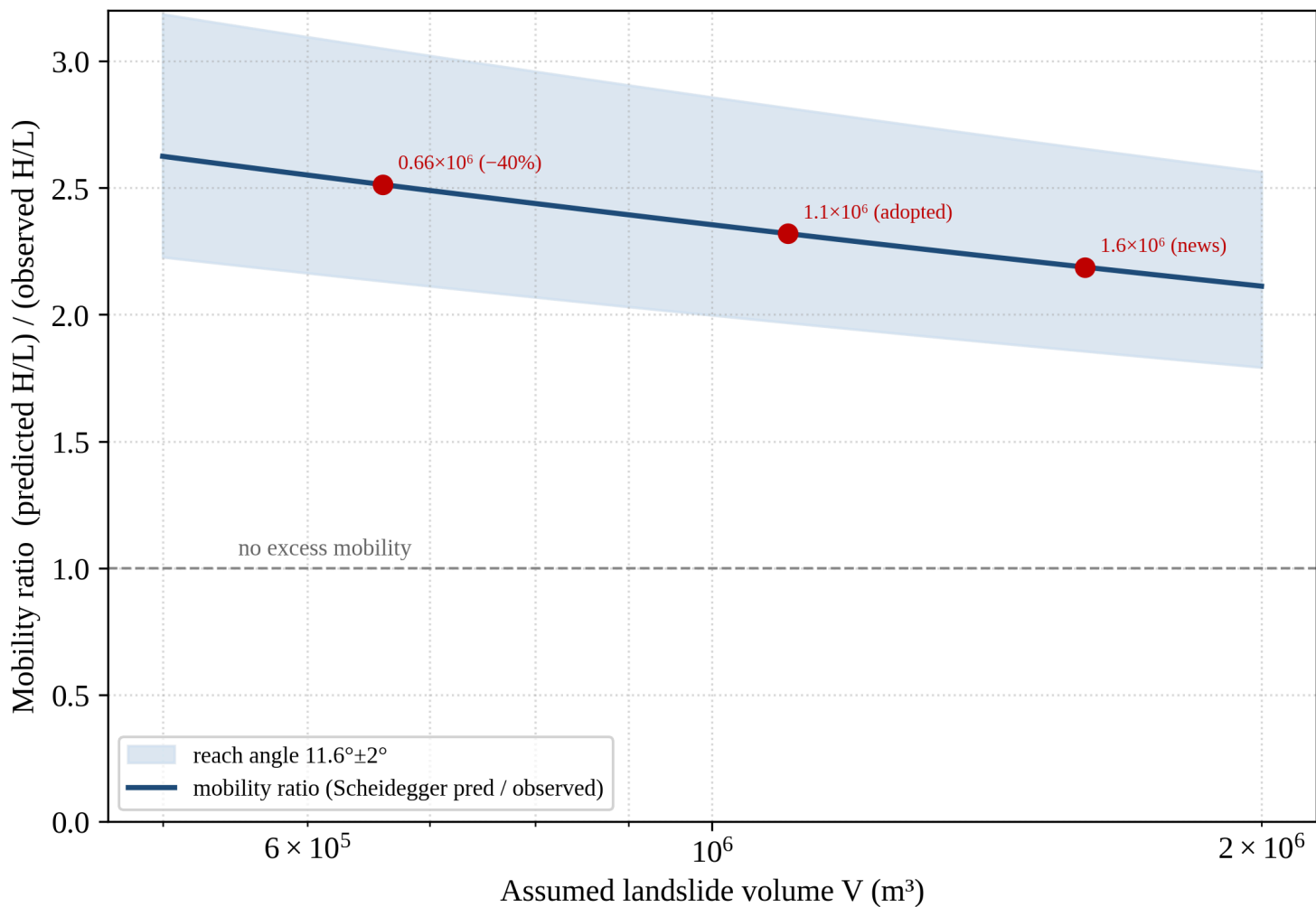


Figure 4

Sensitivity of the mobility ratio (Scheidegger-predicted H/L divided by the observed H/L) to the assumed volume ($0.5\text{--}2.0 \times 10^6 \text{ m}^3$) and to a reach-angle uncertainty of $11.6^{\circ} \pm 2^{\circ}$ (shaded band). The ratio remains above about 2 throughout.

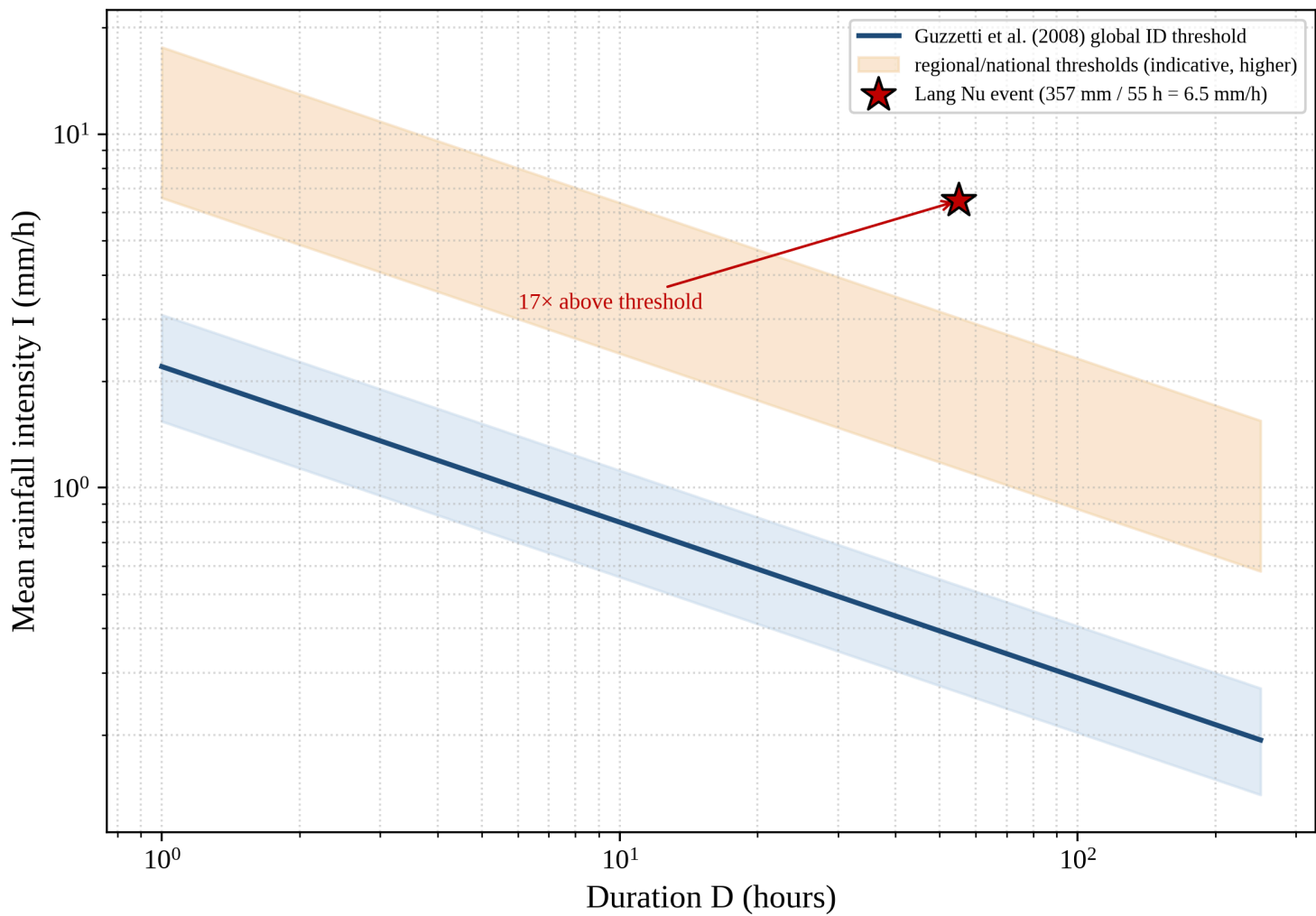


Figure 5

Reported triggering rainfall (356.6 mm over 55 h) relative to the Guzzetti et al. (2008) global minimum intensity–duration threshold; the shaded band schematically indicates the higher regional and national thresholds.

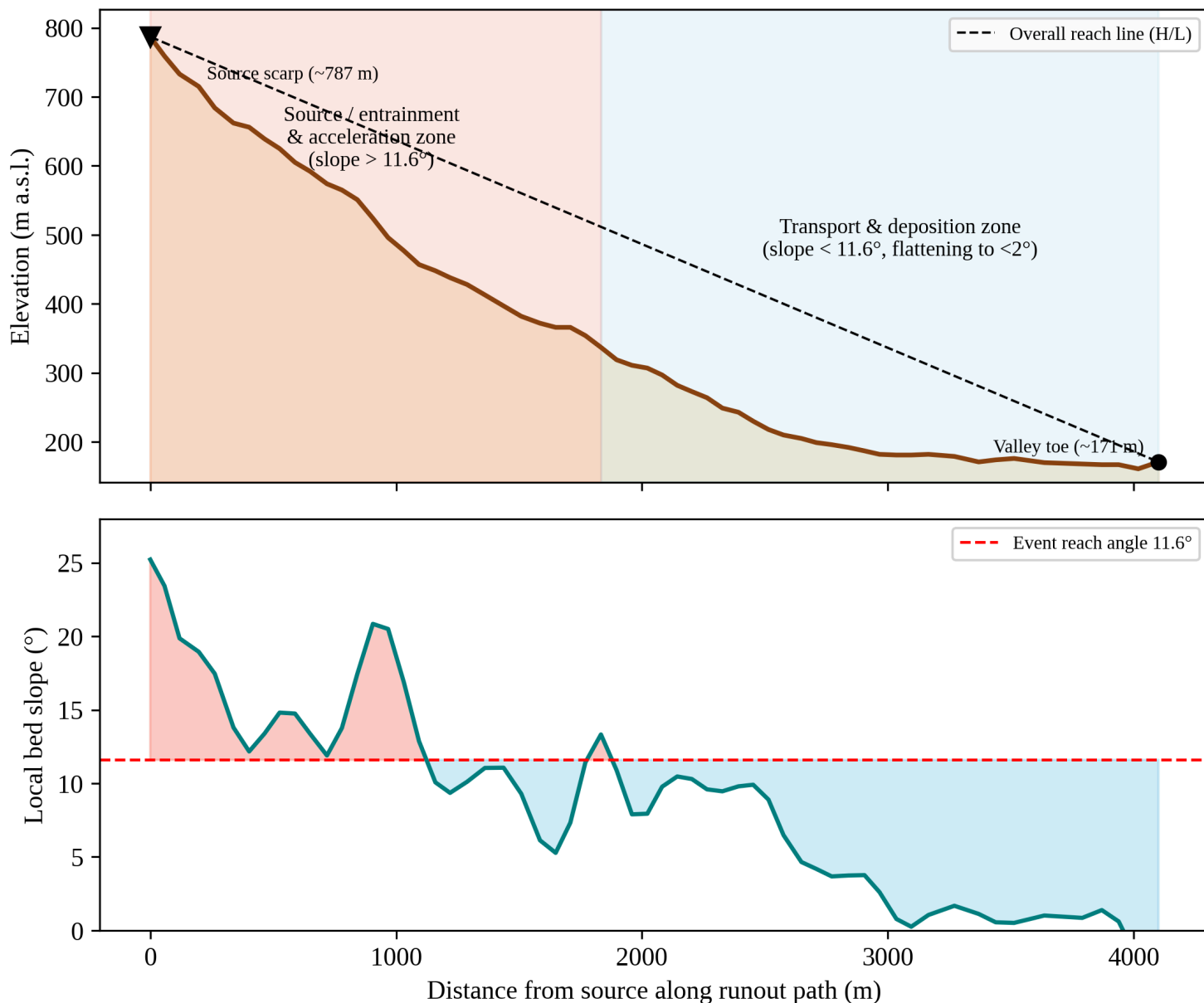


Figure 6

Along-path topographic profile of the landslide (this study). Upper panel: elevation along the mapped centreline, sampled from the 30 m SRTM DEM, from the source scarp (~787 m) to the valley toe (~171 m); the dashed line is the straight source-to-toe reach line. Lower panel: local bed slope; the red dashed line is the 11.6 degree reach angle of the event. Red shading marks the steep source/entrainment-acceleration zone (slope > 11.6 degrees); blue shading marks the transport and deposition zone that flattens to below 2 degrees distally.

Supplementary Files

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