Natural hazard events affecting transportation networks in Switzerland from 2012 to 2016

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Abstract

Switzerland is a country threatened by a lot of natural hazards. Many events occur in built environment, affecting infrastructures, buildings or transportation networks and producing occasionally expensive damages. This is the reason why large landslides are generally well studied and monitored in Switzerland to reduce the financial and human risks. However, we have noticed a lack of data on small events, which have affected roads and railways during these last years. Therefore, we have collected all the reported natural hazard events which have affected the Swiss transportation networks since 2012 in a database. More than 800 events affecting roads and railways have been recorded in five years from 2012 to 2016. These events are classified into six classes: earth flow, debris flow, rockfall, flood, snow avalanche and "others".

Data coming from Swiss online press articles were sorted by Google Alerts. The search is based on more than thirty keywords, in three languages (Italian, French, German). After verifying that the article relates indeed an event which has affected a road or a railways track, it is studied in detail. We get finally the information on more than 170 attributes of events such as event date, event type, event localisation, meteorological conditions as well as impacts and damages on the track and human damages. From this database, many trends over the five years of data collection can be outlined thanks to the high number of event attributes: in particular, the spatial and temporal distributions of the events, as well as their consequences in term of traffic (closure duration, deviation, costs of direct damage, etc.).

Even if the database is imperfect because of the way it was built and because of the short time period considered, it highlights the non-negligible impact of small natural hazard events on roads and railways in Switzerland at a national level. This database helps to better understand and quantify this type of events and to better integrate them in risk assessment.

Keywords

Natural hazard events, floods, landslides, earth flows, rockfalls, debris flows, snow avalanches, transportation networks, Switzerland, database.

1 Introduction

Natural hazards cause many damages to transportation networks around the world (Nicholson & Du, 1997; Hungr et al., 1999; Dalziell & Nicholson, 2001; Karlaftis et al., 2007; Tatano et al., 2008; Erath et al. 2009; Muzira et al., 2010; Jelenius et al., 2012). Particularly on mountainous areas, floods, landslides (considered as earth flows in this study), debris flows, rockfalls and snow avalanches (called avalanches in this paper) can seriously affect the traffic on roads and railways tracks, isolating villages or regions and generating infrastructure and economic damages (Bunce et al., 1997; Budetta et al., 2004; Evans et al., 2005; Collins, 2008; Salcedo et al., 2009; Guemache et al., 2011; Jaiswal et al., 2011; Michoud et al., 2012; Laimer, 2017b).

While large natural hazard events affecting roads and railways are generally well studied and documented, e.g. the Séchilienne landslide (Kasperski et al, 2010), La Saxe landslide (Crosta et al. 2014) or La Frasse landslide (Noverraz and Parriaux, 1990), it is not the case for minor and medium-size events ranging from a few cubic decimetres to a few thousand of cubic meters. They are numerous and often too small, difficult to detect and expensive to monitor (Jaboyedoff et al. 2016a).

The society tendency is to collect disasters events or events having any high social impact (death, high cost, highlighting societal problems, etc.) in a database. The criterion to be listed in the main global disaster databases (EMD-DAT, Swiss Re, Dartmouth) illustrate this since it needs at least ten causalities or other politics or economic criterions (Guha-Sapir et al., 2015; Swiss Re, various dates; Dartmouth Flood Observatory, 2007). The insurance possesses databases that are more detailed but they are usually not available such as the NatCat from Munich Re reinsurance (Tchögl et al, 2006; Bellow et al., 2009; Munich R. E., 2011). At present, most of worldwide, national and regional databases do not generally deal with small events that can be considered as insignificant for the experts (Guzzetti et al. 1994, Malamud et al. 2004; Petley et al. 2005; Devoli et al. 2007; Kirschbaum 2010, Foster et al. 2012; Damm et al. 2014). With noteworthy exceptions like RUPOK database (Bíl et al. 2017), which collects information about consequences of geohazards on transportation networks. The Swiss flood and landslide damage database (Hilker, 2009) contains also small events but no information about track and traffic.

Gall et al. (2009) highlighted the underreporting of small events inducing bias in data. The director of Global Resource Information Database at the UNEP recognised a problem to evaluate the true impact of natural hazards since EMD-DAT database records only events with estimated losses of above 100 000 US$ (Peduzzi, 2009). The Head of the UNISDR, R. Glasser, alerts that governments underestimate the low cost disasters that affect significantly to the societies (Rowling, 2016).

In order to fill partially a gap in the knowledge about small events, we focused on the impacts of natural hazard on road and railways tracks, collecting as much information as possible on the events affecting the Swiss transportation network since 2012.

The goal of this database is to determine the main trends of these events and to evaluate the relevance of such concerns.

2 Study area

The study is applied to the whole Switzerland, which possesses a surface area of 41 285 km^2, with an elevation ranging from 193 m (Lake Maggiore) to 4 634 m a.s.l. (Dufourspitze). The Swiss geography can be divided into three major geomorphologic-climatic regions: the Alps, the Swiss Plateau and the Jura. The Alps cover about 57 % of the Swiss territory (23’540 km^2) with 48 summits over 4 000 m a.s.l. and many inhabited valleys. The Swiss Plateau, located northwest to the Alps, covers about 32 % of the territory (13 360 km^2) at an average altitude of about 500 m a.s.l. and is partially flat with numerous hills. Two-thirds of the Swiss population lives on the Plateau (13 360 km^2) which has a population density of about 450 inhabitants per square kilometre. The Jura Mountains (11% of the territory, 4 385 km^2) is a hilly and a mountain range situated on the north-western border of the plateau with a top summit of 1 679 m a.s.l. (Mont-Tendre). The Swiss climate is a mix of oceanic, continental and Mediterranean climates which varies greatly because of the reliefs. The average annual rainfall is around 900-1 200 mm $years^{-1}$ on the Swiss Plateau, 1 200-2 000 mm $years^{-1}$ on the Jura Mountains and between 500 and 3 000 mm $years^{-1}$ in the Alps (Bär, 1971). The Swiss average temperature is about 5.7 °C (MeteoSwiss, 2018).

3 Data and methods

A database was built over five years during the period 2012-2016, collecting 846 events. The minimum threshold for being included in the database is a traffic disruption (for example, a large velocity reduction) for at least 10 minutes following a natural hazard event that have reached to a transportation track.

We used online press channels as information sources, because it possesses the best ratio in simplicity / efficiency. While an online press review was made every working day from 2012 to 2014, since May 2014, Google^{tm} Alerts (Google, 2018) was introduced with more than fifty keywords in German, French and Italian (see Table 1-SM in Supplementary material (SM)). These around ten received alerts per day permitted to collect the events from the Swiss online press.

Each alert contained two online press articles in average containing one of the fifty keywords. Each article was read in order to identify if the related information concerns a natural hazard event or not which affected a transportation networks. If not, it was not considered.

About 10 % of all these highlighted articles referred to a real natural hazard event. About 800 articles were kept from mid-2014 until the end of 2016. The Swiss traffic information website were also periodically manually checked, as well as few social media pages susceptible to contain some pictures of events, as the official page of the commune of Montreux on Facebook (Montreux, 2014). Otherwise, some events were collected directly in the field.

Here we classified natural hazards according to six categories:

- Static or dynamic floods with only little sedimentation material on the tracks including a few hail events.
- Debris flow, that are often not well described in the media and confounded with landslides or floods. They were often characterized with pictures from the press articles.
- Landslide: superficial or deep sliding of soil mass including shallow landslides.
- Rockfall refers indifferently to rock falls and rockslide.
- Avalanche refers to snow avalanches.
- Other: snowdrifts (mainly during February 2015 in West of Switzerland) and falling trees (mainly during windstorms).

172 attributes are used to describe the events (Table 1; Figures 1-SM and 2-SM in Supplementary material (SM)) and they are subdivided in eight categories: date, location, event characterization, track characterization, damage, weather, geology and sources. Data about date, location, event characterization and damage come from the online press articles. Attributes of the database are shortly presented in Table 1.

Images from the press articles are used to estimate many attributes as the event classification and the volume estimation of the deposit material if it is not estimated in the press article.

The analyses were either performed in a Geographic Information System (GIS) environment for spatial data or in a standard statistical way for all other data. In order to extract general trends of the 846 events collected from 2012 to 2016, the data were characterized by basic statistics descriptors and displayed with histograms and charts.

Weather data come from 24 weather stations of MeteoSwiss. For each event the reported weather conditions are not always coming from the closest station but from the one with a similar topo-climatic situation. The average distance between weather stations and events is 20 km (SD of 18 km) and the average absolute elevation difference is 200 m (SD of 366 m). The rainfall data are given for: the event day, the last five days and the last ten days, providing the antecedent situations.

The deviation lengths for roads were measured using a GIS. Density maps were made using the kernel density function in a GIS with a search radius of 10 km for events map and 20 km for the road density map with both a 500 m output cell size. Results are classified using 10 classes with the Jenks natural breaks method.

The damage levels have been characterized by four levels partially based on Bíl et al. (2014). The first damage level concerns “no closure or no track damage”. Events of this first level generate only traffic slowdowns and small disruptions. They concern mainly floods often triggered by strong storms (vehicles can drive slowly on a flooded road without the need to close the track) (Figure 6E). The reduction of the traffic velocity generally lasts less than two hours. The second level refers to a complete or partial track closure because of the material deposition on the track. If only one lane is closed, the second lane allows to have an alternated traffic moderated with temporarily traffic lights or traffic regulators. Tracks of the second level of damage can reopen after evacuation works, without any repair work.

The third level, “partial damage”, needs superficial repairs and / or minor stabilization of the track embankments because the events generated small damages on the tracks. Finally, the “total destruction” level means that the track embankment has to be reconstructed, requiring many repair works.

For each damage class, costs per square meter was attributed according to the event intensity (small, middle and large) for both the road and railway. A surface area of 100 m^2 is assumed for small events, 200 m^2 for medium and 300 m^2 for large events. Costs are given in Euros with values in mid-January 2018 of 1 EUR = 1.17 CHF = 1.23 USD. On average a “no closure” cost was estimated at EUR 6 per square meter, at EUR 230 for a “closure”, at EUR 400 for a “partial damage”, at EUR 1 000 for a “total destruction” and at EUR 230 for a “unknown” (Table 2-SM). Direct damage costs evaluation was based on road and railways reports (Canton de Vaud et du Valais, 2012; SBB CFF FFS, 2017) and on the basis of repair works experience by civil engineers. Since direct damage costs are difficult to assess (this is event more true for indirect damage costs), the proposed methodology to determine them must be considered, above all, as a tool to compare the costs of the different damage classes. The cost values should not be considered as true costs for all events but as a order of magnitude of the projected costs (please see also section 5.4).

Table 1: Attributes categories to describe events in the database.

Attribute category	Answer the question	Contains	Number of attributes	Main source
ID	Event ID	-	1	-
Date	Which date and time	Year, season, day part	15	Online press article
Location	Where did the event occur?	Region, topography, coordinates	21	Online press article and GIS[1]
Event characterization	Which natural hazard event?	Type of hazard, features, picture	12	Online press article
Track characterization	On which track?	Road/railway, features, deviation	17	Swisstopo[2]
Damage	Which kind of damage?	Damage on track, vehicle, people	11	Online press article
Weather	What was the weather?	Sun, rain, temp., storm, wind, snow	68	MeteoSwiss[3]
Geology	On what soil did it occur?	Soil features	11	Swisstopo[2]
Source	What are information sources?	Addresses of online press articles	16	Online press article

[1] GIS: Geographic Information System
[2] Swisstopo: Swiss Federal Office of Topography
[3] MeteoSwiss: Swiss Federal Office of Meteorology and Climatology

4 Results

4.1 Types of natural hazards processes

421 (~50%) of the 846 collected events are floods, including hail flooding events (8 events, i.e. 1%) (Figure 1A). The second most frequent processes are landslides (192; 23%), followed by rockfalls (96; 11%) and debris flows (68; 8%). The remaining concerns snow avalanches (15; 2%) and “other” events processes (54; 6%) includes snowdrifts (40; 4.5%) and falling trees (14; 1.5%). Snowdrifts mainly result from a unique event in February 2015.

4.2 Spatiotemporal conditions

4.2.1 Spatial distribution

Natural hazard events affecting the Swiss transportation network for the period 2012-2016 are equitably distributed on the geomorphologic-climatic regions Plateau and Alps (371 and 377 events respectively; 44% each). The remaining 12% (98 events) occurred in the Jura area (Figure 1B and Figure 2 and; Table 3-SM). The spatial distribution of natural hazard events beside floods is quite proportional to the surfaces areas of Swiss regions: Alps with 60% of the Swiss territory surface account for 64% of events expect floods, the Plateau for 30% and 31% and Jura for 10% and 5% respectively. The kernel density maps of all event types as well as the road density map are shown in Figure 2-SM.

The majority of the floods (239; 57%) occurred in the Swiss Plateau. Debris flows are occurred mostly in the Alps (66; 96%), as well as rockfalls (84; 88%) and avalanches (16; 100%), which not surprising considering the strong control of the presence of steep slopes. Landslides are more equally distributed with only 55% (107) in the Alps, because they usually occur in moderate slope (Stark and Guzzetti, 2009); The “other” events (snowdrift and falling trees) occurred mostly on the Plateau (41; 79%).

Half of events (412 events; 49%,) occurred in built environment (towns, agglomerations, villages and hamlets) and half (434; 51%) of events occurred in a natural environment (countryside: 211, 25%, ; forest: 185, 22%; mountain above forest limit: 38, 4%) (Figure 1C; Table 4-SM).

By making risk ratios (Miettinen, 1972; Zhang and Kai, 1998; Spiegelman and Hertzmark, 2005) related to the surface of the regions, floods and “other” are over-represented in the Jura and in the Plateau while debris flow, avalanche and rockfalls are over-represented in the Alps

(Figure 3A). Risk ratio related to the length of the roads of the three regions indicates that the Alps have over-represented debris-flow, landslides, rockfalls and avalanches (Figure 3B)

The slope angle distribution (Figure 1D; Table 5-SM), extracted from a 25 m DEM (Swisstopo, 2018), indicates that 40% (339 events) of all events afftect the tracks on slopes ranging from 0° to 5° and 30% (257) between 5° and 15°. 62% (260) of floods affected tracks on the almost flat slope ranging from 0° to 5°, and 43% (30) of debris-flow in 5°-15° slope. A third of landslides (63) and a third of rockfalls (30) events occurred on a 15°-25°. 76% (12) of snow avalanches cross tracks at a slope angle of 10°-30°. Two-thirds (36) of “other” were observed at 0 to 5°.

Eight slope orientations were estimated based on the Swisstopo maps for 72% (609 events) of the recorded events (Figure 3-SM). The slopes oriented to south, south-east and west account for 17% (144) each. The over-representation of these orientation are caused by the debris-flows occurring in the western slopes (mainly because of debris flows that occurred in the the S-Charl valley in 2015). Landslides seems more prone in south and west oriented slope.

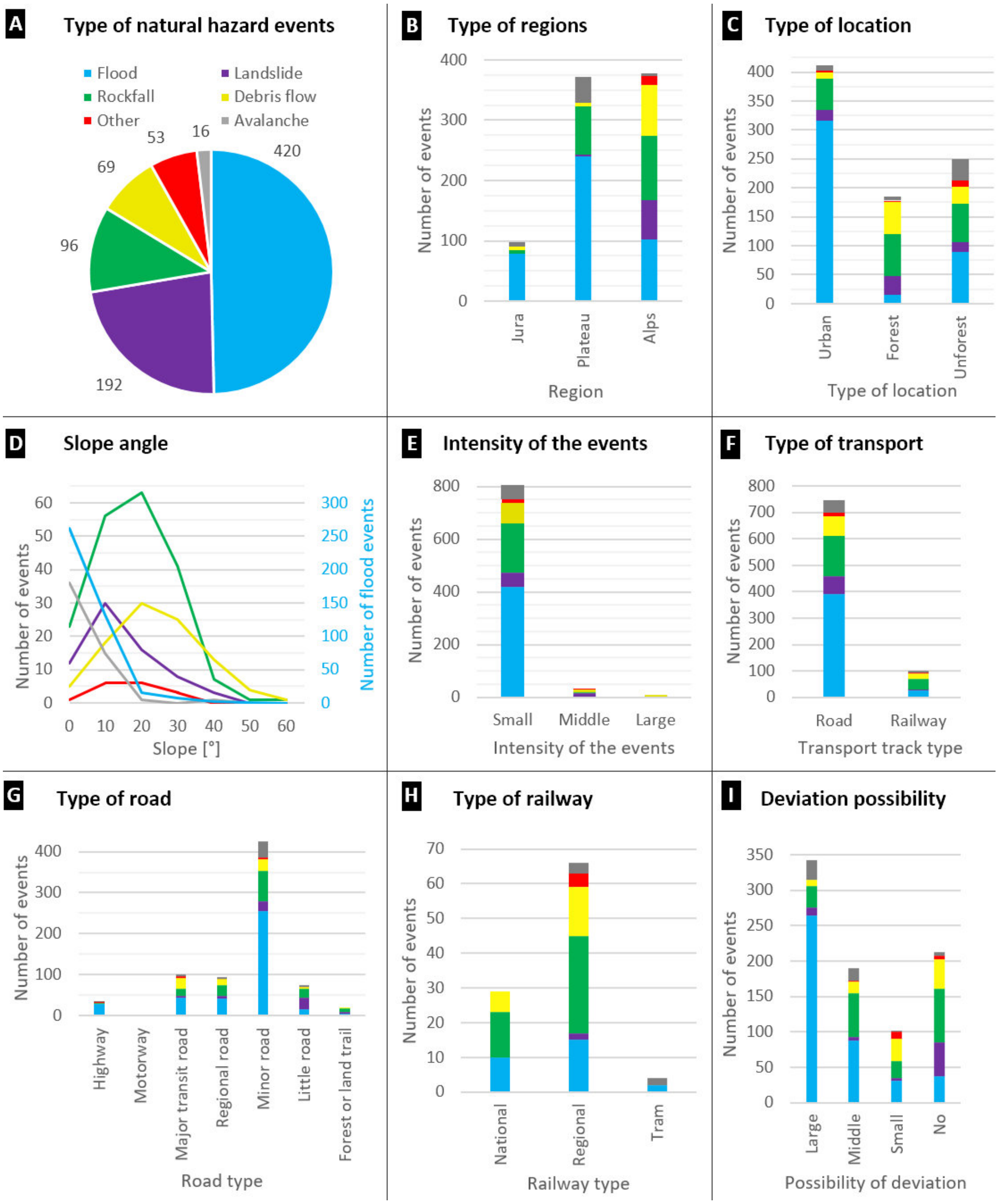

Figure 1: A: Number of events according to natural hazard events on the Swiss transportation network from 2012 to 2016. B: Distribution according to the three large geomorphologic-climatic regions. C Distribution of the type of location. D: Slope angle distribution. Flood events are on the secondary vertical axis. E: Distribution of the events according to intensity. Small event: 0-10 m3; middle event: 10-2000 m3, large event: >2000 m3. F: Distribution of transport mode. G: Road types distribution. H: Railways types distribution. I: Distribution of possibility of deviation. Large possibility of deviations: >3 possibilities; middle: 2-3, small: one possibility; no: no possibility.

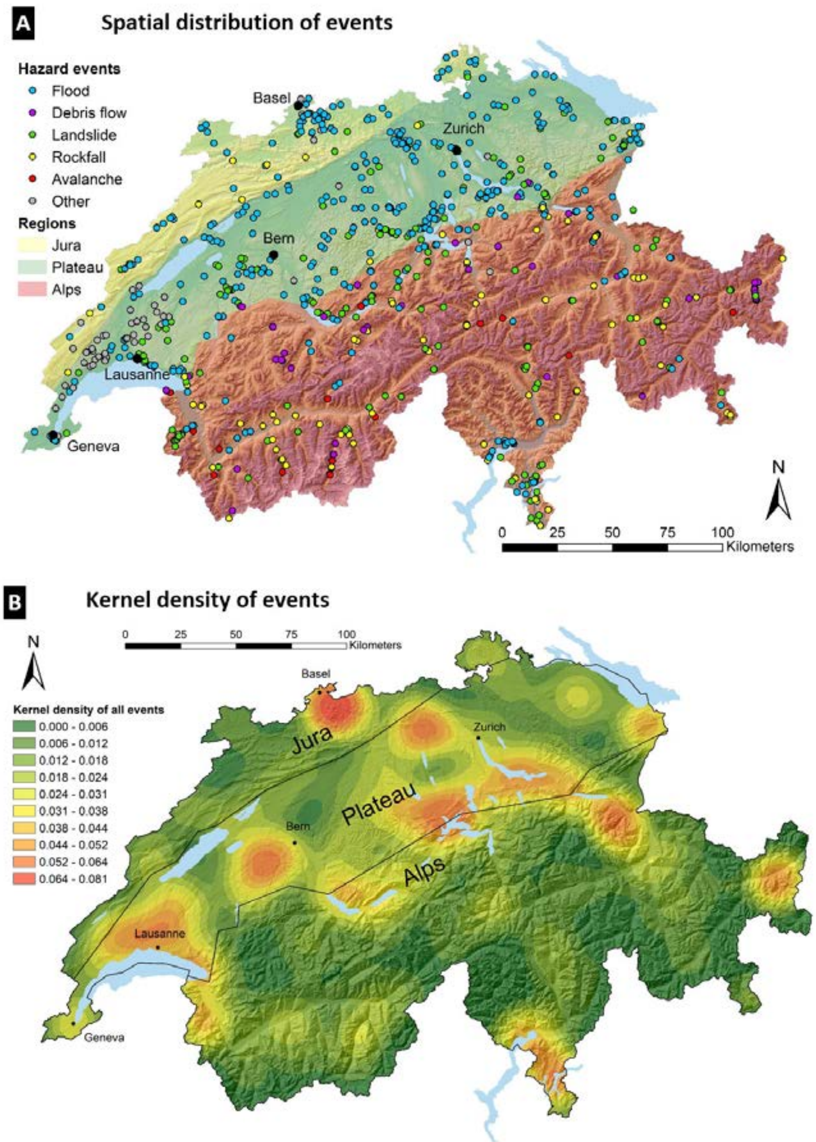

Figure 2: A: Spatial distribution of natural hazard events affecting roads and railways in Switzerland from 2012 to 2016. Source of the map: swisstopo. B: Kernel density of the events (20 km search radius and results classified using 10 classes with the Jenks natural breaks method.).

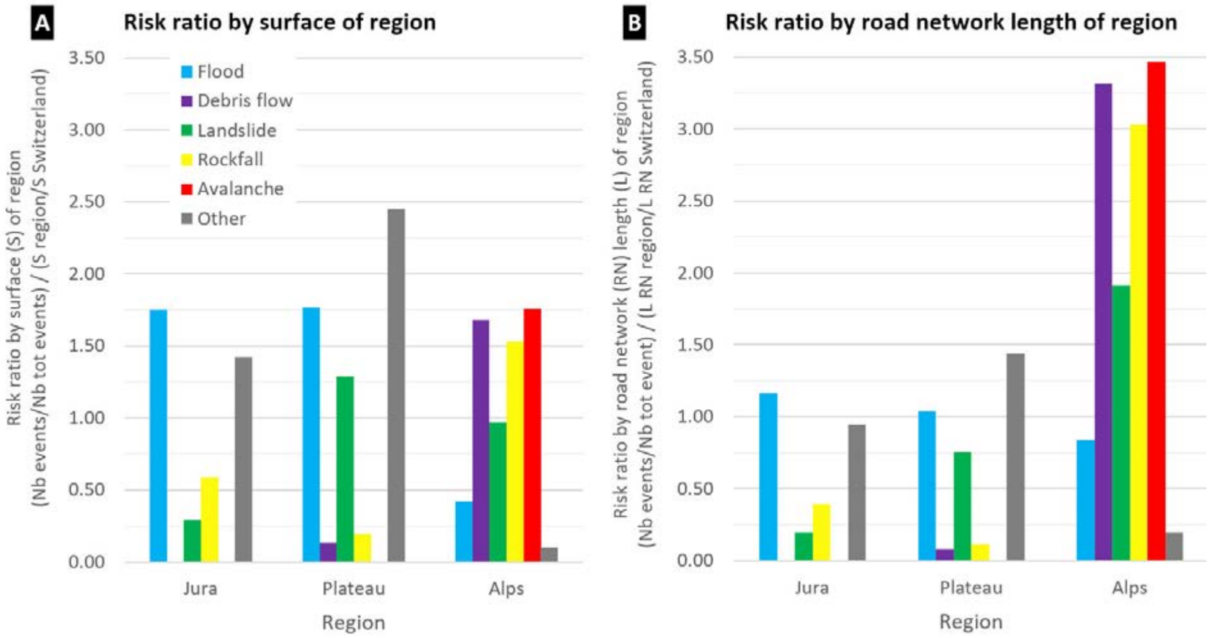

Figure 3: A: Risk ratio by surface of the three geomorphologic-climatic swiss regions. B: Risk ratio by the road network (RN) length of the three geomorphologic-climatic swiss regions.

4.2.2 Event intensity

The debris flow, landslide, rockfall and avalanche events were classified into three intensity classes (Figure 1E and Figure 4; Table 6-SM) defined by volumes:

- Small: below ten m^3.
- Medium: from ten cubic meters to two thousand m^3.
- Large: larger than two thousand m^3.

With one exception (medium intensity), floods were classified -on the basis of the water level and the flooded area- as events with a small intensity (419 floods). “Other” events (snowdrifts and falling trees) were also all categorised as small events (53 events). 95% (804) of all events are classified as small, 4% (33) as medium and 1% (9) as large events. Note that a third (32) of rockfalls are large.

Excluding floods, 39% (146) of the event sources are located at more than 50 m from the track, 35% (185) are located between 0 and 50 m (Table 7-SM). A quarter (95) of the source locations are unknown. Almost all sources close to the tracks (that represents 35% (185) of all events) are human-induced natural hazard events. The sources of debris flows and avalanches in the Alps are located far from the track with natural origin (100% (69) for debris flow, 94% (15) for avalanche). Excluding floods, 80% (339) of the sources are located above the track, 7% (29) below and 14% (58) possess unknown origin (Table 8-SM).

Figure 4: Examples of events affecting roads. Left: small event already removed but still unstable on the uniquely accessible road to the small village of Morcles (Canton of Vaud). Middle: middle event on a minor road in Ollon (Canton of Vaud). Right: large event with a volume estimated at 3500 m^3 that cut a 50 m length on the international road between France and Canton of Valais near the Forclaz pass (Trient). Road closure is estimated of six weeks. Images taken on 24 January 2018 after a winter storm.

4.2.3 Rainfall

The average rainfall during the day of the event is 17 mm (Figure 5A; Table 9-SM). On average, rain amount during the event day is 22 mm, 17 mm, 14 mm, 5 mm and 4 mm for flood, landslide, debris flow, rockfall and avalanches respectively. The maximal precipitation recorded (154 mm) in the database occurred in Canton of Ticino, in November 2014, which triggered a landslide.

The debris flows mostly occurred following strong convective summer storms after a quite sunny day. This means that the precipitations at the location of the debris-flow may be higher than those recorded by the station. Landslides occurred after the greatest amount of rainfall recorded in the last ten days preceding the event. The debris flows occurred a few ten of minutes to a few hours after heavy precipitations, floods after about one day of heavy rainfalls and landslides occurred up to several days after intense precipitations.

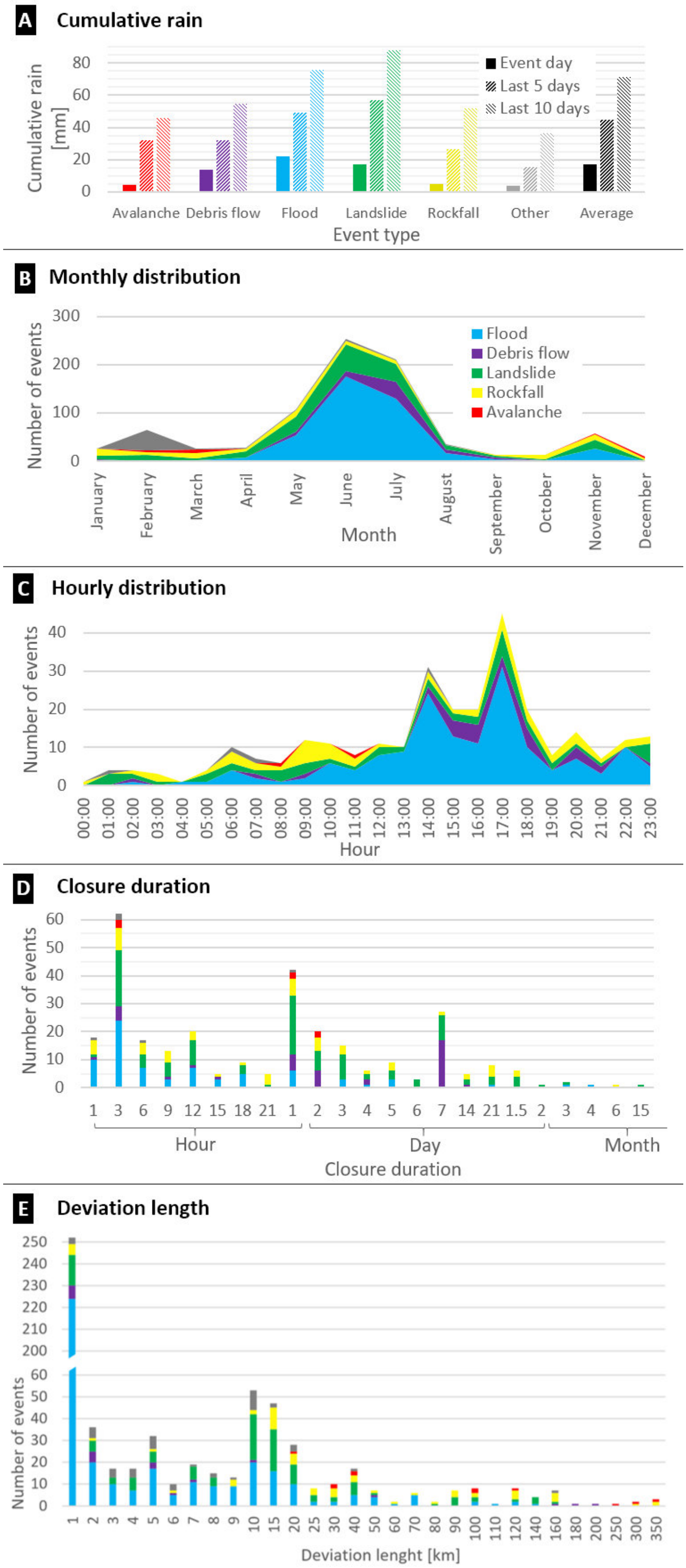

Figure 5: A: Cumulative rain [mm] distribution of the day of natural hazard events and last five and ten days. B: Monthly distribution. C: Hourly distribution. D: Closure duration distribution. E: Deviation length distribution of road closures. The vertical axis is cut between values 60 and 200.

4.3 Temporal parameters

4.3.1 Clustering in time

Fifteen long-lasting rainfalls were selected during the five considered years (Table 2) with durations of two days to fifteen days. 515 events, (i.e. 61 %) affected roads and railways during the 115 days (corresponding to 6% of the five considered years; 4.5 events per days) indicating the negative impact of long-lasting rainfalls. A third of these 515 events are among the 50 major loss events around the world, according to the Munich Re Topic Geo annual reports.

Table 2: Long-lasting rainfalls where occurred 61% of the collected natural hazard events on the Swiss transportation network during from 2012 to 2016.

Date	Number of days	Number of events	Avg number of event by day[2]	Munich Re event[3]
2012.01.06-07	2	2	1	2012.01
2012.11.04-14	11	12	1.1	-
2013.06.01-03	3	26	8.7	2013.06
2014.02.15-18	4	4	1.0	2014.02
2014.06.03-12	10	10	1.0	2014.06
2014.07.04-15	12	44	3.7	-
2014.07.22-31	10	51	5.1	-
2014.11.13-18	6	35	5.8	-
2015.04.27-05.07	11	55	5.0	-
2015.06.05-15	11	75	6.8	-
2015.07.22-25	4	37	9.3	-
2016.06.02-09	10	80	8.0	2016.06
2016.06.15-25	14	49	3.5	-
2016.07.22-28	7	35	5.0	-
Total	115	515[1]	4.5	-

[1] 61% of all events.
[2] Events number / number of days.
[3] Sources: Munich Re, 2013, 2014, 2015 and 2017.

4.3.2 Monthly distribution

The events effecting Swiss roads and railway from 2012 to 2016 are one average 71 events per month with a median value of 32. It ranges from 9 events for December to 253 events for July (Figure 5B; Table 10-SM). Two-thirds of all events (570 events; 68%) occurred during the three months May (107; 13%), June (253; 30%) and July (210; 25%).

85% (357) of floods and 64% (123) of landslides occurred in the period May - July. 89% (61) of debris flow occurred in from May to August. 64% (61) of rockfalls are distributed during the months January, March, May, October and November. 50% (8) avalanches occurred in March. 81% (43) of “other” events occurred in February.

4.3.3 Time of day and hourly distribution

The hour of occurrence is included for 33% (281) of the events (Figure 5C). 57% (89) of floods with a known hour of occurrence occurred between 2 pm to 7 pm, 61% (17) of debris flows occurred between 3 pm and 7 pm. Landslides and rockfalls are fairly well distributed during a day. Nevertheless, 23% (10) of rockfalls occurred between 9 and 11 am.

4.4 Infrastructure parameters

4.4.1 Types of tracks

88%, i.e. 747 of all collected events, affected road tracks, while 12%, i.e. 99 events, affected railway tracks (Figure 1F; Table 11-SM). Among the events affecting roads, 53% were floods, 20% landslides, 10% rockfall, 9% debris-flows and 8% other types. For the railway tracks 42% were landslides, 27% floods, 20% rockfalls, 5% others, 4% avalanches and 2% debris-flows. 79% (668) of all events occurred on minor roads or railways tracks while 21% (178) occurred on major roads or railways.

4.4.2 Roads

The Swiss road network length is about 72 000 km with 1 850 km managed by the Swiss Confederation, among which 1 450 km are highways and motorways, 25 000 km are major (cantonal) roads and regional roads, and about 45 000 km of roads are at the municipal level (Federal Statistical Office, 2018).

Swiss roads are classified into seven classes, according to the Swiss Federal Office of Topography (Figure 1G: Table 12-SM). Highways have separated traffic and a speed limit of 120 km/h, motorways with a 100 km/h speed limit, both account for 3% of the network length accounting for 5% of the events. Major transit roads with a high traffic load (12%) are affected by 13% of the events and roads of regional importance (22%) account for 12% of the events with a lower traffic load, both have a maximum speed of 80 km/h. The three remaining road classes (63%) based on the width of the road, are related to small roads with a low traffic. 65% of flood affected minor roads, and 42%, 48%, 36% and 82% respectively for debris flow, landslide, rockfall, avalanches and other events.

Interestingly, the frequency along highways and motorways corresponds to one event in every 200 km in each year, one in every 650 km for major and transit roads, and one in every 450 km for all types of minor road (minor roads, little roads and forest trails).

4.4.3 Railways

The Swiss railway network is 5 200 km long including 130 km of cogwheel train and 330 km of tram (Federal Statistical Office, 2018).

Railway tracks are classified into three classes: major (34% of the railway network), minor (62%) and trams lines (4%) (CFF, 2018; Federal Statistical Office, 2018) (Figure 1H; Table 13-SM). The major tracks, usually with two lanes, linking the main Swiss or crossing the Alps cities account for 29% (29) of railway events. The minor tracks, often with one lane, are affected by two-thirds (67%; 66) of events. Tram tracks, in or around towns, are affected by 4% (4). 56% of flood occurred on minor tracks and 37% on major tracks.

All debris-flows occurred on minor railways. 68% of landslide affected minor tracks and 32% affected major tracks. 70% of rockfall occurred on minor tracks and 30% on major tracks. All avalanches occurred on minor railways. 60% of “other” occurred on minor tracks and 40% on tram tracks (trees falls).

Concerning the network length of track types, railways tracks are affected by one event in every 250 km in each year, while all tram tracks are affected by one event in every 400 km in each year.

4.4.4 Possibility of deviation

For each event we checked how easy it was to find a deviation track (an alternative route in order to reach the next village avoiding the closure area) (Figure 1I; Table 14-SM). For 40% (342) of the events, more than 3 possibilities of deviation exist, for 23% (190) 1 to 3 deviations possibilities and for 12% (102) only one possibility was found. For 25% (212) of events, it is not possible to take an alternative track to bypass the closure because they occurred in valleys containing only one track

Almost two-thirds (264) of flood events and half (27) of “other” events could be bypassed. There are no deviation possibilities for 70% (48) of debris flow events, 43% (41) of rockfall events and 40% (77) for landslide events. This indicates that it is often impossible to find a deviation path for numerous debris-flows, landslides, rockfalls and avalanches.

4.5 Impacts and damages

4.5.1 On track

80% (677) of all events generated track damages (Figure 6A and Table 15-SM). 149 events (~18% of all events) are categorized in this first damage level “no closure or track damage”.

146 of those events are floods. For 463 events (55%), the tracks were closed because of material on the tracks. In addition to closure, 143 events (17%) belong to the third level “partial damage”. Finally, the “total destruction” level accounts for 6% of all events (53). 38 events (4%) induced damages that could not be estimated.

A third of flood events caused no track closure and the remaining two-thirds of events generated only track closure, floods are the natural hazard which generate the least damages. Floods that does not require track closure come from the fact that vehicles or train can pass through a certain water level. 39% (27) of debris flows generated partial damages and a quarter (18) of debris flows caused the total destruction. Half (96) of landslides generated no track damages but only a track closure and about one-third (71) of landslides generated partial damages on tracks. Half (48) of rockfalls generated only track closures and 39% (37) generated partial damages. Avalanches generated track closures (13; 81%) as well as “other” events (51; 96%) due to snowdrifts.

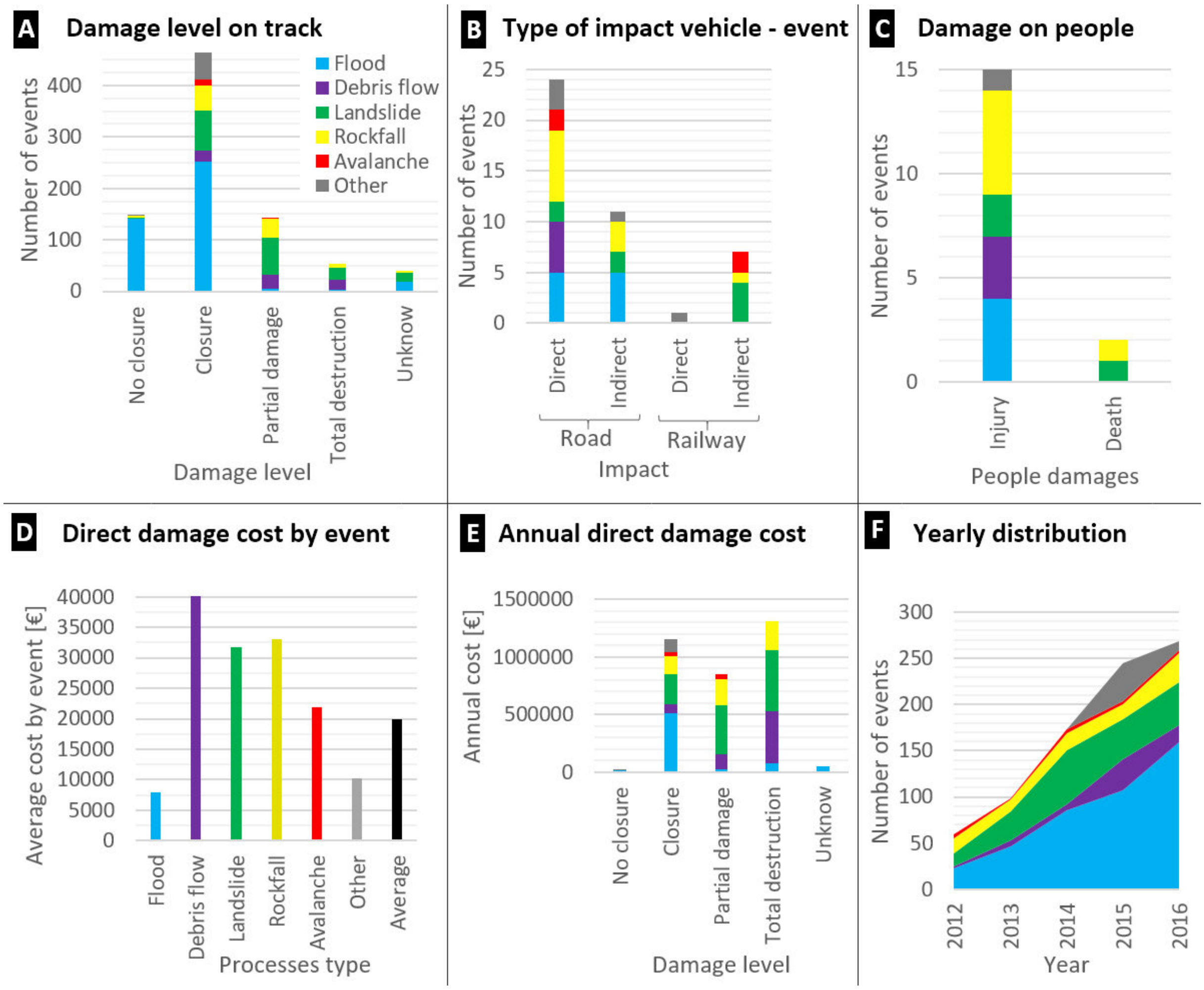

Figure 6: A: Damage distribution. B: Distribution of impact types between vehicle on roads or railways and natural hazard events. C: Distribution of injuries and deaths. D: Average event direct cost distribution. E: Annual direct cost distribution. F: Annual distribution.

4.5.2 On vehicle

43 (5%) of all collected events generated damages on vehicles (Figure 6B and Table 16-SM). 25 (3%) events included direct impact on vehicles, while 18 events (2%) caused indirect impacts on vehicles(when a vehicle collides the material falling on the track). Except a falling tree, which affects a tram directly, all direct impacts concern roads. Two trains were affected indirectly by avalanches, four trains by landslides and one train by rockfalls. Only 1% of all events affecting railways caused direct impact whereas 7% of the events caused indirect impacts. Conversely, 3% of all events affecting roads generated direct impacts while 1% caused indirect impacts.

4.5.3 On people

People are rarely directly affected by events. 831 events (98.2%) of all events did not cause injuries while 1.8% of events (15 events: 13 on roads and 2 on rail tracks) have caused injuries (Figure 6C and Table 17-SM). With 5.2% (5) and 4.3% (3) of events generating injuries, rockfall and debris flow events are natural hazard which generated the highest percentage of injuries. Twenty injured persons have been identified among which 10 were in a train derailment in the Canton of Grisons due to a landslide in August 2014.

Two events (0.2%) caused death in the above-mentioned event in Grison and in a second event occurred in March 2012, which was also in Grisons, where a coach without passengers was directly impacted by a rockfall, killing the driver instantly. Only 0.1% of events on roads caused the death while 1% of events killed people on railways..

4.5.4 Closure duration

Closure duration of 296 events (35%) were collected from the online press articles. Half of those closures (148) lasted less than one day while 41% (121) lasted from one day to one week and 9% (27) lasted over one week with a maximum of 15 months (Figure 5D). Thus, 87% of flood induced closures duration were less or equal to one day. While this percentage decreases to 71% for avalanches, 62% for rockfalls, 59% for landslides and 37% for debris flows.

4.5.5 Deviation length for roads

For the three quarter (638 events) of the case for which the deviation was possible, there lengths vary from 1 km to 350 km (Figure 5E and Table 18-SM). Forty percent (255) of all deviation track lengths are equal to or less than 1 km. One quarter (159) of deviation lengths measure from 2 to 9 km long, 16% (100) from 10 to 19 km long and the remaining 19% (124) deviation paths are over 20 km. The average deviation length in the Alps is 40 km, 9 km in the Jura and 7 km in the Swiss Plateau.

4.5.6 Direct damage costs

Direct damage costs include all costs directly related to the reparation of the track to guaranty the normal traffic service, including the full repair costs of the tracks only. If they are difficult or almost impossible to be assessed, direct damage costs are important in order to five a order of magnitude of the costs directly induced after a natural hazard event on a transportation track.

For the period 2012-2016, the annual direct damage costs for Swiss transportation track was estimated at EUR 3.4 million. For one event the average is EUR 19 900. For flood, it corresponds on average to EUR 8000, to EUR 47 800 for a debris flow, EUR 31700 for a landslide, EUR 33 100 for a rockfall, EUR 21 900 for an avalanche and EUR 10 200 for an “other” event (Figure 6D and Table 19-SM). “The annual costs for “total destruction” correspond to EUR 1.3 million, EUR 1.2 million for “closure” and EUR 0.8 million for “partial damage” (Figure 6E). A “small” event costs, in average, EUR 15 800, EUR 76 200 for a “medium” and EUR 175 700 for a “large” event.

Small events (95% of all events, i.e. 804 events) represent 76% (2.6 mio EUR) of the total direct costs; middle events (4%; 33) represent 15% (0.5 mio EUR) of the costs; large events (1%; 9) represent 9% (0.3 mio EUR) of costs. Roads (86% of the total transportation network length) represent 73% (2.5 mio EUR) of the total cost, while railways tracks (14% of all Swiss tracks) represent 27% (0.9 mio EUR) of all costs.

5 Discussion

5.1 Completeness of the database

The quality of the presented database is affected by several factors. The online press articles, the main source of this database, does not report all natural hazard events affecting Swiss transportation network. The reporting of such events in articles depend on the number of casualties, the severity of the injuries, the resources available in the article redaction, the preventive or educational interest, the presence of images, etc. Article occurrence is theoretically higher in summer, when the actuality is lower because the quieter political activity. In some cases, the sensitivity increases, like after the two tourists killed in Gotthard highway in 2006 while a side of the Eiger summit was collapsing, this made the journalist prone to look at no slope mass movements (RTS, 2006a and 2006b; Liniger M. and Bieri, 2006; Oppikofer et al., 2008). On the contrary, when a lot of events occur simultaneously like during intense storms, only the most significant disasters are reported in the press. The event reporting is probably depending on the perception linked to the region of occurrence. For instance, a 0.5 m^3 rock falling on a track in the plateau has more media impact than if it occurs in the Alpine area, where it is more common.

The collected events from 2012-2016 range from 60 to 269 events per year (Figure 6F and Table 20-SM). But it is biased because Google Alerts were used since May 2014. The data collection was less systematic for the years 2012 and 2013 with 60 and 99 collected events respectively. With Google Alerts the number increased to 245 and 269 for the years 2015 and 2016 respectively. In 2014, the 173 collected events, is a transitional year with about half of the year using Google Alerts. An advantage of the Google Alerts is the variety of the online from almost all the available online newspapers, which is better than unique source as for Badoux et al. (2016). Google Alerts permits mainly to improve the event collection of floods. Moreover, the total number of event increases year after year, even after the use of Google Alerts because of the increase of floods disruptions (Figure 6F). This shows that the use of Google Alerts is not fully responsible of the yearly increase of number of events. Those numbers depend strongly to the weather conditions that are different each year.

Statistical predictions about a small sample of events are intrinsically imprecise (Davies 2013). The annual cost damage by natural hazard in Switzerland (Hilker, 2009) in the period 1972-2007 shows great damages disparities over the years, because some extreme rainfall events or successive storms greatly increase the number of events collected in one year, which was not the case during our period of record.

The collected data must be considered as a photography for a period of time capturing the background composed of “small” intensity events representing 96% of the total amount of events and 76% of the total direct costs.

5.2 Event definition

The terminology of natural hazard event on road and railways is partially inappropriate, because if the origin of the direct event is natural i.e. rainfall, etc., the indirect origin is very often anthropic. Transportation network construction, use and maintenance induce seven changes or actions, potentially affecting slope stability according to the Terzaghi (1950) classification of mechanism of landslides (Jaboyedoff et al., 2016a). These causes of destabilisations are slope re-profiling, groundwater flow perturbation, surface water overland flow modifications, land degradation, inappropriate artificial structures, traffic vibration and ageing of infrastructure that modifies landslide occurrence (Larsen and Parks, 1997; Jaboyedoff et al, 2016). Furthermore, new infrastructures around tracks often induced an under-sizing of existing, which can induce concentration of the surface or ground water flow destabilizing slopes. People are thereby very often responsible for the aggravation of the hazard consequences with constructions built without the sufficient knowledge of natural hazard risk. Laimer (2017b) indicated that along Austrian railway, 72% of events are human-induced.

5.3 Events trends

Some reasons why minor and medium-sized natural hazard events are not well documented are because of their direct consequences, which are often quite rapidly fixed, i.e. the road can be re-opened within a few hours after the event or is only partially closed.

Slope angle values are lower than common values for natural hazard slopes because there are not slope angles at the event origin but at the end of the propagation, as tracks are located generally much lower than sources of propagation.

Several factors must be considered in the slope distribution. An explanation for the lower number of events on north-facing slopes is that there are less tracks on those slopes because there are less buildings on those shadowed slopes. Furthermore, north oriented slopes have less solar heat than south oriented slopes, and thereby, less freeze-thaw cycles. This can partially explain the high number of rockfall events on west, south and east oriented slopes.

This monthly distribution indicates that flood events mostly depend on two meteorological conditions: thunderstorms and long-lasting rainfalls, which occur mainly in spring, particularly with the conjunction of snowmelt, and in summer. The near absence of floods in winter is the result of the Swiss winter climate with the absence of long or brief but intense precipitations and by the fact that the precipitations in mountains fall as snow. However, exceptions are possible with floods caused by winter storms as in January 2018 (RTS, 2018). Debris flow events mostly occurred in summer as a result of powerful and stationary thunderstorms. Landslide events occurred mainly in spring as a result of long-lasting rainfalls with the melting snow, which generate many water, saturated soils and low evaporation. Snowmelt is the second trigger, after intense rainfalls, for landslides on Austrian railway tracks for the time period of 2005-2015 (Laimer, 2017b). Laimer (2017b) has shown that intense precipitations are triggers for 78% of landslides on railway tracks in Austrian during the time period of 2005-2015. Freeze-thaw cycles during the winter season are also the strong trigger for rockfalls.

Rockfalls events do not follow the trend to occur mainly in spring and summer. They occur in every season but mainly in autumn, winter and spring due to numerous freeze-thaw cycles at those seasons, which weaken the cohesion of rocks. Not surprisingly, avalanches occurred mostly in winter. They occurred also in autumn as the result of fresh avalanches on soils, which are not yet covered with snow, and non-effective winter track closures of roads in the

Alps. The total absence of avalanche events in the spring can probably be explained due to the still current road winter closures.

Flood events mostly occurred in the afternoon, probably after strong thunderstorms. Debris flow events mostly occurred in the evening, again probably after strong evening thunderstorms. Landslide event triggers are not time concentrate like the previous event processes. Rockfall events seem to be triggered during thawing which occur mostly in the morning. Snowdrifts from the “other” category began in the afternoon, after a few hours of strong wind. That is why the “other” category events are so concentrated in the afternoon. It should be noted that the time of event does not always match with the real event time, especially for events occurring during the night or on track with little traffic like country roads.

The high proportion of landslides on train tracks can be explained by the presence of soil embankments or unsuitable fill material along railway tracks and due to their grade limitations. In addition, despite more protections than the average, highways are proportionally more vulnerable than other roads because of the alignment with many imposing cuts and fills. Railway tracks, as motorways, require a balanced gradient ratio, and therefore, they must run along the valley sides over far distances. This requires long and steep cut slopes (Laimer, 2017b).

An issue related to regional tracks may be due to their lack of maintenance on track embankments during the last decades, causing landslides and rockfalls on old age infrastructure that were built long before the basics of soil mechanics (Terzaghi, 1925; Michoud et al., 2011; Laimer 2017a, 2017b).

The fact that there are more direct impacts (24) than indirect (11) impacts on roads show that drivers can generally stop their vehicles before being affected by a fallen event unlike trains that cannot be stopped on a short distance reaching the fallen mass (7 indirect impacts and one direct impact). In addition, there is a much higher probability that a vehicle on a road will be directly impacted by an event than a train on a track because road traffic is excessively denser than railways traffic.

Deviation lengths for railways are difficult to evaluate. In case of replacement buses, the distance of deviation is calculated with the distance of the replacement buses on the road. For 72 events on railways (75% of all events on train tracks), there were no possibility of deviation using other train tracks. In case of no replacement service, the deviation length for railway is the distance on train track between the two stations on both sides of the track closure. The average distance of deviation for this last configuration is 65 km.

Comparatively, annual damages caused by natural disasters in Switzerland for the time period of 1972-2011 are estimated at EUR 290 millions per year (OFEV, 2013). Switzerland allocates EUR 2.5 billions each year for protection against natural hazards, which corresponds to 0.6% of its GDP. 21% (EUR 0.5 billion) of this allocated amount concerns intervention and repair (OFEV/OFS, 2007; OFEV/OFS, 2011).

A synthetic example of an event of our database can be summarized as follow: a flood event occurs in June during an afternoon within the Swiss plateau on a small south-oriented slope and on a minor road. It generates a road closure of few hours with a deviation distance of less than one kilometre and causes no injuries or death. The possibility of road deviation is large. On the day of the event, the sun shined for half of the event day and 10 mm of rain fell (20 mm during the last 5 days and 35 mm during the last 10 days) and the average temperature during the event was 20°C. There have been about 1000 lightings around the event location on the event day and the wind speed was 7 km/h blowing a north-east.

5.4 Direct damage cost estimation

Direct damage costs include all costs directly related to the rehabilitation of the track to guaranty the traffic service. All repair costs of the tracks are included. The estimated direct costs did not take into account indirect costs like vehicle repairs (a train repair costs a lot), implementation of deviations, replacement buses in case of railway closure, all costs generated due to the traffic restriction for road and railway users, as well as all mitigation works and protective measures.

Estimation of direct damage costs depend on many factors that are difficult to estimate. The hour has an impact on the cost: repair works during the night or the weekend are greater than office hours. The event location affects the costs too: costs in an alpine valley far away from any construction companies are higher than works in an agglomeration where construction machines and landfill for the excavated material are close to. The date has also an impact on the costs: an event occurring during a time period where weather conditions are difficult will last longer. The emergency of the situation has also an influence on the direct cost: damage on a secondary road or a highway will be treated with a different emergency level. We can also notice the influence of the traffic, the presence of damaged retaining walls and protective measures, the slope angle, the financial situation of the responsible administration for the repair works, necessity of work in the slope or the cliff above the track, etc. Works on railways cost more than roads because the access is often more difficult and because contact line and rails repairs can become very quickly expensive. All those factors can easily vary costs by plus or minus 50%.

An estimation of the direct costs of the “small” events is more credible than the costs of events of greater damage, because the main work is to release the road from fallen materials. Costs estimation for the “middle” events and especially for “larges” ones is more complicated because the repairs require large construction sites which have their own characteristics that can not be compared.

The estimated costs must be considered as order of magnitude of the direct costs generated by natural hazard events on the Swiss transportation network. However, obtained results are more refined than the previous study of Voumard et al. (2016), where costs of event below EUR 8500 were not considered.

5.5 General discussion about natural hazard and transportation networks

Several methods exist to quantify the costs of track closures (Nicholson, 1997; Erath 2009), but they are not satisfactory because of the quantification of costs, especially indirect costs are difficult to calculate, and the resilience must be carefully considered since people often find solutions to skirt the track closure (deferred travel, meeting realized with digital technologies, alternative sources of supply, etc.). The closure costs due to natural hazards, such as traffic jam costs, are not compensated in Switzerland, but models must include the potential loss of income by taxes if the economy of the region is slow down. In addition, there are several ways to replace a transportation route or means. For example, train can be replaced by buses between two stations. Using other train routes can be very complicated and long. For road deviation, they are usually much easier; however, in some valleys in the Alps, deviation lengths can reach more than hundreds of km and sometimes, it is even impossible. It must be noted that the increase of the travel duration in case of railway closures is more relevant for passengers than the distance of deviation itself. Davies (2013) puts back the importance of the event in the context of the affected person. A minor landslide that affect a person is completely unworthy of notice to the vast majority of the population, but is also momentary considered as catastrophic for the person that must reconsider its travel and find an alternative route or even cancel its displacement.

Information acquisition is challenging and hard for such database, because it depends on several people working in field like road menders, railway maintenance workers and forestry workers, who have sometimes no time or little interest to fill the relevant database fields. Hence, there are possible improvements of database quality by using new tools such as off-line collaborative web-GIS (Balram, 2006; Pirotti et al., 2011; Aye et al. 2016; Olyazadeh et al., 2017) that can facilitate the event collection in field.

The collection of the natural hazard events affecting roads and railways can be improved using different communication channels such as Facebook page of the Colorado Department of Transport (CDT) in United States. This diffusion channel allows the CDT to highlight all natural hazard events that affect roads in the Colorado department, allowing to sensitize drivers of their travel impacts.

6 Conclusion and perspectives

Using newspapers and Google Alerts, natural hazard events that have affected the Swiss transportation network from 2012 to 2016 were collected. Collected 846 natural hazard events were characterized by 172 attributes, which makes it unique for Switzerland (Table 1). Our results highlight the impact of natural hazard on the Swiss roads and railways, especially for small events with volume of less than 10 m^3 that are rarely or not collected. They represent 95% of the database events. The direct costs of all events were estimated at EUR 3.4 million per year with an average cost per event at EUR 19 900. Direct costs of small events were estimated at EUR 2.5 million by year, which represents three quarter of the total direct costs.

Because of heavy storms, densification of the infrastructures, traffic increase and lack of funding for track maintenance, we could expect more natural events affecting the Swiss transportation networks. As usual, the key to reduce the natural hazard risk on tracks is obviously financing.

The presented database and its event analysis can be helpful for the decision makers at the three Swiss politic levels (the Confederation, the cantons and the municipalities) to plan and to enforce protective measures in case of observable hot spots in the database.

Risk management in Switzerland may therefore be improved with such a database. For examples, it shows the important alternative ways to bypass the obstacles. We have highlighted that for one quarter of events, there were no deviation routes. This proportion is high and must be reconsidered by the authorities. It is evident that to protect all swiss tracks against natural hazard processes would me much to expensive. Thus, it is essential to guaranty alternative tracks and to fund protective measures with the best ratio cost / risk reduction. Minor roads often belong to the municipalities which does not have a great interest to maintain them. The Cantons and the Confederation would be advised to participate or even to take over the maintenance of some of them that can be vital in case of closure of main roads or railway tracks. This is particularly appropriate in transportation corridor when the minor road is located on the other valley side than the major road. With its national scale, this database helps to consider the risk of transportation networks tracks more from a network perspective than from a track scale.

For this purpose, we created open access online maps of the events in Google Maps and ArcGIS Online (Figure 5-SM-AA and Figure 6-SM-AA) in order to promote the problematic issue. Our analysis also useful to take notice of the real impacts of known little intensity events that can be considered as almost insignificant and that are generally largely unrecognized.

Data availability

Date used in this paper are available on demand.

Competing interests.

The authors declare that they have no conflict of interest.

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Supplementary Material

Table 1-SM: 51 key words (in red) used in the Google Alerts to create the database. Numbers between brackets in the following tables refer to the number of considered elements according to the line or column attribute.

English	French	German	Italian
avalanche	avalanche	Lawinne	valanga
bad weather	intempéries	Unwetter	
flood		Hochwasser	
hail	grêle	Hagel	
heavy rainfall	forte pluies	Heftige Regen	
ice avalanche		Eislawine	
inundation		Überflutung	
inundation	inondation	Überschwemmung	
landslide	glissement de terrain	Erdrutsch	frana
landslide		Hangrutsch	
landslide		Hachrutsche	
landslide		Rüfenniedergang	
landslip	glissement	Rutschung	
mountain	pan de montagne		
mud	boue	Schlamm	
mudflow	coulée de boue	Schlammlawine	
mudslide		Erdlawine	
pirock	caillou	Stein	massi
rockfall		Bergsturz	
rockfall		Felsabbruch	
rockfall	éboulement	Felsbrock	
rockfall	écroulement	Felsbrocken	
rockfall		Felssturz	
rockslide	chute de blocs	Steinschlag	cadono sassi
scree		Geröll	
scree	éboulis	Schutt	
storm	tempête	Sturm	
thunderstorm	orage	Gewitter	
under water	sous l'eau		
wine	vent	Wind	

Table 2-SM: Cost values estimation by square meter for the cost evaluation according event importance, damage level and transport mode.

Damage level [EUR]	Cost by m^2, small event, road	Cost by m^2, middle event, road	Cost by m^2, large event, road	Cost by m^2, small event, train	Cost by m^2, middle event, train	Cost by m^2, large event, train
No closure	5	5	5	5	5	5
Closure	85	130	170	300	340	385
Partial damage	255	300	340	470	510	555
Total destruction	850	890	980	1065	1105	1145
Unknown damage	130	170	215	255	300	340

Table 3-SM: Distribution of event location according the three Swiss geomorphologic-climatic regions and according event processes.

Geomorphologic-climatic region	Flood (420)	Debris flow (69)	Landslide (192)	Rockfall (96)	Avalanche (16)	Other (53)	Average
Jura (98)	19%	0%	3%	6%	0%	15%	12%
Swiss Plateau (371)	57%	4%	42%	6%	0%	79%	44%
Alps (377)	24%	96%	55%	88%	100%	6%	44%
Total (846)	100%	100%	100%	100%	100%	100%	100%

Table 4-SM: Distribution of event location according event processes.

Event location	Flood (420)	Debris flow (69)	Landslide (192)	Rockfall (96)	Avalanche (16)	Other (53)	Average
Town (151)	15%	0%	9%	1%	0%	6%	18%
Village (261)	46%	14%	12%	6%	13%	4%	31%
Forest (185)	4%	46%	38%	58%	13%	13%	22%
Unforest (249)	0%	6%	5%	12%	69%	0%	29%
Total (846)	100%	100%	100%	100%	100%	100%	100%

Table 5-SM: Distribution of slope angle according event processes.

Slope angle	Flood (420)	Debris flow (69)	Landslide (192)	Rockfall (96)	Avalanche (16)	Other (53)	Average
0°-10° (339)	62%	17%	12%	5%	6%	68%	40%
10°-20° (257)	31%	43%	29%	19%	38%	28%	30%
20°-30° (131)	4%	23%	33%	31%	38%	2%	15%
30°-40° (85)	2%	12%	21%	26%	19%	0%	10%
40°-50° (26)	0%	4%	4%	14%	0%	2%	3%
50°-60° (6)	0%	0%	1%	4%	0%	0%	1%
60 and more (2)	0%	0%	1%	1%	0%	0%	0%
Total (846)	100%	100%	100%	100%	100%	100%	100%

Table 6-SM: Distribution of events importance according event processes.

Location of process origin	Flood (420)	Debris flow (69)	Landslide (192)	Rockfall (96)	Avalanche (16)	Other (53)	Average
Small[1] (804)	100%	78%	96%	24%	81%	100%	95%
Middle[2] (33)	0%	19%	3%	43%	19%	0%	4%
Large[3] (9)	0%	3%	1%	33%	0%	0%	1%
Total (846)	100%	100%	100%	100%	100%	100%	100%

[1] Small event: volume <10 m^3.
[2] Middle event: volume between 10-2000 m^3.
[3] Large event: volume > 2000 m^3.

Table 7-SM: Distribution of distances of the process origin types processes according event processes.

Distance of the process origin	Debris flow (69)	Landslide (192)	Rockfall (96)	Avalanche (16)	Other (53)	Average
Near[1] (185)	0%	52%	33%	6%	100%	35%
Far[2] (146)	100%	11%	43%	94%	0%	39%
Unknown (95)	0%	37%	24%	0%	0%	26%
Total (426)	100%	100%	100%	100%	100%	100%

[1] Near: 0-50 m from the track.
[2] Far: > 50 m from the track.

Table 8-SM: Distribution of location of process origin according event processes.

Location of process origin	Debris flow (69)	Landslide (192)	Rockfall (96)	Avalanche (16)	Other (53)	Average
Above track (339)	100%	60%	89%	100%	100%	80%
Below track (29)	0%	14%	2%	0%	0%	7%
Unknown (58)	0%	26%	9%	0%	0%	14%
Total (426)	100%	100%	100%	100%	100%	100%

Table 9-SM: Rainfall [mm] during the natural hazard events.

Rainfall* [mm]	Flood	Debris flow	Landslide	Rockfall	Avalanche	Other	Average
Event day	22	14	17	5	4	4	17
Cum. last 5 days[1]	49	32	57	27	32	15	45
Cum. last 10 days[1]	76	55	88	52	46	36	71
Daily rain avg last 5 days[2]	10	6	11	6	6	3	9
Daily rain avg last 10 days[2]	7	5	9	5	5	4	7
Max daily rain last 5 days[3]	30	21	32	15	18	11	27
Max daily rain last 10 days[3]	33	26	36	20	21	15	30
Abs max daily rain[4]	100	65	154	42	13	39	-
Abs max daily rain last 5 days[4]	154	75	154	77	140	39	-
Abs max daily rain last 10 days[4]	154	75	154	109	140	39	-

* Average by event processes except for absolute values (last three lines of the table).
[1] Cumulative rainfall of the 5 and respectively 10 days ago from the event day.
[2] Daily rainfall average of the 5 and respectively 10 days ago from the event day.
[3] Maximum daily rainfall of the 5 and respectively 10 days from the event day.
[4] Absolute maximum rainfall recorded (i.e. for one event) of the event day, the 5 and respectively 10 days from the event day.

Table 10-SM: Monthly distribution of events according event processes.

Year	Flood (420)	Debris flow (69)	Landslide (192)	Rockfall (96)	Avalanche (16)	Other (53)	Average
January (27)	0%	4%	4%	15%	6%	0%	3%
February (65)	0%	1%	6%	6%	19%	81%	8%
March (26)	1%	0%	2%	13%	50%	2%	3%
April (28)	2%	0%	6%	7%	0%	2%	3%
May (107)	13%	10%	16%	15%	0%	2%	13%
June (253)	41%	16%	29%	7%	0%	8%	30%
July (210)	31%	51%	19%	8%	0%	2%	25%
August (35)	4%	12%	4%	1%	0%	2%	4%
September (14)	1%	6%	2%	2%	0%	0%	2%
October (14)	1%	0%	1%	10%	0%	0%	2%
November (58)	6%	0%	9%	11%	6%	2%	7%
December (9)	0%	0%	1%	4%	19%	0%	1%
Total (846)	100%	100%	100%	100%	100%	100%	100%

Table 11-SM: Distribution of transport mode according event processes.

Transport mode	Flood (420)	Debris flow (69)	Landslide (192)	Rockfall (96)	Avalanche (16)	Other (53)	Total
Road (747)	53%	9%	20%	10%	1%	7%	100%
Railway (99)	27%	2%	42%	20%	4%	5%	100%

Table 12-SM: Distribution of road classes according event processes.

Road classes	Flood (393)	Debris flow (67)	Landslide (151)	Rockfall (76)	Avalanche (12)	Other (48)	Average
Highway (34)	7%	0%	2%	1%	10%	2%	5%
Motorway (2)	0%	0%	1%	0%	0%	0%	0%
Major transit road (99)	11%	8%	11%	36%	36%	6%	13%
Regional road (94)	11%	7%	18%	18%	9%	8%	12%
Urban road (426)	65%	37%	48%	38%	36%	82%	57%
Minor road (72)	4%	42%	15%	4%	9%	2%	10%
Forest or land trail (20)	2%	6%	5%	5%	0%	0%	3%
Total (747)	100%	100%	100%	100%	100%	100%	100%

Table 13-SM: Distribution of railway classes according event processes.

Track class	Flood (27)	Debris flow (2)	Landslide (41)	Rockfall (20)	Avalanche (4)	Other (5)	Average
National (29)	37%	0%	32%	30%	0%	0%	29%
Regional (66)	56%	100%	68%	70%	100%	60%	67%
Tram (4)	7%	0%	0%	0%	0%	40%	4%
Total (99)	100%	100%	100%	100%	100%	100%	100%

Table 14-SM: Distribution of possibility of deviations according event processes.

Possibility of deviation	Flood (420)	Debris flow (69)	Landslide (192)	Rockfall (96)	Avalanche (16)	Other (53)	Total
Large (342)	63%	17%	15%	8%	0%	52%	40%
Middle (190)	21%	7%	32%	17%	7%	33%	23%
Small (102)	7%	6%	13%	32%	66%	4%	12%
No (212)	9%	70%	40%	43%	27%	11%	25%
Total (846)	100%	100%	100%	100%	100%	100%	100%

Table 15-SM: Distribution of track damage according event processes.

Damage level	Flood (420)	Debris flow (69)	Landslide (192)	Rockfall (96)	Avalanche (16)	Other (53)	Total
No closure (149)	34%	0%	1%	3%	6%	4%	18%
Closure (483)	60%	35%	50%	50%	81%	96%	57%
Partial damage (143)	1%	39%	37%	39%	13%	0%	17%
Total destruction (53)	1%	26%	12%	8%	0%	0%	6%
Unknown damage (18)	4%	0%	0%	0%	0%	0%	2%
Total (846)	100%	100%	100%	100%	100%	100%	100%

Table 16-SM: Distribution of damage and impact on vehicle according event processes.

Damage and impact type on vehicle	Flood (420)	Debris flow (69)	Landslide (192)	Rockfall (96)	Avalanche (16)	Other (53)	Total
No damage (803)	98%	93%	96%	89%	80%	89%	95%
Vehicle damage: direct impact[1] (25)	1%	7%	1%	7%	7%	7%	3%
Vehicle damage: indirect impact[2] (18)	1%	0%	3%	4%	13%	4%	2%
Total (846)	100%	100%	100%	100%	100%	100%	100%

[1] Direct impact: a vehicle is directly reach by a hazard.
[2] Indirect impact: a vehicle collides an event mass already fallen on the track.

Table 17-SM: Distribution of injury and death importance according event processes.

Injury and death	Flood (420)	Debris flow (69)	Landslide (192)	Rockfall (96)	Avalanche (16)	Other (53)	Total
No damage on people (828)	99%	96%	98%	93%	100%	98%	98%
Injury (15)	1%	4%	1%	5%	0%	2%	2%
Death (3)	0%	0%	1%	2%	0%	0%	0%
Total (846)	100%	100%	100%	100%	100%	100%	100%

Table 18-SM: Distribution of deviation length on roads according event processes.

Deviation length	Flood (383)	Debris flow (21)	Landslide (116)	Rockfall (58)	Avalanche (11)	Other (49)	Mean
0-1 km (255)	58%	29%	12%	9%	0%	12%	40%
2-5 km (102)	14%	38%	16%	3%	0%	39%	16%
6-9 km (57)	9%	10%	9%	7%	0%	14%	9%
10-19 km (100)	9%	5%	34%	21%	0%	22%	16%
20-49 km (63)	5%	0%	17%	26%	45%	8%	10%
50-99 km (24)	3%	5%	5%	12%	0%	0%	4%
100-249 km (30)	2%	14%	6%	17%	18%	4%	5%
250-350 km (7)	0%	0%	0%	5%	36%	0%	1%
Total (638)	100%	100%	100%	100%	100%	100%	100%

Table 19-SM: Direct damage costs distribution according events types.

Damage level [EUR]	Flood (420)	Debris flow (69)	Landslide (192)	Rockfall (96)	Avalanche (16)	Other (53)	Total
	Annual cost [EUR]						
No closure (149)	12 665	340	85	765	255	170	14 280
Closure (483)	514 250	71 400	262 650	160 650	28 900	107 950	1 145 800
Partial damage (143)	25 500	127 500	425 000	227 800	40 800	0	846 600
Total destruction (53)	72 250	459 850	528 700	246 500	0	0	1 307 300
Unknown damage (18)	45 900	0	0	0	0	0	45 900
Annual cost [million €]	0.67	0.66	1.22	0.64	0.07	0.11	3.36
Avg. cost by event	8 000	47 800	31 700	33 100	21 900	10 200	19 900

Table 20-SM: Annually distribution of events according event processes.

Year	Flood (420)	Debris flow (69)	Landslide (192)	Rockfall (96)	Avalanche (16)	Other (53)	Average
2012 (60)	5%	3%	7%	17%	25%	2%	7%
2013 (99)	11%	10%	16%	14%	6%	2%	12%
2014 (173)	20%	10%	30%	20%	25%	0%	20%
2015 (245)	25%	49%	22%	17%	25%	77%	29%
2016 (269)	38%	28%	24%	33%	19%	19%	32%
Total (846)	100%	100%	100%	100%	100%	100%	100%

Table 21-SM: Summary of event processes key features.

Attribute (with values of the greatest occurrence)	Flood	Debris flow	Landslide	Rockfall	Avalanche	Other	Mean
Event importance	Small	Small	Small	Small	Small	Small	Small
Yearly number of events	84	14	38	19	3	11	169
Months	6, 7	7, 6	6, 7, 5	1, 5, 3, 11, 10	3	2	6, 7
Season	Spring	Summer	Spring	Spring, Winter	Winter	Winter	Spring
Day part	Afternoon	Afternoon	All day	All day	Morning	All day	Afternoon
Hour	12-19	15-19	0-24	0-24	8-13	0-24	14-19
Region	Plateau	Alps	Alps	Alps	Alps	Plateau	Alps, Plateau
Canton	Bern	Graubünden	Valais	Valais	Valais	Vaud	Bern
Slope angle	0-10	10-20	20-30	20-30	10-20	0-10	0-10
Slope orientation	S	W	S	W	N-W	S-E	S, S-W and W
Location	Village	Forest	Forest	Forest	Mountain	Country	Village
Damage on track	Closure	Partial dam.	Closure	Closure	Closure	Closure	Closure
Direct costs by event (Euro)	6 900	39 000	25 700	261 000	155 000	8 600	16 000
Track geometry	Str. line	Wide curve	Wide curve	Wide curve	Wide curve	S. line & w. curve	Wide curve
Crossing	Near	No	No	No	No	No	No
Closure duration	3 hours	1 week	1 day	3 hours	1-2 days	3 hours	3 hours
Possibility of deviation	Large	No	No	No	Small	Middle	Large
Deviation length	0-1 km	No deviation	No deviation	No deviation	250-350 km	2-5 km	0-1 km
Event origin distance	-	Far	Near	Far	Far	Near	Near
Event above bellow	-	Up	Up	Up	Up	Up	Up
Altitude [m a.s.l.]	525	1139	809	897	1274	614	701
Track type	Road	Road	Road	Road	Road	Road	Road
Track importance	Minor	Minor	Minor	Minor	Minor	Minor	Minor
Rainfall event day [mm]	22	14	171	5	4	4	17

Figure 1-SM: Attributes of the database.

Attributes of the UNIL database of natural hazard events affecting the Swiss transportation network (2012-2016) Number of attributes: 172

	EventID	**Date**	Number of attributes: 15													
Category		DATE														
Attribute	EventID	D_IDdate	D_Year	D_Month	D_Day	D_MonthWeek	D_DayName	D_Season	D_Hour	D_HourPrecise	D_DayPart	D_IDDay	D_IDEventSameDay	D_SameClimLongPeriod	D_SameClimShortPeriod	MuenichRe
Description	Unique ID for each event	Unique ID for each event containing the date	Year of the event	Month of the event	Day of the event	Month divided into 4 quarters	Name of the day of the event	Season of the event	Hour of the event hourly rounded	Hour of the event	Day part of the event	Unique ID for each event day (same ID when >1 event per day)	Unique ID for event occured the same day	Long time period in which the event is included	Short time period in which the event is included	Period given by MünichRe in which the event is included
Unit	-	y m d XX	year	month	day	-	-	-	h:m:s	h:m:s	-	y m d	-	y.m.d-y.m.d	y.m.d-y.m.d	y.m.d-y.m.d
Exemple	431	2015050400	2015	5	4	5-1	Monday	Spring	10:00:00	10:15:00	Morning	20150504	2	2015.04.27-2015.07.25	2015.04.27-2015.05.07	2014.06.03-2014.06.12
Comment	-	-	From 2011 to 2015	-	-	First quarter (1) of the 5th month (5)	Useful to categorise business day and weekend	-	-		5 parts: morning, afternoon, evening, night and unknown	Allow to recognise the day when with several events	The maximal ID by event day gives the nb of events during this day			From MuenichRe yearly natural catastrophes analysis
Source	-	-	Online article	Online article	Online article	Online article	Online article	Online article	Online article	Online article	Online article	-	-	-	-	MünichRe
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

	Location	Number of attributes: 21								
Category										
Attribute	L_Canton	L_Commune	L_Detail	L_Precision	L_SitGeo	L_OriSlope	L_Urbanity	L_Slope	L_SlopeRound	L_Lanscape
Description	Canton where occurs the event	Commune where occurs the event	Detail to help the location	Precision of the location	Geographical situation of the event	If slope: orientation of the slope	Urbanity of the event	Slope angle average in an 25 meter radius around the event	Slope angle rounded to the nearest ten	Lanscape of the event locaiotn
Unit	-	-	-	-	-	-	-	[°]	[°]	
Exemple	Valais	Bagnes	-	Accurate	Slope	North-East	Forest	13	13	Dry mountainous landscape of western central Alps
Comment	-	-	-	Three levels of accuracy: accurate, middle and communal accuracy	Four classes: plain, ridge, slope and valley bottom	Nine classes: north, north-east, south-east, south, south-west, west, noth-west and any slope	Seven classes: mountain, forest, country, hamlet, village, agglomeration and town	From 0 ° to 56°	From 0 ° to 60°	36 types
Source	Online article	Online article	Online article	Online article and map	Map	Map	Map	GIS	GIS	GIS
	17	18	19	20	21	22	23	24	25	26

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LOCATION										
L_Areas	L_Area_reg	L_MN03_X	L_MN03_Y	L_MN03_Z	L_MN95_X	L_MN95_Y	L_MN95_Z	L_WGS84_Lo	L_WGS84_La	L_WGS84_Z
Areas of the event location	Regional area of the location	X coordinates in CH1903 coordinate system	Y coordinates in CH1903 coordinate system	Z coordinates in CH1903 coordinate system	X coordinates in CH1903+ coordinate system	Y coordinates in CH1903+ coordinate system	Z coordinates in CH1903+ coordinate system	Longitude in WGS84 coordinate system	Latitude in WGS84 coordinate system	ALtitude in WGS84 coordinate system
		[m]	[m]	[m]	[m]	[m]	[m]	[°]	[°]	[m]
Alpine region	Alps	588456	98247	1377	2588455	1098247	1377	7.289538659	46.03566307	1431
5 types: Alpine region, Swiss Plateau, Tabular Jura, Folded Jura and Independent	3 types: Jura, Plateau and Alps	-	-	-	-	-	-	-	-	-
GIS	Map	GIS	GIS	GIS	GIS	GIS	GIS	GIS	GIS	GIS
27	28	29	30	31	32	33	34	35	36	37

Event characterization Number of attributes: 12

Category	Event characterization											
Attribute	E_Type	E_TypePrec	E_UpDownst	E_UpDownst Risk	E_Provenan	E_Volume	E_Masse	E_Width	E_Importan	E_Other	E_PictureName	E_Picture
Description	Type of natural hazard event	Precise type of natural hazard event	Origin up or downstream of the natural hazard event	Origin up, downstream or only risk of the event	Estimation of the distance of the event origin	Volume of the event	Masse of the event	Width of the event mass on the track	Importance of the event	Other information	Picture name of the event	Picture
Unit	-	-	-	-	[m] or -	[m^3]	[kg]	[m]	-	-	-	-
Exemple	Landslide	Landslide	-	-	-	-	-	-	Small	-	2015050400.jpg	-
Comment	6 types: rockfall, debris flow, landslide, avalanche, flood, other	8 types: rockfall, debris flow, landslide, avalanche, flood, hail, snowdrift, falling tree	3 classes: upstream, downstream and unknown	4 classes: upstream, downstream, risk (no event, only preventive closure) and unknown	3 classes: near (few meters to 10 meters, far (> 10 m) or prevention (only proventive closure)	Estimation of the falled volume on the track of the event	Masse of the event (only for rockfall)	-	3 classes: small, middle, big (huge event)	-	-	-
Source	Online article	Online article	Online article	Online article	Online article	Online article	Online article	Online article	Online article	Online article	Online article	Online article or field visit
	38	39	40	41	42	43	44	45	46	47	48	49

Track caracterization Number of attributes: 17

Category	Track caracterization																
Attribute	T_Type	T_TrainClasses	T_RoadClasses	T_MajorMin	T_Closure	T_DetailClosure	T_ClosureDuration	T_ClosureDurationRound	T_Deviation	T_DistDev	T_DistDevRound	T_DevDetai	T_PossDevi	T_PopDirAf	T_PopIndAf	T_Sinuosity	T_crossing
Description	Distinction between road and railway	Classes of the affected train tracks	Classes of the affected road tracks	Simplified classification of track importance	Track closure or not	Detail of the track closure	Time of track closure in hours	Ronded time of track closure in hours	Deviation or not	Distance of the deviation path	Rounded distance of the deviation path	Deviation detail	Capacity to have other deviation paths	Population directly affected by the track closure	Population indirectly affected by the track closure	Sinuosity og the affected track	Crossing near of the event or not
Unit	-	-	-	-	-	-	[h]	[h]	-	[km]	[km]	-	-	-	-	-	-
Exemple	Road	White	White	Minor	Yes	-	23	24	-	8	10	-	Large	Any	Small	NSC	NO
Comment	2 types: road or railwa	3 classes: national, regional, tram	8classes: highway, semi-highway, red, yellow, white, white dash and black	2 classes: minor and major	Three classes: yes, no, unknown	-	-	-	2 classes: yes or no	-	-	-	4 classes: large, middle, small, any	5 classes: very large, large, middle, small, any	5 classes: very large, large, middle, small, any	6 types: Straight Line, Wide Curve, Tight Curve, Near Wide Curve, Near Tight Curve	4 types: IN a crossing, NEAR a crossing, NO crossinf in the area and unknown (not enough location accuravy
Source	Online article	Map	Map	Map	Online article	Online article	Online article	Online article	Map	Map	Map	Map	Map	Map	Map	Map	Map
	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66

Damage Number of attributes: 11

Category	Damage										
Attribute	D_Form	D_Injured	D_InjuredNb	D_Death	D_DeathNb	D_Vehicule	D_ImpactTy	D_VehiType	D_VehiNb	D_TrackDetail	D_Infras_type
Description	Form of track damage	Injured people?	Number of injured people	Killed people?	Number of killed people	Damage to vehicle	Type of impact between vehicle and event	Type of damaged vehicle	Number of damaged vehicle	Detail of track damage	Type of instrastructure damage
Unit	-	-	-	-	-	-	-	-	-		-
Exemple	?	No	-	No	-	No	-	-	-		-
Comment	6 classes: ? (unknown), NC (no closure), C (closure due to sedimentation), P (partial damage), T (total destruction), and not studied	2 types: yes or no	-	2 types: yes or no	-	2 types: yes or no	Three types: no impact, direct impact or indirect impact	-	-		-
Source	Online article	Online article	Online article	Online article	Online article	Online article	Online article	Online article	Online article		Online article
	67	68	69	70	71	72	73	74	75	76	77

Weather Number of attributes: 68

Category																			
Attribute	M_Meteo	M_Sun	M_Sun_avg_5d	M_Sun_avg_10d	M_Sun_max_5d	M_Sun_max_10d	M_Sun_min_5d	M_Sun_min_10d	M_Rain	M_Rain_5d_cum	M_Rain_10d_cum	M_Rain_max_daily_5d	M_Rain_max_daily_10d	M_Rain_avg_daily_5d	M_Rain_avg_daily_10d	M_Storm_near	M_Storm_near_sum_5d	M_Storm_near_sum_10d	M_Strom_near_max_daily_5d
Description	Rain information for a given time period	Percentage of sun during the event day	Percentage of sun of the last 5 days from event	Percentage of sun of the last 10 days from event	Maximum percentage of sun of the last 5 days from event	Maximum percentage of sun of the last 10 days from event	Minimum percentage of sun of the last 5 days from event	Miximum percentage of sun of the last 10 days from event	Rain the event day	Cumulative rain of the last 5 days from event	Cumulative rain of the last 10 days from event	Maximum daily rain of the last 5 days from event	Maximum daily rain of the last 10 days from event	Average daily rain of the last 5 days from event	Average daily rain of the last 10 days from event	Number of near storms the event day	Number of near storms of the 5 days days from event	Number of near storms of the 10 days days from event	Maximum daily number of near storms of the 5 days from event
Unit		%	%	%	%	%	%	%	mm	mm	mm	mm	mm	mm	mm	-	-	-	-
Exemple	-	4	29.4	34.1	77	98	0	0	0.2	28.7	38.4	19.9	19.9	5.74	3.84	0	0	0	0
Comment	Only for som events	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Near storm: <3 km around the weather station	Near storm: <3 km around the weather station	Near storm: <3 km around the weather station	Near storm: <3 km around the weather station
Source	Sturmarchiv	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss
	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96

Weather

M_Strom_near_max_daily_5d	M_Strom_near_max_daily_10d	M_Storm_far	M_Storm_far_sum_5d	M_Storm_far_sum_10d	M_Strom_far_max_daily_5d	M_Strom_far_max_daily_10d	M_Storm_all	M_Storm_all_sum_5d	M_Storm_all_sum_10d	M_Strom_all_max_daily_5d	M_Strom_all_max_daily_10d	M_Temp_min	M_Temp_min_5d	M_Temp_min_10d	M_Temp_max	M_Temp_max_5d	M_Temp_max_10d	M_Temp_avg	M_Temp_avg_5d
Maximum daily number of near storms of the 5 days from event	Maximum daily number of near storms of the 10 days from event	Number of far storms the event day	Number of far storms of the 5 days days from event	Number of far storms of the 10 days days from event	Maximum daily number of far storms of the 5 days from event	Maximum daily number of far storms of the 10 days from event	Number of all storms the event day	Number of all storms of the 5 days days from event	Number of all storms of the 10 days days from event	Maximum daily number of allstorms of the 5 days from event	Maximum daily number of all storms of the 10 days from event	Minimum temperature the event day	Minimum temperature the last 5 days from event	Minimum temperature the last 10 days from event	Maximum temperature the event day	Maximum temperature the last 5 days from event	Maximum temperature the last 10 days from event	Average temperature the event day	Average temperature the last 5 days from event
-	-	-	-	-	-	-	-	-	-	-	-	[°C]	[°C]	[°C]	[°C]	[°C]	[°C]	[°C]	[°C]
0	0	0	0	2	0	1	2	3	10	1	5	7	1	-3	14	14	15	10	7
Near storm: <3 km around the weather station	Near storm: <3 km around the weather station	Far storm: >3 km around the weather station	Far storm: >3 km around the weather station	Far storm: >3 km around the weather station	Far storm: >3 km around the weather station	Far storm: >3 km around the weather station	-	-	-	-	-	-	-	-	-	-	-	-	-
MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss
96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115

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M_Temp_avg_10d	M_Temp_min_Corr	M_Temp_min_5d_Corr	M_Temp_min_10d_Corr	M_Temp_max_Corr	M_Temp_max_5d_Corr	M_Temp_max_10d_Corr	M_Temp_avg_Corr	M_Temp_avg_5d_Corr	M_Temp_avg_10d_Corr	M_Temp_amp_Corr	M_Temp_amp_5d_Corr	M_Temp_amp_10d_Corr	M_Wind_avg
Average temperature the last 10 days from event	Corrected minimum temperature the event day	Corrected minimum temperature the last 5 days from event	Corrected minimum temperature the last 10 days from event	Corrected maximum temperature the event day	Corrected maximum temperature the last 5 days from event	Corrected maximum temperature the last 10 days from event	Corrected average temperature the event day	Corrected average temperature the last 5 days from event	Corrected average temperature the last 10 days from event	Ttemperature amplitude the event day	Temperature amplitude the last 10 days from the event	Temperature amplitude the last 5 days from the event	Average wind speed the event day
[°C]	[°C]	[°C]	[°C]	[°C]	[°C]	[°C]	[°C]	[°C]	[°C]	[°C]	[°C]	[°C]	[km/h]
7	9	3	-1	16	16	17	12	9	9	9	12	15	8
-	Correction with height difference bewteen weather station and event location with lapse rate of -0.65 °C for + 100m altitude	Correction with height difference bewteen weather station and event location with lapse rate of -0.65 °C for + 100m altitude	Correction with height difference bewteen weather station and event location with lapse rate of -0.65 °C for + 100m altitude	Correction with height difference bewteen weather station and event location with lapse rate of -0.65 °C for + 100m altitude	Correction with height difference bewteen weather station and event location with lapse rate of -0.65 °C for + 100m altitude	Correction with height difference bewteen weather station and event location with lapse rate of -0.65 °C for + 100m altitude	Correction with height difference bewteen weather station and event location with lapse rate of -0.65 °C for + 100m altitude	Correction with height difference bewteen weather station and event location with lapse rate of -0.65 °C for + 100m altitude	Correction with height difference bewteen weather station and event location with lapse rate of -0.65 °C for + 100m altitude	-	-	-	-
MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss
116	117	118	119	120	121	122	123	124	125	126	127	128	129

M_Wind_avg_5d	M_Win_avg_10d	M_Wind_max	M_Wind_max_5d	M_Wind_max_10d	M_Wind_dir	M_Win_dir_5d	M_Win_dir_10d	M_Snow	M_Fresh_snow	M_Fresh_snow_5d	M_Fresh_snow_10d	M_Accronym_Stn_Weath	M_Alt_Stn_Weath	M_Diff_Alt_Stn_Weath_Event	M_Dist_Stn_Weath
Average wind speed the 5 last days from event	Average wind speed the last 10 days from event	Maximum wind speed the event day	Maximum wind speed the 5 last days from event	Maximum wind speed the last 10 days from event	Average wind direction the event day	Average wind direction the last 5 days from event	Average wind direction the last 10 days from event	Snow cover height the event day	Fresh snow cover height the event day	Fresh snow cover height the 5 last days from event	Fresh snow cover height the 5 last days from event	Accronym of the used weather station	Altitude of the used weather station	Altitude difference between the weather station and the even location	Distance between the weather station and the even location
[km/h]	[km/h]	[km/h]	[km/h]	[km/h]	[°]	[°]	[°]	[cm]	[cm]	[cm]	[cm]	-	[m] a.s.l.	[m]	[km]
9	10	32	38	46	47	48	63.9	0	0	0	0	ZER	1638	-261	36
-	-	-	-	-	0° = North, 90° = East, 180° = South, 270° = West	0° = North, 90° = East, 180° = South, 270° = West	0° = North, 90° = East, 180° = South, 270° = West	-	-	-	-	-	-	-	-
MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss
130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145

Geology Number of attributes: 11

Category	Geology										
Attribute	G_watershed	G_Geol	G_Tecto_f	G_Geol_f	G_Tec1_f	G_Tec2_f	G_Tec3_f	G_Acquifer	G_Hydrogeology	G_Productivity	G_Geology
Description	Watershed on the event			Geology	Tectonic 1	Tectonic 2	Tectonic 3	Aquifer	Hydrogeology	Productivity of the event field	General geology
Unit	-	-	-	-	-	-	-	-	-	-	-
Exemple	RHONE	er	pi	Gneiss et micaschistes (y compris migmatites et phyllites; princ. metasediments)	Nappes de socle cristallin penniques moyennes	Nappe du Mont-Fort	-	Aquifer reservoirs in coherent rocks	Sparsely productive aquifer reservoirs in non-karstified, cracked and porous coherent rocks	Variable productivity	Sericite gneiss
Comment	-	-	-	-	-	-	-	-	-	-	-
Source	Swisstopo	Swisstopo	Swisstopo	Swisstopo	Swisstopo	Swisstopo	Swisstopo	Swisstopo	Swisstopo	Swisstopo	Swisstopo
	146	147	148	149	150	151	152	153	154	155	156

Source Number of attributes: 16

Category	Source							
Attribute	Source1	Source2	Source3	Source4	Source5	Source6	Source7	Source8
Description	Source 1 for the event	Source 2 for the event	Source 3 for the event	Source 4 for the event	Source 5 for the event	Source 6 for the event	Source 7 for the event	Source 8 for the event
Unit	-	-	-	-	-	-	-	-
Exemple	https://www.rts.ch/info/suisse/6749453-le-chablais-et-le-bas-valais-restent-en-etat-d-alerte-face-aux-pluies.html	http://www.24heures.ch/vaud-regions/riviera-chablais/A-Monthey-les-secours-sont-prets-a-evacuer-les-riverains-de-la-Vieze/story/22490259	http://www.24heures.ch/suisse/geneve-subit-grande-crue-arve-1935/story/10943703	http://www.24heures.ch/vaud-regions/monthey-reveille-soulagee-evacuation-300-personnes/story/19307318	http://www.lenouvelliste.ch/articles/valais/canton/inondation-a-st-gingolph-temoignages-du-president-et-de-restaurateurs-378561	https://www.letemps.ch/Page/Uuid/b0e525de-f0c0-11e4-8a43-4ad205b10b56/Les_eaux_en_furie_dans_toute_la_Suisse	http://www.arcinfo.ch/articles/regions/neuchatel-et-littoral/inondations-a-cornaux-et-a-lignieres-378552	http://www.romandie.com/news/Le-Chablais-fortement-touche-par-les-inondations/589780.rom
Comment	-	-	-	-	-	-	-	-
Source	Google Alerts	Google Alerts	Google Alerts	Google Alerts	Google Alerts	Google Alerts	Google Alerts	Google Alerts
	157	158	159	160	161	162	163	164

Category	Source							
Attribute	Source9	Source10	Source11	Source12	Source13	Source14	Source15	Source16
Description	Source 9 for the event	Source 10 for the event	Source 11 for the event	Source 12 for the event	Source 13 for the event	Source 14 for the event	Source 15 for the event	Source 16 for the event
Unit	-	-	-	-	-	-	-	-
Exemple	http://www.rts.ch/info/suisse/6749453-inondations-et-rivieres-en-crue-apres-les-fortes-pluies-.html	http://www.24heures.ch/suisse/suisse-romande/certaines-routes-valaisannes-fermees-cause-deluge/story/27182180	https://www.rfj.ch/rfj/Actualite/Region/20150501-La-Roche-Saint-Jean-a-deux-doigts-de-l-inondation.html	http://www.20min.ch/ro/news/romandie/story/25748211	-	-	-	-
Comment	-	-	-	-	-	-	-	-
Source	Google Alerts	Google Alerts	Google Alerts	Google Alerts	Google Alerts	Google Alerts	Google Alerts	Google Alerts
	165	166	167	168	169	170	171	172

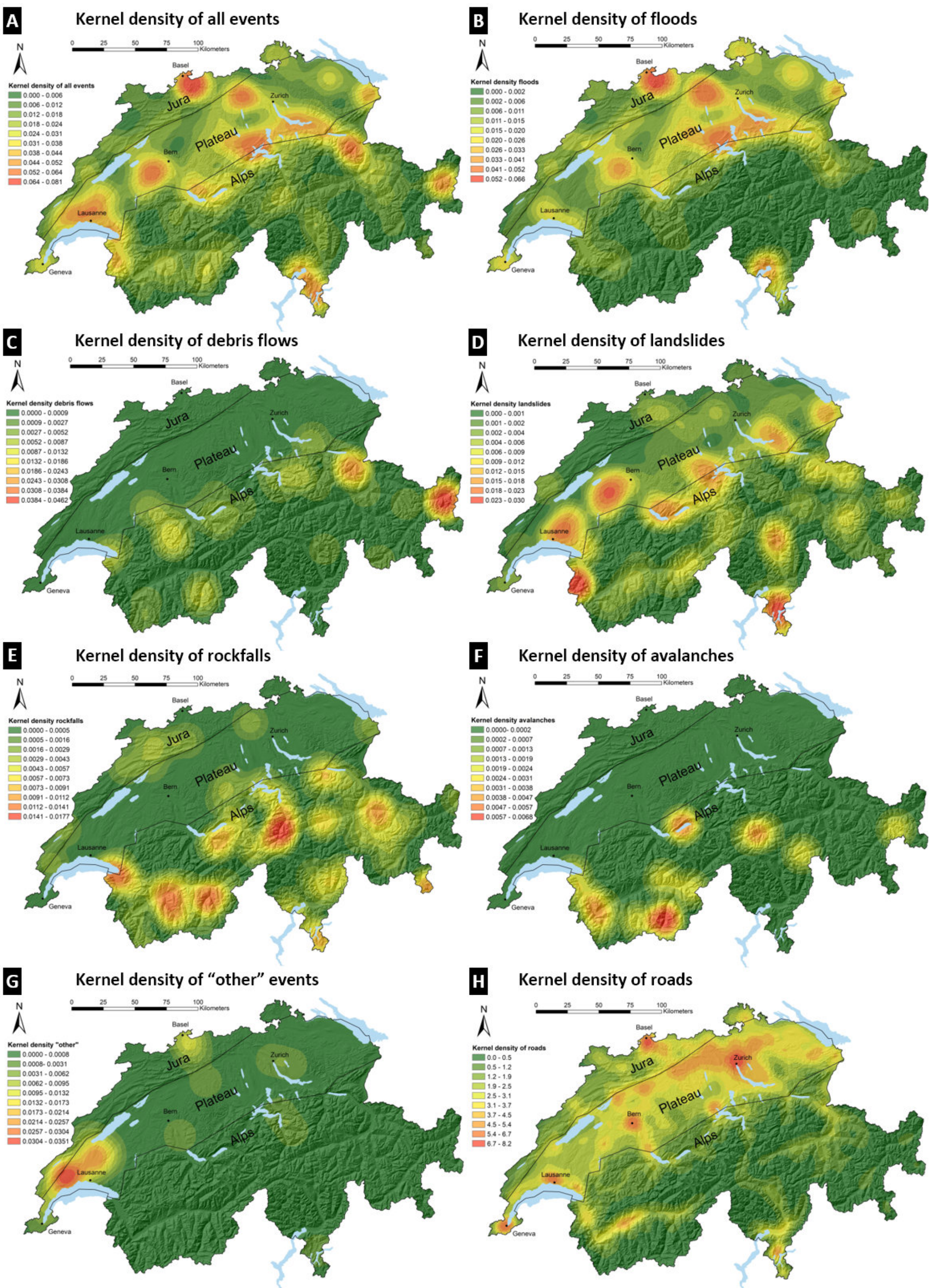

Figure 2-SM: Kernel densities maps. Search radius for events: 20 km. Search radius for road network: 10 km. Results were classified using 10 classes with the Jenks natural breaks method. A: All events; B: Floods; C: Debris flows; D: Landslides; E: Rockfalls; F: Avalanches; G: "Other"; H: Roads. Hillshade and map ground sources: swisstopo.

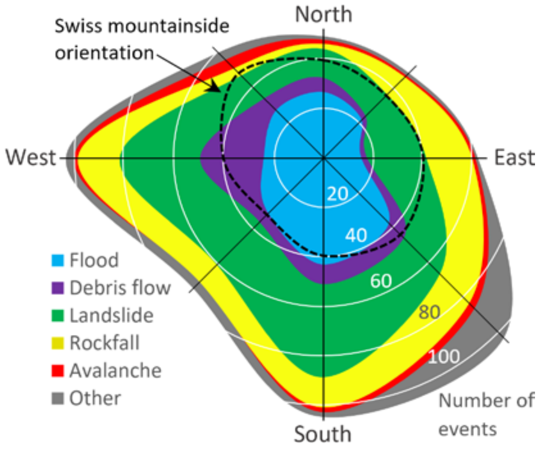

Figure 3-SM: Slope orientation distribution of natural hazard events on the Swiss transportation network from 2012 to 2016. Relative distribution of Swiss mountainsides orientation is given with the black dashed line.

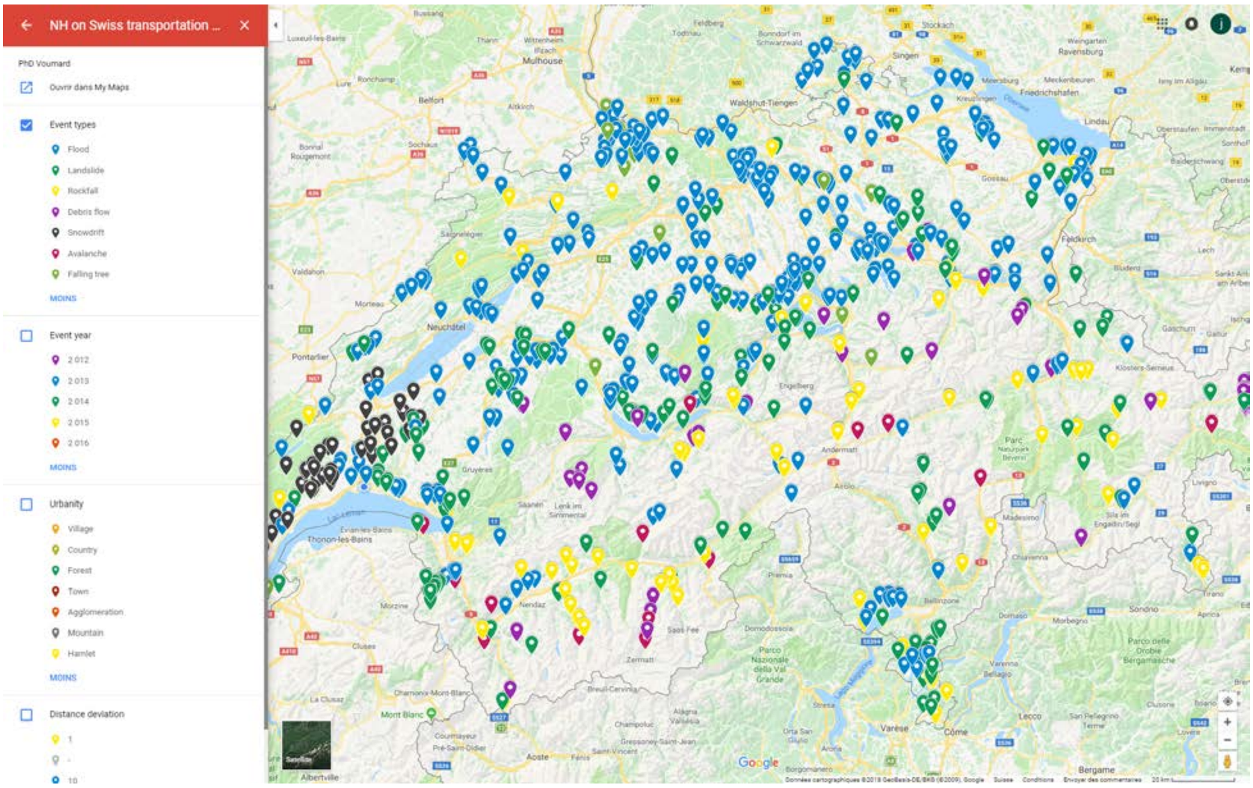

Figure 4-SM: Database on Google Maps. Available at (last access: 25 January 2018) : https://www.google.ch/maps/@46.7199391,7.1246016,8z/data=!4m2!6m1!1s1qtu6LEYum-7ghpPg9WWzWwgPHYA?hl=fr, last access: 25 January 2018.

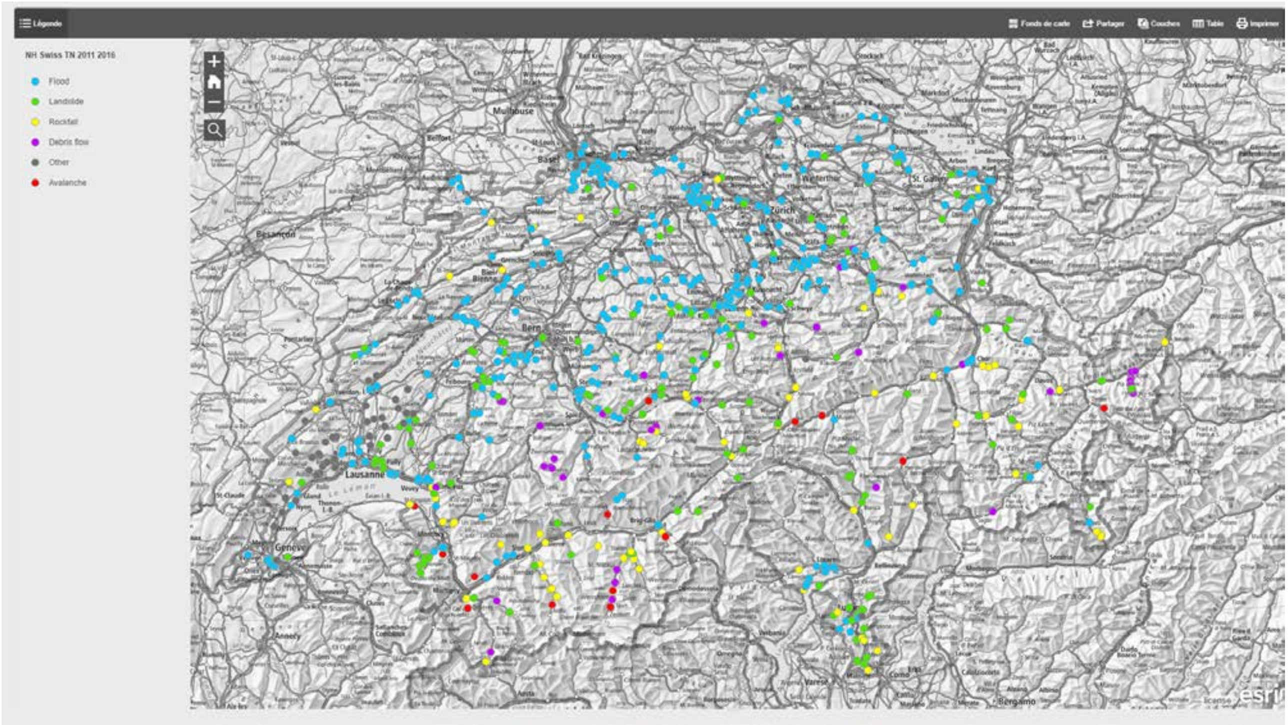

Figure 5-SM: Database on ArcGIS online. Available at (last access: 25 January 2018): http://unil.maps.arcgis.com/apps/MapTools/index.html?webmap=34ee3eb719a647889abd34175969d781, last access: 25 January 2018.