DYNAMICS OF THE RAPID TOPOGRAPHIC CHANGES AFTER RECENT MORAINE BREACH: A CASE STUDY OF THE DJANKUAT CATCHMENT, CENTRAL CAUCASUS

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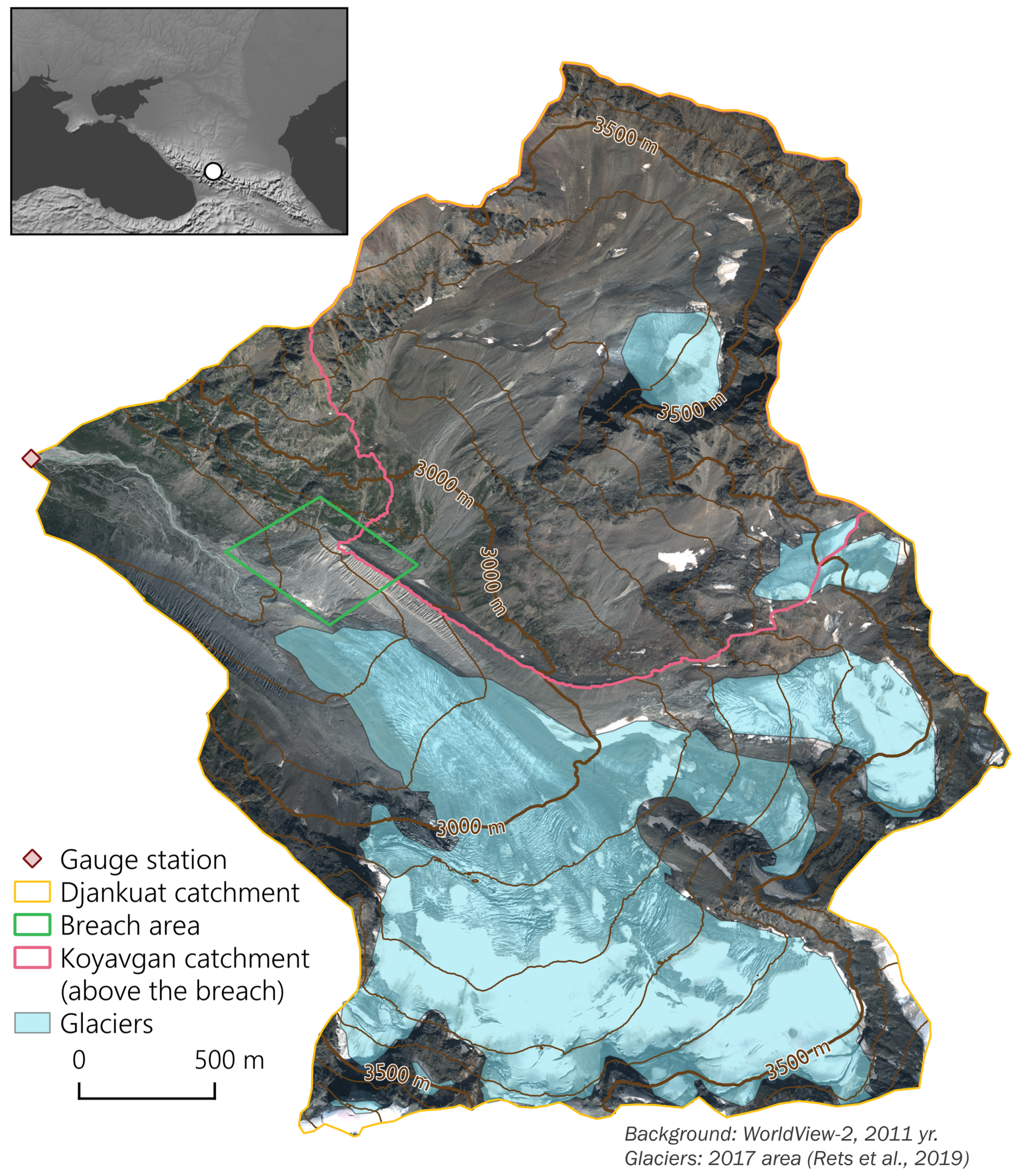


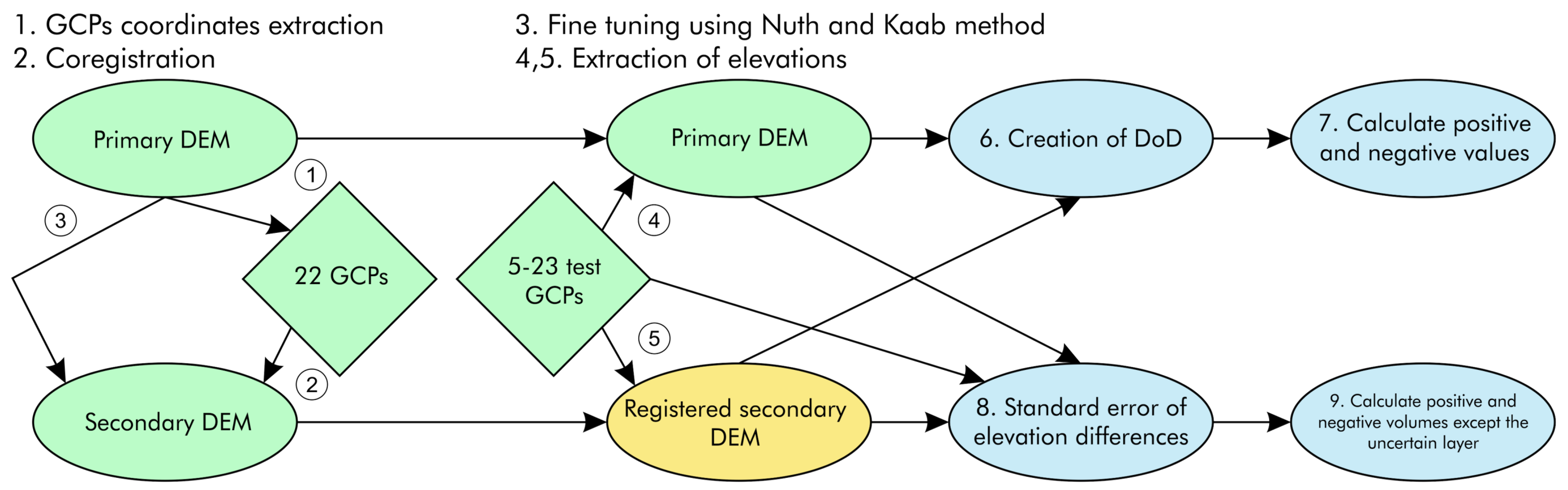
Background: WorldView-2, 2011 yr.
Glaciers: 2017 area (Rets et al., 2019)

01. Introduction

- Instability in proglacial areas is often expressed in the high occurrence of intensive surface processes.
- The moraine collapse is one of the most severe events that lead to significant surface changes in the valley. Usually, the moraine breach is initiated by a combination of factors: ice dynamics, intense rainfall or snowmelt, seismic activity, and landslides.
- In the Caucasus region moraine failures were frequently reported. The goal of this study is to **quantify the terrain transformation** due to the moraine breach over a period of several years after the formation, and to **evaluate the input of sediments** into the SY.

02. Study site

- **The Djankuat River catchment** (43.20 N, 42.74 E).
- 27% of the catchment area (out of 9.1 km²) is glacierized; all glaciers experience negative dynamics.
- Typical alpine terrain. Dominant elements are lateral moraines formed during the LIA. Their height is up to 50-55 m.
- On the right side of the valley is a large glacial cirque **Koiavgan** (total catchment area 3.03 km², cirque is 0.6 km²). Here starts the left tributary, which breaches the moraine downstream.
- This section of the lateral moraine collapsed on **1st July 2015** and the Koiavgan Creek redirected its course.



Workflow for the breach terrrain dynamics assessment

03. Methodology

03.01 Moraine gullies

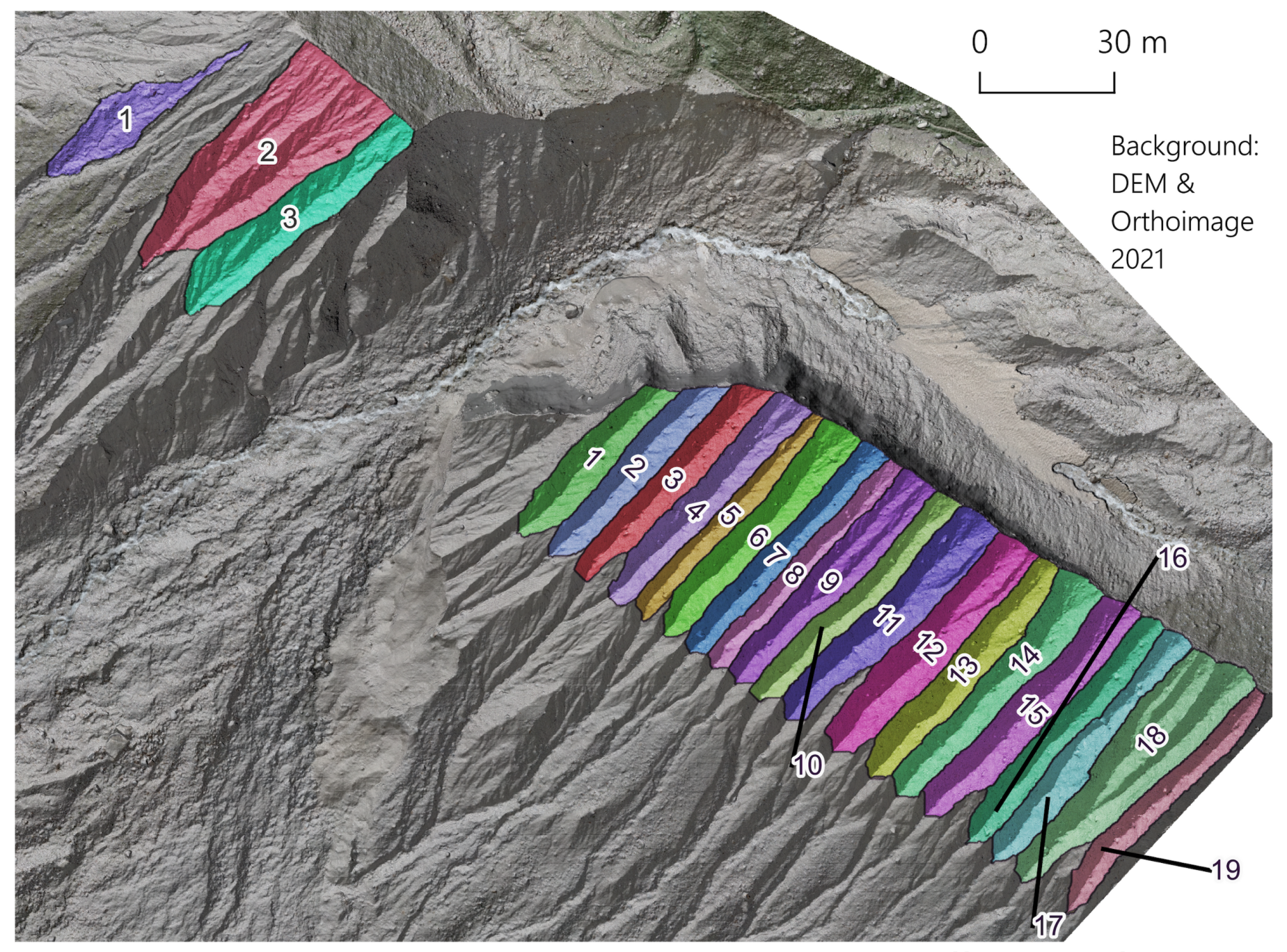
Very sensitive to DEMs co-registration erorrs

Another approch required

- Stable surfaces near the drainage divide of the gullies
- Active erosion at the thalweg zone and at the banks

Volume and average depth calculation for every gully (out of 21). Through the construction of baseline surfaces obtained via interpolation (Delaunay triangulation). Cathments' borders for every DEM.

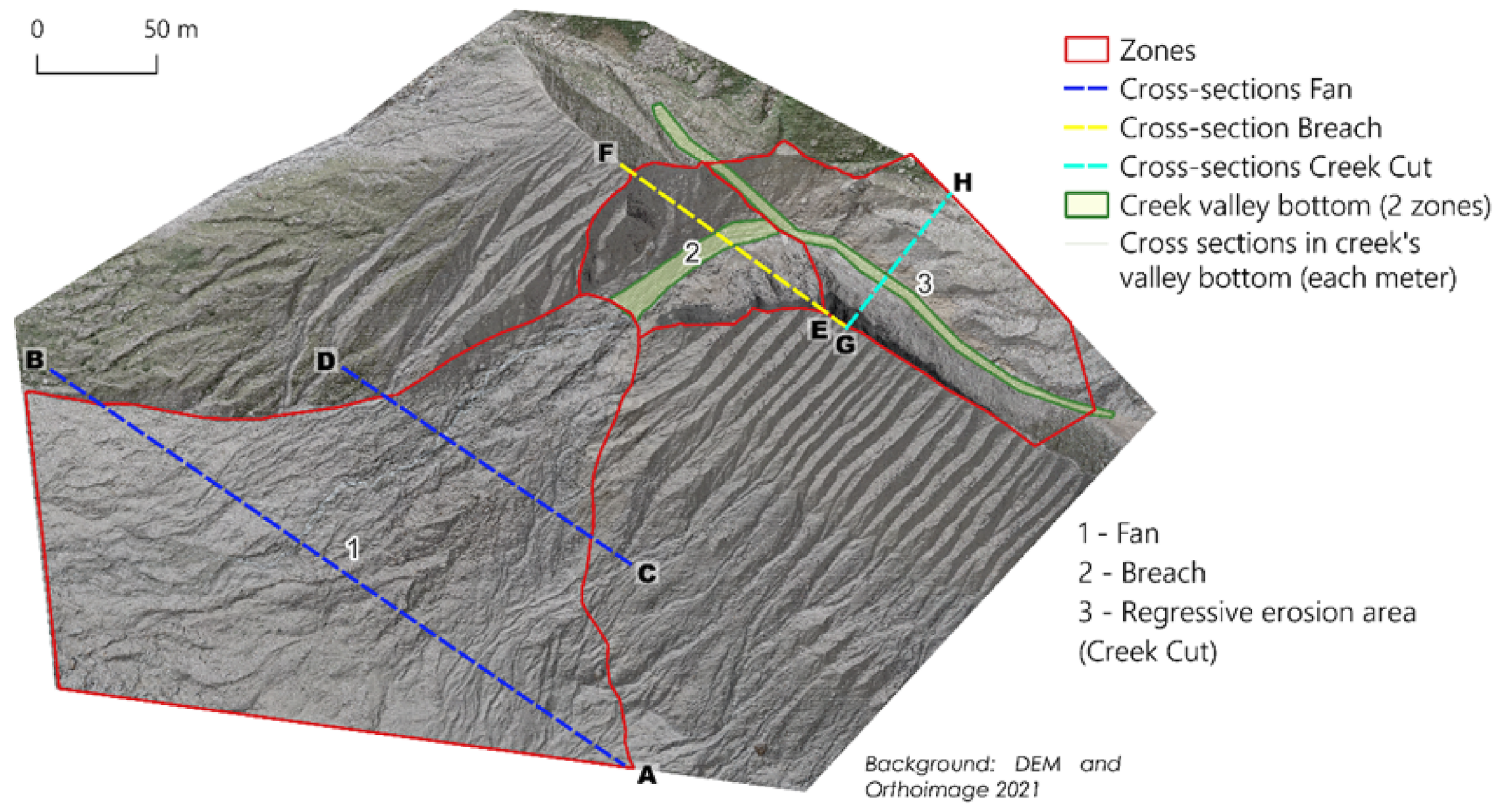
Drainage divides height change significance:
1) Wilcoxon rank test;
2) Height distribution via the Pearson chi-square method.



Gullies catchments

03.02 Breach area

Source: high-resolution satellite images and UAV surveys' images: 2010, 2017 (1 m res. DEMs, stereo imagery); 2019, 2021, 2022 DEMs from UAV surveys (0.063 – 0.089 m res.)



The breach area

03.03 Snow cover and hydrometeorology

Snow cover

Source: 1-day MODIS NDSI

Methodology: 1) two zones (downstream and upstream sectors); 2) detection of abrupt changes (melting start) via the Pettitt test;

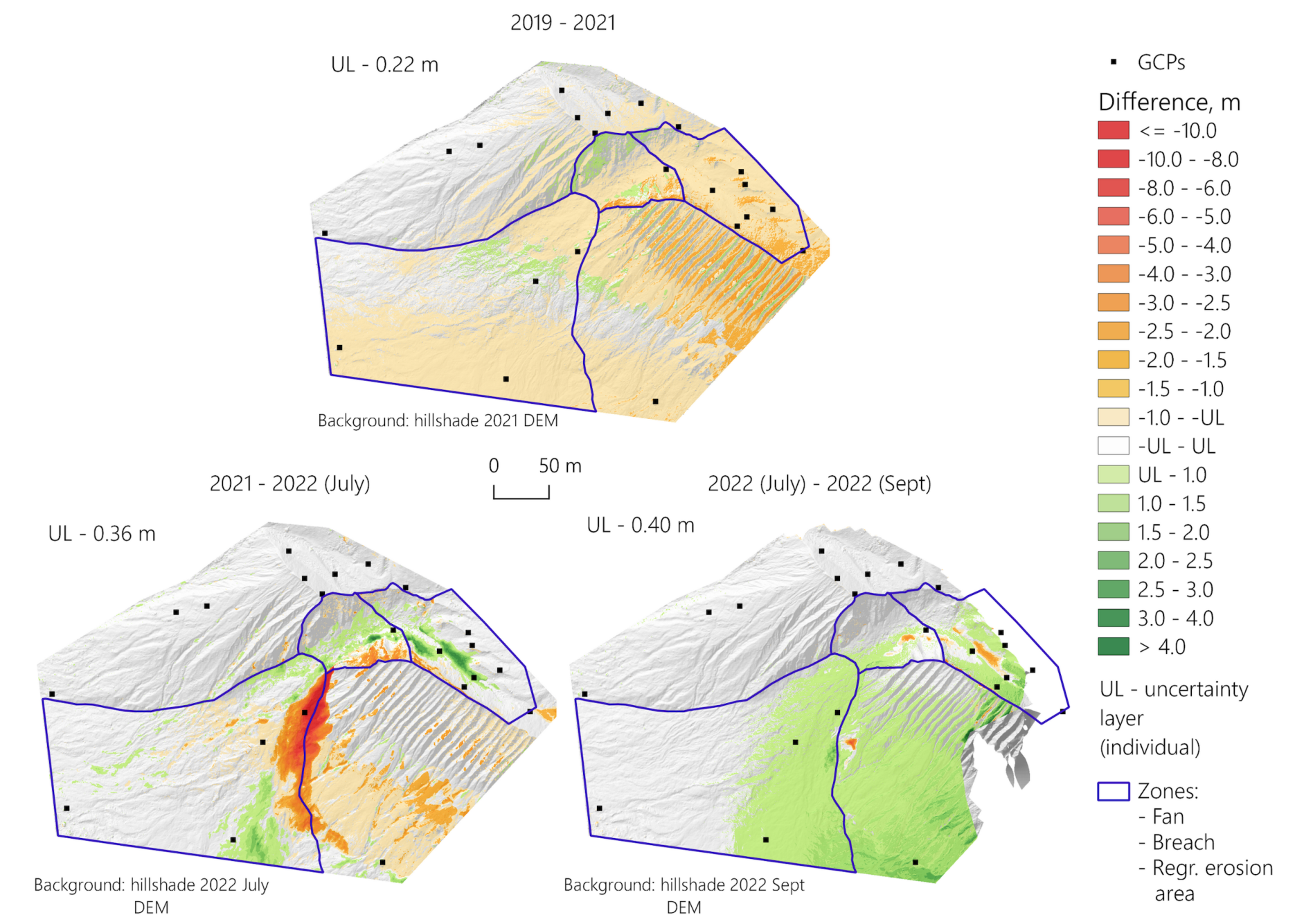
Hydrometeorology

Ablation seasons 2007-2022

- Water discharge
- Daily mean air temperature
- Daily rainfall sums
- Suspended sediment concentration

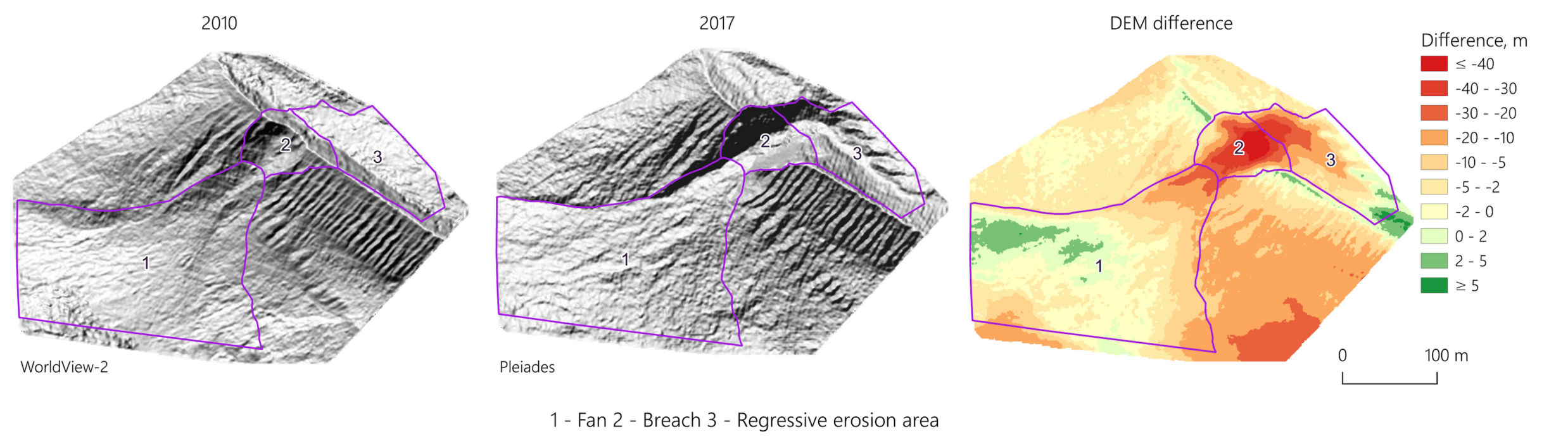
04. Results

04.01 Breach area



Annual changes

Start	End	Erosion, m³	Deposition, m³	Net Change, m³
Fan (Zone 1) – S=36,783 m²				
2015	2017	*-84,600*	*57,756*	*-26,844*
2017	2019	*-15,219*	*36,295*	*21,076*
2019	2021	-844	4,742	3,898
2021	2022-1	-9,314	5,239	-4,075
2022-1	2022-2	-988	7,530	6,542
Breach (Zone 2) – S=4,920 m²				
2015	2017	*-113,280*	*836*	*-112,444*
2017	2019	*-6,647*	*21,200*	*14,553*
2019	2021	-670	164	-506
2021	2022-1	-314	2,652	2,338
2022-1	2022-2	-267	612	345
Creek Cut (Zone 3) – S=10,524 m²				
2015	2017	*-67,668*	*7,454*	*-60,214*
2017	2019	*-24,575*	*11,634*	*-12,941*
2019	2021	-1,379	17	-1,362
2021	2022-1	-1,136	2,974	1,838
2022-1	2022-2	-1,653	932	-721



1 - Fan 2 - Breach 3 - Regressive erosion area

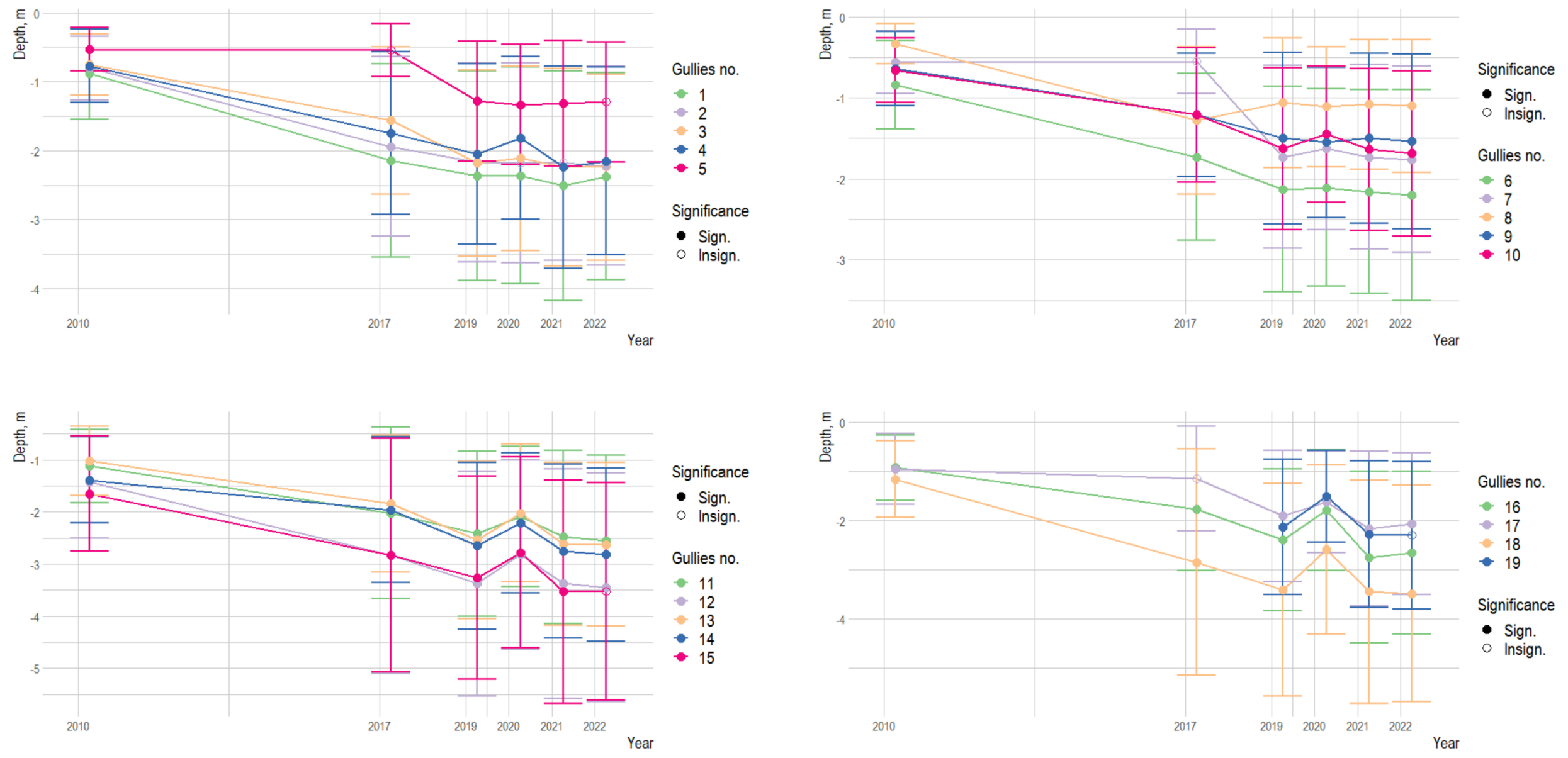
Total change

Zone	-, m³	+, m³	±, m³
1	-94,758	67,737	-27,021
2	-121,178	25,464	-95,714
3	-70,183	10,445	-59,738
All	-286,119	103,646	-182,473

04.02 Moraine gullies

For the gullies on the right side from the breach (18) there is a clear **erosional trend**. Gullies closer upper in the valley experienced more deepening. In total -10,200 m³ eroded for a 12-year interval (-921 m³ per year). Only 1-5 volume changes per interval were not significant.

For three gullies on the left side (down the breach), there is **no clear erosional trend**. Initially (2010-2017) it was deepening. Followed by stabilization and deposition. More dependent on the breach formation.



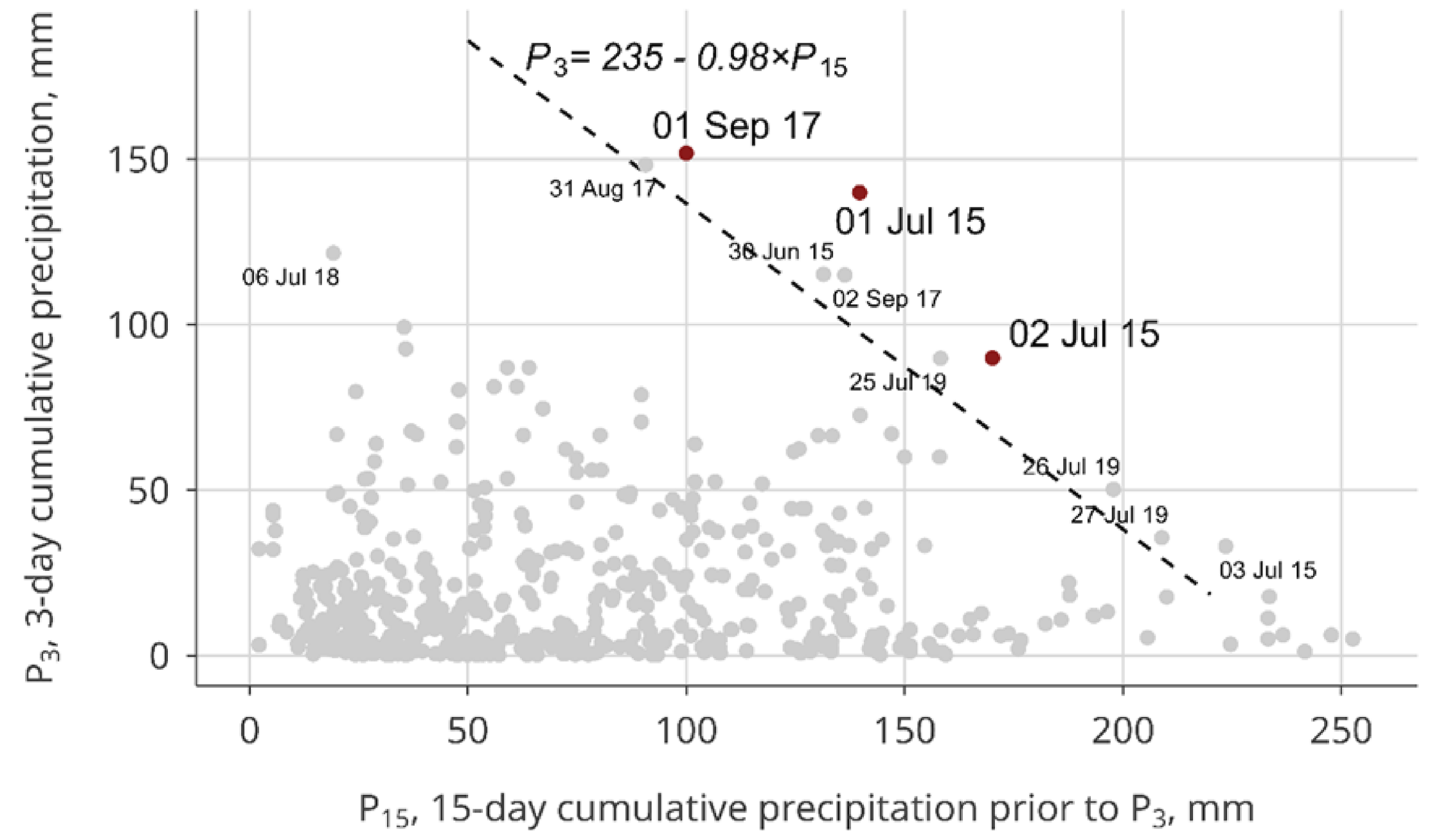
Right-side gullies deepening

05. Discussion

Snow cover. The year 2015 is exceptional as the melting started in the entire basin on the same date, while for other years on average, 10 days delay was typical.

Exceedance probability (SSL). Five events (2015-2021) with the AEP <10%: three in 2015, one in 2017, and 2018. The breach was formed during the event of 0.1% AOP (1000 years).

Rainfall threshold. The analysis highlights the events occurred 30 Jun - 02 Jul 2015; 31 Aug - 02 Sep 2017 and 25-27 Jul 2019;



Proposed rainfall threshold

06. Conclusion

- The breach formation and the following terrain development are caused by **extreme meteorological events** (high precipitation and air temperature).
- The volumetric assessment accuracy of the breach terrain change detection is dependent on the position of ground control points.
- The sediments entering Djankuat River due to the breach and Koiavgan Creek (downstream) erosion contribute to **at least 50 percent of the total SY** for particular years.

Dynamics of the rapid topographic changes after recent moraine breach: a case study of the Djankuat catchment, Central Caucasus

Kedich et.al, 2023

Supplementary Materials

Methodology

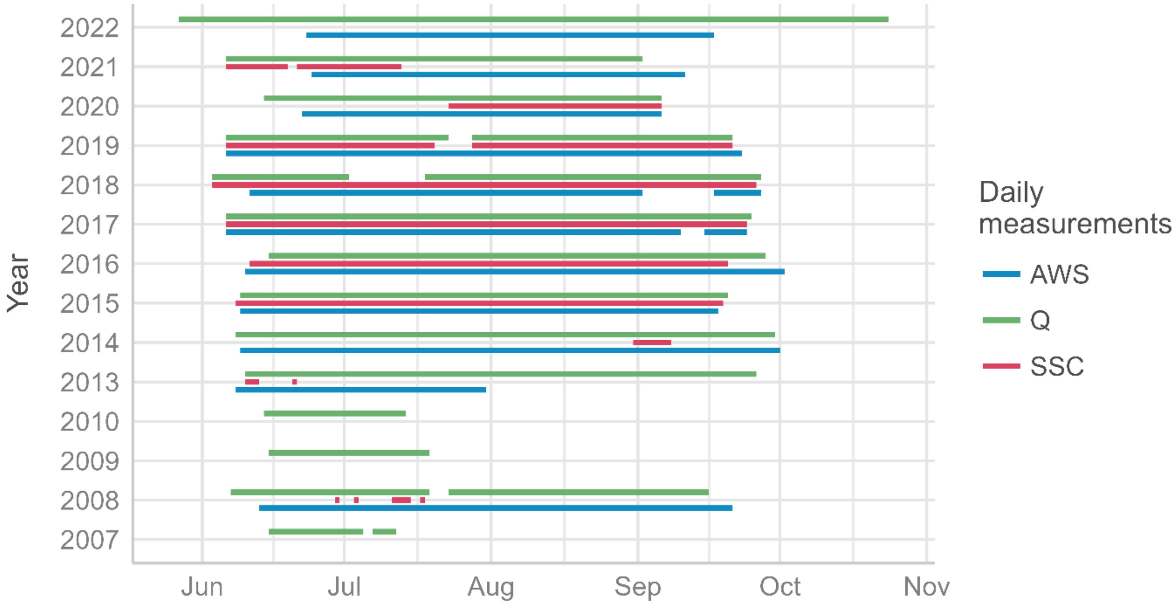


Figure 1 — Hydrometeorological data availability for the 2007-2022 period at DGS.

Results

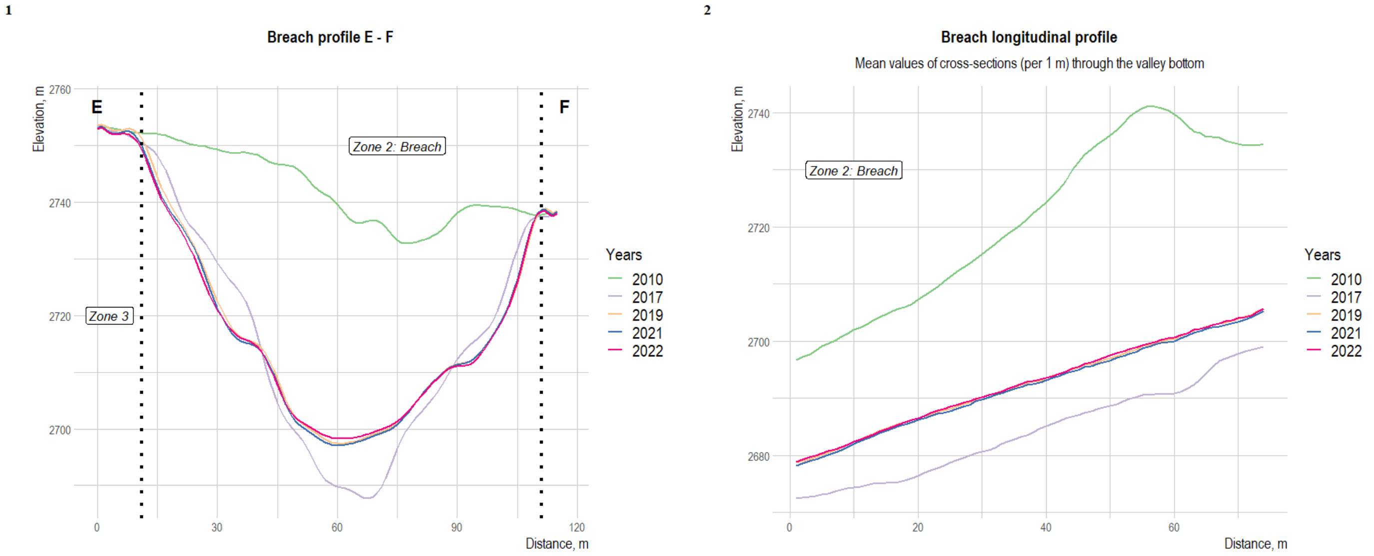


Figure 2 — 1. cross-sectional profile through the breach; 2. Longitudinal profile created from averages from the series of cross-sectional profiles per every meter along the creek valley bottom

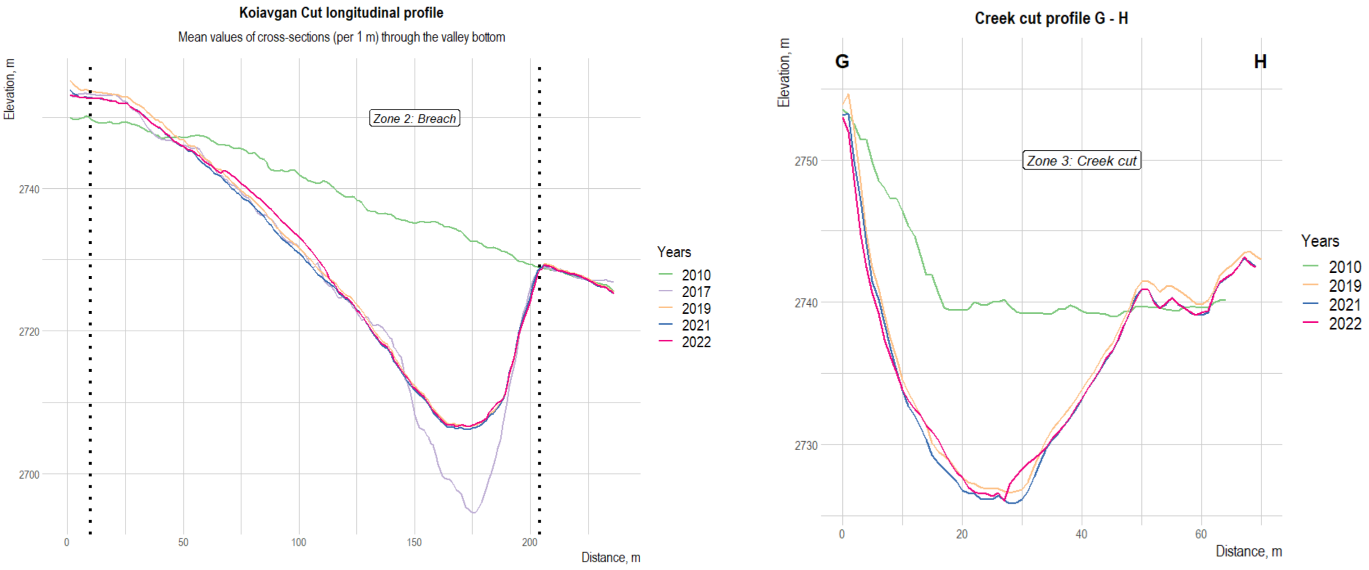


Figure 3 — Koiavgan Creek longitudinal profile (based on cross-sectional profiles of the creek valley bottom drawn per every meter); Creek cut cross-sectional profile G-H

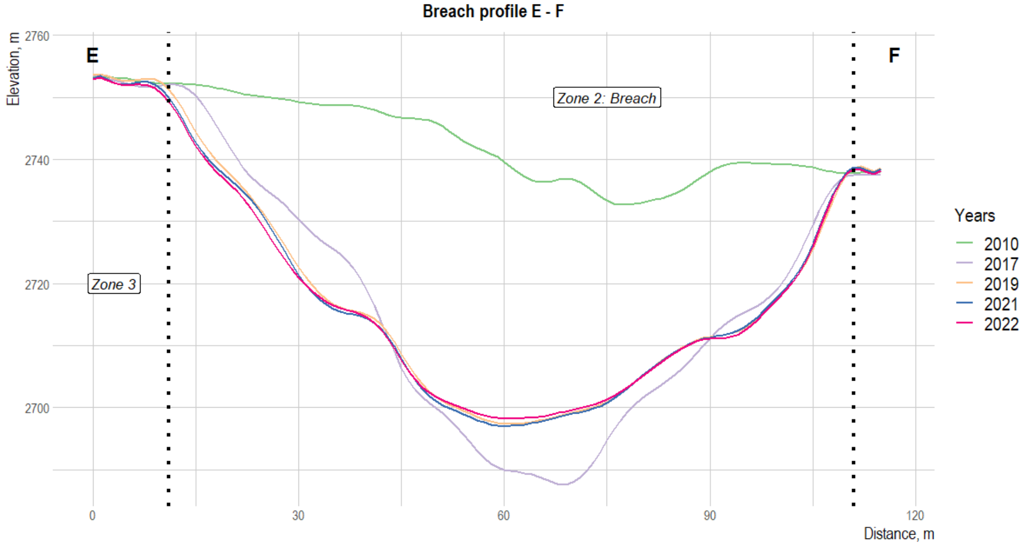


Figure 4 — Breach cross-sectional profile E-H

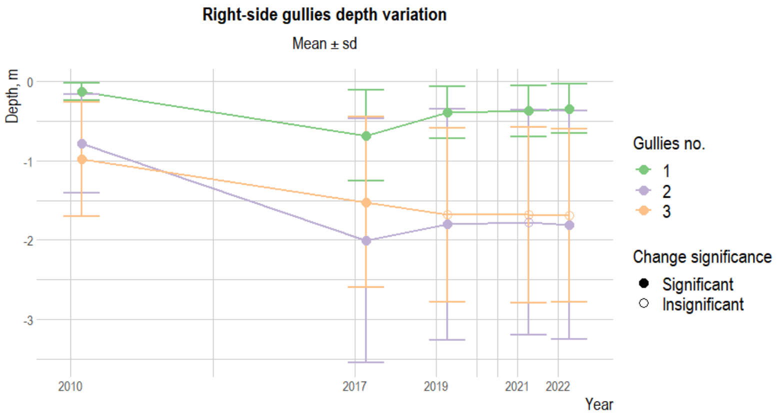


Figure 5 — Gullies' depth development to the right side of the breach (down the main Djankuat valley); Mean ± SD

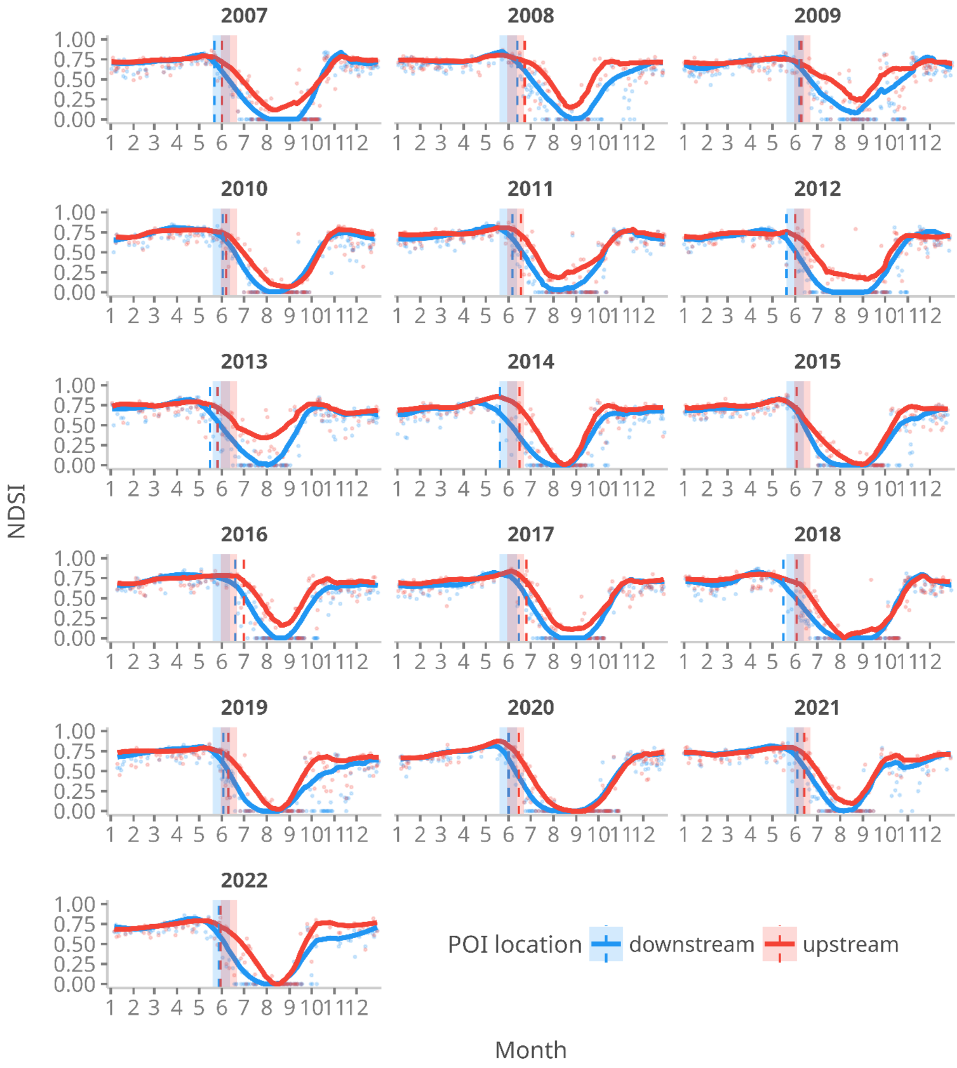


Figure 6 — Timeseries of the changing NDSI pattern during the 2007-2022 period. NDSI values were retrieved from MODIS products and further smoothed using a Savitzky-Golay weighting filter.

Table 1. Event-based suspended sediment loads (t/event) at the DGS for the period 2015–2021.

year	n	range	Total	Mean	SD	Median	Max	Min
2015	138	08 Jun - 19 Sep	21993	159	820	46.5	9500	1.1
2016	131	14 Jun - 19 Sep	7784	59.4	89.5	33	600	1.7
2017	135	06 Jun - 24 Sep	9225	68.3	170	30	1800	1.9
2018	115	03 Jun - 27 Sep	5138	44.7	213	20	2300	4.1
2019	145	06 Jun - 21 Sep	3161	21.8	27.2	13	200	0.17
2020	91	22 Jul - 05 Sep	912	10	8.82	7.2	53	0.35
2021	38	06 Jun - 14 Jul	2057	54.1	73.3	30	400	2.6

Table 2. Most extreme hydrological events in terms of suspended sediment export (with AEP < 10%) during the 2015-2021 period.

Year	Start	End	Duration, hour	Q_{mean}, m^3/s	Q_{max}, m^3/s	SSC_{mean}, g/m^3	SSL, t/event	AEP
2015	2015-07-01 05:00	2015-07-01 17:00	12	5.88	8.46	28630	9466	0.1%
2018	2018-07-02 12:00	2018-07-18 21:00	393	3.57	4.39	525	2288	2.5%
2017	2017-09-01 00:00	2017-09-01 06:00	6	2.27	2.66	38287	1825	4.5%
2015	2015-07-02 12:00	2015-07-03 11:00	23	3.88	4.12	5291	1545	5%
2015	2015-07-01 18:00	2015-07-02 11:00	17	4.46	4.72	4256	1172	7.2%

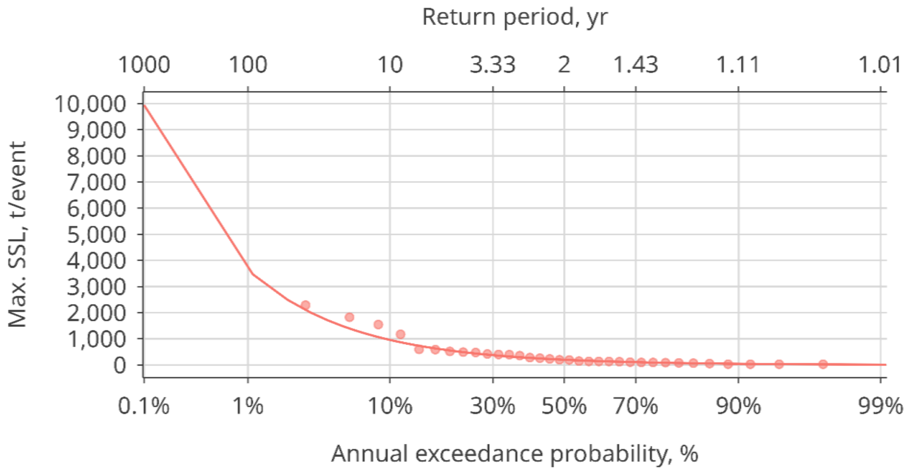


Figure 7 — Annual exceedance probabilities of five annual maximum hydrological events in terms of SSL for 2015-2021 period.