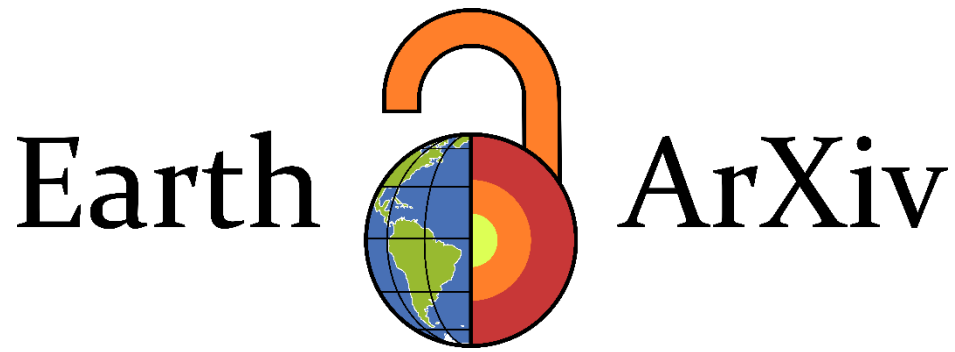




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Title: A multi-source quantitative reconstruction of the 26 August 2026 Bhote Koshi rock-ice avalanche-debris-flow-flood cascade, Nepal

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A multi-source quantitative reconstruction of the 26 August 2026 Bhote Koshi rock-ice avalanche-debris-flow-flood cascade, Nepal

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Abstract

On 26 August 2026, a catastrophic transboundary mass-flow and flood cascade originated in the upper Lhende Khola-Bhote Koshi headwaters and propagated through the Bhote Koshi, Trishuli, and Narayani river system in Nepal. Early public descriptions used the glacial lake outburst flood (GLOF) label, but subsequent seismic, satellite, video, field, hydrological, and damage-assessment evidence supported a more complex sequence of rock-ice avalanche, progressive entrainment and debris-flow transformation, followed by downstream flood-wave routing. This study aims to provide a reproducible, evidence-weighted quantitative reconstruction using publicly available data through 7 October 2026. Official hydrometeorological timelines, peer-reviewed source-process studies, preliminary satellite mapping, the Government of Nepal Rapid Damage and Needs Assessment, and dated human-impact snapshots were harmonized. Propagation and warning-time metrics, hydrological amplification, paired channel-width change at 22 sections, exposure and infrastructure severity ratios, and sectoral concentration of disaster effects and recovery needs were calculated. The source-to-border segment was reported at approximately 188 km/h (52.2 m/s), declining to 23-26 km/h in lower-river segments which was explained by a descriptive log-linear decay model at 80.1% of variation across six reported segment speeds. The public-warning anchor at 09:15 Nepal Standard Time occurred 38 minutes after the source seismic signal, after the flood had already passed or disabled upper-corridor stations, leaving only five minutes to the Betrawati station-failure proxy but 365 minutes to the reported Devghat flood-wave arrival. At Devghat, stage rose from 4.76 to 6.57 m, and discharge increased from approximately 2,600 to 5,850 m³/s where the reported 19.96 million m³ excess volume represented 34.8% of total flow volume during 14:10-18:00. All 22 mapped channel sections widened, from a mean of 66.1 to 266.5 m with the mean post/pre width ratio of 4.49

(bootstrap 95% CI 3.65-5.39; one-sided Wilcoxon $p=1.99 \times 10^{-5}$). The official assessment recorded USD 2.695 billion in disaster effects and USD 4.775 billion in recovery needs, with energy accounting for 54.0% of needs. The results showed that Nepalese cryospheric risk screening, early warning, and infrastructure design must expand from lake-centric hazard concepts to process-chain surveillance that connects unstable rock-ice source areas, entrainment-prone transport corridors, temporary blockages, and exposed downstream assets.

Keywords: *rock-ice avalanche, debris flow, flash flood, cascading hazards, early warning, channel widening, rapid damage*

1. Introduction

High-mountain disasters often receive a familiar hazard label even when the event itself involves several interacting processes. This is particularly relevant in Nepal, where glacial lake outburst floods (GLOFs) are a well-recognized hazard (1,2). The country contains thousands of glacial lakes, including several classified as potentially dangerous, while settlements, roads, hydropower projects, and other infrastructure increasingly occupy narrow Himalayan River corridors (3,4). However, not every destructive flood originating in a glacierized basin is a GLOF. A lake-centered interpretation can therefore be misleading when an event begins with the collapse of a rock-ice slope, transforms through the entrainment of sediment and water, creates temporary channel blockages, and eventually propagates downstream as a sediment-rich flood. The 26 August 2026 Rasuwa-Bhote Koshi disaster (5) provides a striking example of this problem.

The event originated in a steep, glacierized catchment north of the Nepal-China border. Available satellite and geophysical evidence indicates that a large rock-ice mass detached from the high mountain slope, producing a seismic signal that was initially interpreted as an earthquake, although the immediate trigger of the initial slope failure remains uncertain (6–8). The resulting mass movement rapidly travelled downstream, entraining sediment and water and evolving into a debris flow and flood. It severely affected the Gyirong-Rasuwa-Gadhi border corridor before propagating through the Bhote Koshi, Trishuli, and Narayani river system. Upstream hydrometric stations failed as the event passed, while stations farther downstream recorded a prolonged flood pulse (9). Post-event satellite observations documented extensive channel widening, erosion, and sediment deposition (10). The disaster also caused severe human losses and widespread damage to settlements, roads, bridges, hydropower facilities, and other infrastructure (11).

This 2026 Bhote Koshi disaster belongs to a broader class of rapidly evolving Himalayan cascade hazards. A similar 2021 Chamoli disaster in India showed how a high-speed rock-ice avalanche can transform into a highly mobile, sediment-rich flow and cause severe damage far downstream (12). The Bhote Koshi corridor itself had also experienced major flood-driven geomorphic change previously in July 2016. During that Bhotekoshi/Sunkoshi GLOF, the flood transported large boulders, altered channel morphology, and damaged sections of the Araniko Highway and hydropower infrastructure (4). More recently, the 2024 Thame disaster in Nepal involved cascading drainage from two small glacial lakes, showing that destructive floods can emerge from linked processes that are not adequately represented by lake size alone (13). These

events differ in their initial failure mechanisms, yet each demonstrates how a disturbance in steep glacierized terrain can change rapidly as it moves downstream. Correctly identifying that process chain is therefore essential before selecting a hazard model, estimating downstream impacts, or designing an early-warning strategy(14–16).

The 2026 Bhote Koshi disaster has already been examined from several angles, and a considerable amount of quantitative information is available as of 7 October 2026. However, the evidence is spread across hydrological reports, satellite studies, process reconstructions, modelling, situation reports, and damage assessments, each describing a different part of the event. Even apparently similar numbers are not always directly comparable. Estimates of the source area, for example, may refer to the initial failure zone, the detached rock-ice mass, or a larger source and flow-path footprint. A gauge failure time is also different from flood arrival or peak stage, just as an early satellite count of damaged structures differs from a later field-based inventory. Human-impact figures continue to change as search and identification progress. As a result, the main gap is no longer a lack of observations, but the absence of a consistent quantitative reconstruction that brings these different lines of evidence together without losing their original meaning or hiding the uncertainty and disagreement among them.

This study therefore aims to reconstruct the 26 August 2026 Bhote Koshi disaster as a connected source-to-downstream cascade using publicly available evidence from the first six weeks after the event. The analysis first evaluates whether the available observations support classification as a rock-ice avalanche-debris-flow-flood cascade. It then examines how the event changed downstream through variations in propagation speed, warning time, hydrological response, channel widening, infrastructure exposure, and economic impacts. Comparable measurements were harmonized where possible, while conflicting or differently defined values were kept separate and documented. By bringing these lines of evidence together, the study seeks to clarify not only what happened during this event, but also what it means for monitoring, early warning, and infrastructure planning in other high-mountain river systems where one process can rapidly transform into another.

2. Study area and disaster setting

2.1 Transboundary headwaters and downstream corridor

The 26 August 2026 Bhote Koshi disaster originated in steep, glacierized terrain on the northern flank of the Langtang Himal near the Nepal-China border (**Figure 1**). Published source estimated place the initiation zone at approximately 28.27–28.29° N and 85.52–85.53° E, at about 5,000–5,200 m elevation. The USGS seismic solution associated with the mass movement was located at 28.271° N, 85.515° E, while satellite-based rapid mapping placed the detachment slightly farther northeast. The failed mass entered the Lhende Khola-Bhote Koshi drainage system roughly 20 km upstream of Rasuwagadhi and then propagated through the downstream river network.

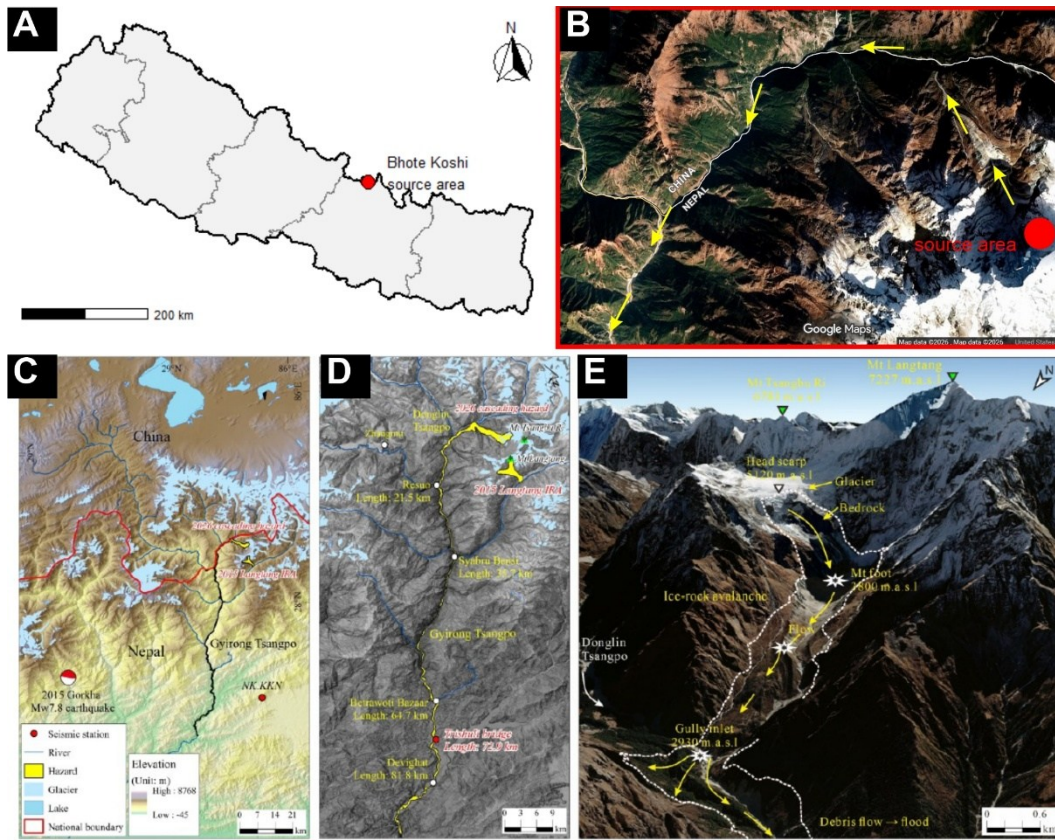


Figure 1. Location and geographic setting of the 26 August 2026 Bhote Koshi disaster. (A) Red solid circle on Map (bottom) represents the transboundary source region near the Nepal-China border. (B) Enlarged satellite view obtained from google maps (top) of the glacierized source area on the northern flank of the Langtang Himal, showing the Nepal-China border and the approximate location of the initial rock-ice failure as well as the downstream corridor (yellow

arrows). (C) Hazard location and regional topographic features, (D) extent of the 2026 cascading hazard, and (E) characteristics of the source and flow gully. C-E were adapted from Zhao et al. (2026).

2.2 Event chronology

A strong long-period seismic signal was recorded at approximately 08:37 NST on 26 August 2026. The signal, initially catalogued as an earthquake, was subsequently classified by the USGS as a landslide-related mass-movement event with an equivalent magnitude of 5.2. The initial failure rapidly descended into the Lhende drainage, entrained sediment and water, and reached the Rasuwagadhi border corridor within minutes. Upstream hydrometric stations stopped transmitting soon after the event began, while surviving downstream stations allowed the Flood Forecasting Division to continue tracking the flood through the Trishuli and Narayani system.

3. Methodology

3.1 Analytical framework and research questions

We analyzed the event as a connected source-pathway-receptor system (17). The source domain included the unstable glacier-rock slope and initial mass failure. The pathway extended from the steep headwater channel through zones of entrainment, temporary blockage, the Gyirong-Rasuwagadhi border corridor, and the downstream Bhote Koshi-Trishuli-Narayani River network. The receptor domain included exposed populations, settlements, roads, bridges, hydropower facilities, public services, and warning systems. With this framework the disaster was examined as an evolving cascade in which both the physical process and its consequences changed downstream.

We followed an evidence-weighted approach to analyze the event. We retained the terminology and measurement definitions used in the original sources for direct observations and calculated derived quantities transparently from published values. We treated model-dependent estimates as scenario results rather than observations. Where sources disagreed or measured different aspects of the event, we kept the reported values separate unless their definitions, spatial extent, reference period, and units were directly comparable. **Table 1** summarizes the research questions, quantitative evidence, and analytical approach used in the study.

Table 1. Research questions, data and indicators, and corresponding analytical approaches.

ID	Research question	Quantitative evidence	Analytical approach
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Q1	What process chain best explains the event?	Seismic classification, source characteristics, rainfall, lake evidence, entrainment, temporary impoundment, and runout	We compared four candidate mechanisms using an evidence-weighted classification
Q2	How did propagation change downstream?	Segment distance, travel time, calculated velocity, and event chronology	We calculated segment velocities and characterized downstream changes in propagation speed
Q3	How did warning opportunity vary downstream?	Warning issuance, station failure, threshold crossing, flood arrival, and peak-stage times	We calculated operational lead times relative to the 09:15 NST warning reference
Q4	How large were the hydrological and geomorphic changes?	Stage, discharge, flood volume, and 22 paired pre/post-event channel widths	We quantified hydrological change and tested channel widening using paired statistics, bootstrap intervals, and rank-based analyses
Q5	How were infrastructure impacts and economic burdens distributed?	Affected buildings, road damage, bridge losses, hydropower capacity, economic effects, and recovery needs	We calculated exposure and severity ratios, sector shares, HHI, and recovery leverage
Q6	How do inconsistencies among public sources affect the reconstruction?	Conflicting times, distances, source-area definitions, damage estimates, and human-impact records	We applied predefined harmonization rules and retained unresolved discrepancies explicitly

3.2 Data source, harmonization and reproducibility

We compiled quantitative data from eight principal sources covering event chronology, hydrology, source processes, geomorphic change, infrastructure damage, economic impacts, and human consequences. **Table 2** summarizes the role and main limitation of each core source. We selected sources according to the type of evidence being analyzed rather than applying a single hierarchy to the entire event. We relied primarily on official station and assessment records for hydrological observations, operational timelines, infrastructure impacts, and nationally consolidated economic estimates. For source characteristics and process interpretation, we gave greater weight to peer-reviewed multi-source studies, while satellite-based assessments provided measurements of rapid geomorphic change. We treated preprint outputs as model-dependent estimates and used news reporting only when it provided dated government figures that were not

yet available in a finalized assessment. This approach allowed us to select the source with the most direct and clearly defined evidence for each variable.

Table 2. *Core evidence sources, analytical role, and limitations.*

Source	Status	Primary analytical use	Principal limitation
CHWRR (2026)(18)	Official hydrological assessment	Event chronology, hydrometric observations, rainfall, stage, discharge, flood volume, and segment travel times	Contains internal inconsistencies in some reported times and distances
NDRRMA (2026)(19)	Official RDNA	Buildings, infrastructure, economic effects, losses, recovery needs, and human-impact data	Provisional multi-sector assessment based on information available at the reporting cutoff
USGS (2026)(6)	Federal hazard agency assessment	Seismic reclassification and identification of a non-tectonic mass-movement source	Rapid event attribution rather than a complete process reconstruction
Zhao et al. (2026) (8)	Peer-reviewed study	Source zone, cascade stages, runout, velocity, and conditioning factors	Immediate trigger of the initial failure remains unresolved
Guo et al. (2026) (7)	Peer-reviewed/online-first study	Source and flow footprints, entrainment, glacier motion, and ERA5-Land meteorological context	Meteorological analysis uses reanalysis data and does not establish event-specific causation
Tsou et al. (2026) (10)	Preliminary scientific assessment	Paired channel-width measurements, satellite damage mapping, and secondary hazards	Spatially limited and not peer reviewed at the time of analysis
Park (2026) (5)	Preprint modelling study	Scenario-based mass-flow and downstream routing reconstruction	Source-release volume is model calibrated rather than independently measured
AP (7 October 2026) (20)	News report citing government data	Latest dated figures for recovered bodies, missing persons, affected population, and damaged homes	Used only as a dated administrative snapshot rather than a finalized impact assessment

We transcribed the published quantitative data into structured comma-separated files and cross-checked the entries against the original sources by reproducing reported totals, ratios, and percentages where possible. We standardized all event times to Nepal Standard Time (NST) and used the seismic signal at 08:37 NST as the physical event anchor. For the warning analysis, we adopted 09:15 NST as the conservative public-warning reference because this time appears in the

official propagation chronology. The same assessment reports SMS dissemination between 09:05 and 09:14. We therefore also considered 09:05 as a sensitivity reference, which increases each calculated downstream warning lead by 10 min.

During harmonization, we combined values only when they represented the same variable, spatial extent, reference period, and measurement unit. We retained station failure, warning-threshold crossing, flood arrival, and peak stage as separate event markers because they represent different stages of the flood response. We likewise kept source-zone area, detached-mass footprint, and source-plus-flow-path area separate where published studies used different spatial definitions. For economic data, we distinguished physical damage, economic loss, total effects, early recovery needs, and long-term recovery needs. We did not average values that were based on incompatible definitions.

3.3 Process classification, propagation, and warning analysis

We evaluated four candidate explanations for the initiation and development of the event: a regional rainfall-driven flood, failure of a pre-existing glacial lake, a tectonic earthquake-triggered flood, and a rock-ice avalanche that subsequently entrained sediment and water, interacted with temporary impoundments, and transformed into a debris flow and downstream flood. We compared these explanations against independent evidence from seismic observations, satellite imagery, source-zone characteristics, rainfall records, lake observations, runout characteristics, and downstream geomorphic change. We classified the level of support for each explanation as contradicted, weakly supported, partly compatible, or strongly supported. For this comparison, we defined a conventional GLOF as rapid drainage from a pre-existing glacier-related lake following failure or overtopping of its retaining dam. We treated temporary impoundments that formed after the initial mass movement as intermediate components of the cascade rather than evidence of a lake-initiated GLOF. This distinction allowed us to separate the initiating mechanism from processes that developed later as the moving mass interacted with the channel, sediment, and river water.

We reconstructed downstream propagation using the segment distances and travel times reported in the official hydrological assessment. For each segment i , we calculated mean propagation speed as $v_i = 60 \times \frac{d_i}{t_i}$, where d_i is distance in kilometres and t_i is reported travel time in minutes.

We calculated the overall source-to-Devghat travel time directly from the documented event chronology (**Table 5**). The six segment rows total 352 min, although the same official assessment reports an overall duration of approximately 402 min. The interval between the 08:37 NST source signal and the detailed 15:20 NST Devghat arrival is 403 min. We therefore used 403 min for the overall propagation calculation and retained the individual segment rows only for local speed estimates. Using the reported pathway length of 201 km, we calculated the corresponding overall mean propagation speed as 29.9 km/h.

We then examined how warning opportunity changed downstream. For each location (j), we calculated operational warning lead time as $L_j = T_j - T_w$, where T_j is the documented local event time and T_w is the conservative public-warning reference of 09:15 NST. We interpreted negative values as locations where the documented event marker had already occurred before the warning reference. Because the available markers included station failure, warning-threshold crossing, reported flood arrival, and peak stage, we retained the marker type for each location and interpreted L_j as an operational warning opportunity rather than as a uniform estimate of flood-front arrival time. We repeated the calculation using 09:05 NST as a sensitivity reference to examine the effect of the earlier reported start of SMS dissemination.

3.4 Hydrological and geomorphic analysis

We quantified the downstream hydrological response using the stage, discharge, and flood-volume estimates reported for Devghat in the official hydrological assessment (18). We calculated absolute stage rise as $\Delta H = H_{peak} - H_{initial}$ and relative stage rise as $\Delta H\% = \frac{H_{peak} - H_{initial}}{H_{initial}} \times 100\%$. We expressed discharge amplification as the ratio of Q_{peak} to $Q_{initial}$, the excess increment was $Q_{peak} - Q_{initial}$. Mean discharge during the reported 14:10-18:00 volume window was volume divided by 13,800 seconds. The excess-volume fraction was calculated as $F_{excess} = \frac{V_{excess}}{V_{total}}$. These calculations were based on the discharge estimates reported in the official hydrological assessment and were used only to characterize the downstream flood response.

We quantified geomorphic change using the 22 paired pre- and post-event channel-width measurements reported by Tsou et al. (2026) between Syabrubesi and Trishuli/Bidur (10). For each cross-section i , we calculated absolute widening as $R_i = \frac{W_{after,i}}{W_{before,i}}$, and absolute widening as $\Delta W_i = W_{after,i} - W_{before,i}$. We summarized the distribution of channel change using the

arithmetic mean, median, geometric mean, interquartile range, and aggregate width ratio. We estimated percentile-bootstrap 95% confidence intervals for the mean and median width ratios using 20,000 resamples.

To test whether channel widening was systematic across the measured reaches, we used a one-sided paired Wilcoxon signed-rank test (21) comparing pre- and post-event widths. We then used Spearman rank correlation (22) to examine whether the width ratio varied with approximate pre-event riverbed elevation. As an exploratory analysis, we used a Mann-Whitney test (23) to compare width ratios between the published V-shaped valley sections and the lower-valley or confluence sections. We selected rank-based tests because of the small sample size and because we did not assume normally distributed width changes. Detailed cross-section coordinates and original channel delineations were unavailable, so we could not explicitly account for spatial dependence among neighboring sections. We therefore used these tests to identify patterns in the available measurements rather than to establish causal relationships.

3.5 Exposure, economic impacts, and human-impact records

We quantified infrastructure exposure and damage using the Rapid Damage and Needs Assessment (RDNA) (19). We calculated district-level shares of affected buildings relative to the reported total of 7,570 buildings and used the associated household and population figures to describe the distribution of exposure. For transportation infrastructure, we calculated the proportion of assessed road length classified as completely damaged, and the proportion of motorable bridges washed out by both number and total length. We also calculated the share of assessed hydropower capacity that was under construction at the time of the disaster. These ratios refer only to assets included in the RDNA and were not interpreted as proportions of Nepal's total infrastructure stock.

We examined the distribution of economic effects and recovery needs across sectors using proportional shares and the Herfindahl-Hirschman Index (HHI) (24): $HHI = \sum_{k=1}^k (S_k)^2$, where S_k is sector k 's share of total economic effects or recovery needs and k is the number of sectors included in the assessment. Higher HHI values indicate greater concentration of the total burden in a smaller number of sectors, while lower values indicate a more dispersed distribution. We calculated the index separately for economic effects and recovery needs so that we could compare the concentration of observed impacts with the allocation of planned recovery expenditure.

We also calculated recovery leverage R_L as $R_L = \frac{N_{total}}{E_{total}}$, where N_{total} is the total estimated recovery and reconstruction need and E_{total} is the total recorded economic effect. Values greater than 1 indicate that estimated recovery requirements exceeded the recorded effects. We interpreted this ratio as a recovery-planning indicator rather than as a direct multiplier of disaster loss because recovery estimates also include resilient reconstruction and disaster-risk-reduction measures.

We treated human-impact figures separately from the infrastructure and economic calculations because casualty and missing-person records continued to change after the disaster. For the latest status available within our study period, we used the government figures reported on 7 October 2026 as a dated administrative snapshot rather than as a final casualty count (20).

4. Results

4.1 Mechanism attribution: a cascade rather than a single-process GLOF

Our evidence-weighted assessment most strongly supported a rock-ice avalanche followed by debris-flow transformation and downstream flood routing (**Table 3**). The seismic signal initially associated with an earthquake was subsequently reclassified by the USGS as a mass-movement signal (6). Satellite and field-based studies independently identified a fresh glacier-rock failure zone and a strongly scoured transport corridor. Zhao et al. (2026) reconstructed more than 7 km of initial rock-ice avalanche motion, followed by more than 13 km of debris-flow propagation and over 80 km of downstream flooding, giving a total runout exceeding 100 km (8). Together, these observations support a progressive source-to-downstream cascade rather than a single-process flood.

The available evidence provided little support for either a tectonic earthquake or intense short-duration rainfall as the primary initiating mechanism. At Kyangjing, only 1.5 mm of precipitation was recorded during the six hours preceding the reported failure, compared with 27.0 mm over the preceding 24 h. The maximum 10-min rainfall during this six-hour period was 0.14 mm. Guo et al. (2026) similarly reported 72-h ERA5-Land precipitation totals of 8.3 mm at the source and 15.3 mm near Gyirong Port (7). Stable hydrological conditions in tributaries outside the affected main-stem corridor provided additional evidence against a regional rainfall-driven flood. We also found no robust evidence that drainage of a pre-existing moraine- or ice-dammed lake initiated the event. Temporary impoundments and subsequent water releases occurred during

the cascade, but these developed after the initial mass movement. The evidence supporting and contradicting each candidate mechanism is summarized in **Table 3**.

Table 3. *Evidence-weighted assessment of candidate event mechanisms.*

Candidate mechanism	Assessment	Main evidence	Residual uncertainty
Regional extreme-rainfall flood	Contradicted as primary mechanism	Very low six-hour rainfall; unaffected tributary gauges downstream; localized seismic mass-movement signal.	Rain and antecedent moisture may still have contributed to background conditioning.
Tectonic earthquake trigger	Contradicted by current evidence	USGS reclassified the signal as landslide/debris-flow energy rather than a tectonic earthquake.	The seismic signal identifies the timing of mass movement but not the immediate slope-failure trigger.
Conventional pre-existing lake-breach GLOF	Weakly supported	No robust evidence that drainage of a pre-existing moraine- or ice-dammed lake initiated the event.	Temporary blockage lakes and water release occurred within or after the cascade.
Rock-ice avalanche → debris flow → flood	Strongly supported	Fresh source scar, seismic timing, very high initial speed, entrainment corridor, video, downstream attenuation, satellite morphology.	Exact initial volume and short-term detachment trigger remain uncertain.

Published estimates of the source and initial transport characteristics are summarized in **Table 4**. Guo et al. (2026) mapped a 0.72 km² ice-rock source area, while Zhao et al. (2026) reported approximately 0.75 km². Larger published estimates represented different features and were therefore not directly comparable. The official assessment reported a broader detached glacier-rock area of approximately 2.0 km², while Tsou et al. (2026) mapped approximately 7.8 km² when the source and initial movement path were considered together. Guo et al. (2026) independently mapped a 7.30 km² ice-rock and debris-flow corridor. Reported source elevations placed the head scarp at approximately 5,060–5,120 m a.s.l.

The initial movement was also exceptionally rapid. Zhao et al. (2026) estimated an average velocity of 46.7 m/s over the first 21.5 km, based on a minimum travel time of 7 min 40 s. The official source-to-Rasuwadhi estimate of 188 km/h corresponds to 52.2 m/s, while video-based reconstruction cited by Zhao et al. (2026) indicated a lower velocity of approximately 19 m/s as the flow approached the border-port area. These estimates describe different portions of the

evolving flow and were therefore retained separately rather than combined into a single source velocity.

Table 4. *Selected source-process metrics and definition caveats.*

Metric	Value	Source	Definition/caveat
Source-zone area	0.72 km ²	Guo et al. (2026) (7)	Mapped ice-rock source area
Source-zone area	0.75 km ²	Zhao et al. (2026) (8)	Mapped source zone
Broader detached area	2.0 km ²	CHWRR (2026) (18)	Glacier including rock mass; different footprint definition
Source plus initial path	7.8 km ²	Tsou et al. (2026) (10)	Source and initial movement path
Flow corridor	7.30 km ²	Guo et al. (2026) (7)	Mapped ice-rock/debris-flow corridor
Head scarp	about 5,060-5,120 m a.s.l.	Tsou; Zhao (8,10)	Independent approximations
Average to port	46.7 m/s	Zhao et al. (2026) (8)	21.5 km in at least 7 min 40 s
Official source-border segment	188 km/h = 52.2 m/s	CHWRR (2026) (18,25)	Rounded distance and time
Arrival at port	about 19 m/s	Yang et al. (2026) (25)	Video back-calculation
Model scenario release	35.4 million m ³	Park (2026) (5)	Best-fit model scenario; not a measurement

Evidence for longer-term climatic and geomorphic preconditioning was present, but the immediate detachment trigger remained unresolved (8,26). Published analyses documented glacier retreat, exposed and fractured bedrock, hanging ice, spatial variations in glacier motion, and positive temperature anomalies during 2026 (7). These observations are consistent with progressive weakening of the source area, but they do not identify the specific process that initiated failure on 26 August. We therefore classified a rock-ice avalanche-debris-flow-flood cascade as strongly supported while leaving the immediate trigger unassigned.

4.2 Propagation and transformation downstream

We found a pronounced decrease in propagation speed as the event moved from the source area into the downstream river system. As summarized in **Table 5**, the reported segment speed decreased from 188 km/h between the source and Rasuwagadhi to 83 km/h between Rasuwagadhi and Syabrubesi, 65 km/h to Betrawati, 29 km/h to Phurke Khola, and 23 km/h to Muglin, before increasing slightly to 26 km/h between Muglin and Devghat. Our independently calculated speeds closely matched the reported values. We calculated a maximum segment speed of 188.6 km/h in

the uppermost reach and a minimum of 23.2 km/h between Phurke Khola and Muglin, representing an 87.7% reduction from the initial source-to-border value.

Table 5. *Reported propagation segments and independently recalculated mean speeds.*

Segment	Distance km	Time min	Reported km/h	Recalc. km/h	End chainage km
Source to Rasuwagadhi border	22.0	7	188	188.6	22.0
Border to Syabrubesi	13.8	10	83	82.8	35.8
Syabrubesi to Betrawati	32.2	30	65	64.4	68.0
Betrawati to Phurke Khola (Malekhu)	53.3	110	29	29.1	121.3
Phurke Khola to Kalikhola (Muglin)	46.4	120	23	23.2	167.7
Kalikhola (Muglin) to Devghat	33.3	75	26	26.6	201.0

Note: Segment distances, travel times, and reported speeds are from CHWRR (2026). We calculated mean segment speeds independently from the reported distances and travel times. The six segment durations sum to 352 min and were therefore not used to determine the overall source-to-Devghat travel time.

Our descriptive log-linear analysis showed a clear downstream reduction in propagation speed (**Figure 2A**), with $\beta = -0.0108$ per km and $R^2 = 0.801$. The fitted relationship gave a speed-halving distance of approximately 64 km. We also identified an important inconsistency in the reported travel times. The six segment durations in **Table 5** sum to 352 min, whereas the official assessment reports an overall duration of approximately 402 min. Using the detailed event chronology, we calculated 403 min between the 08:37 NST source signal and the 15:20 NST Devghat arrival. We therefore used 403 min for the overall source-to-Devghat calculation, which produced a mean propagation speed of 29.9 km/h over the reported 201 km pathway. Because the six segments represent different stages of an evolving rock-ice avalanche, debris flow, and river flood, we treated the fitted relationship as descriptive only.

We also found a strong downstream increase in warning opportunity as travel time increased. Relative to the conservative 09:15 NST public-warning reference, the Rasuwagadhi and Syabrubesi stations had already stopped transmitting 35 and 25 min earlier, respectively, while Betrawati stopped only 5 min after the warning reference. Farther downstream, we calculated more than 2 h of operational lead at Phurke Khola and more than 6 h by the reported flood-wave arrival at Devghat. **Table 6** presents the complete chronology used in these calculations and identifies the type of timing marker available at each location.

Table 6. *Selected event chronology and operational warning opportunity relative to the 09:15 NST public-warning reference.*

NST	Event	Marker type	Minutes vs 09:15
08:37	Seismic/source signal	trigger proxy	-38
08:40	Rasuwadga station ceased	station failure/arrival proxy	-35
08:50	Syabrubesi station ceased	station failure/arrival proxy	-25
09:05	FFD first notified	institutional notification	-10
09:15	Public SMS warning	warning issued	+0
09:20	Betrawati station ceased	station failure/arrival proxy	+5
11:26	Phurke warning threshold	warning threshold	+131
11:43	Phurke danger threshold / station lost	danger threshold/failure	+148
13:00	Muglin crossing	reported flood crossing	+225
15:20	Devghat flood-wave arrival	reported wave arrival	+365
16:00	Devghat peak 6.57 m	peak stage	+405

We did not treat the timing markers in Table 6 as equivalent measurements of flood-front arrival. In the upper corridor, station failure was the available proxy for passage of the destructive flow, whereas farther downstream the records included threshold crossing, reported flood passage, wave arrival, and peak stage. We therefore interpreted the calculated lead times as operational warning opportunities associated with the available marker at each location. When we repeated the calculations using 09:05 NST, the earliest reported start of SMS dissemination, all downstream lead times increased by 10 min, but the overall spatial pattern remained unchanged. As shown in **Figure 2B**, warning opportunity was negative or very limited in the upper corridor and increased progressively farther downstream.

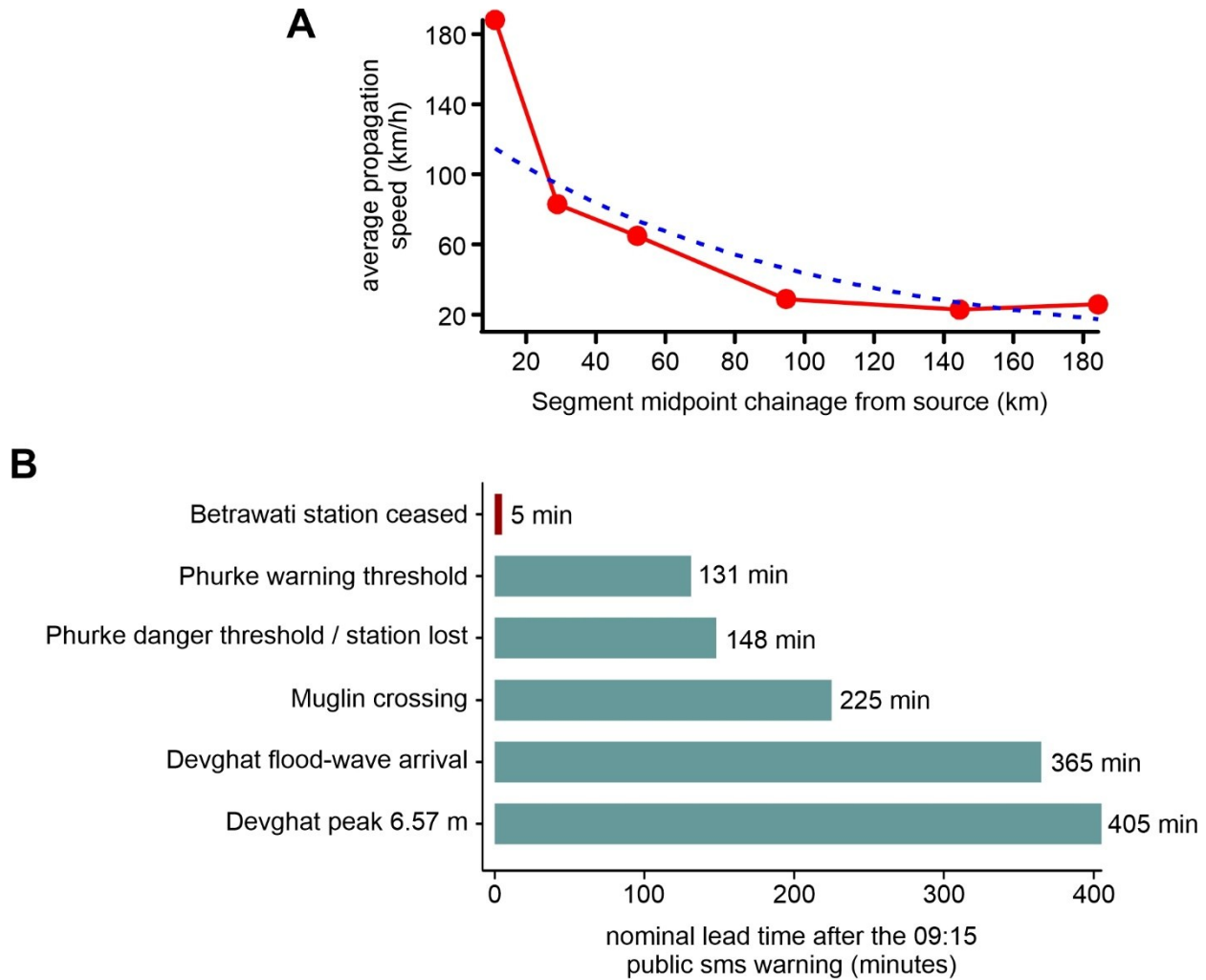


Figure 2. (A) Reported mean propagation speed by river segment (red) and descriptive downstream fit, $R^2=0.80$ (blue). (B) Operational warning opportunity relative to the 09:15 NST public-warning reference at selected locations along the Bhote Koshi-Trishuli-Narayani corridor.

4.3 Hydrological response and geomorphic transformation

We found a substantial hydrological response in the lower river system despite the marked reduction in propagation speed downstream. At Devghat, river stage increased from 4.76 m at 13:20 NST to a peak of 6.57 m at 16:00 NST, corresponding to a rise of 1.81 m or 38.0%. Over the same interval, the mean rate of stage rise was approximately 0.68 m/h. Reported discharge increased from about 2,600 to 5,850 m³/s, giving a discharge amplification ratio of 2.25 and an absolute increase of 3,250 m³/s, equivalent to 125%. **Table 7** summarizes these hydrological observations and the quantities we derived from them.

Table 7. *Reported hydrological observations and derived flood-response indicators.*

Indicator	Reported values	Derived interpretation
Devghat stage	4.76 → 6.57 m	Rise 1.81 m; +38.0%
Devghat discharge	2,600 → 5,850 m ³ /s	Ratio 2.25; +3,250 m ³ /s
Volume, 14:10-18:00	57.40 million m ³ total	Mean about 4,159 m ³ /s
Excess volume	19.96 million m ³	34.8% of interval volume; mean about 1,446 m ³ /s
Furke stage	7.50 → 10.48 m	Station then lost
Kalikhola stage	7.40 → 12.30 m	Maximum exceeded danger threshold

During the 14:10–18:00 NST interval, the official assessment reported a total flow volume of 57.40 million m³ at Devghat, of which 19.96 million m³ was estimated as excess volume above the underlying river flow. From these values, we calculated a mean total discharge of approximately 4,159 m³/s and a mean excess discharge of approximately 1,446 m³/s. The excess component represented 34.8% of the total reported volume during this period. Upstream observations showed similarly rapid stage increases. At Phurke Khola, stage reportedly increased from approximately 7.50 to 10.48 m before the station was lost, while at Kalikhola it increased from approximately 7.40 to 12.30 m. In contrast, the official assessment reported relatively stable conditions on the Marsyangdi and Kali Gandaki tributaries, showing that the pronounced hydrological response was concentrated along the river system connected to the source.

The hydrological pulse was accompanied by widespread geomorphic change. We found that all 22 cross-sections reported by Tsou et al. (2026) were wider after the event than before it. Mean channel width increased from 66.1 to 266.5 m, giving a mean absolute widening of 200.4 m. Median width increased from 60.0 to 240.0 m, while the ratio of summed post-event width to summed pre-event width was 4.03. **Figure 3A** shows the paired measurements and illustrates that widening occurred throughout the measured corridor rather than at only a few isolated sections.

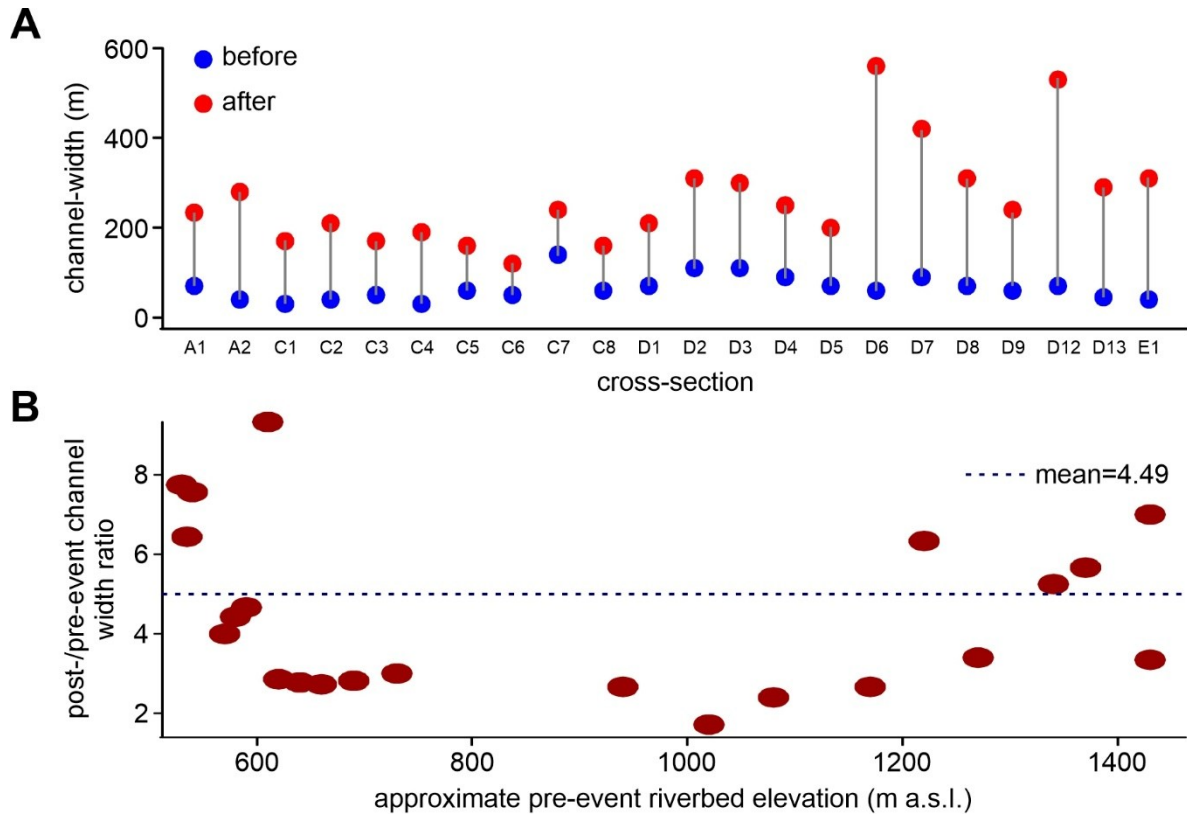


Figure 3. (A) Paired pre- and post-event channel widths at 22 cross-sections between *Syabrubesi* and *Trishuli/Bidur*. (B) Channel-width expansion ratio versus approximate pre-event riverbed elevation for the 22 measured cross-sections.

Our section-by-section analysis produced a mean width ratio of 4.49, with a 95% bootstrap confidence interval of 3.65–5.39. The median ratio was 3.70, with a 95% confidence interval of 2.82–5.67. The one-sided paired Wilcoxon signed-rank test showed that post-event widths were systematically greater than pre-event widths ($p = 1.99 \times 10^{-5}$). The largest proportional change occurred at section D6 near the Betrawati confluence, where channel width increased from 60 to 560 m, corresponding to a width ratio of 9.33.

We found no significant monotonic relationship between width ratio and approximate pre-event riverbed elevation (Spearman $\rho = -0.26$, $p = 0.248$). As shown in **Figure 3B**, large expansion ratios occurred across different elevations rather than following a simple downstream or elevation-dependent pattern. The published V-shaped valley sections had a median width ratio of 3.37, compared with 4.21 for the lower-valley and confluence sections, but this difference was not statistically significant in our exploratory Mann-Whitney comparison ($p = 0.276$). We therefore found strong evidence for widespread channel widening across the measured corridor, but the

available cross-sections did not show a simple relationship between the magnitude of widening and elevation or broad valley class.

4.4 Infrastructure exposure and economic consequences

We found substantial infrastructure exposure across the downstream corridor, with affected buildings concentrated in a small number of districts. The RDNA recorded 7,570 affected private buildings associated with 8,317 households and 32,963 people across five districts. **Figure 4A** shows the district-level distribution of affected buildings, while **Table 8** summarizes the main exposure and infrastructure-severity indicators used in our analysis.

Table 8. *Selected exposure and infrastructure severity indicators.*

Indicator	Value	Interpretation boundary
Affected private buildings	7,570	Five-district assessed total
Estimated affected households	8,317	Model/assessment-linked households
Associated population	32,963	Not a casualty total
Road length completely damaged	55 of 69 km (79.7%)	Assessed damaged road inventory
Motorable bridges washed out	33 of 37 (89.2%)	Count share
Motorable bridge length washed out	2,792 of 3,032 m (92.1%)	Length share
Trail bridges affected	68 spans; 10,670.86 m	RDNA assessed inventory
Hydropower capacity assessed	759.025 MW	Operating plus under construction
Hydropower under construction	508.625 MW (67.0%)	Share of assessed hydropower capacity
Modelled debris deposition	30.524 million m ³	Across 94.075-km modeled corridor

The economic assessment showed that recovery requirements substantially exceeded the recorded damage and losses. The RDNA estimated USD 1.812 billion in physical damage and USD 0.883 billion in economic losses, giving total economic effects of USD 2.695 billion. Physical damage therefore represented 67.2% of total effects and economic losses 32.8%. Total recovery and reconstruction needs were estimated at USD 4.775 billion. From these values, we calculated a recovery leverage ratio of 1.77, meaning that estimated recovery needs were 77% greater than the recorded economic effects.

We also found that both the economic burden and planned recovery were concentrated in a limited number of sectors. Infrastructure accounted for 46.6% of total effects and 65.5% of recovery needs, while the energy sector alone represented 37.0% of effects and 54.0% of needs.

Energy, private buildings, and disaster-risk-reduction measures together accounted for 80.4% of total recovery needs. **Figure 4B** compares economic effects and recovery needs across the major sectors and shows how the composition of the recovery program differed from the distribution of recorded effects.

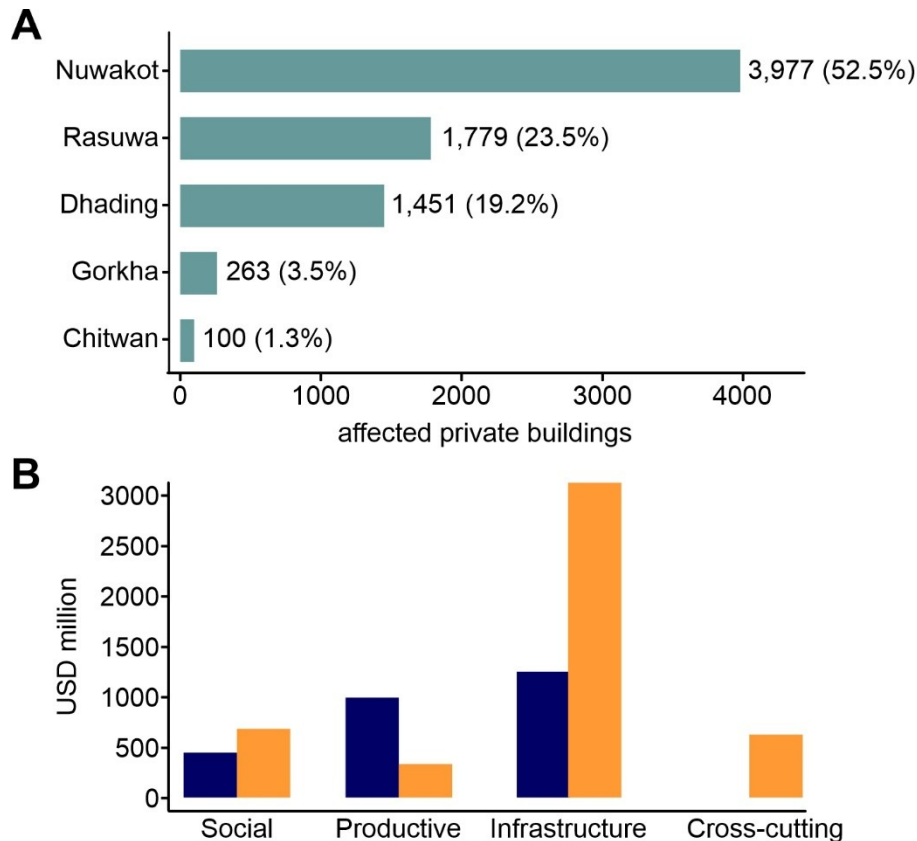


Figure 4. (A) Distribution of assessed affected private buildings by district. (B) Total economic effects and recovery needs by major sector.

Our concentration analysis showed the same shift quantitatively. We calculated an HHI of 0.380 for economic effects and 0.471 for recovery needs, indicating that recovery requirements were more concentrated across sectors than the recorded damage-and-loss distribution. **Figure 5** places these concentration measures alongside selected infrastructure-severity indicators, including complete road damage, bridge loss, hydropower construction exposure, and the concentration of major recovery needs. Because these percentages use different denominators, we

present them as separate diagnostic indicators rather than combining them into a composite severity index.



Figure 5. Selected infrastructure-severity and recovery-concentration indicators.

4.5 Human-impact records and source uncertainty

We found that the reported human impacts changed substantially as search, identification, and registry reconciliation continued after the disaster. The 10 September RDNA recorded 1,377 recovered bodies or remains, 5,130 people missing, and 13,676 people rescued. By 20 September, Situation Report 30 listed 1,451 recovered, 5,786 missing, and 13,784 rescued. The latest snapshot included in our analysis, dated 7 October, reported at least 1,455 recovered bodies and 5,285 people still missing. The same update reported nearly 33,000 affected people and approximately 7,500 damaged or destroyed homes. **Table 9** shows how the principal human-impact records changed during the study period.

Table 9. Dated human-impact registry snapshots used in the analysis.

Date	Source	Recovered bodies/deaths	Missing	Rescued	Interpretation
2026-09-10	NDRRMA RDNA	1,377	5,130	13,676	Provisional registry at RDNA reporting cutoff
2026-09-20	NDRRMA Situation Report 30	1,451	5,786	13,784	Search and registry reconciliation ongoing
2026-10-07	Government status reported by AP	1,455	5,285	Not reported	Latest dated government snapshot used in this study

The temporal pattern in **Table 9** shows why we did not treat the missing-person register as a fixed estimate of mortality. Between 20 September and 7 October, the number of recovered

bodies increased only slightly, from 1,451 to 1,455, while the number of people listed as missing decreased from 5,786 to 5,285, a reduction of 501. We therefore retained recovered and missing persons as separate administrative categories and did not combine them to produce a single death toll.

Our source audit identified several inconsistencies that materially affected the quantitative reconstruction. The six propagation segments in the official hydrological assessment sum to 352 min, whereas the same assessment reports an overall duration of approximately 402 min and the detailed chronology gives 403 min between the 08:37 NST source signal and the 15:20 NST Devghat arrival. Using 352 min instead of 403 min would increase the calculated mean propagation speed over 201 km from 29.9 to approximately 34.3 km/h. The assessment also reports Devghat arrival as 14:20 NST in one section and 15:20 NST in the detailed chronology, with the latter consistent with the reported overall duration of approximately 6 h 42 min. Warning timing similarly varies between SMS dissemination at 09:05–09:14 and a 09:15 public-warning reference; using 09:05 increases all downstream warning leads by 10 min without changing their spatial pattern. Other differences reflect definitions rather than reporting errors. Source-zone estimates of 0.72 and approximately 0.75 km² describe comparable areas, whereas 2.0 km² represents a broader detached area and 7.30–7.8 km² includes portions of the initial transport corridor. Likewise, the early satellite estimate of at least 2,587 destroyed structures covers a narrower mapped corridor and a different damage category than the later RDNA total of 7,570 affected private buildings across five districts. Overall, these discrepancies did not alter the main process classification or broad downstream patterns, but they affected estimates of propagation speed, warning opportunity, source dimensions, damage, and human impacts. We therefore retained differences in reporting time and variable definition explicitly rather than averaging non-equivalent values.

5. Discussion

5.1 From GLOF classification to cascading process hazards

Our reconstruction indicates that the 26 August 2026 Bhote Koshi disaster is better understood as a rock-ice avalanche-debris-flow-flood cascade than as a conventional GLOF. This interpretation is supported by the non-tectonic seismic signal, the mapped glacier-rock failure zone, rapid initial movement, extensive entrainment, and the progressive transition from mass movement to debris flow and downstream river flood. Water was clearly important as the event

developed, and temporary impoundments formed along the flow path, but we found no convincing evidence that drainage of a pre-existing glacial lake initiated the disaster.

The scale of the disaster also cannot be explained by the initial failure alone. The source zone mapped independently by Guo et al. (2026) and Zhao et al. (2026) was approximately 0.72–0.75 km², yet the disturbance developed into a cascade extending more than 100 km downstream. Guo et al. (2026) documented progressive entrainment along the transport corridor, while Zhao et al. (2026) reported valley-wall scour reaching approximately 100–200 m above the valley floor in parts of the upper pathway. Our analysis of the published cross-sections further showed that all 22 measured river sections widened after the event, with mean width increasing from 66.1 to 266.5 m. Taken together, these observations show that the valley and river network were not simply conduits carrying material released at the source. They became active parts of the event as the moving mass incorporated sediment and water, altered the channel, and changed its flow characteristics downstream. This behavior has parallels with other major Himalayan cascades, for example, the Chamoli disaster, although the initiating mechanisms differ. Their differences suggest that the initial hazard category alone does not adequately describe the downstream behavior of high-mountain cascades. Once a rock-ice avalanche enters a steep, sediment-rich drainage network, its consequences depend not only on the initial failed volume but also on entrainment, channel confinement, available water, temporary blockage and release, and sediment storage along the pathway. For hazard assessment, this means that identifying a potentially unstable source is only the first step. The capacity of the downstream corridor to transform and amplify the initial disturbance also needs to be considered when estimating runout, flood magnitude, and potential impacts.

5.2 Downstream transformation, geomorphic change, and warning

Our results show that the cascade changed substantially as it moved downstream, but this transformation did not produce a simple decline in hazard. Propagation speed fell from approximately 188 km/h in the source-to-Rasuwagadhi reach to 23–26 km/h in the lower segments, reflecting the transition from a rapidly moving mass flow to a slower river flood. At the same time, the channel-width analysis showed substantial geomorphic change throughout the measured corridor. All 22 cross-sections widened, the mean width increased by more than 200 m, and the largest proportional expansion occurred near the Betrawati confluence, where width increased from 60 to 560 m. We found no significant monotonic relationship between widening ratio and

elevation. This suggests that decreasing propagation speed should not be interpreted as a corresponding decline in local geomorphic impact.

The spatial variability in widening points to the importance of conditions along individual river reaches. Channel confinement, bank material, tributary confluences, sediment availability, and temporary deposition can influence where erosion and lateral channel expansion become most severe. Our cross-section dataset is not sufficient to isolate the contribution of each factor, but the magnitude and variability of the observed widening show that a fixed pre-event channel boundary cannot represent the full area potentially affected by a sediment-rich cascade. Exposure assessments based only on inundation within an existing channel or design-flood footprint may therefore underestimate lateral erosion, channel migration, and avulsion. This is particularly relevant for roads, bridges, hydropower facilities, and transmission infrastructure located on narrow river terraces.

The downstream transformation had a different effect on warning opportunity. In the upper corridor, the event reached or disabled the Rasuwagadhi and Syabrubesi monitoring stations before the 09:15 NST public-warning reference, and Betrawati had only about 5 min of operational lead. Farther downstream, increasing travel time created much larger warning windows, exceeding 2 h at Phurke Khola and 6 h by the reported flood-wave arrival at Devghat. The contrast indicates that warning requirements differ fundamentally between source-proximal and downstream locations. Near the source, there may be too little time to wait for conventional downstream hydrometric confirmation, whereas farther downstream the evolving flood can be tracked and arrival estimates updated as new observations become available.

For the upper corridor, the 2026 event therefore points to the value of rapid detection methods that can recognize the initiating mass movement itself, including seismic or infrasound monitoring, automated image analysis, and other near-real-time observations of unstable high-mountain slopes. Such detection would need to be linked to predefined communication and evacuation procedures because even a technically successful warning has limited value when only minutes are available for response. Farther downstream, surviving hydrometric stations, cameras, field observations, and flood-routing information can provide progressively better estimates of arrival time and severity. The failure of several upstream stations during the event also shows why monitoring networks need redundancy, particularly where individual instruments are located directly within the expected flow path.

Taken together, these findings reveal an important longitudinal contrast. Distance from the source generally increased the time available for warning, but it did not produce a predictable reduction in geomorphic disturbance. Effective risk management along such corridors therefore requires both dynamic monitoring of the moving hazard and exposure assessments that allow the river itself to change during the event, rather than assuming that the pre-event channel remains fixed.

5.3 Infrastructure risk extends beyond individual projects

The infrastructure losses show that the 2026 disaster affected the river corridor as an interconnected system rather than as a collection of isolated assets. These losses occurred along the same corridor that contained settlements, hydropower projects, transmission infrastructure, and access routes. Damage to one component could therefore affect the operation or recovery of others. A hydropower facility, for example, may remain structurally intact but still become inaccessible if connecting roads and bridges are lost. These findings have implications for how infrastructure risk is assessed in Himalayan river basins. Project-level assessments commonly evaluate the hazard at an individual facility, yet a long-runout cascade can simultaneously affect headworks, bridges, roads, transmission systems, construction areas, and downstream communities. The 2026 event also involved processes that may not be represented adequately by a conventional design flood alone. Sediment-rich flow, channel widening, debris impact, temporary blockage and release, bridge obstruction, and loss of access can occur together and can alter conditions well beyond the footprint of an individual project.

A basin- or corridor-scale approach would better capture these dependencies. For hydropower in particular, hazard assessment should consider not only whether floodwater reaches a project site, but also how upstream mass movements, sediment entrainment, channel change, bridge failure, and transportation disruption could affect project operation and emergency access. The same approach is relevant to roads and transmission networks because their failure can restrict evacuation and delay repair of other damaged infrastructure. The high concentration of recovery needs in the energy sector therefore reflects more than damage to generating capacity alone. It also shows how closely infrastructure recovery is tied to the functioning of the wider river corridor.

5.4 Implications for Himalayan cryospheric risk assessment

The 2026 Bhote Koshi event occurred within a high-mountain environment undergoing glacier retreat, warming, and changes in ice-rock support, all of which can influence long-term slope stability. Previous studies have shown that glacier thinning, permafrost degradation, meltwater infiltration, and exposure of fractured bedrock can progressively destabilize steep mountain slopes (27–29). For the Bhote Koshi source area, published observations of glacier retreat, exposed and fractured bedrock, hanging ice, and spatial variations in glacier motion are consistent with such preconditioning. Our reconstruction, however, did not identify the immediate trigger of the 26 August failure, and the available rainfall observations do not indicate an exceptional short-duration precipitation event immediately beforehand. We therefore distinguish between long-term climatic preconditioning and event-specific trigger attribution. The available evidence supports the former as plausible but does not establish that climate change directly triggered this individual failure.

This distinction is important for Nepal’s broader cryospheric hazard agenda. Existing GLOF inventories and downstream flood assessments remain essential because potentially dangerous glacial lakes continue to pose substantial risk. Recent work has also improved the treatment of uncertainty in modelling downstream exposure from potentially dangerous lakes, while the 2024 Thame disaster showed that linked small lakes can generate damaging cascades (13,30). The 2026 Bhote Koshi event adds a different failure pathway. In this case, a major cryospheric flood developed without evidence that drainage of a pre-existing glacial lake initiated the disaster. A national monitoring strategy focused only on known dangerous lakes would therefore capture an important part of the hazard landscape, but not all of it.

Our findings support extending cryospheric hazard assessment from inventories of individual sources toward connected source-pathway-receptor systems. Potential source areas could include not only glacial lakes but also hanging glaciers, unstable glacier-rock margins, recently deglaciated slopes, and rock slopes directly connected to steep glacierized channels. The downstream pathway is equally important because relief, channel confinement, sediment availability, tributary confluences, and temporary blockage potential can determine whether an initial failure attenuates or develops into a much larger cascade. Linking these source and pathway characteristics with settlements, transportation networks, hydropower facilities, transmission systems, and evacuation routes would provide a more complete representation of downstream risk.

The multi-source nature of this study also highlights the importance of retaining uncertainty when reconstructing rapidly evolving disasters. We found that apparently small differences among public records could materially alter derived quantities. Other differences, such as the published source-area estimates, reflected different spatial definitions rather than measurement disagreement. Human-impact records changed as identification and registry reconciliation progressed and could not be reduced reliably to a single early mortality estimate. For rapid post-disaster research, these differences should remain visible rather than being resolved through averaging or selection without explanation. This distinction between robust process-level conclusions and unresolved event-specific quantities is important when rapid scientific evidence is used to guide monitoring, modelling, and risk reduction after high-mountain disasters.

6. Conclusions and future perspectives

The 26 August 2026 Bhote Koshi disaster demonstrates that high-mountain hazards cannot always be understood from their initiating process alone. A disturbance originating in a glacierized source area can change substantially as it interacts with water, sediment, and valley morphology, making the downstream pathway an active part of the evolving hazard. This supports a broader source-pathway-receptor approach to cryospheric risk assessment, in which glacial-lake monitoring is complemented by attention to unstable rock-ice slopes, sediment availability, channel connectivity, temporary blockages, and downstream exposure. The same perspective is relevant to early warning and infrastructure planning, particularly in Himalayan River corridors where settlements, roads, bridges, hydropower facilities, and communication networks are closely interconnected.

Our reconstruction also demonstrates the value of integrating hydrological, geophysical, remote-sensing, and impact data while preserving differences in their definitions, timing, spatial coverage, and uncertainty. However, the study relied primarily on publicly available secondary data, and the absence of complete raw hydrometric records, high-resolution topography, detailed channel delineations, and field observations limited our ability to independently constrain some aspects of the event. Future research combining these datasets with field measurements and higher-resolution observations could better resolve source processes, entrainment, downstream transformation, and associated uncertainties. More broadly, as Himalayan cryospheric environments continue to change, hazard research should move beyond inventories of individual

hazardous features toward understanding how interacting processes develop across entire mountain-river systems, providing a stronger basis for monitoring, early warning, and resilient infrastructure planning across high-mountain regions.

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Author contributions

TK contributed to literature review and data collection. NP performed calculations and formal analysis. NP wrote and reviewed the original manuscript draft.

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The author declares no competing interests.

Ethics statement

The study uses publicly reported aggregate disaster data and does not analyze identifiable individual-level records.

Data availability

The data compiled for the formal analysis of the study is available upon request to the corresponding author.

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