Multi-Sensor Satellite-Based Retrospective Early-Warning Assessment of the 26 August 2026 Flood Event in the Langtang Region of Nepal

Avideh Asadollahi
PhD in Industrial Engineering, Islamic Azad University, Tehran, Iran
Email:avidehasadollahi@gmail.com
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Abstract

Rapid-onset floods in high-mountain environments can be difficult to anticipate because their triggering mechanisms may involve interactions among precipitation, glacierized terrain, surface-water dynamics, and sudden geomorphological disturbances. This study presents a retrospective multi-sensor satellite assessment of the flood event reported in the Langtang region of Nepal on 26 August 2026. The objective was to determine whether remotely sensed observations could identify potentially relevant environmental changes several days before the event.

A Google Earth Engine-based workflow was developed using ERA5-Land precipitation, Sentinel-1 synthetic aperture radar (SAR), Sentinel-2 multispectral imagery, MODIS snow-cover observations, the GLIMS glacier inventory, and the JRC Global Surface Water dataset. The analysis followed a sequential workflow consisting of precipitation anomaly assessment, persistent-water screening, glacier inventory screening, candidate source identification, SAR disturbance analysis, optical validation, temporal precursor analysis, and retrospective early-warning scoring.

Cumulative precipitation during 1–21 August 2026 was 322.14 mm, compared with a 2020–2025 mean of 336.44 mm and a standard deviation of 44.10 mm, corresponding to an anomaly of −14.31 mm and a standardized anomaly of −0.24. Thus, cumulative pre-event precipitation was not anomalously high relative to the selected baseline. In contrast, a glacierized source region approximately 1.96 km from the independently selected source point exhibited substantial multi-sensor change. The leading GLIMS glacier candidate had an inventory area of 2.23 km², while approximately 2.16 km² of its surface exhibited the defined SAR-change signal. The resulting affected fraction was approximately 97.08%. Direct source-area analysis also indicated changes in NDSI, NDVI, and MODIS-derived snow-cover metrics.

A retrospective early-warning index increased substantially during the days preceding the event, reaching a maximum score of 44.51 during the T−5 to T−3 day interval. However, the predefined strong-precursor threshold of 60 was not reached. The results therefore indicate that detectable multi-sensor precursor signals existed several days before the event, but the available observations

and heuristic index were insufficient to demonstrate a reliable operational early-warning capability.

The study demonstrates the potential value of integrating SAR, optical, thermal/snow-cover, precipitation, glacier inventory, and surface-water information within a common geospatial framework. More importantly, it provides a reproducible workflow for retrospective investigation of rapid-onset mountain flood events in data-sparse regions.

Keywords: Nepal; Langtang; flood; glacier; remote sensing; Sentinel-1; Sentinel-2; MODIS; ERA5-Land; Google Earth Engine; early warning; multi-sensor analysis

1. Introduction

High-mountain floods can develop through a range of interacting processes, including intense precipitation, snow and ice instability, landslides, temporary blockage of drainage pathways, sudden release of impounded water, and glacier-related hydrological disturbances. In complex mountain environments, identifying the dominant mechanism after an event is challenging, while identifying potentially useful precursor signals before an event is even more difficult.

Satellite remote sensing provides an opportunity to examine these processes using complementary observations. Synthetic aperture radar (SAR) is particularly useful for observing changes in surface backscatter under conditions where optical imagery may be affected by cloud cover. The Sentinel-1 mission provides C-band SAR observations suitable for repeated monitoring of terrestrial surfaces (Torres et al., 2012). Sentinel-2 provides multispectral observations at relatively high spatial resolution and is particularly useful for detecting changes in snow, ice, vegetation, and surface water (Drusch et al., 2012).

Satellite-based precipitation and reanalysis products provide an additional environmental dimension. ERA5-Land provides a spatially consistent representation of land-surface water and energy variables and can be used to investigate temporal variability and anomalies in precipitation and other land-surface conditions (Muñoz-Sabater et al., 2021). Long-term surface-water datasets such as the JRC Global Surface Water dataset provide complementary information on persistent and changing water bodies (Pekel et al., 2016). Glacier inventories such as the Global Land Ice Measurements from Space (GLIMS) database provide a spatial framework for identifying glacierized areas that may warrant further investigation (Raup et al., 2007).

The integration of these data sources within cloud-based geospatial environments makes it possible to conduct multi-temporal analyses over large and remote regions. Google Earth Engine provides a planetary-scale platform for processing and analysing large collections of satellite and environmental datasets (Gorelick et al., 2017).

The 26 August 2026 flood event in the Langtang region of Nepal provides an opportunity to investigate whether a combination of these satellite observations could have identified environmental changes before the event. Rather than assuming a specific triggering mechanism, this study evaluates several competing environmental signals and examines their temporal behaviour.

The central research question is:

Could multi-source satellite observations detect signs of an approaching flood several days before the 26 August 2026 event in Langtang, Nepal?

The study is intentionally framed as a **retrospective early-warning assessment**, rather than a claim of operational prediction. The objective is to determine whether measurable precursor signals existed and whether their magnitude and timing were sufficient to support a potentially useful early-warning framework.

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2. Study Area and Event Context

The study focuses on the Langtang region of northern Nepal, within the high-relief Himalayan environment. The region contains extensive glacierized terrain, steep slopes, narrow valleys, and complex drainage networks. These characteristics make the area potentially susceptible to compound hydrological and geomorphological hazards.

For the broader event analysis, an event reference point at approximately **85.55°E, 28.22°N** was used. A separate source-search point at approximately **85.515°E, 28.271°N** was subsequently used to investigate a potentially relevant glacierized source region.

The distinction between the event reference point and the source-search point was maintained throughout the analysis. The event point represents the location used for the broader flood and hydrological assessment, whereas the source point represents the independently selected area used for investigating potential upstream glacier-related disturbance.

Because the available satellite observations do not independently establish a single causal mechanism, the analysis does not assume that the event was necessarily caused by a glacier collapse, glacial lake outburst flood, landslide dam failure, or extreme rainfall. Instead, these possibilities are evaluated indirectly through their expected environmental signatures.

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3. Data and Methods

3.1 Analytical Framework

The analysis was implemented primarily in Google Earth Engine (GEE), which enables large-scale processing of satellite imagery and environmental datasets within a cloud-based geospatial environment (Gorelick et al., 2017).

The overall workflow consisted of the following stages:

1. Pre-event precipitation assessment.
2. Persistent surface-water screening.
3. Glacier inventory screening.
4. Identification of potentially relevant glacierized source areas.
5. Sentinel-1 SAR disturbance analysis.
6. Sentinel-2 optical analysis.
7. MODIS snow-cover analysis.
8. Multi-sensor temporal precursor assessment.
9. Construction of a retrospective early-warning index.
10. Interpretation of the results within the context of operational early-warning limitations.

The objective was not to establish causality from a single sensor, but to determine whether independent observations showed temporally consistent environmental change.

3.2 Precipitation Analysis

ERA5-Land was used to assess precipitation conditions before the event. ERA5-Land is a land-focused reanalysis dataset designed to provide a consistent representation of land-surface processes and is suitable for analysing temporal anomalies (Muñoz-Sabater et al., 2021).

The primary pre-event precipitation analysis covered **1–21 August 2026**. This period was compared with the corresponding August-period baseline derived from **2020–2025**.

The following statistics were calculated:

- 2026 pre-event precipitation mean;
- 2020–2025 baseline mean;
- baseline standard deviation;
- precipitation anomaly; and
- standardized precipitation anomaly (Z-score).

The standardized anomaly was calculated as:

$$Z = \frac{P_{2026} - \bar{P}_{2020-2025}}{\sigma_{2020-2025}}$$

where P_{2026}represents cumulative precipitation during the 2026 pre-event period, $\bar{P}_{2020-2025}$represents the corresponding baseline mean, and $\sigma_{2020-2025}$represents the baseline standard deviation.

This analysis was designed to evaluate whether unusually high cumulative precipitation preceded the event. It does not exclude the possibility of a short-duration or sub-daily precipitation extreme that may not be represented by the cumulative pre-event statistic.

3.3 Surface-Water Screening

Persistent surface water was evaluated using the JRC Global Surface Water dataset. The dataset provides information on the spatial and temporal distribution of surface water derived from long-term satellite observations (Pekel et al., 2016).

An initial search area extending approximately **50 km** around the event reference point was examined using a persistent-water threshold corresponding to a Global Surface Water occurrence of at least 50%.

The analysis identified approximately **38.90 km²** of persistent water within the 50 km search area. This value represents the total persistent-water area within the search region and **does not represent the area of a single lake**.

A more focused analysis around the glacierized source region identified approximately **0.706 km²** of persistent water within 10 km. Individual water-body polygons were subsequently extracted and ranked for further investigation.

These observations were treated as hydrological context rather than direct evidence of a glacial lake outburst flood.

3.4 Glacier Inventory Screening

The GLIMS glacier inventory was used to identify glacierized areas potentially relevant to the event (Raup et al., 2007).

Glacier candidates within approximately 50 km of the event reference point were screened using glacier area and spatial proximity. Candidate glaciers larger than 0.05 km² were retained for further analysis.

For the more detailed source-region analysis, the area around the independently selected source point at approximately **85.515°E, 28.271°N** was examined.

Within a 5 km search radius, **69 glacier candidates** were identified.

The leading candidate was:

- **GLIMS ID:** G085526E28256N
- **Inventory area:** 2.23 km^2
- **Distance from source-search point:** 1.96 km

This glacier was selected as the leading glacierized source candidate for subsequent multi-sensor analysis.

Importantly, identification as a leading candidate does not demonstrate that the glacier collapsed. The candidate designation only indicates that its location and observed surface changes warranted detailed investigation.

3.5 Sentinel-1 SAR Analysis

Sentinel-1 C-band SAR observations were used to investigate changes in surface backscatter. The Sentinel-1 mission provides weather-independent radar observations that can be used for monitoring changes in terrestrial surfaces (Torres et al., 2012).

The analysis used the Sentinel-1 Ground Range Detected (GRD) collection with VV polarization and Interferometric Wide (IW) mode.

For the source-area investigation, SAR observations were compared across several periods, including:

- August 2025;
- early August 2026;
- 10–18 August 2026; and
- 18–26 August 2026.

The primary change metric was derived from differences between representative SAR observations from the selected periods.

For the leading glacier candidate, the analysis produced a SAR change metric of approximately **18.02 dB**. Approximately **2.16 km^2** of the 2.23 km^2 inventory area exhibited the defined SAR-change signal.

Thus:

$$\frac{2.16}{2.23} \times 100 \approx 97.08\%$$

Approximately **97.08% of the inventory area** therefore exhibited the defined SAR-change signal.

This result indicates a substantial surface disturbance within the selected glacier polygon. However, SAR backscatter change alone cannot uniquely distinguish glacier collapse from other processes such as changes in surface moisture, snow conditions, debris exposure, roughness, or viewing geometry. For this reason, SAR results were interpreted jointly with optical and MODIS observations.

3.6 Sentinel-2 Optical Analysis

Sentinel-2 multispectral observations were used to examine changes in snow/ice, vegetation, and surface-water-related spectral responses. The Sentinel-2 mission provides high-resolution multispectral observations across the visible, near-infrared, and shortwave-infrared portions of the electromagnetic spectrum (Drusch et al., 2012).

Three spectral indices were considered:

Normalized Difference Snow Index

$$NDSI = \frac{Green - SWIR}{Green + SWIR}$$

Normalized Difference Vegetation Index

$$NDVI = \frac{NIR - Red}{NIR + Red}$$

Normalized Difference Water Index

$$NDWI = \frac{Green - NIR}{Green + NIR}$$

The source-area analysis produced the following direct change metrics:

- **NDSI change:** 0.181
- **NDVI change:** 0.038
- **NDWI change:** 0.046

These changes indicate that the spectral properties of the selected source area changed substantially relative to the comparison period.

A separate temporal analysis examined successive pre-event intervals. NDSI change increased from **0.182** during the 30–14 to 14–7 day comparison, to **0.277** during the 14–7 to 7–3 day comparison, and to **0.394** during the 7–3 to 3–0 day comparison.

NDVI change similarly increased from:

- 0.056,
- to 0.076,
- to 0.130.

The progressive increase toward the event provides an additional indication of increasing surface disturbance.

3.7 MODIS Snow-Cover Analysis

MODIS/Terra daily snow-cover observations were incorporated to provide a complementary medium-resolution observation of snow-related surface conditions. The MODIS/Terra MOD10A1 Collection 6.1 product provides daily snow-cover information at approximately 500 m spatial resolution (Hall & Riggs, 2021).

A MODIS-derived change metric was calculated for the selected source area and compared across successive pre-event intervals.

The resulting temporal values were:

- **8.44** for the 30–14 to 14–7 day comparison;
- **10.00** for the 14–7 to 7–3 day comparison; and
- **14.89** for the 7–3 to 3–0 day comparison.

The increasing MODIS change metric provides an additional independent indication of increasing surface-state variability approaching the event.

Because MODIS has a substantially coarser spatial resolution than Sentinel-1 and Sentinel-2, its results were used primarily as supporting temporal evidence rather than as a source for precise delineation of the disturbance.

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4. Retrospective Multi-Sensor Early-Warning Index

4.1 Rationale

The central objective of the study was to determine whether multiple satellite-derived signals became stronger as the event approached.

To evaluate this question, a retrospective Early Warning Index (EWI) was constructed using four components:

1. Sentinel-1 SAR change;
2. Sentinel-2 NDSI change;
3. Sentinel-2 NDVI change; and
4. MODIS change.

The index was intentionally designed as a **heuristic research indicator**, not as a probabilistic hazard model.

4.2 Index Formulation

The index was calculated as:

$$EWI = 40 \min\left(\frac{\Delta SAR}{10}, 1\right) + 20 \min\left(\frac{\Delta NDSI}{0.40}, 1\right) + 15 \min\left(\frac{\Delta NDVI}{0.15}, 1\right) + 15 \min\left(\frac{\Delta MODIS}{15}, 1\right)$$

The maximum possible score was therefore **90**.

The analysis used five retrospective temporal windows:

- **T−14 to T−10 days**
- **T−10 to T−7 days**
- **T−7 to T−5 days**
- **T−5 to T−3 days**
- **T−3 to T−1 days**

A score of **60 or greater** was defined within the analysis as a strong precursor threshold.

This threshold should not be interpreted as a validated warning threshold. The index has not been calibrated against a historical event catalogue and therefore cannot be interpreted as a probability of flooding.

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5. Results

5.1 Pre-Event Precipitation

The cumulative precipitation analysis produced the following results:

Metric	Value
2026 pre-event precipitation	322.14 mm
2020–2025 baseline mean	336.44 mm
Baseline standard deviation	44.10 mm
Precipitation anomaly	−14.31 mm
Z-score	−0.24

The 2026 cumulative precipitation was therefore slightly below the 2020–2025 baseline mean.

The standardized anomaly of **−0.24** is close to zero and does not indicate an extreme cumulative precipitation anomaly.

This result provides no strong evidence that unusually high cumulative precipitation during 1–21 August was the dominant direct precursor to the event.

However, this conclusion is restricted to the analysed cumulative period and temporal resolution. It does not rule out the possibility of a short-duration rainfall event occurring close to the event date.

5.2 Glacierized Source Candidate

The glacier screening identified **69 glacier candidates within 5 km** of the source-search point.

The leading candidate, GLIMS ID G085526E28256N, had:

- an inventory area of 2.23 km²;
- a distance of 1.96 km from the source-search point;
- a SAR change metric of 18.02 dB;
- approximately 2.16 km² of SAR-affected area; and
- approximately 97.08% of its inventory surface exhibiting the defined SAR-change signal.

The corresponding NDSI change was approximately **0.066**, while the final exploratory candidate score was **79.81**.

These observations identify the glacierized area as the most prominent candidate source region in the investigated set.

The result should nevertheless be interpreted as evidence of **major glacier-associated surface disturbance**, rather than confirmation of physical glacier collapse.

5.3 Multi-Sensor Source-Area Response

The source-area analysis showed consistent changes across multiple sensor types.

Sensor / indicator	Observed change
Sentinel-1 SAR	18.02 dB
SAR-affected area	2.16 km^2
Fraction of glacier polygon affected	97.08%
Sentinel-2 NDSI	0.181
Sentinel-2 NDVI	0.038
Sentinel-2 NDWI	0.046
MODIS change metric	22.34

The directionally consistent changes across radar, optical, and MODIS observations increase confidence that the detected signal represents a substantial environmental surface change rather than a feature observed by only one sensor.

Nevertheless, the observations do not uniquely identify the physical process responsible for the change.

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6. Temporal Precursor Analysis

The temporal analysis provided the strongest evidence for an approaching change.

6.1 Sentinel-1

The SAR change metric increased substantially in the period immediately preceding the event.

The observed values were:

- **T−14 to T−7:** 1.35 dB
- **T−7 to T−5:** 8.83 dB

This increase indicates that the SAR disturbance became substantially stronger during the final approximately seven days before the event.

Because Sentinel-1 acquisition frequency is constrained by orbital coverage and acquisition schedules, the temporal sampling does not provide continuous monitoring.

6.2 Sentinel-2

The optical indices showed an increasing trend toward the event.

Temporal comparison	NDSI change	NDVI change
30–14 → 14–7 days	0.182	0.056
14–7 → 7–3 days	0.277	0.076
7–3 → 3–0 days	0.394	0.130

Both NDSI and NDVI changes increased during the successive periods approaching the event.

The strongest change occurred during the final interval, indicating that the source-area surface state became increasingly different from the preceding reference period.

6.3 MODIS

The MODIS change metric also increased toward the event:

Temporal comparison	MODIS change
30–14 → 14–7 days	8.44
14–7 → 7–3 days	10.00
7–3 → 3–0 days	14.89

The agreement between the MODIS temporal trend and the Sentinel-2 results provides independent supporting evidence for increasing surface-state change.

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7. Early-Warning Index Results

The retrospective Early Warning Index produced the following scores:

Retrospective window	EWI score
T−14 to T−10	9.43
T−10 to T−7	10.80
T−7 to T−5	8.99
T−5 to T−3	**44.51**
T−3 to T−1	17.06

The highest score was **44.51**, observed during the **T−5 to T−3 day interval**.

Although this was the strongest precursor window, it remained below the predefined strong-precursor threshold of **60**.

The results therefore suggest that the event was associated with a measurable multi-sensor precursor signal several days before occurrence, but the signal was not sufficiently strong, continuous, or calibrated to justify an operational warning.

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8. Discussion

8.1 Rainfall Versus Surface-Disturbance Signals

One of the most important findings is the contrast between the precipitation analysis and the satellite-derived surface-disturbance indicators.

Cumulative precipitation during the analysed pre-event period was close to, and slightly below, the historical baseline. The Z-score of −0.24 provides little support for an interpretation based solely on unusually high cumulative precipitation.

In contrast, Sentinel-1, Sentinel-2, and MODIS observations indicated increasing surface disturbance toward the event.

This contrast does not demonstrate that rainfall played no role. Precipitation can influence snow and ice stability, meltwater production, slope saturation, and drainage conditions even when cumulative precipitation is not statistically extreme. In addition, the analysis does not resolve short-duration rainfall extremes.

The result instead suggests that **extreme cumulative rainfall was not necessary to explain the observed precursor pattern** and that glacierized-surface disturbance deserves further investigation.

8.2 Evidence for a Glacier-Associated Source

The leading glacier candidate showed several characteristics that made it particularly relevant:

1. It was located only approximately 1.96 km from the selected source-search point.
2. It had a substantial inventory area of 2.23 km².
3. Approximately 97.08% of the inventory area exhibited the defined SAR-change signal.
4. Optical indices also changed substantially.
5. MODIS observations showed an increasing change metric toward the event.
6. The multi-sensor disturbance increased during the final days before the event.

Taken together, these observations support the interpretation of a **major glacier-associated surface disturbance**.

However, satellite observations alone do not establish the precise geomorphological mechanism.

Possible mechanisms may include changes in snow and ice cover, debris exposure, ice or rock instability, surface-water interaction, localized mass movement, or a combination of processes.

Therefore, the present study deliberately avoids the stronger claim that a glacier collapse has been confirmed.

8.3 Implications for GLOF and Temporary-Dam Hypotheses

Persistent surface-water screening identified water bodies within the broader upstream environment. The presence of these water bodies establishes a potentially relevant hydrological context, but it does not by itself demonstrate that a glacial lake outburst flood occurred.

Similarly, the analysis does not provide direct evidence sufficient to confirm the formation and subsequent failure of a temporary landslide or ice-rock dam.

A stronger assessment would require additional evidence, potentially including:

- high-resolution optical imagery immediately before and after the event;
- detailed digital elevation models;
- geomorphological mapping;
- time-series lake-area measurements;
- river discharge observations;
- field observations;
- high-resolution commercial satellite imagery; and
- independent event documentation.

The current findings should therefore be regarded as evidence supporting further investigation rather than as definitive attribution of the flood mechanism.

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9. Can the Event Be Considered Predictable?

The central research question can be answered cautiously.

Retrospective answer: partially yes.

The analysis indicates that measurable multi-sensor changes were detectable before the event. In particular, increasing SAR, NDSI, NDVI, and MODIS-derived changes were observed as the event approached.

The strongest retrospective Early Warning Index signal occurred approximately **3–5 days before the event**.

However, the maximum EWI score was only **44.51**, below the defined strong-precursor threshold of 60.

Furthermore, the available satellite observations were temporally discontinuous, and the index was not statistically calibrated against historical events.

Therefore, the results **do not demonstrate that an operational warning could reliably have been issued three to five days in advance**.

A more defensible conclusion is:

The event exhibited detectable multi-sensor precursor signals several days before occurrence, but the available observations were insufficient to demonstrate a reliable operational early-warning capability.

This distinction is important because retrospective detectability is not equivalent to operational predictability.

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10. Limitations

Several limitations should be considered when interpreting the findings.

10.1 Retrospective design

The analysis was conducted after the event. Therefore, the results demonstrate retrospective detectability rather than real-time predictive performance.

10.2 Satellite acquisition frequency

Sentinel-1 and Sentinel-2 do not provide continuous observations at the event location. Important changes may occur between acquisitions.

10.3 Cloud and snow effects

Optical observations can be affected by clouds, illumination, atmospheric conditions, and rapidly changing snow properties. This limitation is particularly relevant in high-mountain environments.

10.4 Spatial resolution differences

Sentinel-1 and Sentinel-2 provide considerably finer spatial information than MODIS. Consequently, the MODIS signal should not be interpreted as an exact spatial representation of the disturbance.

10.5 Rainfall temporal resolution

The precipitation analysis focused on cumulative rainfall during 1–21 August. It cannot exclude short-duration rainfall extremes occurring closer to the event.

10.6 Heuristic early-warning index

The EWI is an exploratory index rather than a statistically calibrated probability model. Its component weights and thresholds were defined within the analysis framework and require validation against independent historical events before any operational use.

10.7 Causal attribution

The observed satellite changes cannot, by themselves, establish whether the event resulted from glacier collapse, ice-rock avalanche, landslide-dam failure, GLOF, rainfall, or a combination of processes.

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11. Reproducibility and Computational Framework

The analysis was implemented using Google Earth Engine, which enables cloud-based processing of satellite and environmental datasets at large spatial and temporal scales (Gorelick et al., 2017).

The principal datasets used were:

- Sentinel-1 SAR;
- Sentinel-2 multispectral imagery;
- ERA5-Land precipitation;
- MODIS/Terra snow-cover observations;
- GLIMS glacier inventory; and
- JRC Global Surface Water.

The workflow was designed to be reproducible and transferable to other high-mountain flood events.

The principal methodological sequence can be summarized as:

Rainfall → Surface Water → Glacier Inventory → Candidate Source Detection → SAR Disturbance → Optical Validation → Multi-Sensor Temporal Analysis → Retrospective Early-Warning Assessment

The primary scientific contribution is therefore not limited to the interpretation of a single event. Rather, the study provides a framework that can be applied to other rapid-onset mountain hazards where the triggering mechanism is uncertain.

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12. Conclusions

This study conducted a retrospective multi-sensor satellite assessment of the 26 August 2026 flood event in the Langtang region of Nepal.

The main findings are:

1. **Cumulative pre-event precipitation was not anomalously high.**
   Rainfall during 1–21 August 2026 was 322.14 mm, compared with a 2020–2025 mean of 336.44 mm. The resulting standardized anomaly was −0.24.
2. **A prominent glacierized source candidate was identified.**
   The leading GLIMS candidate was located approximately 1.96 km from the source-search point and had an inventory area of 2.23 km².
3. **The candidate glacier exhibited extensive SAR change.**
   Approximately 2.16 km², or 97.08% of the inventory area, exhibited the defined SAR-change signal.

4. **Optical and MODIS observations independently indicated surface change.**
   Sentinel-2 NDSI, NDVI, and NDWI changed substantially, while MODIS observations showed increasing change toward the event.
5. **The disturbance intensified toward the event.**
   Sentinel-1, Sentinel-2, and MODIS indicators generally showed stronger changes during the final days before 26 August.
6. **A retrospective precursor signal was detected approximately 3–5 days before the event.**
   The highest Early Warning Index score was 44.51 during T−5 to T−3 days.
7. **Operational early warning cannot yet be claimed.**
   The maximum index score remained below the exploratory threshold of 60, and the index has not been independently calibrated or validated.

Overall, the evidence is more consistent with a **multi-sensor surface-disturbance precursor in a glacierized environment** than with an explanation based solely on anomalously high cumulative rainfall.

The study does not establish that a glacier collapse or GLOF occurred. Instead, it identifies a spatially and temporally coherent disturbance that warrants further geomorphological and hydrological investigation.

The principal conclusion is therefore:

The 26 August 2026 event exhibited detectable multi-sensor precursors several days before occurrence, but the available observations were insufficient to demonstrate a reliable operational early-warning capability.

Future research should focus on automated near-real-time monitoring, higher-frequency satellite observations, high-resolution digital elevation models, hydrological observations, and validation against a larger catalogue of glacier-related flood events.

Data and Code Availability

The analysis was conducted in Google Earth Engine using publicly available satellite and environmental datasets. The computational workflow and analysis scripts can be made available through an associated public code repository to support reproducibility and future methodological development.

References

Drusch, M., Del Bello, U., Carlier, S., et al. (2012). Sentinel-2: ESA's optical high-resolution mission for GMES operational services. *Remote Sensing of Environment, 120*, 25–36. doi:10.1016/j.rse.2011.11.026

Gorelick, N., Hancher, M., Dixon, M., et al. (2017). Google Earth Engine: Planetary-scale geospatial analysis for everyone. *Remote Sensing of Environment, 202*, 18–27. doi:10.1016/j.rse.2017.06.031

Hall, D. K., & Riggs, G. A. (2021). MODIS/Terra Snow Cover Daily L3 Global 500m SIN Grid, Version 6.1. NASA National Snow and Ice Data Center Distributed Active Archive Center. doi:10.5067/MODIS/MOD10A1.061

Muñoz-Sabater, J., Dutra, E., Agustí-Panareda, A., et al. (2021). ERA5-Land: A state-of-the-art global reanalysis dataset for land applications. *Earth System Science Data, 13*, 4349–4383. doi:10.5194/essd-13-4349-2021

Pekel, J.-F., Cottam, A., Gorelick, N., et al. (2016). High-resolution mapping of global surface water and its long-term changes. *Nature, 540*, 418–422. doi:10.1038/nature20584

Raup, B. H., Racoviteanu, A., Khalsa, S. J. S., et al. (2007). The GLIMS geospatial glacier database: A new tool for studying glacier change. *Global and Planetary Change, 56*, 101–110. doi:10.1016/j.gloplacha.2006.07.018

Torres, R., Snoeij, P., Geudtner, D., et al. (2012). GMES Sentinel-1 mission. *Remote Sensing of Environment, 120*, 9–24. doi:10.1016/j.rse.2011.05.028