Human-Robot Collaboration for Disaster Relief

Graduation Progress Week 1.2(.2)

Graduation Studio Extraterrestrial Architecture MSc 3 | Maria Dumitrache

Coordinators and tutors: Henriette Bier (A), Arwin Hidding (A), Peng Lee (A), Ferry Adema (BT), Luka Peternel (ME)

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Syabrubesi – Bhote Koshi Flood, Aug 2026
Position: Human-robot Collaboration

2. MATERIAL AVAILABILITY AND DAMAGE ANALYSIS
3. VERNACULAR ARCHITECTURE
Floodproofing

4. HUMAN-ROBOT COLLABORATION APPROACH

1. RECAP

1.1. Location Description and Problem Statement

Bhote Koshi flood at Syabrubesi, Nepal

Event Data

A major flash flood entered Nepal through the Bhote Koshi River at approximately 9:00 AM on 26 August 2026, causing significant loss and damage across Rasuwa, Nuwakot and Dhading districts. (Nepal Flash Flood 2026 - Nepal | ReliefWeb, n.d.)

The cause of the flood remains under investigation, with authorities assessing the possibility of a glacial lake outburst flood (GLOF) or another upstream hydrological event. (India, n.d.)

1,453 people reported dead
5,179 people still missing
13,795 people have been rescued
1,109 displaced people remain in 21 displacement centers

Context

By official count, the Bhotekoshi flood now the deadliest flood in Nepal's modern record.

The Rasuwa corridor floods again and again. Between 2022 and 2026, five significant flash floods hit the Rasuwa district. In 2025, the Lhende-Bhote Koshi river system flooded twice, on 8 and 30 July. Together, the floods killed at least 20 people. The cause of the July 2025 event was different: a supraglacial lake on Tibet's Purepu Glacier rapidly drained, causing a flash flood.

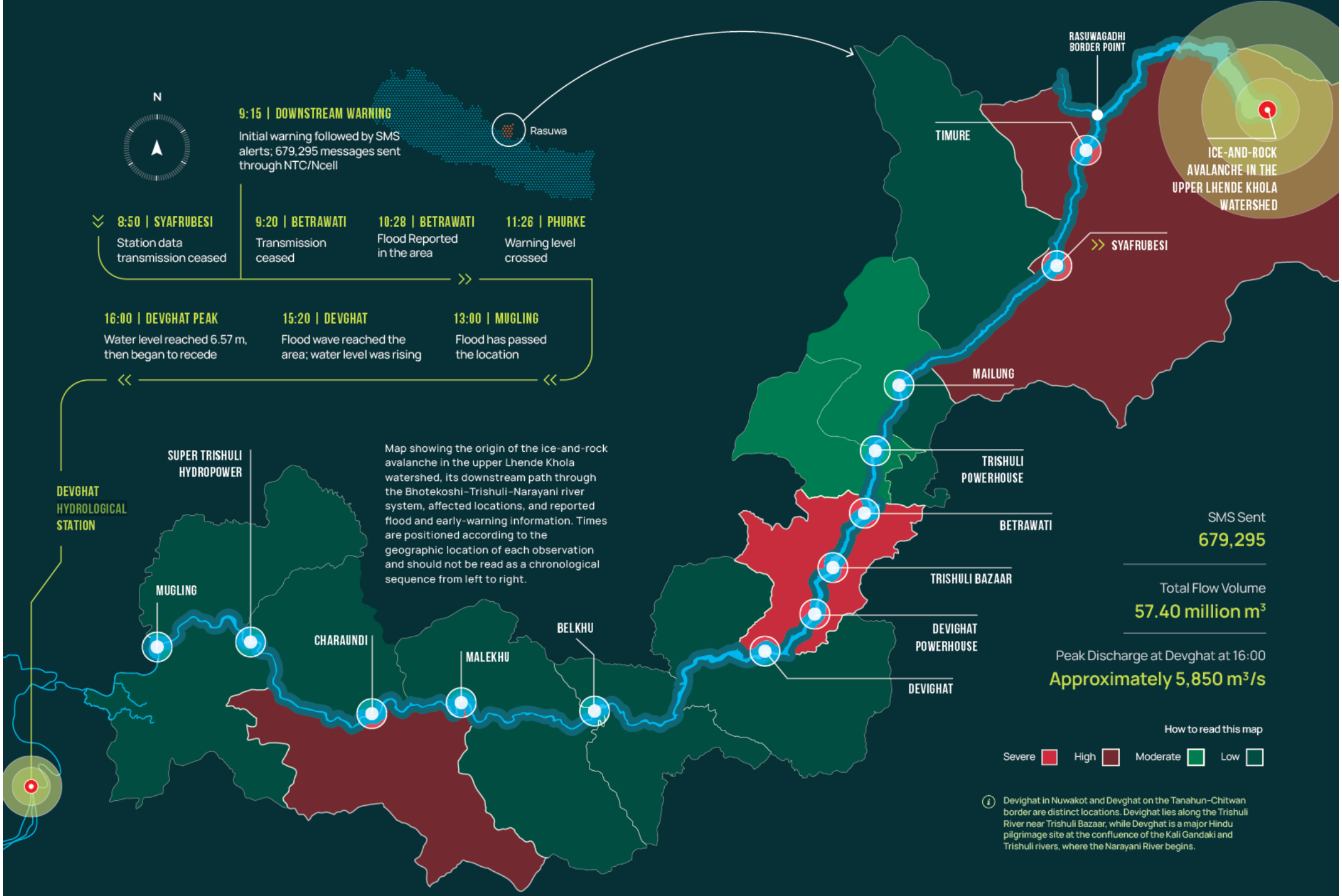


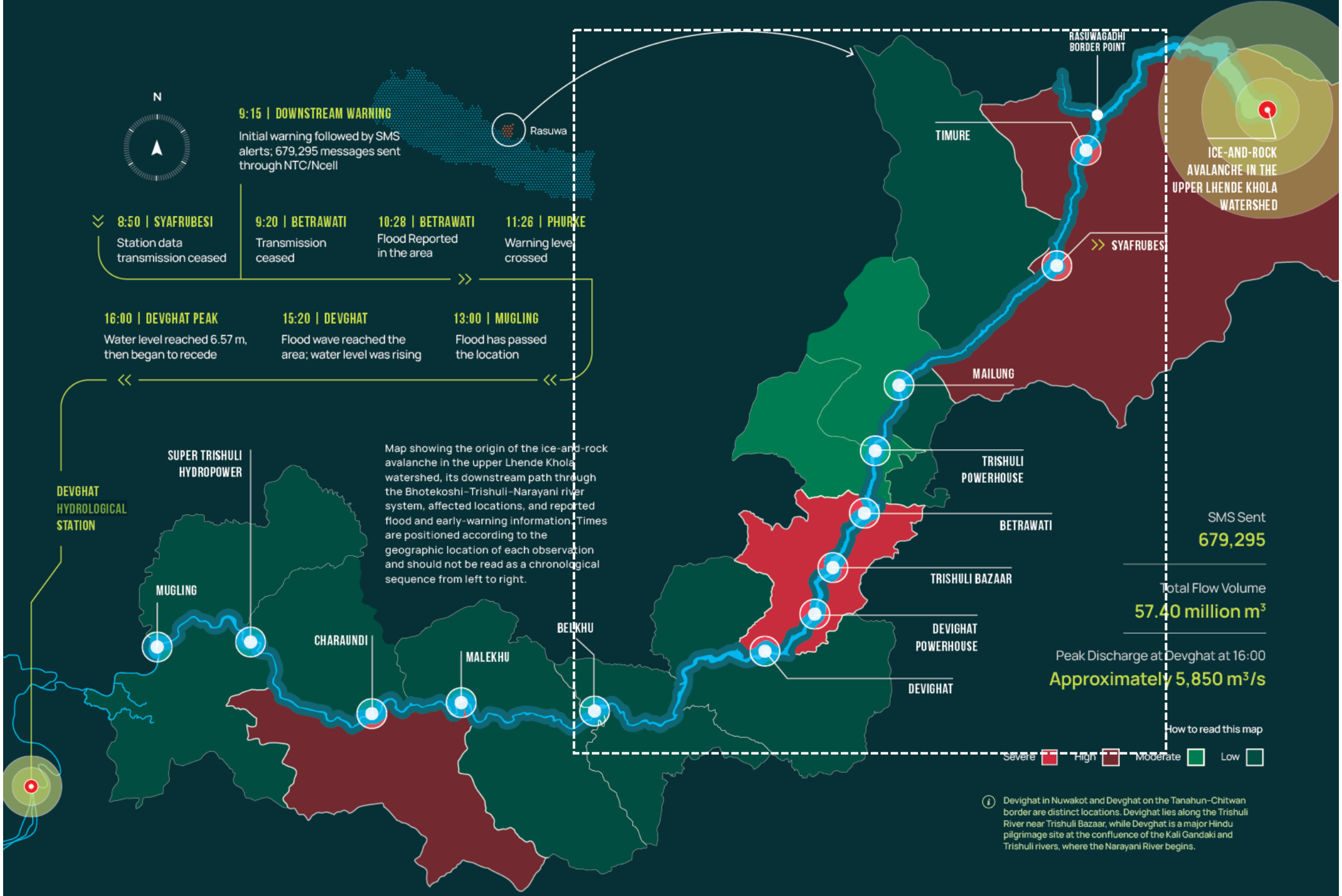


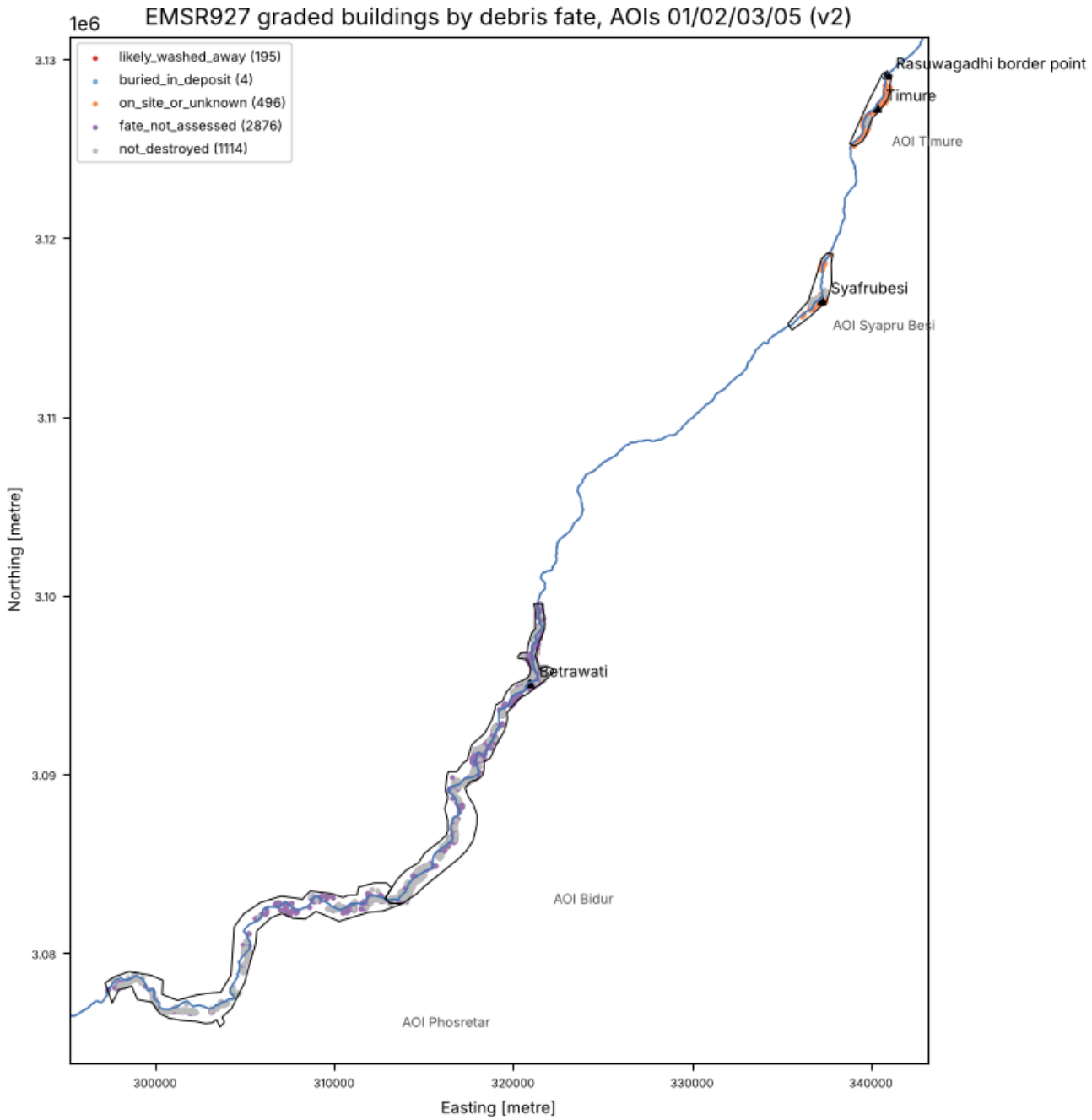
Syabrubesi, Napal

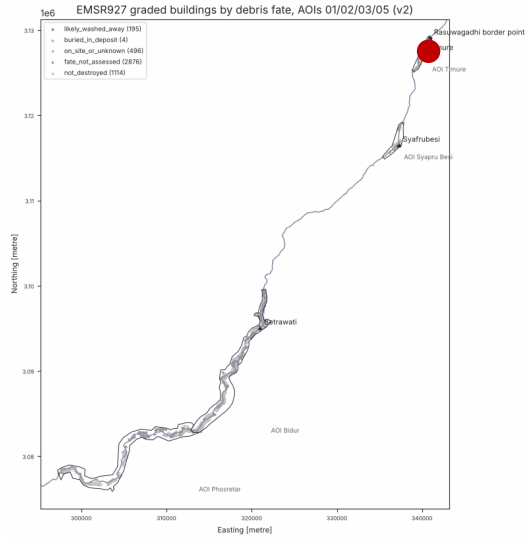



ice and rock
avalanche
trigger
Timure
Syapru Besi
Betrawati
Bidur
Galchhi
Phosretar


N
9:15 | DOWNSTREAM WARNING
Initial warning followed by SMS alerts; 679,295 messages sent through NTC/Ncell
Rasuwa
8:50 | SYAFRUBESI
Station data transmission ceased
9:20 | BETRAWATI
Transmission ceased
10:28 | BETRAWATI
Flood Reported in the area
11:26 | PHURKE
Warning level crossed
16:00 | DEVGHAT PEAK
Water level reached 6.57 m, then began to recede
15:20 | DEVGHAT
Flood wave reached the area; water level was rising
13:00 | MUGLING
Flood has passed the location
RASUWAGADHI BORDER POINT
TIMURE
ICE-AND-ROCK AVALANCHE IN THE UPPER LHENDE KHOLA WATERSHED
SYAFRUBESI
MAILUNG
TRISHULI POWERHOUSE
BETRAWATI
TRISHULI BAZAAR
DEVIGHAT POWERHOUSE
DEVIGHAT
BELKHU
MALEKHU
CHARAUNDI
MUGLING
SUPER TRISHULI HYDROPOWER
DEVGHAT HYDROLOGICAL STATION
Map showing the origin of the ice-and-rock avalanche in the upper Lhende Khola watershed, its downstream path through the Bhotekoshi–Trishuli–Narayani river system, affected locations, and reported flood and early-warning information. Times are positioned according to the geographic location of each observation and should not be read as a chronological sequence from left to right.
SMS Sent
679,295
Total Flow Volume
57.40 million m³
Peak Discharge at Devghat at 16:00
Approximately 5,850 m³/s
How to read this map
Severe
High
Moderate
Low
Devighat in Nuwakot and Devghat on the Tanahun–Chitwan border are distinct locations. Devighat lies along the Trishuli River near Trishuli Bazaar, while Devghat is a major Hindu pilgrimage site at the confluence of the Kali Gandaki and Trishuli rivers, where the Narayani River begins.

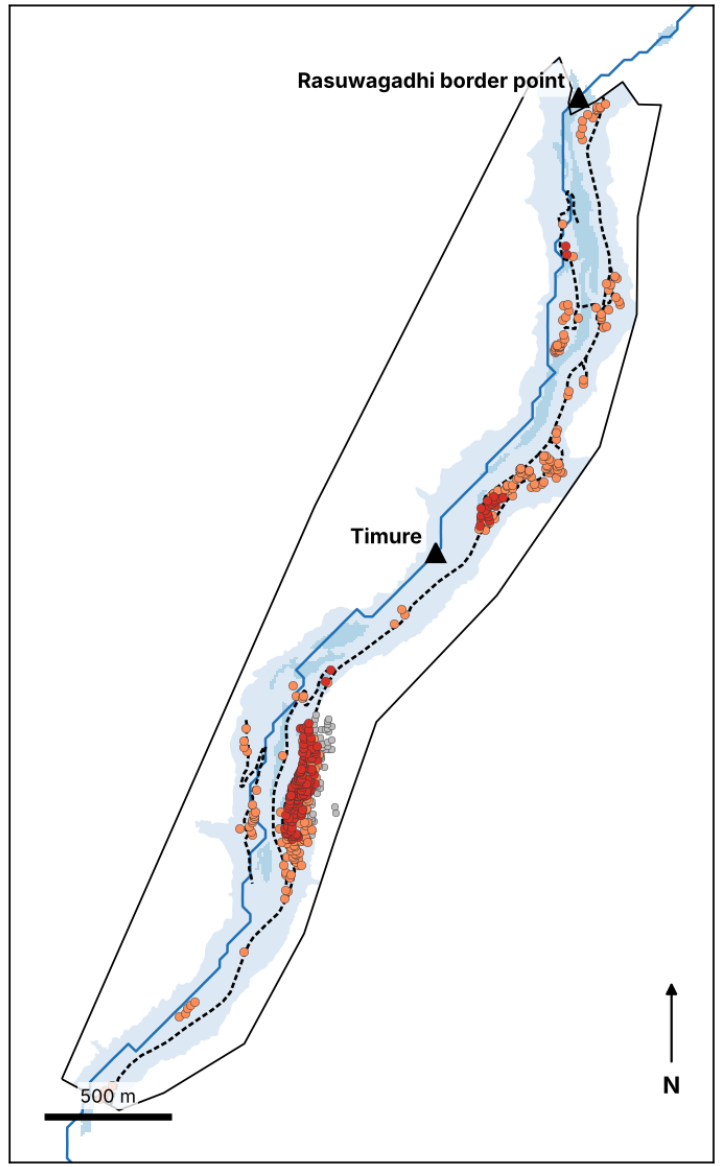

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EMSR927 graded buildings by debris fate, AOIs 01/02/03/05 (v2)
1e6
likely_washed_away (195)
buried_in_deposit (4)
on_site_or_unknown (496)
fate_not_assessed (2876)
not_destroyed (1114)
Rasuwagadhi border point
Timure
AOI Timure
Syafrubesi
AOI Syapru Besi
Betrawati
AOI Bidur
AOI Phosretar
Northing [metre]
Easting [metre]
3.13
3.12
3.11
3.10
3.09
3.08
300000
310000
320000
330000
340000



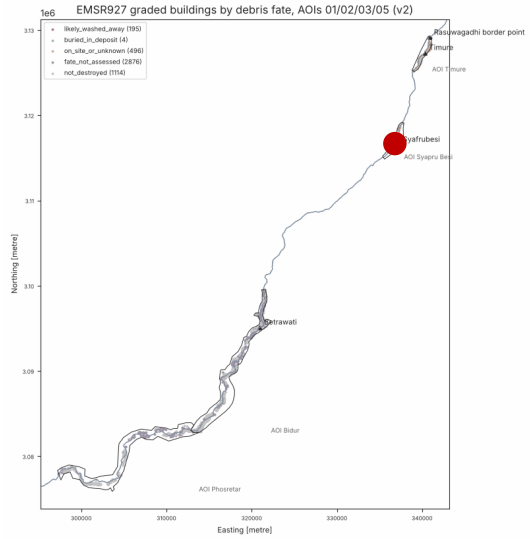
Timure (EMSR927 AOI02): building damage and likely debris fate

Building status: Copernicus EMS GRA PRODUCT, photo-interpretation. Debris fate tested only where Geopera terrain data exists.



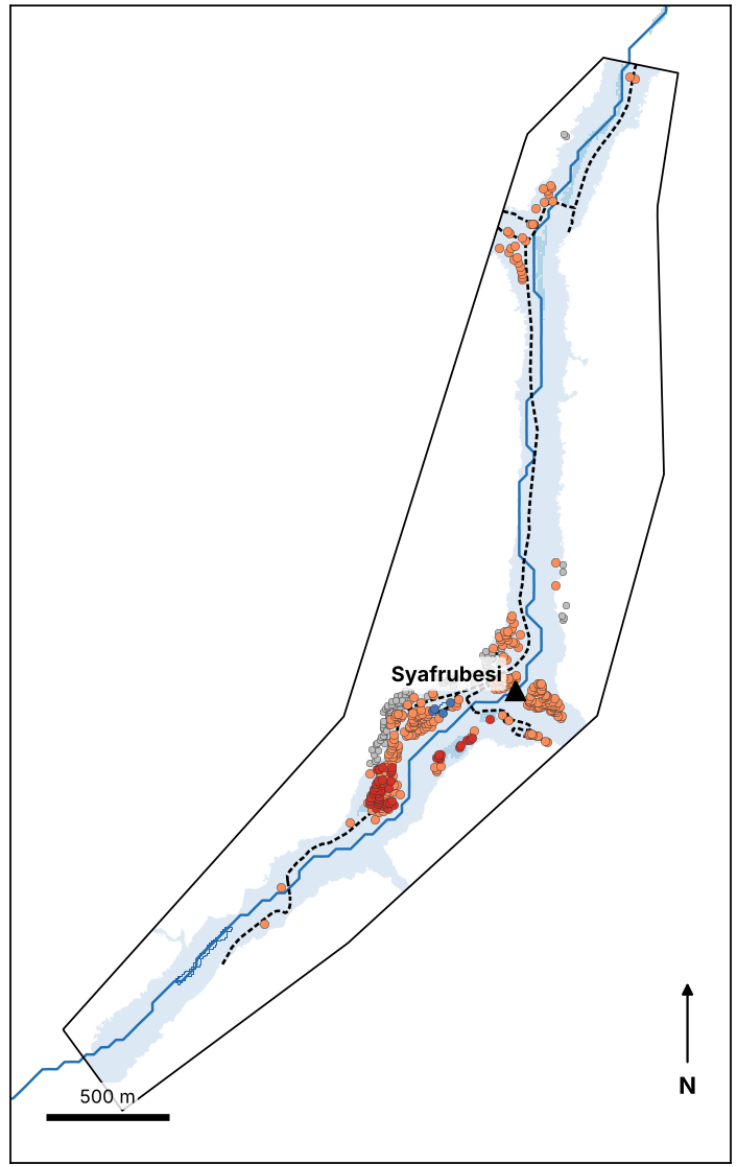
- Destroyed, likely washed away (146)
- Destroyed, debris on site / unknown (226)
- Damaged or possibly damaged (59)
- River centreline (Geopera)
- Road graded destroyed (EMS)
- Flood trace (EMS observed event)
- Erosion (Geopera, corrected)

Destroyed 372 · Damaged 33 · Possibly damaged 26
Gross debris (expected) 77,116 m³ · Re-usable stone on site 2,102–2,531 m³
Volumes are modelled (RDNA Table 52 × Gosaikunda RM (Table 10)), not measured.



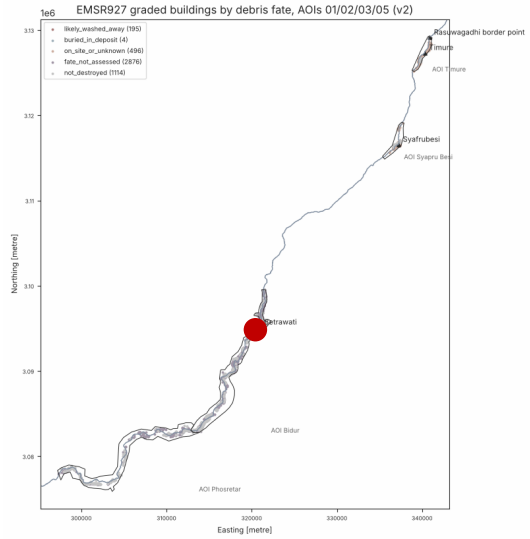
Syapru Besi (EMSR927 AOI01): building damage and likely debris fate

Building status: Copernicus EMS GRA PRODUCT, photo-interpretation. Debris fate tested only where Geopera terrain data exists.



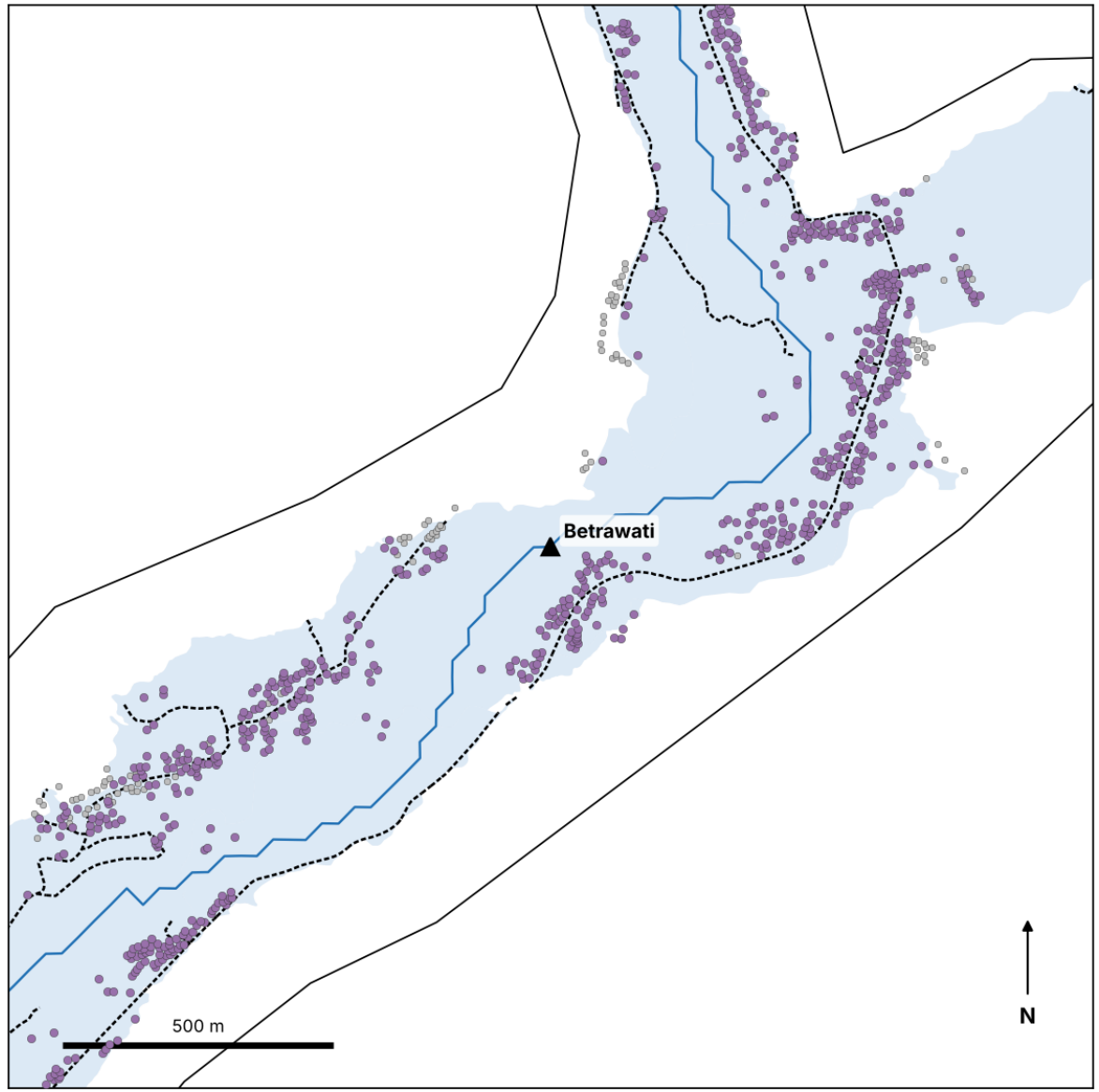
- Destroyed, likely washed away (49)
- Destroyed, buried in deposit (4)
- Destroyed, debris on site / unknown (270)
- Damaged or possibly damaged (110)
- River centreline (Geopera)
- Road graded destroyed (EMS)
- Flood trace (EMS observed event)
- Erosion (Geopera, corrected)

Destroyed 323 · Damaged 32 · Possibly damaged 78
Gross debris (expected) 66,958 m³ · Re-usable stone on site 2,511–3,024 m³
Volumes are modelled (RDNA Table 52 × Gosaikunda RM (Table 10)), not measured.



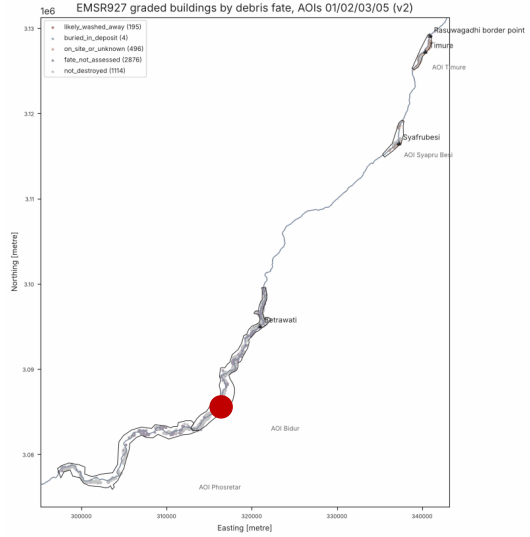
Betrawati close-up (2 × 2 km, inside AOI03 "Bidur")

Town point: Geopera settlement_arrival_times. Counts below are for this 2 × 2 km box only.



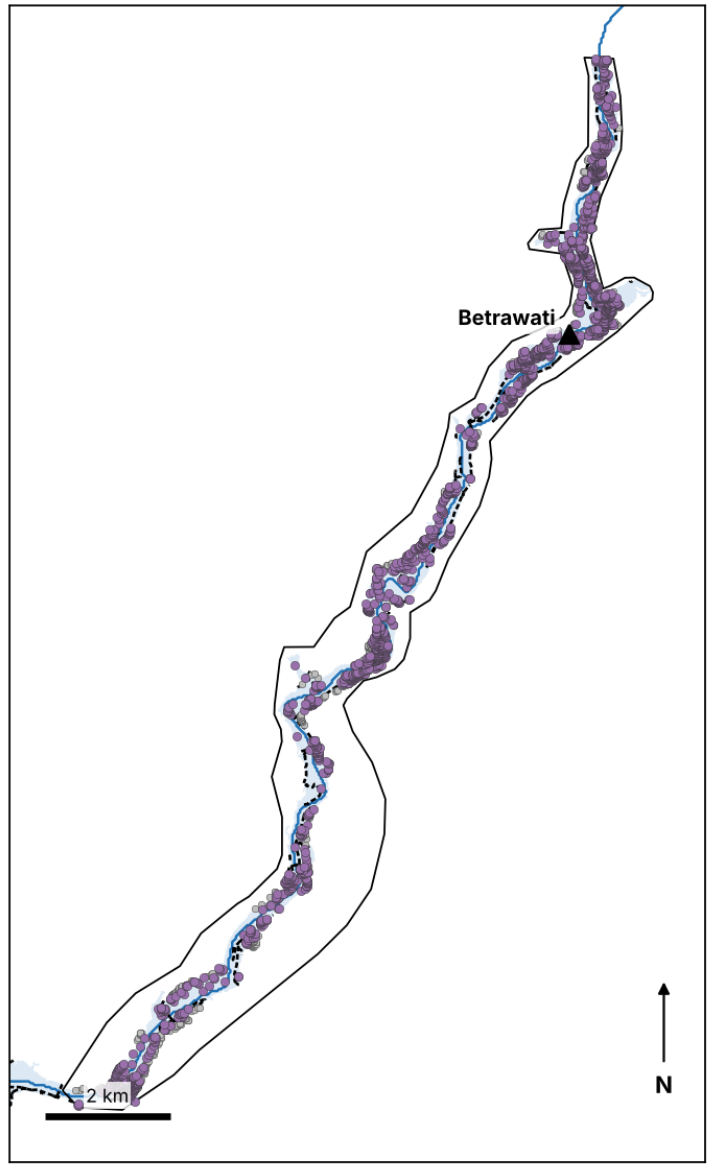
- Destroyed, fate not assessed (no terrain data) (711)
- Damaged or possibly damaged (100)
- River centreline (Geopera)
- Road graded destroyed (EMS)
- Flood trace (EMS observed event)

Destroyed 711 · Damaged 55 · Possibly damaged 45
Gross debris (expected) 124,283 m³ · Re-usable stone on site 7,821–9,385 m³
Volumes are modelled (RDNA Table 52 × all 7,570 affected buildings (AOI spans several local levels)), not measured.



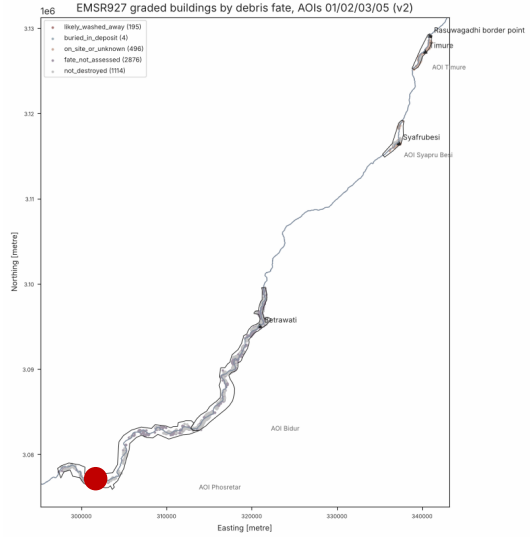
Bidur (EMSR927 AOI03): building damage and likely debris fate

Building status: Copernicus EMS GRA MONIT01, photo-interpretation. Debris fate tested only where Geopera terrain data exists.



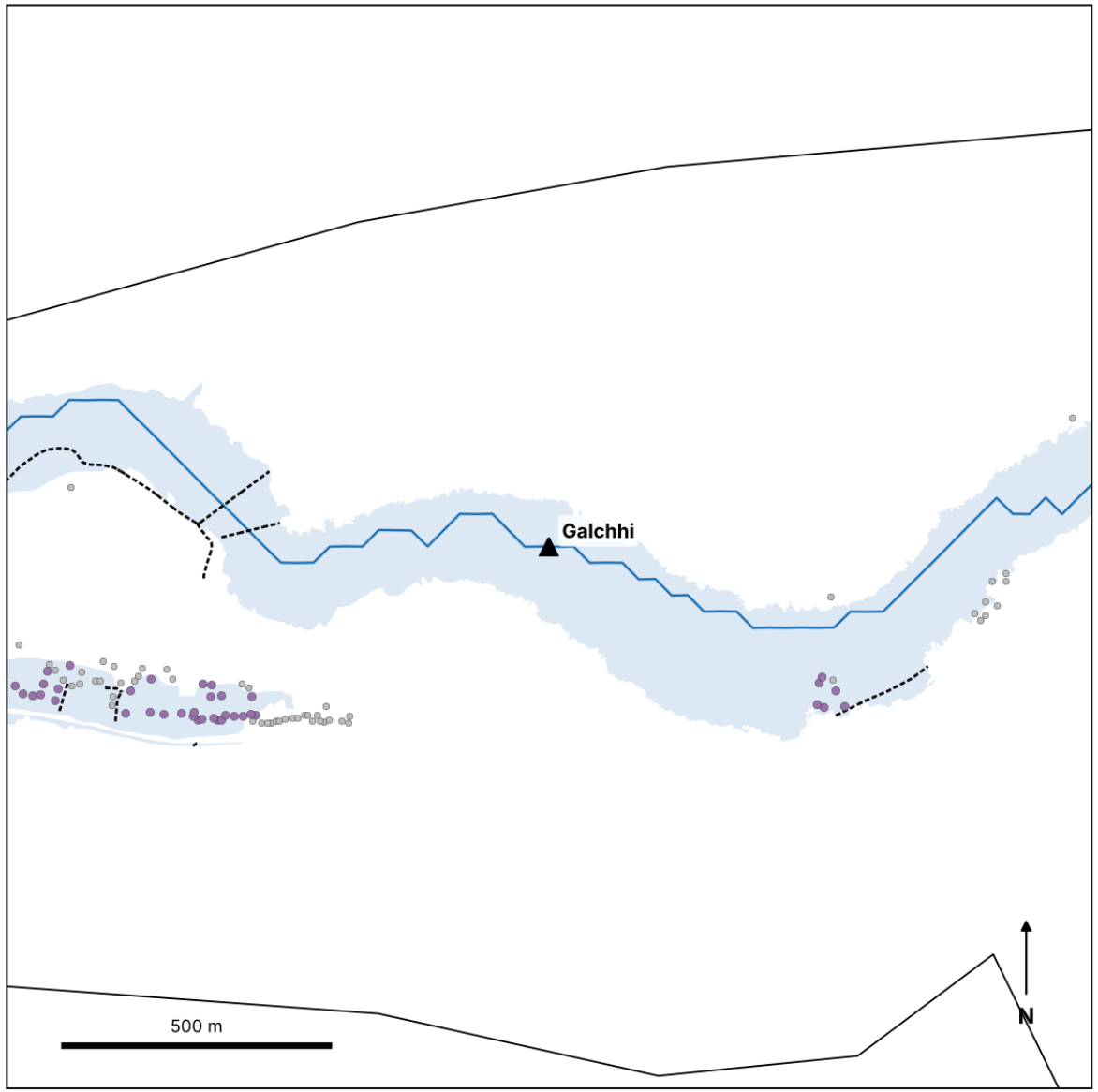
- Destroyed, fate not assessed (no terrain data) (2479)
- Damaged or possibly damaged (579)
- River centreline (Geopera)
- Road graded destroyed (EMS)
- Flood trace (EMS observed event)

Destroyed 2479 · Damaged 246 · Possibly damaged 333
Gross debris (expected) 433,329 m³ · Re-usable stone on site 27,269–32,723 m³
Volumes are modelled (RDNA Table 52 × all 7,570 affected buildings (AOI spans several local levels)), not measured.



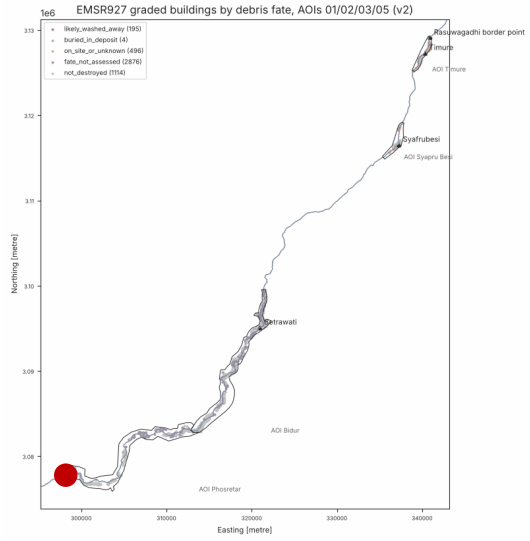
Galchhi close-up (2 × 2 km, inside AOI05 "Phosretar")

Town point: Geopera settlement_arrival_times. Counts below are for this 2 × 2 km box only.



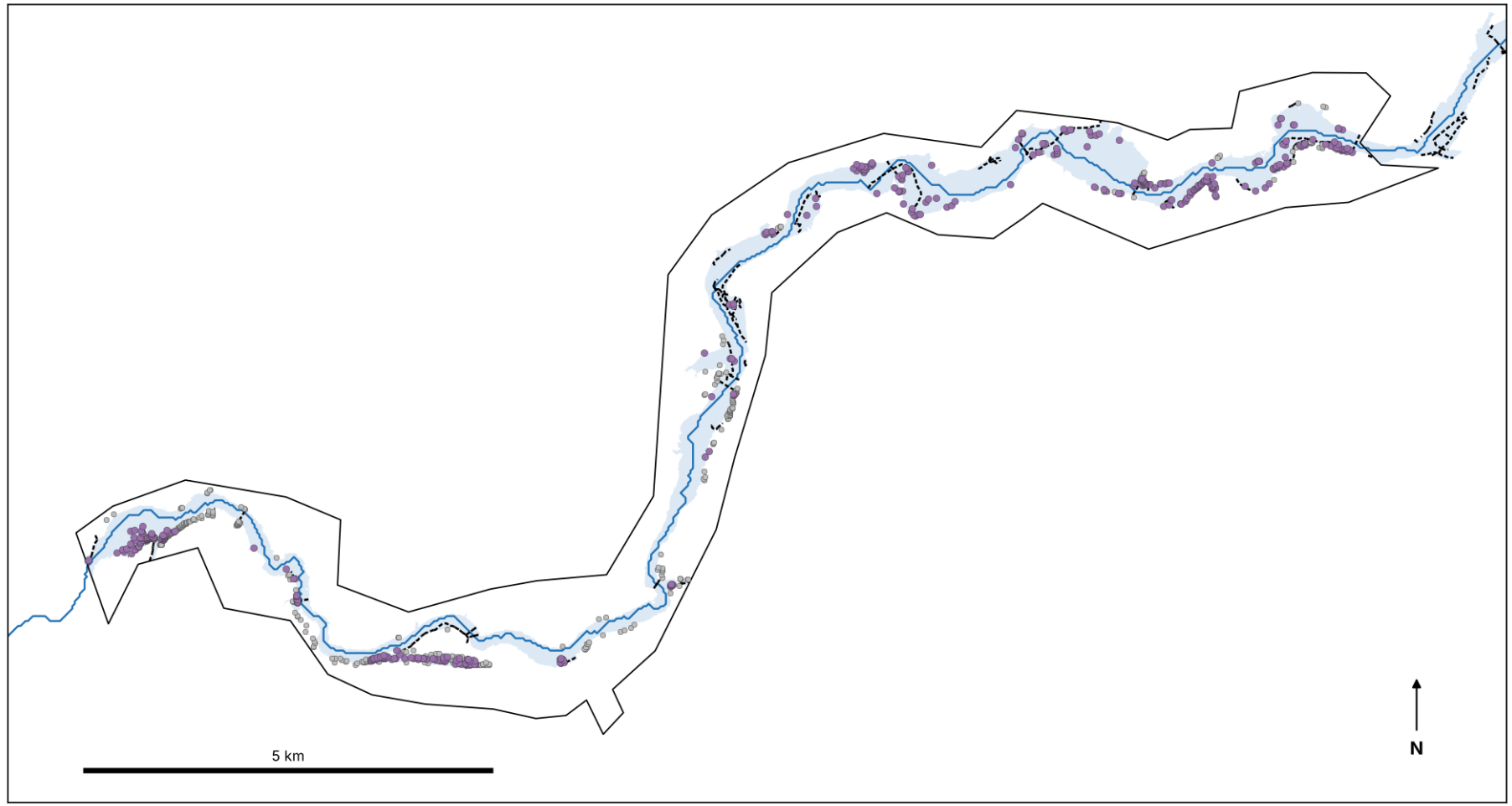
- Destroyed, fate not assessed (no terrain data) (38)
- Damaged or possibly damaged (53)
- River centreline (Geopera)
- Road graded destroyed (EMS)
- Flood trace (EMS observed event)

Destroyed 38 · Damaged 23 · Possibly damaged 30
Gross debris (expected) 6,642 m³ · Re-usable stone on site 418–502 m³
Volumes are modelled (RDNA Table 52 × all 7,570 affected buildings (AOI spans several local levels)), not measured.



Phosretar (EMSR927 AOI05): building damage and likely debris fate

Building status: Copernicus EMS GRA MONIT01, photo-interpretation. Debris fate tested only where Geopera terrain data exists.



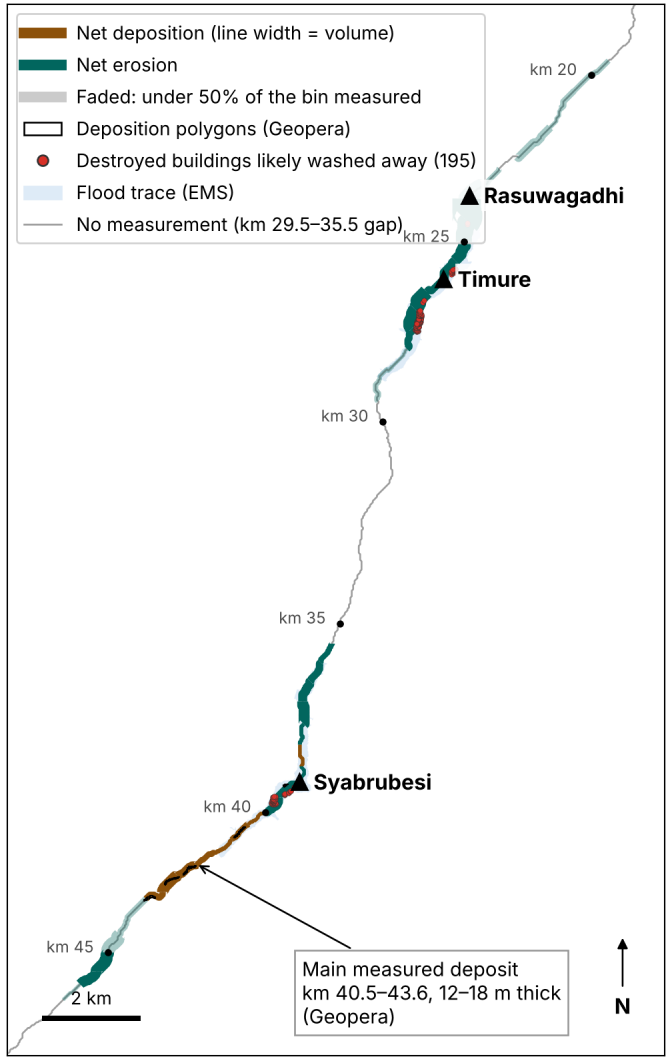
- Destroyed, fate not assessed (no terrain data) (397)
- Damaged or possibly damaged (366)
- River centreline (Geopera)
- Road graded destroyed (EMS)
- Flood trace (EMS observed event)

Destroyed 397 · Damaged 116 · Possibly damaged 250
Gross debris (expected) 69,396 m³ · Re-usable stone on site 4,367–5,240 m³
Volumes are modelled (RDNA Table 52 × all 7,570 affected buildings (AOI spans several local levels)), not measured.

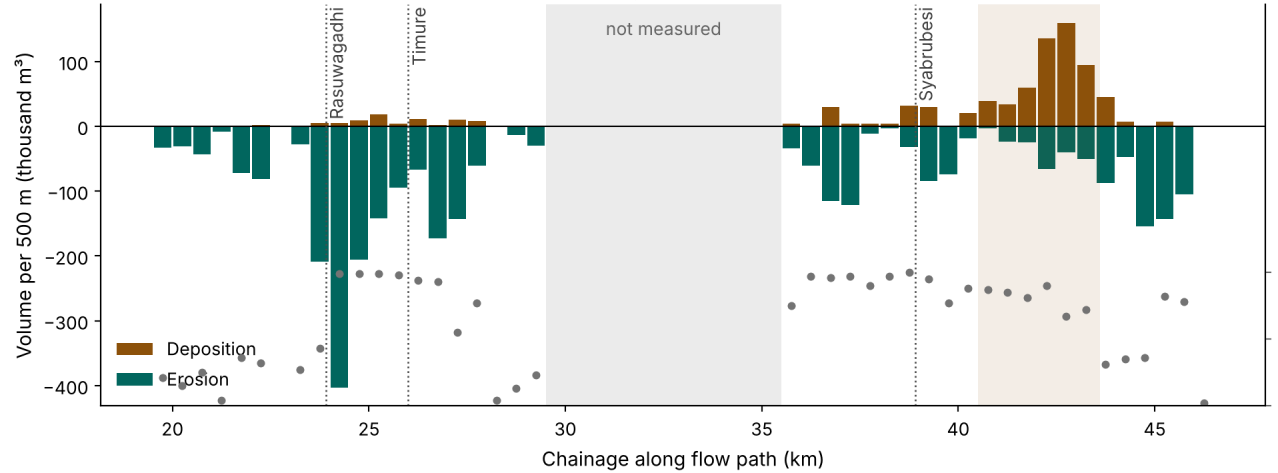
Where the flood debris went: measured near the source, modelled downstream

Building rubble cannot be separated from sediment in either dataset (RDNA: "Building debris may be mixed with sediment within settlement areas"). Measurements exist only for reaches A and B.

A Measured net change per 500 m of river, reaches A and B

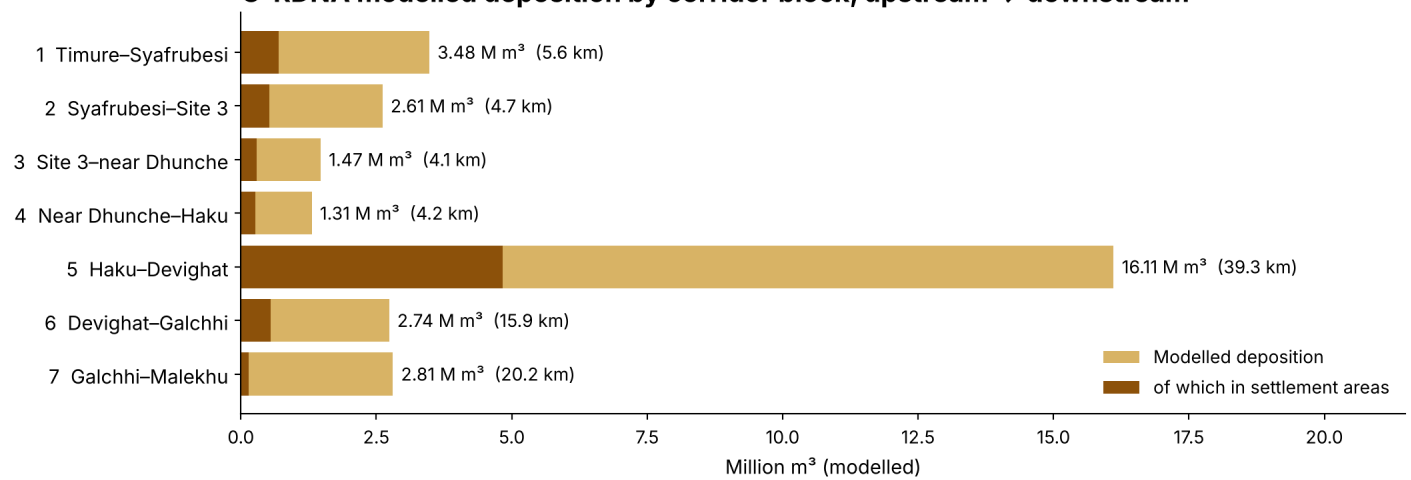


B Measured deposition and erosion along the river (measured cells only)



Reach A (km 19.5–29.5): +78 / −1,839 thousand m³. Reach B (km 35.5–46.5): +711 / −1,303. Bins km 40.5–44.0: +567.
Measured cells only (dots = % of bin measured), so true volumes are larger where coverage is low.

C RDNA modelled deposition by corridor block, upstream → downstream

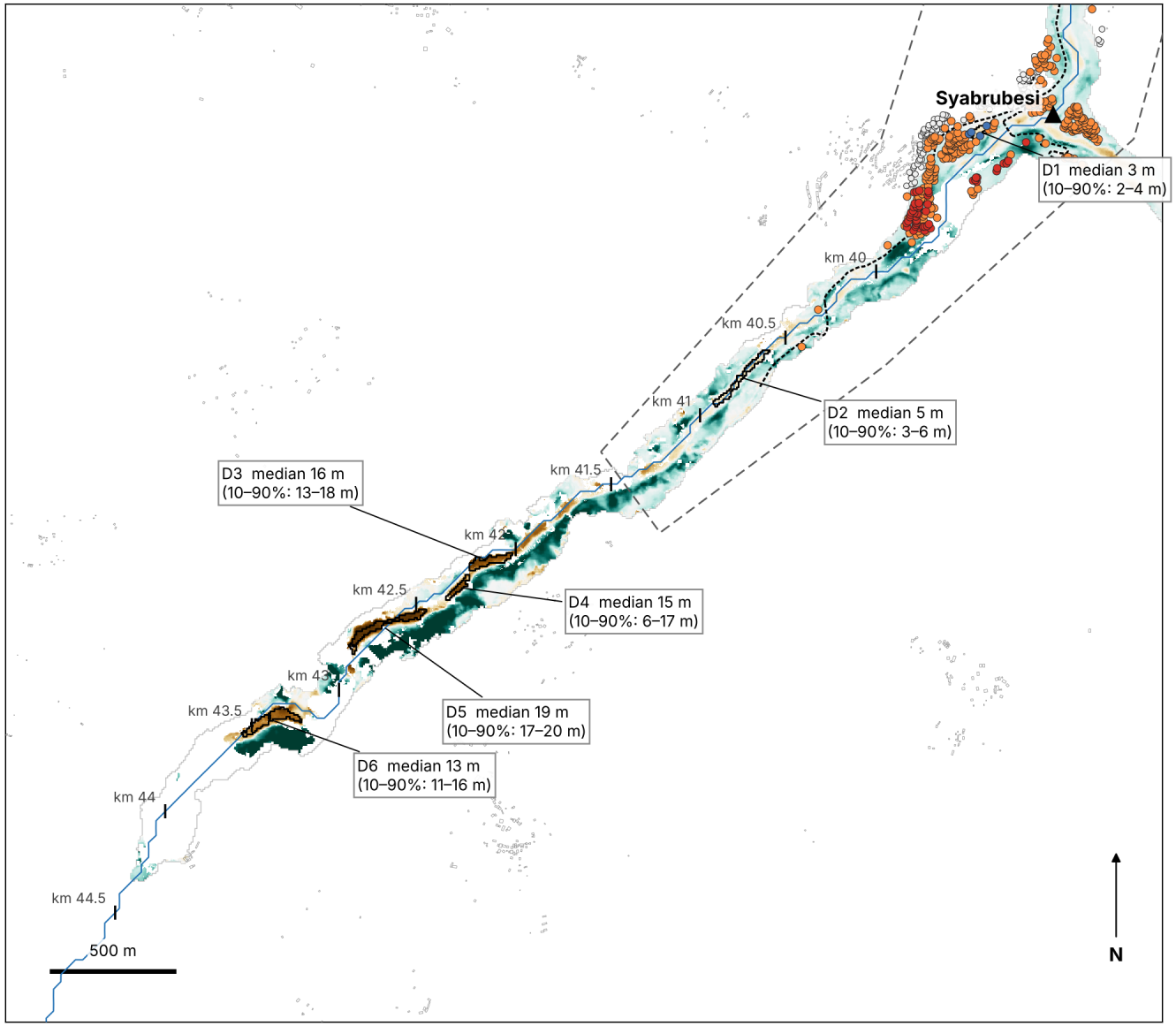


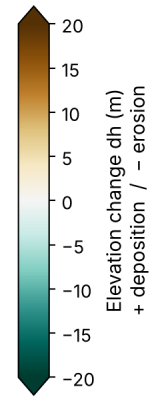
RDNA Table 52: 30.52 M m³ modelled deposition (7.29 M m³ in settlement areas) over 94.1 km, from assumed factors.
Not mapped: block lengths do not match the flow path (block 1 = 5.6 km; Timure–Syabrubesi = 12.9 km along it).
Contradiction: block 1 is modelled as 3.48 M m³ deposition; Geopera measures net erosion in its covered bins.

Sources: Geopera v1.1 (CC BY-NC 4.0, derived from WorldView-3 © Vantor): per_km_budget.csv, deposition polygons, centreline · Copernicus EMS EMSR927 (© European Union) · RDNA Rasuwa–Bhotekoshi Flood 2026, Table 52 (NPC/NDRRMA). EPSG:32645.

Below Syabrubesi: the destroyed bazaar and the 13–19 m deposit 3–4.5 km downstream

Geopera dh raster (stereo DSM minus pre-event HMA DEM, 2 m, bias-corrected, measured cells only; SHA-256 verified). Shown only inside the modelled flood extent. Buildings: Copernicus EMS EMSR927 AOI01 grading.





- Destroyed, likely washed away (49)
- Destroyed, buried in deposit (4)
- Destroyed, debris on site / unknown (239)
- Damaged or possibly damaged (106)
- Road graded destroyed (EMS)
- OSM building footprints (Geopera census)
- Deposition polygons D1–D6 (Geopera, corrected)
- Flow-path centreline
- Modelled flood extent (only cells inside are shown)
- EMS AOI01 edge

Thickness inside the deposition polygons (dh raster, measured cells)

D1	km 39.2	median 3.4 m	90th pct 3.9 m	9 thousand m³
D2	km 40.8	median 4.6 m	90th pct 6.3 m	27 thousand m³
D3	km 42.1	median 16.1 m	90th pct 17.6 m	79 thousand m³
D4	km 42.3	median 15.2 m	90th pct 16.7 m	34 thousand m³
D5	km 42.7	median 18.8 m	90th pct 19.7 m	146 thousand m³
D6	km 43.4	median 13.5 m	90th pct 16.4 m	102 thousand m³

D1–D6: 397 thousand m³ in 32,640 m² (98% of polygon area measured).
D2–D6 (km 40.5–44.0): 388 thousand m³ = 68% of the 567 thousand m³ Geopera measured in the bins of that reach.

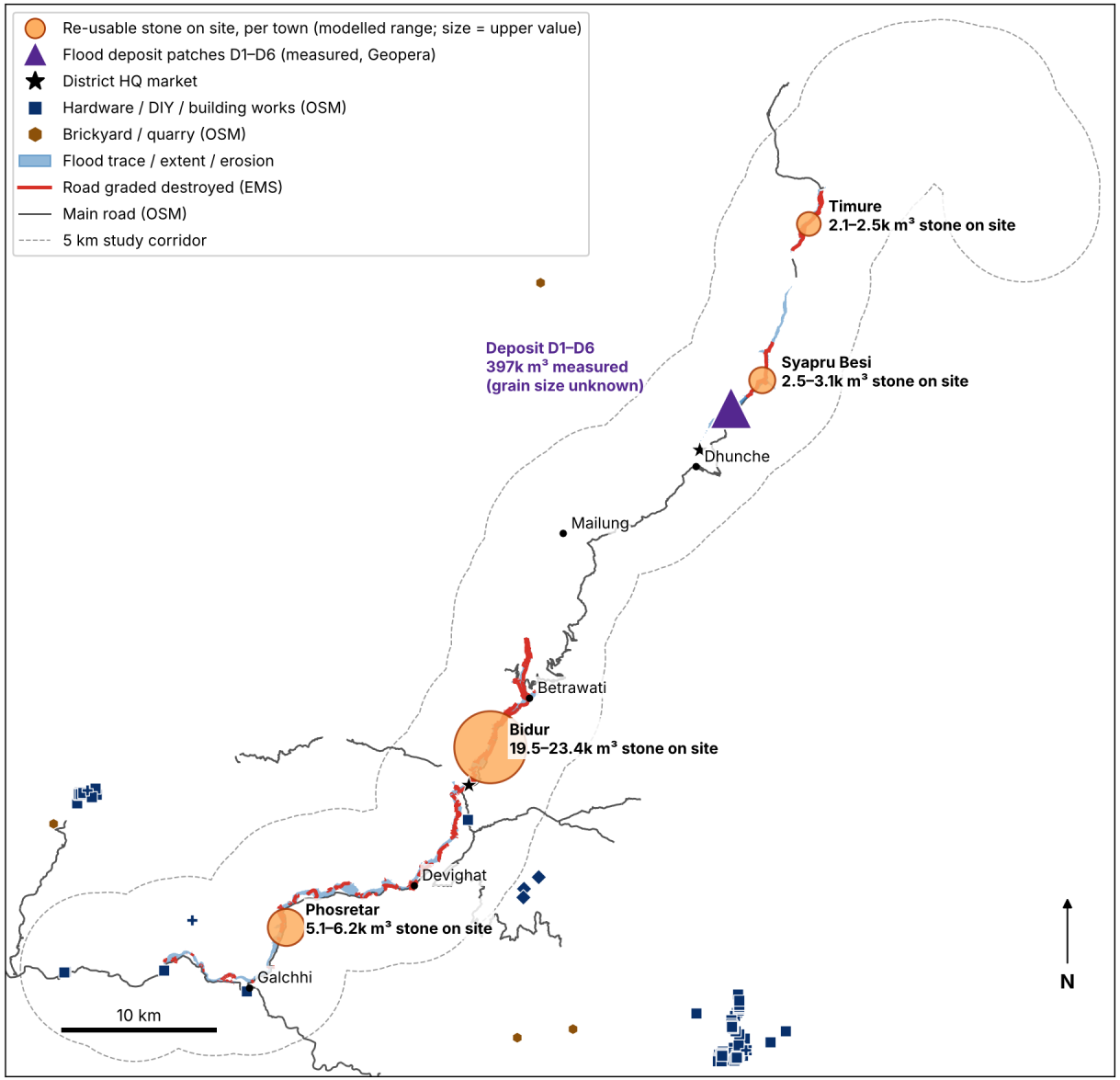
Caveats: the colours outside D1–D6 include valley-wall pixels; Geopera's floor mask is not public, so wall values are not flood signal. Uncertainty raster not applied (not received). Deep erosion next to D5–D6 may be real incision or wall pixels; not separable here. Grain size unknown: thickness ≠ usable stone.

Sources: Geopera v1.1 bhotekoshi_dh_syabrubesi_2m.tif, deposition polygons, flood extent, centreline (CC BY-NC 4.0, derived from WorldView-3 © Vantor) · Copernicus EMS EMSR927 AOI01 (© European Union). EPSG:32645.

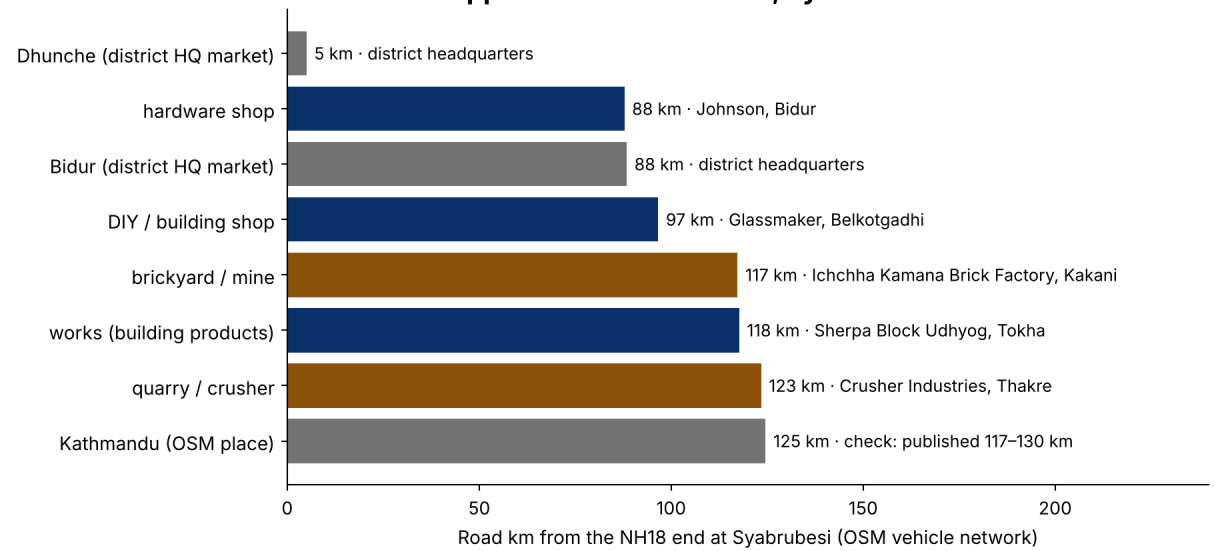
What can be built with, Rasuwagadhi to Galchhi: stores, debris and the flood deposit

Timber is left out: standing trees are not a legal or seasoned source. Bamboo is not yet mapped (no presence data for Rasuwa / Nuwakot).

A Stores, building debris and the flood deposit

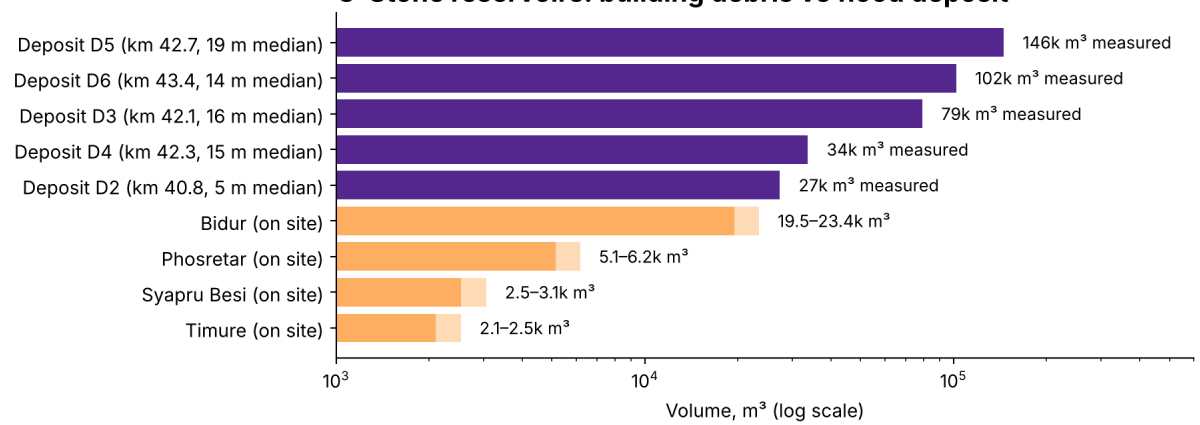


B Nearest mapped store of each kind, by road



No store, works or quarry is mapped in OSM inside Rasuwa: a gap in the map, not proof that none exist.

C Stone reservoirs: building debris vs flood deposit



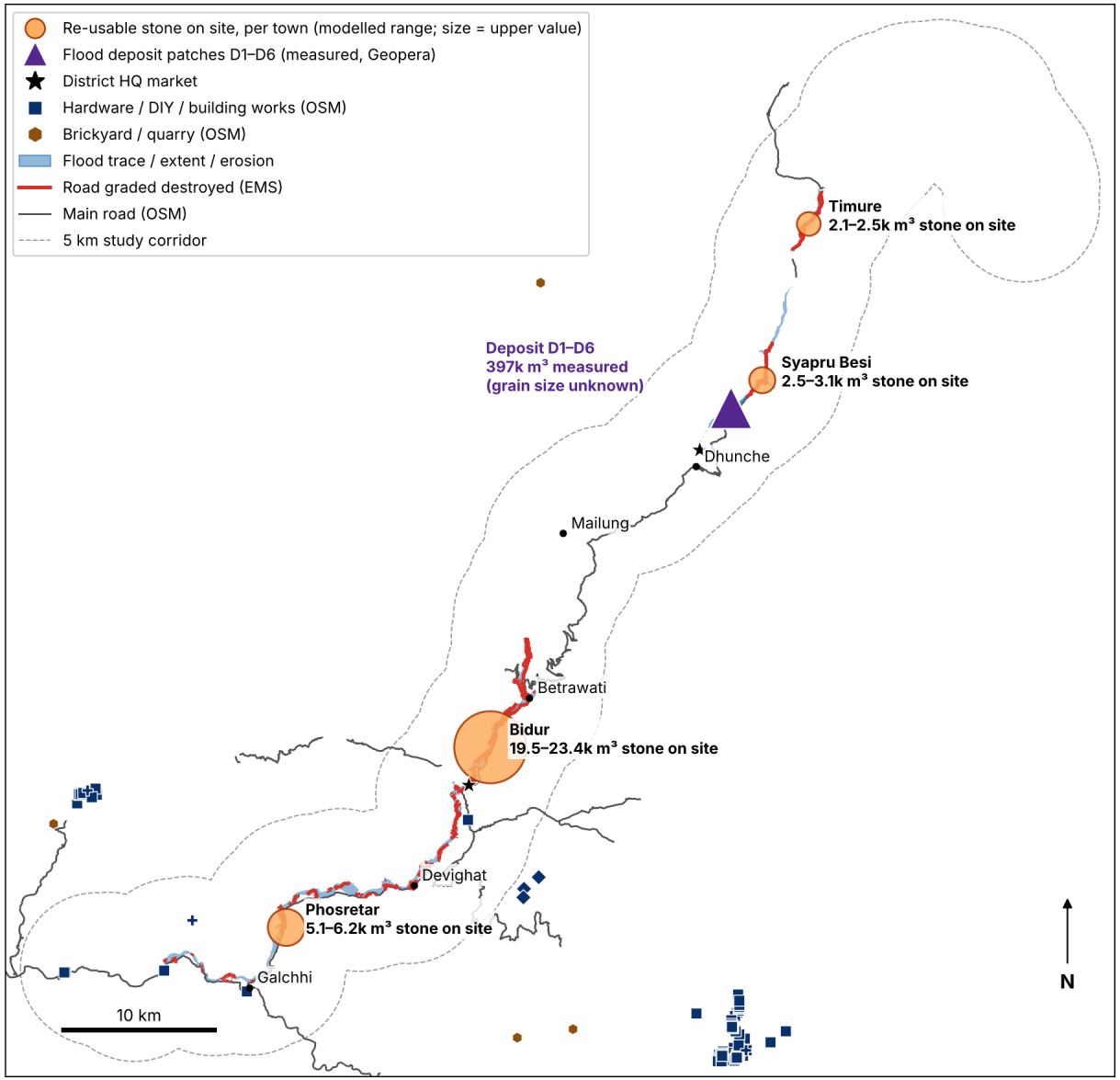
On-site stone is modelled (EMS grading × RDNA factors). Deposit volume is measured but is bulk sediment: the share of buildable stone is unknown. Extraction needs Langtang NP permission and royalty; Melamchi 2078 flood deposits required a separate IEE/EIA.

Sources: OpenStreetMap contributors (ODbL), QuickOSM export 19 Nov 2026 · Copernicus EMS EMSR927 (© European Union) · Geopera v1.1 (CC BY-NC 4.0) · UNDP/GoN RDNA 2026 Tables 10, 52 · geoJSON-Nepal (MIT) · LNP & BZ Management Plan 2077/78–2081/82. EPSG:32645.

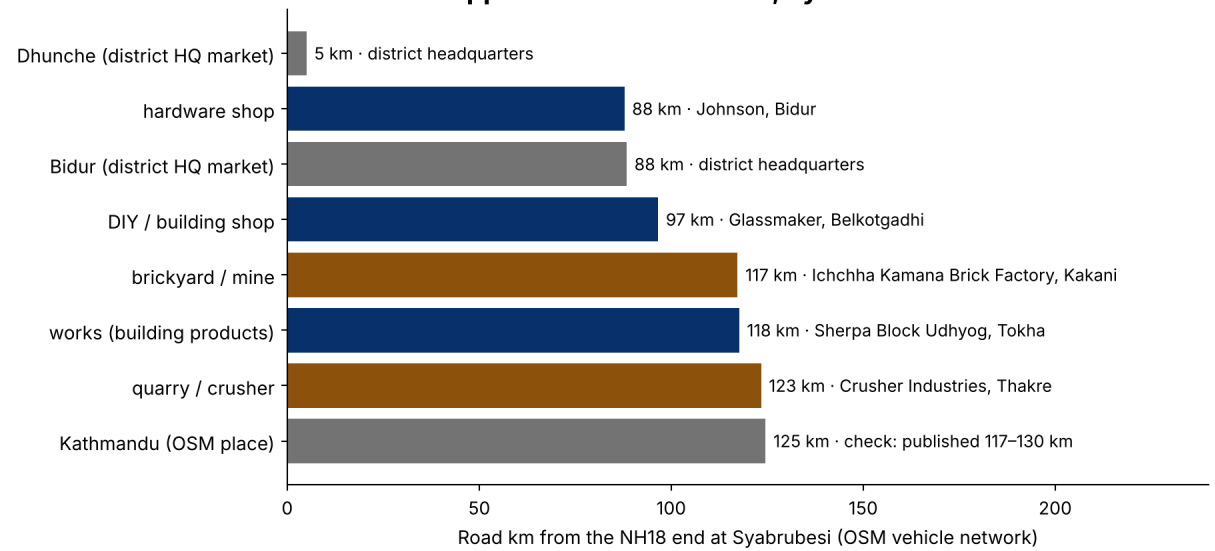
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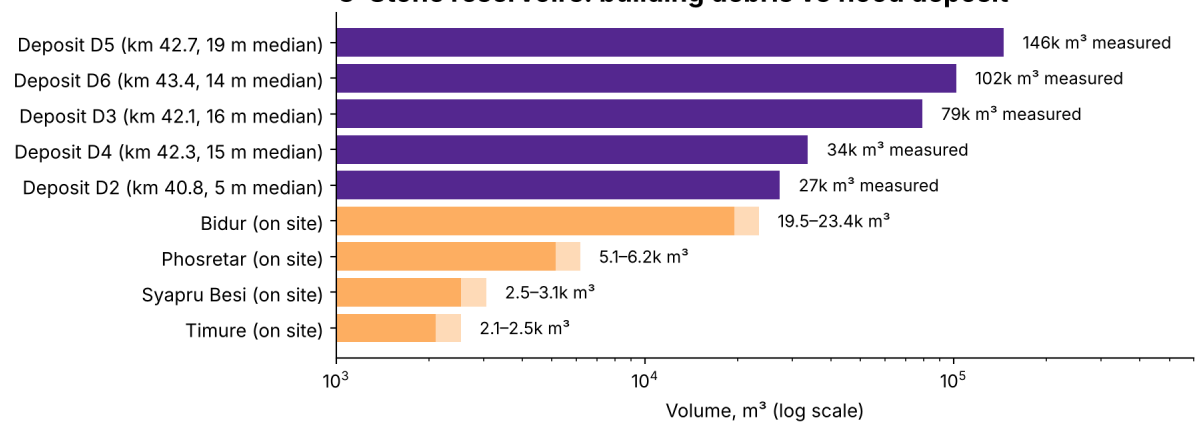


B Nearest mapped store of each kind, by road



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Sources: OpenStreetMap contributors (ODbL), QuickOSM export 19 Nov 2026 · Copernicus EMS EMSR927 (© European Union) · Geopera v1.1 (CC BY-NC 4.0) · UNDP/GoN RDNA 2026 Tables 10, 52 · geoJSON-Nepal (MIT) · LNP & BZ Management Plan 2077/78–2081/82. EPSG:32645.

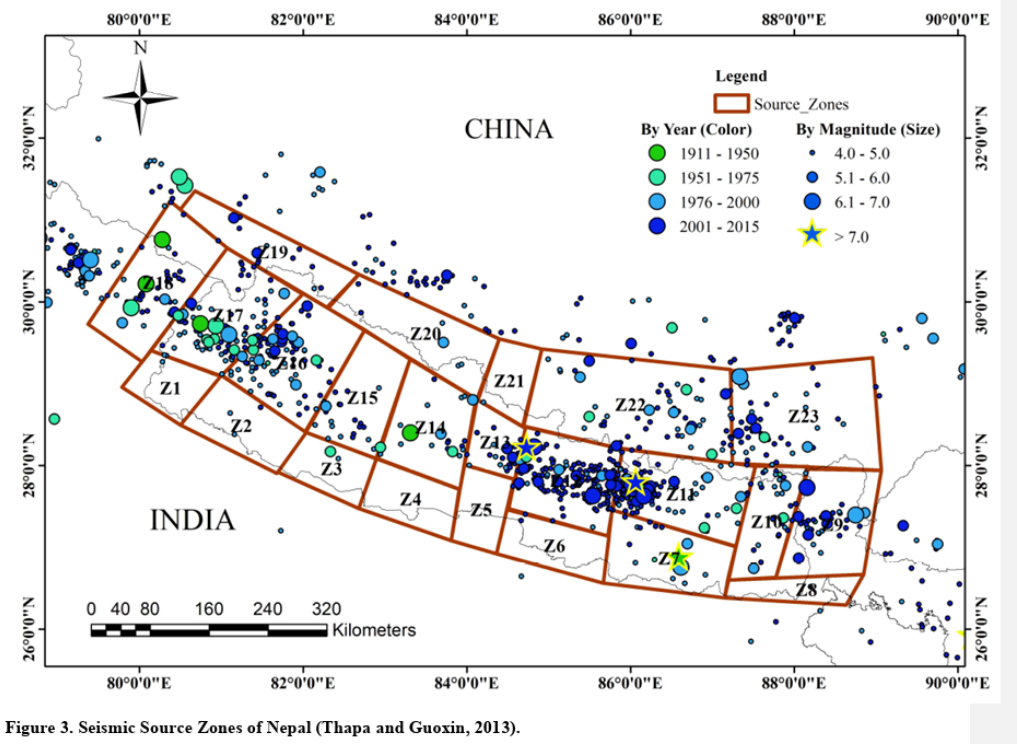
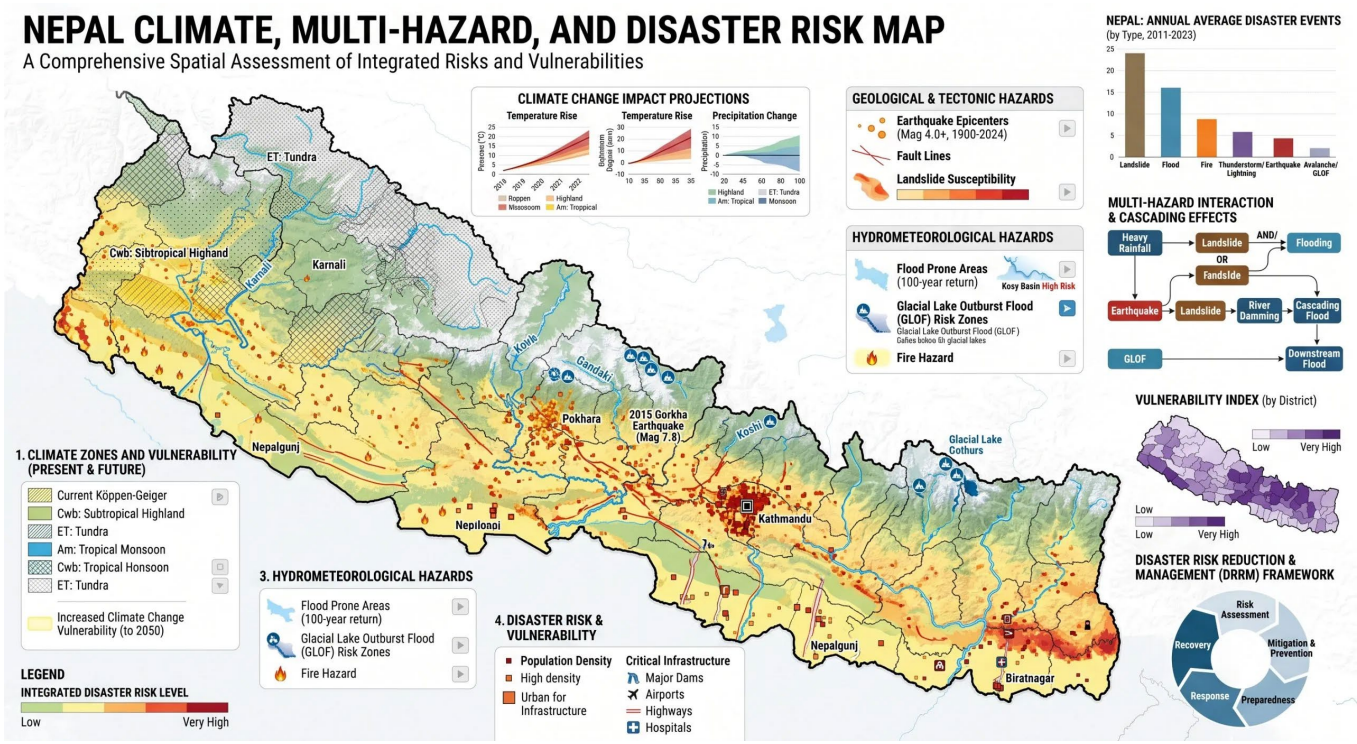


Figure 3. Seismic Source Zones of Nepal (Thapa and Guoxin, 2013).



2. Material Analysis and Damage Estimation

Reconstruction Need

600 long term houses - most was masonry, which makes it debris reuse plausible

2,319 mud-and-stone;
3,215 brick-and-cement;
2,036 RC

Syabrubesi Alone

>240 destroyed, 32 damaged

Material Available

388 thousand t of m^3 of debris

Stone and flood debris are the only materials available in bulk at Syabrubesi itself. Everything else (cement, steel, CGI, most sand) comes 105–122 km by a road that was cut for six weeks and still runs on temporary bridges.

In Melamchi after 2015, only 50–60% of stone and ~25% of timber and CGI could be salvaged.

Sand and aggregate are legally constrained.

Timber is physically available but expensive and permit-bound.

Transport sets the price of non-local materials.

>>

Techniques to be used by material availability

Mu-and-stone
Bamboo – after 3-5 years
Timber – max 2.83 m^3 locally sources per household due to Langtang national reservation

Design requirements based on loss

Replace: 283 residential buildings
Repair: 31 residential buildings.

49 of which require new plots

3. VERNACULAR ARCHITECTURE

1.1. Floodproofing

Terai plains: Tharu (living with recurring river floods)

Material weakness

Vernacular mud houses on the Terai fall apart in floods. A CRS/NHSRP project found that lime-stabilized mud plasters and floors with rice husk ash, sand and straw stay intact in water. This is an NGO improvement to the tradition, not an indigenous practice.

Material advantages

The construction of low-cost houses with bamboo walls and thatch roof minimizes losses and reduce the cost of rebuilding and restoration after the passage of floods and other natural disasters (Mahottari District).

Terraces

Terracing breaks up the slope, which slows runoff in heavy rain and keeps the soil from washing away. Protecting forest above the terraces matters too, because uphill forest absorbs large volumes of water and reduces the saturation that can trigger landslides. Note that traditional terraces slope outward, and ICIMOD's improved terraces exist to fix the erosion and runoff problems of those outward-sloping terraces. Not every traditional practice is protective.

Agriculture

Communities in Chure areas of Sindhuli District have adopted biological measures such as planting bamboo and grasses along the slope and along the seasonal streams in order to reduce flood risks to settlements.



Terrace agriculture



Tamang traditional houses

Dry stone stacking – not earthquake proof, but established tradition
Wood in the mountains, bamboo in the hills

3. VERNACULAR ARCHITECTURE

1.1. Floodproofing

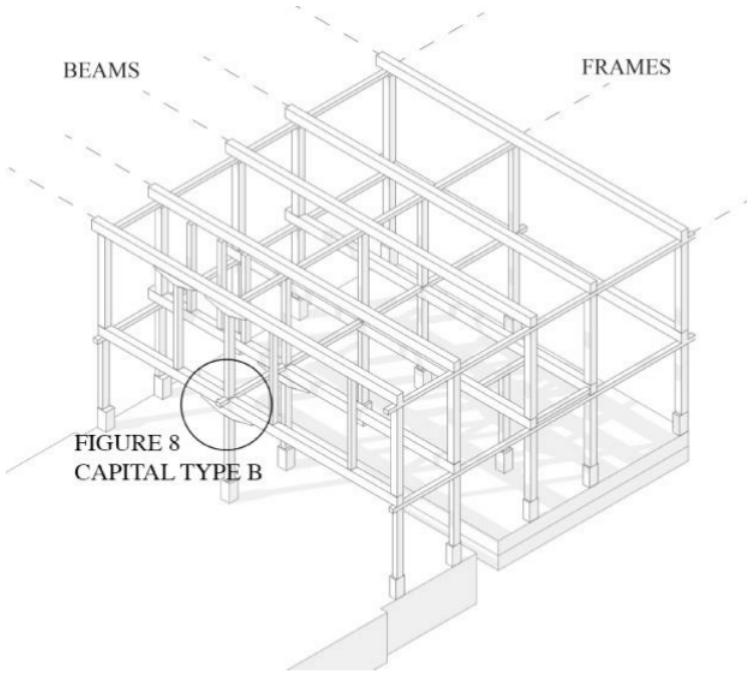


Figure 7. Timber structure axonometric view (Authors).

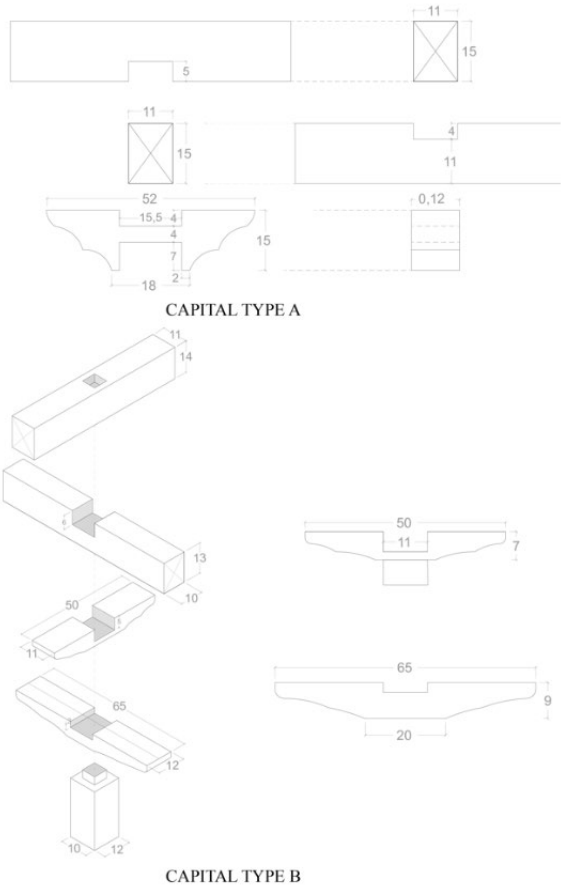
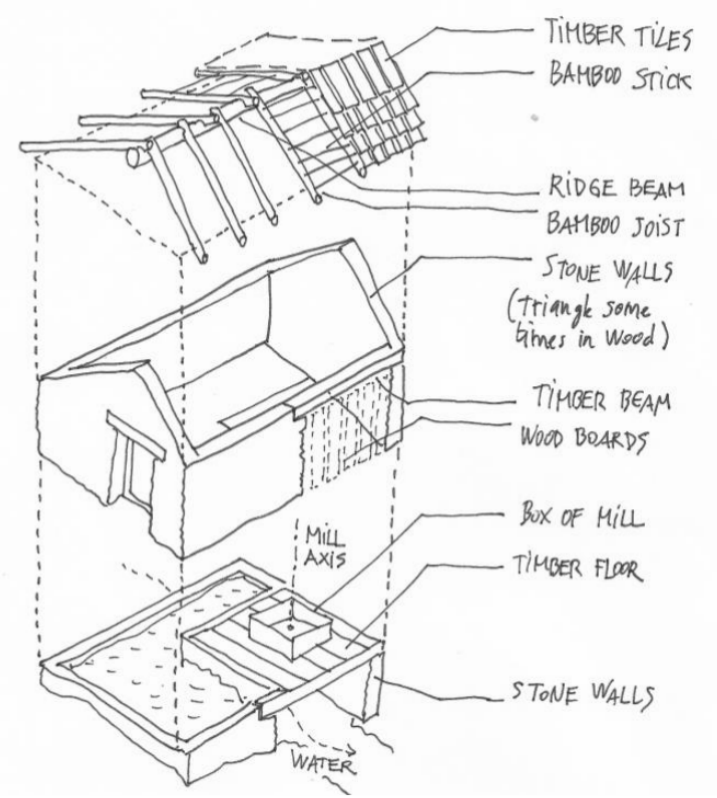


Figure 8. Detail of structural assemblies (Authors).



4. Human-Robot Collaboration Approach

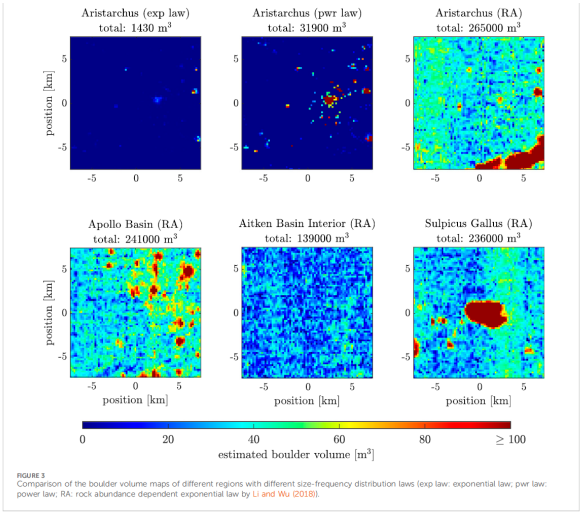


FIGURE 3
Comparison of the boulder volume maps of different regions with different size-frequency distribution laws (exp law: exponential law; pwr law: power law; RA: rock abundance dependent exponential law by Li and Wu (2018)).

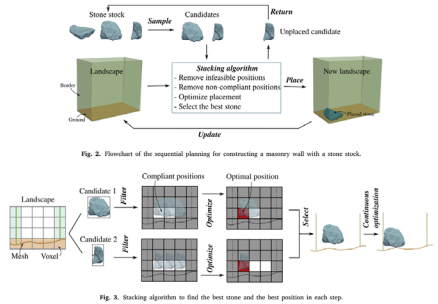


Fig. 2. Flowchart of the sequential planning for constructing a masonry wall with a stone stock.

Fig. 3. Stacking algorithm to find the best stone and the best position in each step.

Using robots for sorting material >>

Sorted material goes into a database, per classes >>

Material labeling by robot >>

Material database used to estimate the potential for new houses >>

Organize a layout - parametric planning of the houses across the valley meaning the order and type of house is determined by the robot with certain attributes to be set as priorities >>

(CFD simulation,)

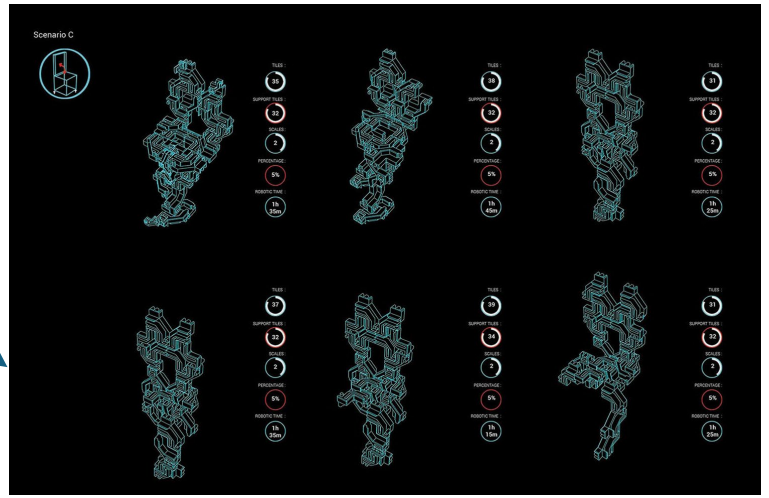
"Boulders can be identified by their bright appearance followed by a shadow, while the order of bright and dark pixels is opposite to how it is the case for craters (Gawronska et al., 2020; Boazman et al., 2022)."

remotely

3.1 Manual boulder mapping

We used images taken by the Lunar Reconnaissance Orbiter (LRO) Narrow Angle Camera (NAC) (Robinson, 2010; Robinson et al., 2010; Speyerer et al., 2012; Humm et al., 2016; Mahanti et al., 2016) to quantify the availability of boulders at the two sites of interest. The NAC images were obtained as EDR (Experimental Data Record) and processed using ISIS3 (Laura et al., 2023) to derive georeferenced images, following Bickel et al. (2021). The mapping of the boulders then was done using QGIS² version 2.18.28. Some minor processing steps of the resulting shapefiles were done with Python and GDAL (GDAL/OGR contributors, 2020).

The two NACs have a nominal resolution of 0.5 $^{m}/_{pixel}$ at an altitude of 50 km, enabling the detection of "blocks" with horizontal sizes of about 1 m (Robinson et al., 2010). The size of most boulders



Questions

What happens at the interface between the robotic task and the manual labor?
After establishing the material inventory, and generating the housing reconstruction plan, how does the human take over?

What are other needs that can be tackled by computerization?