https://doi.org/10.5194/nhess-2021-169
Preprint. Discussion started: 18 June 2021

Natural Hazards and Earth System Sciences
Discussions
Open Access

Geo-historical analysis of flood impacts in Alpine catchments (HIFAVa database, Arve River, France, 1850 – 2015).

Eva Boisson[1], Bruno Wilhelm[1], Emmanuel Garnier[2], Alain Mélo[3], Sandrine Anquetin[1], Isabelle Ruin[1].

[1] University Grenoble Alpes, CNRS, Institut des Géosciences de l'Environnement (IGE), Grenoble, France.
[2] University Franche-Comté, CNRS, Laboratoire Chrono-environnement (LCE), Besançon, France.
[3] AXALP, Annecy, France; associate member at University Savoie Mont-Blanc, CNRS, EDYTEM - UMR 5204, Le Bourget du Lac, France.

Correspondance to : Eva Boisson (eva.boisson@univ-grenoble-alpes.fr)

Abstract

In France, flooding is the most common and damaging natural hazard. Due to global warming, it is expected to globally exacerbate, and it could be even more pronounced in the European Alps that warm at a rate twice as high in the Northern Hemisphere. The Alps are densely populated, increasing exposure and vulnerability to flood hazard. To approach long-term evolutions of past flood occurrence and related socio-economic impacts in relation to changes in the flood risk components (i.e. hazard, exposure and vulnerability), the study of historical records is highly relevant.

To this aim we analyze the newly constituted database of *Historical Impacts of Floods in the Arve Valley* (HIFAVa) located in French Northern Alps and starting in 1850. This database reports for the first-time flood occurrences and impacts in a well-documented Alpine catchment that encompasses both a hydrological and societal diversity.

We analyze past impacts in regard to their characteristics and evolution in both time and space. Our results show an increasing occurrence of impacts from 1920 onwards, which is more likely related to indirect source effect and/or increasing exposure of goods and people rather than hydrological changes. The analysis reveals that small mountain streams and particularly glacial streams caused more impacts (67%) than the main river. While increase in heavy rainfall and ice melt are expected to enhance flood hazard in small Alpine catchments, this finding calls to pay a particular attention to flood risk assessment and management in small catchments.

Keywords : flood risk, exposure, vulnerability, history, socio-economic impacts, French Alps.

https://doi.org/10.5194/nhess-2021-169
Preprint. Discussion started: 18 June 2021

Natural Hazards and Earth System Sciences
Open Access
Discussions

1. Introduction.

On the mainland French territory flood is the most common and damaging natural hazard in terms of economic cost and number of municipalities concerned (Ministère de la Transition écologique, 2020). In highland regions, these events can be caused, among others, by summer thunderstorms, rain on thaw saturated soils, rain on snow or glacial lake outburst (Merz and Blöschl, 2003). The topography induces flood events with highly contrasted dynamics; from sudden events with large sediment transport in the upstream small catchments to multi-day events flooding large parts of the valley floor. This diversity of hydrological dynamics adds to the complexity in flood risk management. Furthermore, climate change is expected to increase extreme precipitation (Min et al., 2011) that could in turn increase flooding (Gobiet et al., 2014; Blöschl et al., 2020). This is especially the case for the European Alps where an increase in summer heavy rainfalls (Giorgi et al., 2016; Ménégoz et al., 2020) may threaten densely populated mountainous valley especially exposed and vulnerable to climate extremes (IPCC, 2019). With its long history of flooding, the densely populated Arve valley located in the Northern French Alps is indeed prone to experience the latter effects of global warming in the future.

Historical records constitute a source of reliable data to characterize past hydrological events because they contribute to give a comprehensive representation of these events and of their changes over long time scales in spite of the lack of instrumental data (Garnier and Desarthe, 2013; Barriendos et al., 2014; Wetter, 2017; Wilhelm et al., 2019). Impacts are considered as all types of outcomes for humans, society and ecosystems occurring in the aftermath of a physical phenomenon (IPCC, 2012).

The historical analysis of past events is useful for the study of catastrophe as we can hypothesize that these remarkable events are etched in the community's memory (Papagiannaki et al., 2013). Indeed, it is because these events have impacted the society that they are recorded in the historical records, i.e. have left a "social signature". Those high impact events can come close to the notion of a catastrophe as they can lead to a societal upheaval (Soanes and Stevenson, 2009) sometimes deleterious but also beneficial (behavioral change promoting prevention) (Garnier, 2017). High impact events are by nature rare, often resulting in a lack of available data (e.g. description of the event, time, extent, damages caused etc.). However, historical approach allows a social and spatio-temporal contextualization of the data (Giacona et al., 2017), making the reconstruction (date, impacts) of major flood events possible (Barriendos et al., 2003, 2019) and attesting the social apprehension of the phenomenon (Gil-Guirado et al., 2016).

Numerous historical databases were built to document past flood occurrence and magnitude, such as the Prediflood database (Barriendos et al., 2014), and some, as the database from Thoumas (2019), allow to analyze the climatic fluctuations. In contrast to these latter databases focusing on hydrological events, some databases collected the socioeconomic impacts of floods such as the APAT database (Lastoria et al., 2006), the press database on natural hazards and climate change from Llasat et al. (2009), the database of high-impact weather events in Greece from Papagiannaki et al. (2013), the EUFF database (Petrucci et al., 2019) and the SMC-Flood database (Gil-Guirado et al., 2019). Some databases stand out as the participative flood database ORRION (Giacona et al., 2019) or the database built by the RISC-KIT project (Garnier et al., 2018) which aim to develop methods and management tools and discuss the trajectories of vulnerability.

Floods, as natural hazards, are physical phenomena naturally occurring and can, when certain conditions are met, cause harm to societies. They can be interpreted as a social construction (Beck, 1992) since exposure of human activities and social vulnerability play a large role in the severity of the impacts. Flood impacts databases, constituted from historical records, can be considered as the expression of society's concerns, risk perceptions (fear,

https://doi.org/10.5194/nhess-2021-169
Preprint. Discussion started: 18 June 2021

habit) and values (based on reported impacts). The recording of flood impacts, or the failure to record them, provides a subjective measure of the events that were considered worth reporting for various reasons across historical periods. Flood impacts result from the interaction between the natural phenomenon and the dynamics of exposure and vulnerability. As vulnerability we understand the inclination to damage of various exposed goods, activities or people constituting a given territory (Leone and Vinet, 2006). We consider the vulnerability as a dynamic system articulated to numerous physical and societal factors (Antoine, 2011). This system can evolve in time and space (Cutter, 2003). Major natural disasters, such as floods, are often displayed as unforeseeable events whereas the historical facts give evidence of the contrary (Garnier, 2016, 2019). Yet the society's vulnerability may increase as the past disasters are forgotten, leading to a "society of risk" (Garnier, 2019). Historical approach allows to explore the trajectories of hazard and vulnerability in response to changes in climate, land use and flood risk management (Gil-Guirado et al., 2016).

The present paper introduces a newly constituted database of flood impacts of the Arve River and its tributaries (Northern French Alps). The database called "*Historical Impacts of Floods in the Arve Valley"* (HIFAVa) covers all impacts caused by hydrological events that occurred since 1850.
The study of this database, the first one documenting a mountainous catchment, ultimately aims at analyzing the interactions between social and natural dynamics engendering flood impacts. In this paper we analyse the impacts with respect to their nature and evolution in both time and space.

2. Study area: the Arve River.

2.1. Description of the physical setting of the Arve River.

The Arve River is located in the Northern French Alps (Figure 1), flowing from the high elevations of the Mont-Blanc summit (4810m a.s.l.) to the Swiss lowlands (330m a.s.l.), where it flows into the Rhône River. The surface area of its catchment is 2164 km² with the largest part higher than 1000m a.s.l.. The main tributaries of the Arve River are the Giffre, the Borne, the Menoge and the Foron Rivers. Since 1850, i.e. the start date of the studied period, the Arve River is already almost completely embanked (Mougin, 1914; Gex, 1924; Peiry and Bravard, 1989).
Due to large difference of altitude between high and lowlands, the Arve flows can be defined by two hydrological regimes following an upstream to downstream continuum:

- The upstream part of the catchment (down to the city of Sallanches; Figure 1), has a glacio-nival regime due to the numerous glacial tributaries lowing from the Mont Blanc massif (Viani et al., 2018). Low flows occur in winter and early spring (December to March) and the high flows in summer (maximum in July and August) because of the strong contribution of ice melting (Bernard, 1900). Floods mainly occur in summer due to the synchronicity of both ice melt and intense subdaily rain storms. In this part of the catchment, the flood plain is narrow and the slope inclination is high.
- At lower elevations (i.e. downstream Sallanches) the regime becomes more and more nival downward. Low waters mainly occur in winter and reach the highest levels between late spring and early summer with the snowmelt. Between Sallanches and Bonneville, floods mainly occur in summer and autumn due to the conjunction of intense daily rain storm, snow melt and, in a lesser extent, ice melt contribution. Downstream Bonneville, floods occur at any time of the year due to even more various hydro-meteorological interplays. The valley floor is here wide and may be affected by extended flooding.

https://doi.org/10.5194/nhess-2021-169
Preprint. Discussion started: 18 June 2021

Natural Hazards and Earth System Sciences
Discussions

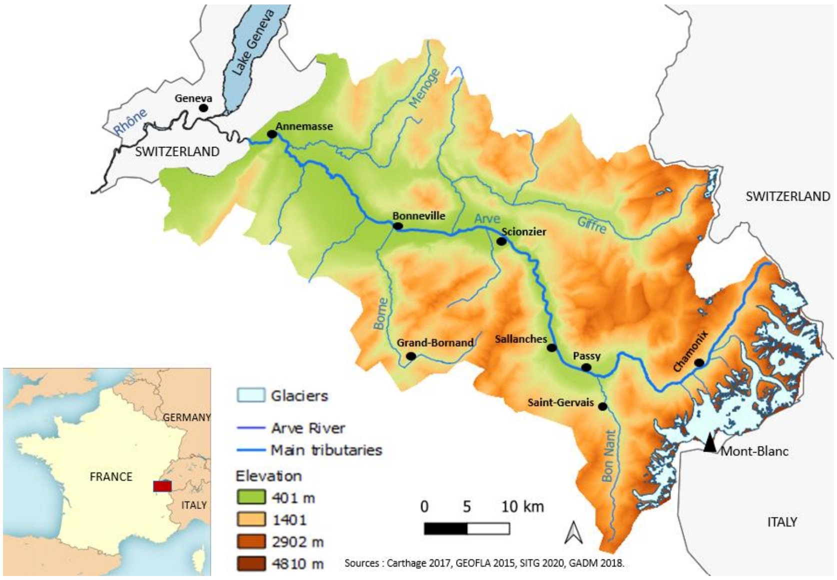


Figure 1. The Arve catchment with its location in the Northern French Alps, its topography, its main hydrological network and the main cities.

2.2. Socioeconomic setting and land use.

There are 106 municipalities located in the Arve catchment, globally facing a major population growth since 1850. For instance, the population has been multiplied by a factor of three in about 170 years at Chamonix (2 304 to 8 611 inhabitants between 1848 and 2016) and by a factor of thirty-four in Annemasse (1 047 to 35 712 inhabitants between 1848 and 2017) (INSEE, 2019). These numbers also hide large seasonal variations related to tourism activities. This is particularly the case in Chamonix where the number of residents increases up to ten times in high season. Most inhabitants live in the valley floor and the foothills that also welcome most of the farming, industrial and tourism activities as well as the main transportation routes and urban areas. Since 1965 and the opening of the Mont-Blanc Tunnel Highway the Arve valley is a major trans-Alpine route connecting France and Italy.

The socioeconomic setting of the valley follows an upstream-downstream distribution pattern. The period from 1850 to 1913 experienced a great touristic development (thermal bath of Saint-Gervais and mountaineering in Chamonix). The economy around Chamonix is essentially based on mountain tourism. In 1921, 250000 tourists were visiting Chamonix each year (Gex, 1924). In 2015 the lodging capacity in the valley reached around 416400 equivalent touristic beds. This part of the valley has undergone a rapid urbanization. In 1804, the discovery and exploitation of spring water for hydrotherapy in Saint-Gervais (Gex, 1924) fostered the construction of touristic accommodations. Around Bonneville, the valley is a densely populated corridor characterized by an old bar turning industry, born from the watch manufacture and nearby hydropower resources. The small valleys of the Arve tributaries are sparsely populated and the economy is based on tourism and farming. Due to the attractiveness of the city of Geneva, the valley from Bonneville to the Rhône River confluence is characterized from the 1960's by a major population growth, extended industrial areas and strong urbanization. Between the town of Cluses and Geneva the valley floor is almost continuously built-up.

3. Material and methods of the HIFAVa database.

3.1. Collecting data from historical archives.

A first historical study has been carried out to draw a flood chronicle of the Arve valley between the 18th and the 21th century, with a particular focus on the hydro-meteorological circumstances of the flood events (Mélo et al., 2015). As sources are more abundant over the last 165 years (1850-2015), this period was defined as the studied time frame of the HIFAVa database. Only events mentioned in at least two sources were integrated in the database. Since 2015, data have been further collected to complete the preliminary dataset from Mélo et al. (2015).

Information on floods and related impacts has been collected from various sources. Primary sources range from handwritten archives like municipal acts to departmental archives (e.g. reports of the *Préfecture* and of town councils). Secondary and tertiary sources are respectively made of published documents (newspapers, reports, books) and pre-existing databases. The database of historical records providing a chronological and synthetic layout of the data is composed of (Table A1):

<u>Manuscript materials:</u>

- Most of the manuscripts are kept in the departemental archives (*Archives Départementales de Haute-Savoie*: ADHS) (Conseil départemental de la Haute-Savoie, n.d.) or in the municipal archives (*Archives municipals* : AM) of the towns of Chamonix, Cluses and Bonneville. The departmental and municipal archives also contain records older than the Savoy annexation by France in 1860. The records can be private or from a public institution.

<u>Printed materials:</u>

- Articles of scientific journal and books used in this study have been published since 1914. They mostly correspond to analyses of the regional hydrology (Mougin, 1914; Rousset-Mestrallet, 1986) but they can also focus on single hydrological events (Pardé 1931; Rougier 2002; Goy 2002) and risk assessment (Douvinet et al., 2011).
- Open-access online municipal risk prevention plans (*Plan de Prévention des Risques* : PPR ; and *Plan de Prévention du Risque Inondation* : PPRI) (Préfecture de la Haute-Savoie, n.d.) as preventive regulatory documents used to delineate risk areas, often compile historical flood events that affected municipalities.

<u>Newspapers:</u>

- Most of the newspapers used are regional, but one is published at national level (*Le Figaro*) and another is printed in Geneva, Switzerland (*Le Journal de Genève*). Most of the newspapers can be found online or are kept in the departmental or municipal archives. Newspapers describe the causes and consequences of the event and sometimes provide instrumental data and illustrations. They also inform about the public authority response and the past ongoing discussion.

<u>Other records:</u>

- The national database of historical flooding (*Base de Données Historiques sur les Inondations* : BDHI) that gathers floods events considered as “remarkable” in the French territory (Ministère de la Transition Ecologique, n.d.; Boudou, 2015) has been used.
- The database created by the department of Restoration of Mountainous Areas (*Restauration des Terrains en Montagne* : RTM) from the public institution managing the French public forests (*Office National des Forêts* : ONF). The ONF-RTM database gathers transcriptions of observations of the RTM officials as well as information collected from diverse primary sources. These data (labelled RTM in the HIFAVa

https://doi.org/10.5194/nhess-2021-169
Preprint. Discussion started: 18 June 2021

Natural Hazards and Earth System Sciences
Open Access
EGU
Discussions

database) are freely available through the open-access and online ONF-RTM database (RTM and ONF, 2012). Some specific ONF-RTM reports are also included in the HIFAVa. The RTM database was built to assist the management of small tributaries.
- A movie realized in 1990 by the RTM is also mentioned as a source.
- Some records are from the *Syndicat Mixte d'Aménagement de l'Arve et de ses Affluents* (SM3A), which is the institution in charge of the management of the Arve River and its tributaries since 1994.

3.2. Characteristics of the HIFAVa database.

The database has been built using the free and open-source relational database management system PostgreSQL and is accessible through its package pgAdmin.
HIFAVa contains 916 distinct flood impacts caused by 321 flood events. The primary key is the impact ID. Therefore, each impact is recorded as a unique line and described through various variables (Table 1 and Table A2). The river that triggered the flood is mentioned when possible (94% of cases). For instance, no river name has been attributed to the impacts related to overland flow in January 1979. The accuracy of the impact location varies from specific addresses (house, bridge, neighborhood) to the municipality scale. When the source is not accurate enough to distinguish distinct locations of several impacts, they are all referenced under a unique impact ID. In other words, sometimes an event caused numerous impacts registered under distinct ID because it was possible to localize each impact precisely (at the hamlet scale) and sometimes we can only localize the impacts at the municipality scale so they are register under the same ID. The severity of an event can not be estimate by the number of ID registered in the database. The most recent sources are often highly informative, allowing impacts to be more precisely located.

Impacts occurring the same day on a given river are expected to be caused by the same flood event. As a result, the date is the key used to connect each impact to a flood event. This "flood event" definition has been extrapolated to impacts occurring the same day in different catchments, assuming that two impacts occurring the same day can be caused by the same hydrometeorological event given the moderate surface area of the Arve catchment. The accuracy of the date is rated on a certainty scale (hour, day, month, year). Based on information contained in the records, we distinguish when possible the hydrometeorological events (e.g. rainfall, intense and short rainfall, melting of snow, frozen soil, glacial outburst, wet period before the event) which caused the flood and the different flood types (e.g. river flooding, overland flow, sediment transport) leading to the impacts.

3.3. Text mining.

The flood impacts of the HIFAVa were categorized through a text quantitative content analysis with the KH Coder software (Higuchi, 2015). The description of the impacts comes from comments contained in the records. The most frequent words have been gathered in order to determine representative categories of the database content. A category is made of several words assigned to a coding rule. Categories have been inspired by the flash flood impact severity scale of Diakakis (2020). This analysis has led to the following seven categories with example of the assigned words:
- Transport network: e.g. "road", "bridge", "railway", "street".
- Urbanized areas and residential buildings: e.g. "house", "town", "basement".
- Natural environment: e.g. "forest", "field", "yield", "sediment transport".
- Protection infrastructures and dams: "dikes" and "dam".
- Industrial, commercial and recreational facilities: e.g. "mill", "factories", "golf", "camping", "hotel", "school".
- Critical installations: "drain", "power transformer".
- Victims: "dead", "injured", "missing", "evacuee".

https://doi.org/10.5194/nhess-2021-169
Preprint. Discussion started: 18 June 2021

Natural Hazards and Earth System Sciences
Discussions

A more in-depth analysis will be conducted later on to define severity classes based on the nature of the impacts. This future analysis will be based on the work of Barriendos et al., (2003), Llasat et al (2005, 2013) and Boudou et al. (2015).

ID	Event	Sources	Start_day	Start_month	Start_year	Start_date	Time_unc	Hour	River	Impacts	Municipality	Impact_latitude	Impact_longitude	Space_unc	Count	Hydrometeo_descript	Water_level	Flood_description	Impacts_decription
140	58	Payot 1951 / Goy 2002 / RTM / BDHI	12	7	1892	12/07/1892	D		Bon Nant	Thermal Bath, victims	Saint-Gervais-les-Bains	45.8965	6.70596	A	175	No entry		Debris flow. 30 minutes to flow from the Tête Rousse glacier to the Arve confluence.	More than 175 victims, destruction of most of Thermal Bath, mud over the first floor.
670	263	RTM / Dauphiné libéré : 26/07/1996, 27/07/1996, 30/07/1996 and 02/08/1996	24	7	1996	24/07/1996	H	11 pm	Arve	City center	Chamonix-Mont-Blanc	45.9257	6.87057	A	0	No entry	0,4m	Debris flow, logjam under bridges.	Numerous houses and the city center are under water. Fuel oil pollution due to basement flooding.

Table 1. Extract of the HIFAVa database showing its structure. Refer to the Online Resource 2 for details about the column contents.

4. Results and discussion.

4.1. Evolving sources over time.

During the studied period, the diversity and the quantity of sources in which mentions of impacts have been found fluctuate (Figure 2). Among the existing databases used, the BDHI database for instance continuously covers the studied period but was sporadically informative since it only contains two mentions of flood impacts in the Arve catchment, respectively in 1892 and in 1987. By contrast, the SM3A database appears later (1979) in the studied time frame.

https://doi.org/10.5194/nhess-2021-169
Preprint. Discussion started: 18 June 2021

Natural Hazards and Earth System Sciences
Discussions

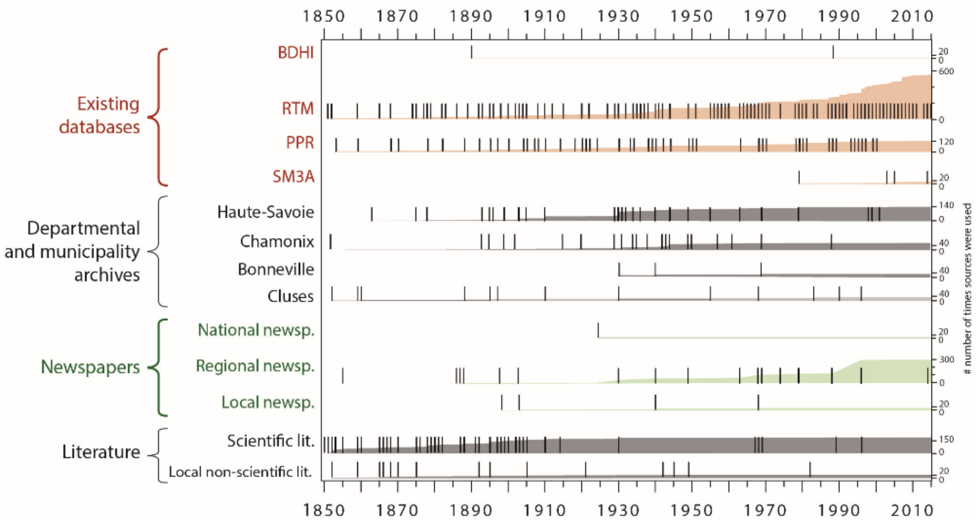


Figure 2. Number and diversity of studied sources to document flood impacts.

RTM (38% of the sources), regional newspapers (20%) and scientific literature (13%) constitute the main sources of information on past flood impacts throughout the studied time period. Sources from the literature are particularly useful (54%) to document the period between 1850 and 1910. Then, materials from the departmental and municipality archives are abundant between 1900 and 1970, especially those from Haute-Savoie (20% of the total registered sources for this period) and Chamonix (7%). Between 1940 to 2015, the RTM represents 58% of the sources describing the impacts.
One of the evolutions of the sources is the increase in the newspaper articles mentioning flood impacts. Following the 1881 press freedom French law, the 1880-1889 decade marks the emergence of articles recording natural hazards, such as flood impacts (Ferenczi, 1996). However, the 1855 flood in Bonneville was already reported by the swiss newspaper, *Le Journal de Genève*.
Although a few sources (e.g. the municipal archives of Sallanches) remain to be examined, most of them have been analyzed in order to constitute the database. Hence, we consider that we have a comprehensive view of past flood impacts since 1850 over the whole Arve catchment.

4.2. Changes in impacts over time and space.

From 1850 to 1920, the number of impacts fluctuates and only four years are remarkable with more than 15 impacts (1852, 1878, 1895 and 1910). From 1920, years with such a large number of impacts become more frequent (1930, 1940, 1944, 1968, 1979, 1987, 1990, 1996, 1997 and 2007) and the total amount of impacts per year reaches 54 in 1996 (Figure 3). The decennial moving average of the impacts' number highlights an overall increase over the 165 years, punctuated by periods with less frequent impacts (in 1910-1923, 1950-1960 and 1975-1980).
Besides, the number of recorded flood events stays relatively stable between 1.5 and 3 events per year on average until 1990, then it rises up to 4.5 events per year. Therefore, the overall increase in recorded impacts seems partly disconnected to changes in flood occurrence. Only the latest period (1990-2015) of increasing impacts may be partially due to a rise in flood occurrence. In particular, the increase in flood impacts starting in the 1920's and well-marked

https://doi.org/10.5194/nhess-2021-169
Preprint. Discussion started: 18 June 2021

since the 1960's, especially by repeated years with very high numbers of impacts, may be explained by other processes as discussed in the next section.

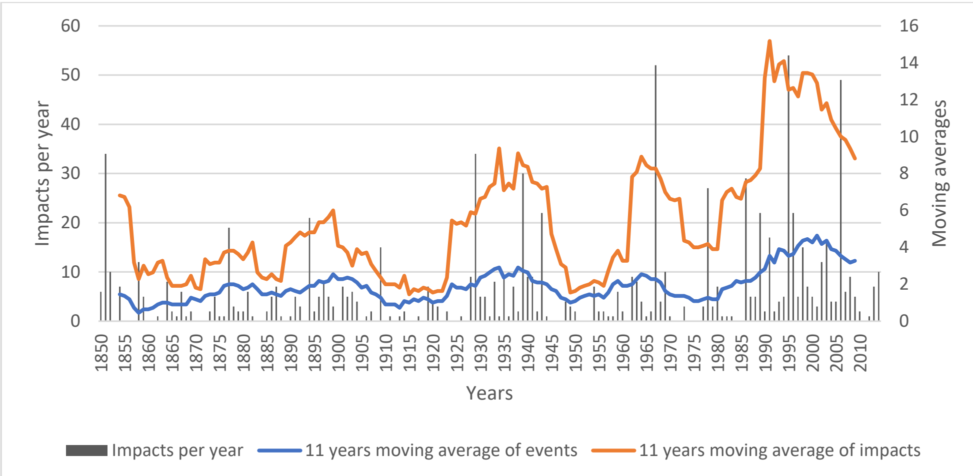


Figure 3. Occurrence of impacts and moving averages of impacts and associated flood events.

When analyzing the spatial distribution of the flood impacts, we can see that they are spread over the entire catchment (Figure 4). They are, however, mainly gathered in the Arve valley around Chamonix and Bonneville (24 and 12,5% of total impacts recorded in the Arve catchment). These high numbers may be due to the fact that these towns are both among the most densely populated and the closest towns to the Arve River. The impacts caused by the Arve River floods represent 33% of all recorded impacts, and its two main tributaries, the Giffre and the Borne Rivers, have only caused 8% of the recorded impacts. In fact, most impacts are due to small torrential streams (53%). Among them, almost a third is related to glacial tributaries, while these tributaries are localized only in the uppermost part of the catchment near Chamonix. For instance, small torrential tributaries such as the Arveyron, the Grépon (left bank tributary close to Chamonix) or the Bon Nant have caused alone more impacts than the Borne River itself.

https://doi.org/10.5194/nhess-2021-169
Preprint. Discussion started: 18 June 2021

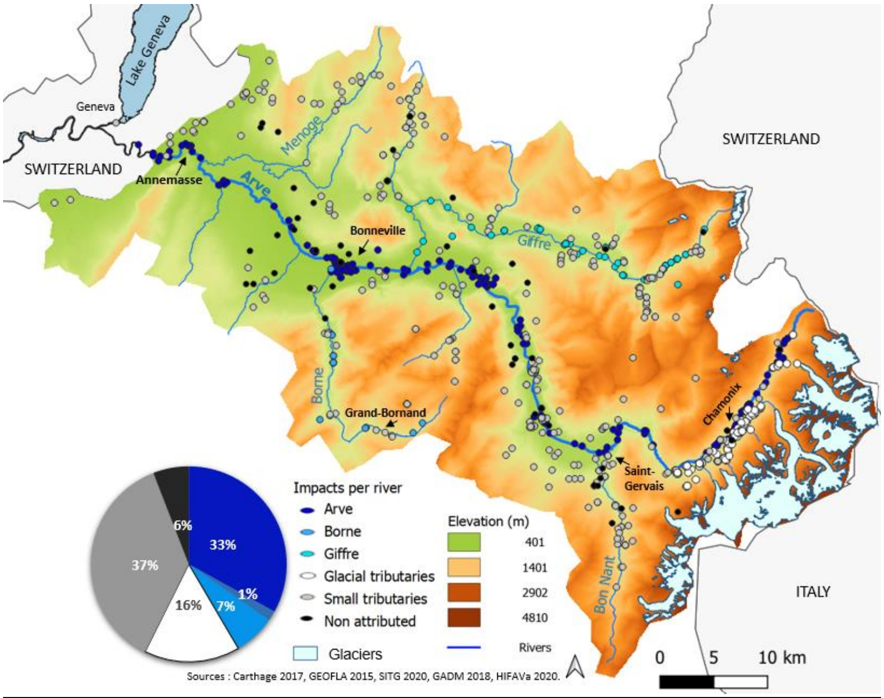


Figure 4. Location and distribution of flood impacts caused by the Arve and its tributaries. The category "non attributed" corresponds to the part of impacts for which it was not possible to attribute a river, either because events are related to overland flows or because of the location between two or more rivers.

The Arve tributaries produced disasters characterized by numerous and major flood damage. Among them, the 1987 Borne River flooding in its uppermost part washed away the municipal campsite of the village of the Grand-Bornand causing 23 casualties and heavy economic losses (Meunier, 1990). In addition, the 1892 glacial lake outburst from the Tête Rousse glacier in the Bon Nant River (which literally translated means "Good Stream") swept away the thermal bath of Saint-Gervais (Figure A1) and 33 houses causing at least 175 casualties. The glacier was drained in 2010 and is today closely monitored to avoid such a brutal and disastrous natural event (Garambois et al., 2016).
All these high impacts events are due to sudden, highly-dynamic summer floods of tributaries, often aggravated by large sediment transport. Some towns located along the Arve River – such as Sallanches – are more prone to tributary's floods because embankments have been built and efficiently prevent impacts from the Arve flooding. In contrast, there are very few impacts recorded in high altitude, probably due to the sparse human settlements.

4.3. Potential drivers of changes in the number and spatial distribution of impacts.

The increase in the number of impacts starting in the 1920's and well-marked from the 1960's can be explained by multiple factors such as indirect source effect, increasing flood activity and/or increasing exposure of goods and people. However, the flood occurrence did not change significantly before the 1990's (Figure 3). Therefore, the increase in impacts cannot be explained by changes in flood occurrence, at least prior to 1990.

https://doi.org/10.5194/nhess-2021-169
Preprint. Discussion started: 18 June 2021

Natural Hazards and Earth System Sciences
Open Access
EGU
Discussions

To decipher the potential source effect in the increase in impacts since 1960, maps of the impacts by sources have been drawn for the periods before and after 1960 (Figure 5). For the first period (1850-1959), three main sources describe 64% of the impacts (literary records 28%, RTM 18% and departmental and municipal archives 18%) and for 29% the information comes from more than one source. The impacts are mainly gathered along the Arve and the Giffre Rivers, especially in the valley of Chamonix and between the towns of Cluses and Bonneville.

For the second period (1960-2015), the RTM reports 65% of the impacts, and 20% come from multiple sources while departmental and municipal archives and the PPR/PPRI describe 5% each. Information coming only from literature decreases substantially (122 described impacts in the first period to 3 impacts in the second), SM3A records start in 1979 and only document the Giffre and the Bon Nant Rivers. The distribution of the impacts is much more scattered across the whole catchment than during the first period. The impacts are not anymore gathered along the Arve River, since most of them result from small tributaries. Impacts described by more than one source are located in the valley of Chamonix and around Bonneville, probably because these economic and touristic centers arouse interest of many sources (newspapers, departmental and municipal archives and RTM). The touristic specificity of valley and its international stature can explain the media coverage. We can assume that, floods are more likely to be reported in newspapers as when they happen in a location known by the reader. In addition, the strong emergence of the RTM since 1940 (Figure 2) can explain the rise in impacts caused by small tributaries illustrates by the Figure 5. Following the floods of the Rhône, the Loire and the Garonne in 1854, the 1858 law against urban flooding places flood control at the heart of the national legislation for the first time. In the following, the RTM department was formed for the reforestation of mountains slope in order to prevent the reproduction of major floods. The department became quickly efficient and since 1860 collected numerous reports. Built for the study and management of small tributaries, the RTM database became the main source of information since 1930 for the HIFAVa database.

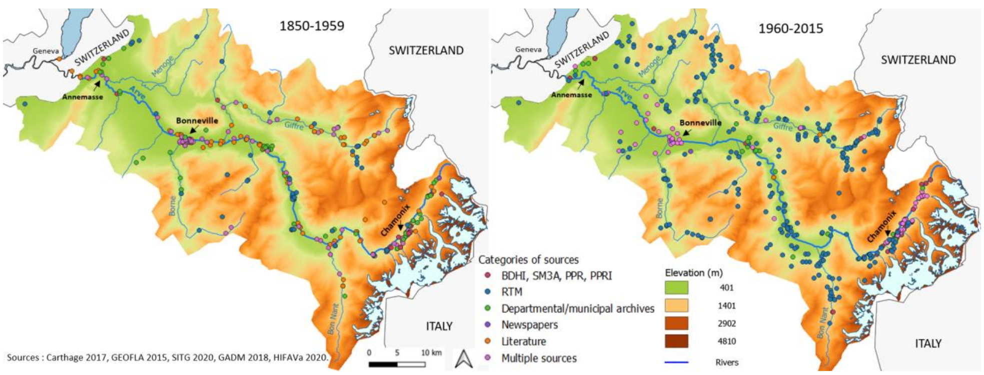


Figure 5. Distribution of the sources describing the recorded flood impacts in the Ave catchment during two periods: 1850-1959 and 1960-2015.

The rise in the number of impacts per flood may be partly explained by the fact that distinct impact types in the same location were reported and therefore referenced under distinct impact ID while they were not differentiated in previous periods. Recent sources seem to provide more accurate information on the impacts and their locations. In older sources, impacts are most of the time documented at the city scale (21% of the impacts for the first period, and 10% for the second period). Thereby, all these impacts are stored in the database in a single line with an uncertainty code for the impact location corresponding to the municipal level. In most recent

https://doi.org/10.5194/nhess-2021-169
Preprint. Discussion started: 18 June 2021

Natural Hazards and Earth System Sciences
Open Access
Discussions

sources, impacts' locations are described more accurately allowing to record them at a resolution up to the building scale. As a result, impacts are stored in as many lines as impacts locations can be identified, with an uncertainty code for the impact's location corresponding to the building or neighborhood level (85% of the impacts for the second period). For example, in 1996 fifty-three impacts where recorded for a same event and fifty of them where located in distinct places in Chamonix. The rise in impacts can also be due to numerous impacts in different locations, as the flood of 1990 which impacted six towns in two different sub-catchments (the Arve and the Giffre catchments). However, in order to overcome the bias induced by the recording of impacts according to their location, we have aggregated the impacts at the municipality level. That is to say, all the impacts reported for a given municipality that were caused by the same event (thus the same day) are recorded under the same line in the database. This results in 562 "aggregated" impacts instead of 917 impacts initially. From these data, we have redrawn Figure 3 (Figure A2) comparing the moving average of impacts and associated events. We can see that the trends are significantly the same. There is an increase of impacts (here starting soon as 1890s) and a late increase of events (1990s). Thus, the way the impacts are stored in the database (by location or by municipality) does not affect the observed temporal changes in impacts.

Changes in exposure and vulnerability related to land use is another potential explanation of the rise in the number of impacts (Magnan et al., 2012; Garnier and Desarthe, 2013; Camuffo et al., 2020). A major population growth happened, especially in Bonneville and Chamonix, leading to a strong and fast urban sprawl in the flood plain between the 1950's and the 2010's as shown by aerial photographs (Figure 6). They also show the vanishing of the alluvial forest (Dufour and Piégay, 2006) and cultivated fields to the benefit of urbanization in both towns. The population growth in the Arve Valley varies according to the towns. Upstream, in Chamonix, the demographic expansion dates back to the early 20th century with the flourish of mountain tourism. In downstream towns – e.g. Bonneville and Annemasse – the expansion starts in the 1950's because of the economic attractiveness of Geneva.

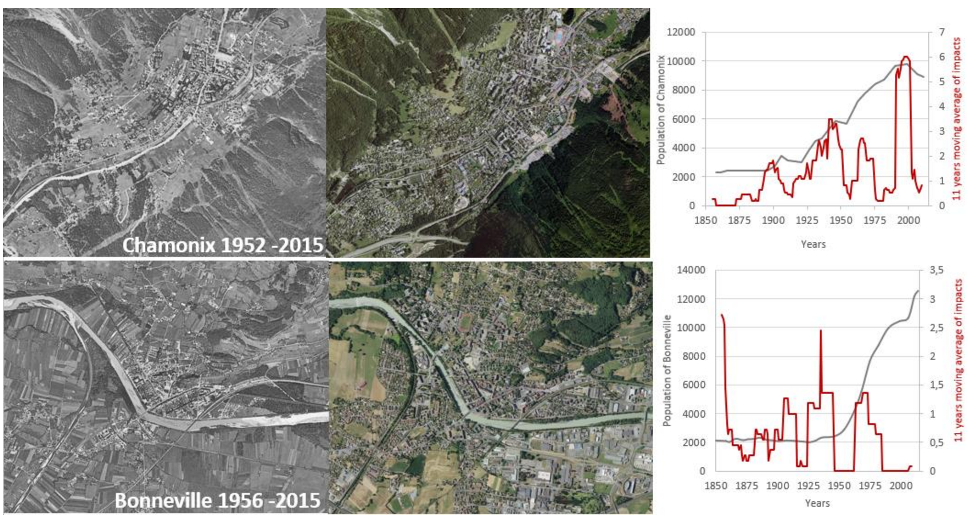


Figure 6. Land use evolution and expansion demographic associated with impacts of Chamonix and Bonneville from 1848 to 2011 (© IGN).

Besides these numbers, the urban expansion and the growth in tourism come with the arrival of new residents in the valley (Haute-Savoie : la plus forte croissance démographique de

https://doi.org/10.5194/nhess-2021-169
Preprint. Discussion started: 18 June 2021

Natural Hazards and Earth System Sciences Discussions

métropole, 2020), unaware of the local hazard history. The valley narrowness, the demand for land and the loss of memory of past events have led to build in historical flood-prone area, resulting in an increased exposure. For instance, in 1944 recently built houses in Chamonix were washed away by the Grépon River. The same situation also happened during the 1968 flood that destroyed a new residential area in Bonneville. In Chamonix, the number of impacts punctually increase from year to year, somehow mirroring the population growth (Figure 6). Increasing exposure due to population growth and urbanization may then explain the increasing number of impacts. One can, however, notice the decrease in impacts after the disastrous 1996 flood event. This is due to the heightening of the dikes after the 1996 flood. In Bonneville, the link between the number of impacts and the population growth is not clear.

4.4. Nature of the flood impacts.

The quantitative analysis of text content reveals the distribution of the impact categories by river and illustrates the diversity of the catchment in terms of land use and economic development (Figure 7). This analysis of text content is particularly relevant because it allows to overcome the database scarcity of quantitative information on the severity of the flood. Indeed, it is difficult to estimate the severity of the flood event as the flow rate and the water height are only exceptionally mentioned. However, a link can be made between the impact nature and the severity of the event (Barriendos et al., 2019).

The number of occurrences of the words determining the category is here named as the number of mentions. For the overall Arve catchment, damage to the transport network is the most frequent (406 mentions), followed by damage to urbanized areas (286) and natural environment (253). Impacts on transport network are in proportion equally distributed among river types (all around 30%). Impacts on industrials facilities are mainly caused by the Arve and the Giffre Rivers as their wider valleys allow the installation of these facilities. The Giffre and the Borne Rivers have caused the least impacts specifically on urban areas, probably because of less dense population and of an economy based on farming and tourism activities.

https://doi.org/10.5194/nhess-2021-169
Preprint. Discussion started: 18 June 2021

Natural Hazards and Earth System Sciences
Open Access
Discussions

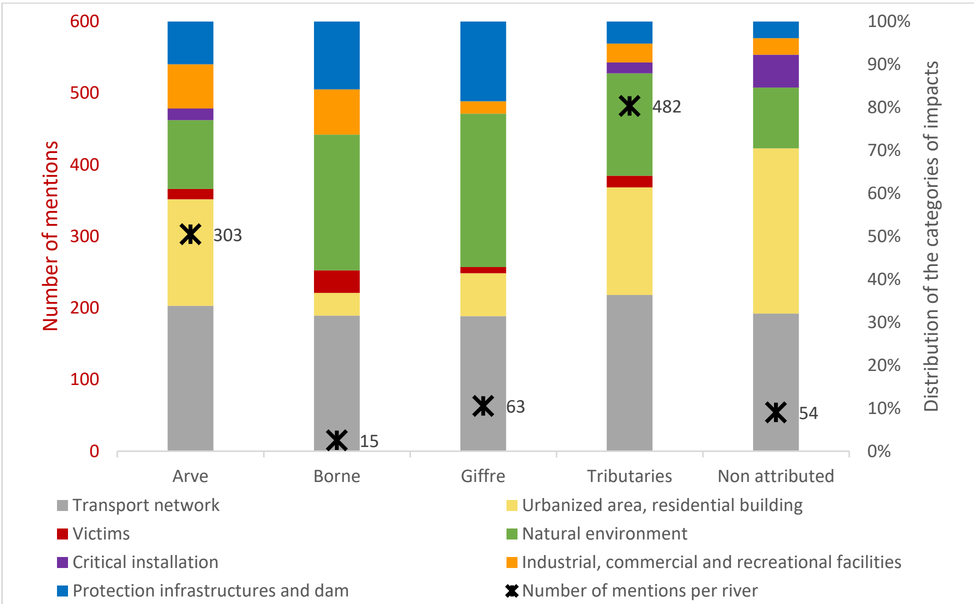


Figure 7. Distribution of flood impacts according to the river types. The class "non attributed" correspond to all impact with no assigned river (e.g. overland flows).

Most of the mentions of victims refer to impacts caused by tributaries (20 out of 28). They have caused 80% of the deadly impacts registered since 1850 in the whole catchment, e.g. the 1892 glacial lake outburst and the 1987 flood of Grand-Bornand. The mentions of victims of the Borne River should belong to the small tributaries class as the impacts occurred in the uppermost part of the catchment. This high mortality may be due to sudden and strong floods and to less developed infrastructure of flood protection on the tributaries.

To track potential changes in the nature of impacts since 1850, they are scrutinized by decades over the last 165 years (Figure 8). Impacts on transportation networks are present in every decade since 1850 but they increase after 1930 as well as impacts on urbanized area and natural environment categories. It was not until 1960 that impacts on the industrial, commercial and recreational facilities category increased. Mentions about critical installation (sewers and water pipes) are recorded for the first time in the 1960's. Mentions of victims are present in almost every decade. Two decades (1950 and 1970) stand out in terms of category's distribution.

Nevertheless, no major evolution of the impacts categories can be seen, except the emergence of mentions of critical installations in the 1930's. The categories used for the analyze have been inspired by a recent paper from Diakakis (2020) but in order to deepen our analysis of the historical evolution of the impacts' nature some other and more precise classifications should be tested in the future as well as the evolution of the assigned words.

https://doi.org/10.5194/nhess-2021-169
Preprint. Discussion started: 18 June 2021

Natural Hazards and Earth System Sciences
Open Access
Discussions

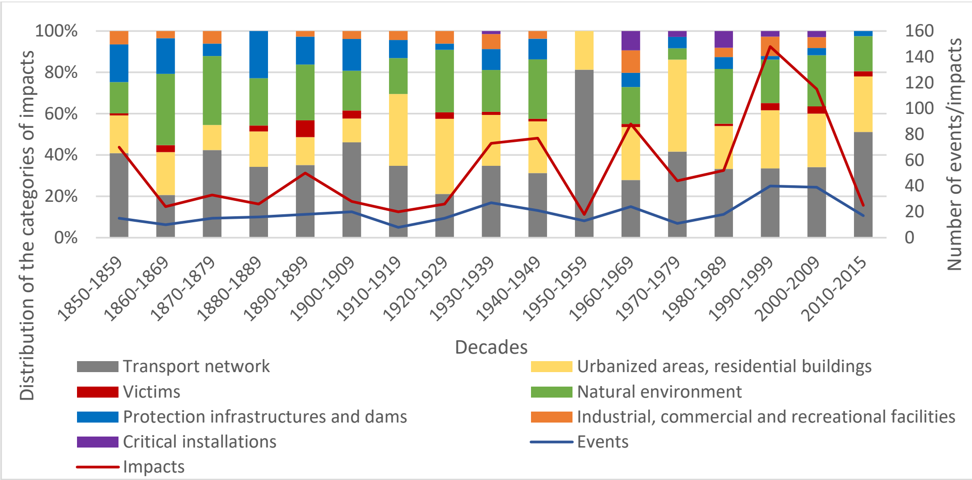


Figure 8. Decennial histogram of the evolution of the categories of impacts divided by the number of events.

This analysis of proportions, however, hinders changes in absolutes values. For instance, at the catchment scale there is a slight increase in the number of mentions of the victims category since 1980 (16 out of 28) (Figure 8). This increase is not easily noticeable when looking at proportions of impacts categories because of the strong augmentation in the total number of mentions since 1930. Yet, apart from the disaster in the Grand-Bornand in 1987, since 1931 all the mentions of victims refer to evacuations, recues or injuries.

The number of impacts has been almost multiplied by two since 1920. Hence, the mentions of impacts on natural environment for the period 1850-1930 were multiplied by more than two compared to the period 1960-2015. During the first period, mentions of impacts on natural environment refer mainly to forest, field and crops, while after 1960 there is no mention of field or crops and most of the mentions are about gullying, deposition of sediments and banks. This is in agreement with the evolution of the land use due to the demographic growth, i.e. the observed vanishing of forest areas and cultivated land to the benefit of urbanization (Figure 6). Yet, mentions of impacts on urbanized areas during 1960-2015 has been multiplied almost by four compared to the 1850-1930 period. This agrees with observed changes in land use characterized by urban sprawl.

5. Conclusions.

We collected historical information from 1850 onwards to document flood impacts in the Arve valley, an Alpine catchment characterized by a high hydrological and socioeconomic diversity. The analysis of the HIFAVa database led to acknowledge the rise in the number of impacts starting in 1920 and well-marked from 1960. This rise does not seem to be related to increased flood hazard since it does not follow changes in flood occurrence, except partially for the latest period (1990-2015). Instead, more frequent impact could be explained by increased exposure related to the demographic growth (tourism and economic attractiveness of Geneva) and/or by the evolution of the sources, in particular the emergence of the RTM.

There are two main types of flood events causing impacts in the catchment, e.g. floods related to the main river and those related to the smaller mountain streams. Floods from these small streams are characterized by sudden and fast hydrological responses and large sediment transport, making hazard management difficult. They caused two third of the 916 recorded impacts with numerous casualties and gathered impacts, such as the 1892 Bon Nant and the

https://doi.org/10.5194/nhess-2021-169
Preprint. Discussion started: 18 June 2021

Natural Hazards and Earth System Sciences
Open Access
Discussions

1987 Borne rivers floods. In contrast, slow rising floods of the Arve River last in general several days, affect a large area and trigger mainly economics consequences and no casualties. The 1968 flood affecting a large part of the Arve catchment is an exemplary case of this flood type. The analysis of the nature of the impacts does not reveal a clear evolution over the last 165 years. However, further work is required to define more detailed categories allowing to question the evolution of the assigned words since 1850. Additional investigations of the municipal archives and interviews of local flood risk managers should also be undertaken to allow answering some key questions, such as the definition of high-impacts events in this very valley. The processes of risk memory transmission and the evolution of the local political risk management will be queried for the purpose of understanding the evolution of the social vulnerability. The following study of this database aim to better understand how hazard, exposure and vulnerability combines to trigger high impacts events across the recent history of the Arve catchment.

https://doi.org/10.5194/nhess-2021-169
Preprint. Discussion started: 18 June 2021

557 **Appendixes**

558

559 Table A1. List of the historical records – or their origin – used to provide information about flood events
560 and impacts collected in the HIFAVa database. The date mentions the year of publication for books
561 and period covered by the newspapers.

Manuscript materials	**Printed materials**	**Newspapers**	**Other records**
ADHS	AM Cluses	ADHS	BDHI
AM Bonneville	Conard 1931	Le Messager (1965-1968)	RTM (movie 1990)
AM Chamonix	Douvinet 2011	Le Dauphiné libéré (1963-2014)	SM3A
AM Cluses	Goy 2002	Journal de Genève (1855-1978)	
	Mestrallet 1986	La Croix 74 (1898)	
	Mougin 1914	L'Allobroge (1903-1940)	
	Parde 1931	Le Faucigny (1968)	
	Payot 1951	Le Figaro (1924)	
	PPR	Le Messager (1940)	
	PPRI	Le Mont-Blanc républicain (1903)	
	Rannaud 1916	Le Progrès (1898)	
	Rougier	L'Industriel Savoisien (1910)	
	RTM	La Revue Savoisienne (1887-1889)	

562

563
564
565 Table A2. Presentation of the HIFAVa database showing its structure with each data entry.

id	[PK] serial	Primary key. ID number of an impact.
event	integer	Number of the event that triggers the impact. In case of an hydro-meteorological event, several impacts located at different places on different river are associated to the same event.
sources	integer	The different sources that provide information.
start_day	integer	Start day of event.
start_mont	integer	Start month of event.
start_year	integer	Start year of event.
start_date	date	Start date of event.
hour	text	Start hour of event.
time_unc	text	Uncertainty of the start date. H means that the start date is known at the hour scale, D at the day scale, M at the month scale and Y at the year scale. By default, when the day and/or the month is not known, "1" is attributed to start_day and/or start_month.
duration	real	Duration of event
river	text	River that trigger the flood (the cell may be empty if the impacts are not related to river flooding).
impact	text	Nature of impact.
municipality	text	Municipality where the impact is located.
imp_lat	real	Latitude of the impact in decimal degrees.

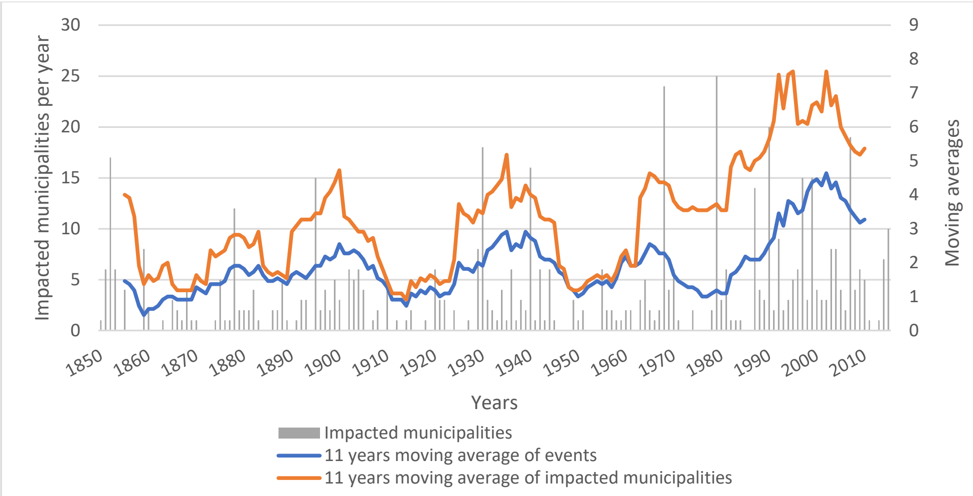
imp_long	real	Longitude of the impact in decimal degrees.
Space_unc		Describe the spatial scale of impact location. A means that the impact is located at the scale of a point on a map, B at the scale of a part of a city, C at the scale of a city, D at a coarser scale than the one of a city.
count	integer	Number of victims
hydrometeo_descript	text	Description of the hydrometeorological event according to the sources.
precipitation	real	Precipitation rate given in the sources (mm).
flood_descrpt	text	Description of the flood from the sources
river_water_level	real	Water level of the river (m).
water_level	real	Water level of flooded area (m).
discharge	real	Discharge of the river (m3/s)
impact_descrpt	text	Description of the impacts according to the sources.

Figure A1. The wiped-out thermal bath of Saint-Gervais after the debris flow of the 12th of July 1892 (Thermes de Saint-Gervais Mont-Blanc, 2021).

Figure A2. Occurrence of impacts and moving averages of impacted municipalities and associated flood events (one line = one municipality impacted by a flood event).

https://doi.org/10.5194/nhess-2021-169
Preprint. Discussion started: 18 June 2021

Natural Hazards and Earth System Sciences
Discussions
Open Access



Acknowledgments: We would like to thank the *Syndicat Mixte d'Aménagement de l'Arve et de ses Affluents* who shared its database of events and impacts. The HIFAVa database was partly fed thanks to the funding of the projects Labex ITEM CrHistAl and OSUG2020 RHAAP. This study was developed in the framework of *CDP-Trajectories* of the Grenoble-Alpes University (France) funded by the *Agence Nationale de la Recherche* through the project "*Investissements d'avenir*" (ANR-15-IDEX-02).

Bibliography:

Antoine, J.-M.: Vulnérabilité et adaptation des sociétés montagnardes à la torrentialité au cours du Petit Âge Glaciaire dans les Pyrénées, soe, 53–66, https://doi.org/10.4000/soe.685, 2011.

Barriendos, M., Coeur, D., Lang, M., Llasat, M. C., Naulet, R., Lemaitre, F., and Barrera, A.: Stationarity analysis of historical flood series in France and Spain (14th–20th centuries), Nat. Hazards Earth Syst. Sci., 3, 583–592, https://doi.org/10.5194/nhess-3-583-2003, 2003.

Barriendos, M., Ruiz-Bellet, J. L., Tuset, J., Mazón, J., Balasch, J. C., Pino, D., and Ayala, J. L.: The "Prediflood" database of historical floods in Catalonia (NE Iberian Peninsula) AD 1035-2013, and its potential applications in flood analysis, Hydrol. Earth Syst. Sci., 18, 4807–4823, https://doi.org/10.5194/hess-18-4807-2014, 2014.

Barriendos, M., Gil-Guirado, S., Pino, D., Tuset, J., Pérez-Morales, A., Alberola, A., Costa, J., Balasch, J. C., Castelltort, X., Mazón, J., and Ruiz-Bellet, J. L.: Climatic and social factors behind the Spanish Mediterranean flood event chronologies from documentary sources (14th–20th centuries), Global and Planetary Change, 182, 102997, https://doi.org/10.1016/j.gloplacha.2019.102997, 2019.

Beck, U.: Risk Society : Towards a New Modernity, Sage., London, 1992.

Bernard, C.: Restauration et conservation des terrains en montagne : les terrains et les paysages torrentiels (Haute-Savoie), Impr. nationale (Paris), 60 pp., 1900.

Blöschl, G., Kiss, A., Viglione, A., Barriendos, M., Böhm, O., Brázdil, R., Coeur, D., Demarée, G., Llasat, M. C., Macdonald, N., Retsö, D., Roald, L., Schmocker-Fackel, P., Amorim, I., Bělínová, M., Benito, G., Bertolin, C., Camuffo, D., Cornel, D., Doktor, R., Elleder, L., Enzi, S., Garcia, J. C., Glaser, R., Hall, J., Haslinger, K., Hofstätter, M., Komma, J., Limanówka, D., Lun, D., Panin, A., Parajka, J., Petrić, H., Rodrigo, F. S., Rohr, C., Schönbein, J., Schulte, L., Silva, L. P., Toonen, W. H. J., Valent, P., Waser, J., and Wetter, O.: Current European flood-rich period exceptional compared with past 500 years, Nature, 583, 560–566, https://doi.org/10.1038/s41586-020-2478-3, 2020.

Boudou, M.: Approche multidisciplinaire pour la caractérisation d'inondations remarquables : enseignements tirés de neuf évènements en France (1910-2010), Geography, Université Paul Valéry - Montpellier I, Lyon, 462 pp., 2015.

Boudou, M., Denis, C., Michel, L., and Freddy, V.: Grille de lecture pour la caractérisation d'évènements remarquables d'inondations en France: Exemple d'application pour la crue de mars 1930 dans le bassin de la Garonne et du Tarn, 22, 2015.

Camuffo, D., della Valle, A., and Becherini, F.: A critical analysis of the definitions of climate and hydrological extreme events, Quaternary International, 538, 5–13, https://doi.org/10.1016/j.quaint.2018.10.008, 2020.

Conseil départemental de la Haute-Savoie: Archives départementales de Haute-Savoie, n.d.

Cutter, S. L.: The Vulnerability of Science and the Science of Vulnerability, Annals of the Association of American Geographers, 93, 1–12, https://doi.org/10.1111/1467-8306.93101, 2003.

Diakakis, M., Deligiannakis, G., Antoniadis, Z., Melaki, M., Katsetsiadou, N. K., Andreadakis, E., Spyrou, N. I., and Gogou, M.: Proposal of a Flash Flood Impact Severity Scale for the classification and mapping of flash flood impacts., 2020.

https://doi.org/10.5194/nhess-2021-169
Preprint. Discussion started: 18 June 2021

Douvinet, J., Defossez, S., Anselle, A., and Denolle, A.-S.: Les maires face aux plans de prévention du risque inondation (PPRI), 40, 31, https://doi.org/10.3917/eg.401.0031, 2011.

Dufour, S. and Piégay, H.: Forêts riveraines des cours d'eau et ripisylves : spécificités, fonctions et gestion, Rev. For. Fr., https://doi.org/10.4267/2042/6704, 2006.

Ferenczi, T.: L'invention du journalisme en France, Naissance de la presse moderne à la fin du XIXème siècle, Payot., Paris, 274 pp., 1996.

Garambois, S., Legchenko, A., Vincent, C., and Thibert, E.: Ground-penetrating radar and surface nuclear magnetic resonance monitoring of an englacial water-filled cavity in the polythermal glacier of Tête Rousse, 81, 2016.

Garnier, E.: Genève face à la catastrophe 1350-1950. Un retour d'expérience pour une meilleure résilience urbaine., Slatkine, Genève, Suisse, 195 pp., 2016.

Garnier, E.: Xynthia, February 2010: Autopsy of a Foreseable Catastrophe, in: Management of the Effects of Coastal Storms: Policy, Scientific and Historical Perspectives, Quevauviller, P., 111–148, 2017.

Garnier, E.: Lessons learned from the past for a better resilience to contemporary risks, 28, 778–794, 2019.

Garnier, E. and Desarthe, J.: Cyclones and Societies in the Mascarene Islands 17th-20th Centuries, AJCC, 1–13, https://doi.org/10.4236/ajcc.2013.21001, 2013.

Garnier, E., Ciavola, P., Spencer, T., Ferreira, O., Armaroli, C., and McIvor, A.: Historical analysis of storm events: Case studies in France, England, Portugal and Italy, 134, 10–23, 2018.

Gex, F.: La Haute-Savoie aujourd'hui et il y a 100 ans avec un tableau de la population par commune de 1801 à 1921., Librairie M. Dardel, Chambéry, 1924.

Giacona, F., Eckert, N., and Martin, B.: A 240-year history of avalanche risk in the Vosges Mountains based on non-conventional (re)sources, 17, 887–904, https://doi.org/10.5194/nhess-17-887-2017, 2017.

Giacona, F., Martin, B., Furst, B., Glaser, R., Eckert, N., Himmelsbach, I., and Edelblutte, C.: Improving the understanding of flood risk in the Alsatian region by knowledge capitalization: the ORRION participative observatory, Nat. Hazards Earth Syst. Sci., 19, 1653–1683, https://doi.org/10.5194/nhess-19-1653-2019, 2019.

Gil-Guirado, S., Espín-Sánchez, J.-A., and Del Rosario Prieto, M.: Can we learn from the past? Four hundred years of changes in adaptation to floods and droughts. Measuring the vulnerability in two Hispanic cities, Climatic Change, 139, 183–200, https://doi.org/10.1007/s10584-016-1768-0, 2016.

Gil-Guirado, S., Pérez-Morales, A., and Lopez-Martinez, F.: SMC-Flood database: a high-resolution press database on flood cases for the Spanish Mediterranean coast (1960–2015), Nat. Hazards Earth Syst. Sci., 19, 1955–1971, https://doi.org/10.5194/nhess-19-1955-2019, 2019.

Giorgi, F., Zsolt Torma, C., Coppola, E., and Ban, N.: Enhanced summer convective rainfall at Alpine high elevations in response to climate warming, 9, 2016.

Gobiet, A., Kotlarski, S., Beniston, M., Heinrich, G., Rajczak, J., and Stoffel, M.: 21st century climate change in the European Alps—A review, Science of The Total Environment, 493, 1138–1151, https://doi.org/10.1016/j.scitotenv.2013.07.050, 2014.

Goy, J.: Autour de la catastrophe de l'établissement thermal de Saint-Gervais-les-Bains en 1892 : problèmes d'histoire des catastrophes naturelles., Les pouvoirs publics face aux risques naturels dans l'histoire., Grenoble, 39–49, 2002.

Higuchi, K.: KH Coder, 2015.

Haute-Savoie : la plus forte croissance démographique de métropole: https://www.insee.fr/fr/statistiques/3689656, last access: 1 August 2020.

INSEE: Populations légales communales depuis 1968, 2019.

IPCC: Managing the risks of extreme events and disasters to advance climate change adaptation, Intergovernmental Panel on Climate Change, 2012.

IPCC: The Ocean and Cryosphere in a Changing Climate, Intergovernmental Panel on Climate Change, Genève, Suisse, 2019.

Lastoria, B., Simonetti, M. R., Casaioli, M., Mariani, S., and Monacelli, G.: Socio-economic impacts of major floods in Italy from 1951 to 2003, Adv. Geosci., 7, 223–229, https://doi.org/10.5194/adgeo-7-223-2006, 2006.

Leone, F. and Vinet, F.: La vulnérabilité, un concept fondamental au cœur des méthodes d'évaluation des risques naturels, in: La vulnérabilité des sociétés et des territoiresface aux menaces naturelles, GESTER, 2006.

Llasat, M. C., Llasat-Botija, M., and López, L.: A press database on natural risks and its application in the study of floods in Northeastern Spain, Nat. Hazards Earth Syst. Sci., 9, 2049–2061, https://doi.org/10.5194/nhess-9-2049-2009, 2009.

Llasat, M. C., Llasat-Botija, M., Petrucci, O., Pasqua, A. A., Rosselló, J., Vinet, F., and Boissier, L.: Towards a database on societal impact of Mediterranean floods within the framework of the HYMEX project, Nat. Hazards Earth Syst. Sci., 13, 1337–1350, https://doi.org/10.5194/nhess-13-1337-2013, 2013.

Llasat, M.-C., Barriendos, M., Barrera, A., and Rigo, T.: Floods in Catalonia (NE Spain) since the 14th century. Climatological and meteorological aspects from historical documentary sources and old instrumental records, Journal of Hydrology, 313, 32–47, https://doi.org/10.1016/j.jhydrol.2005.02.004, 2005.

Magnan, A., Duvat, V., and Garnier, E.: Reconstituer les « trajectoires de vulnérabilité » pour penser différemment l'adaptation au changement climatique, Nat. Sci. Soc., 20, 82–91, https://doi.org/10.1051/nss/2012008, 2012.

Mélo, A., Wilhelm, B., Giguet-Covex, C., and Arnaud, F.: Construire une chronique d'inondations : évènements hydrologiques et histoire climatique dans le bassin de l'Arve (Alpes du Nord, France) entre les XVIIIe et XXIe siècles., 40, 411–419, 2015.

Ménégoz, M., Valla, E., Jourdain, N. C., Blanchet, J., Beaumet, J., Wilhelm, B., Gallée, H., Fettweis, X., Morin, S., and Anquetin, S.: Contrasting seasonal changes in total and intense precipitation in the European Alps from 1903 to 2010, 1–37, https://doi.org/10.5194/hess-2019-690, 2020.

https://doi.org/10.5194/nhess-2021-169
Preprint. Discussion started: 18 June 2021

Merz, R. and Blöschl, G.: Regional flood risk—what are the driving processes?, 40–58, 2003.

Meunier, M.: La catastrophe du Grand Bornand : crue torrentielle du Borne le 14 juillet 1987, 78, 103–114, 1990.

Min, S.-K., Zhang, X., Zwiers, F. W., and Hegerl, G. C.: Human contribution to more-intense precipitation extremes, Nature, 470, 378–381, https://doi.org/10.1038/nature09763, 2011.

Ministère de la Transition écologique: Prévention des risques naturels, 2020.

Ministère de la Transition Ecologique: Base de Données Historiques sur les Inondations, n.d.

Mougin, P.: Les torrents de la Savoie, Société d'histoire de la Savoie, Grenoble, 1914.

Papagiannaki, K., Lagouvardos, K., and Kotroni, V.: A database of high-impact weather events in Greece: a descriptive impact analysis for the period 2001–2011, Nat. Hazards Earth Syst. Sci., 13, 727–736, https://doi.org/10.5194/nhess-13-727-2013, 2013.

Pardé, M.: Les crues de l'Arve en octobre 1930, rga, 19, 495–497, https://doi.org/10.3406/rga.1931.4782, 1931.

Peiry, J. L. and Bravard, J. P.: Evolution naturelle d'un remplissage sédimentaire intramontagnard et impacts des aménagements contemporains : L'exemple de la vallée de l'Arve (74), La Houille Blanche, 221–225, https://doi.org/10.1051/lhb/1989018, 1989.

Petrucci, O., Aceto, L., Bianchi, C., Bigot, V., Brázdil, R., Pereira, S., Kahraman, A., Kılıç, Ö., Kotroni, V., Llasat, M. C., Llasat-Botija, M., Papagiannaki, K., Pasqua, A. A., Řehoř, J., Rossello Geli, J., Salvati, P., Vinet, F., and Zêzere, J. L.: Flood Fatalities in Europe, 1980–2018: Variability, Features, and Lessons to Learn, Water, 11, 1682, https://doi.org/10.3390/w11081682, 2019.

Préfecture de la Haute-Savoie: Données communales : plans de prévention des risques naturels (PPRN), Les services de l'Etat en Haute-Savoie, n.d.

Rougier, H.: Les inondations du 24 juillet dans la haute vallée de l'Arve : faits et conséquences à tirer pour l'aménagement du territoire., Les pouvoirs publics face aux risques naturels dans l'histoire., Grenoble, 51–64, 2001.

Rousset-Mestrallet, M.: Des torrents et des hommes. Trois siècles d'histoire à Samoëns., Imprim'off 7, Marignier, 150 pp., 1986.

RTM and ONF: Base de Données RTM, 2012.

Soanes, C. and Stevenson, A.: Catastrophe, Concise Oxford English Dictionary, 11 (revised), 2009.

Thermes de Saint-Gervais Mont-Blanc: The wiped-out thermal bath of Saint-Gervais after the debris flow of the 12th of July 1892., https://www.thermes-saint-gervais.com/wp-content/uploads/2018/07/STGMB-7.jpg, 30 March 2021.

Thoumas, P.: Histoire des crues du Roubion (Drôme, France) depuis 1501 AD, une approche hydrologique des fluctuations climatiques sur cinq siècles, physio-geo, 14, 87–111, https://doi.org/10.4000/physio-geo.8984, 2019.

https://doi.org/10.5194/nhess-2021-169
Preprint. Discussion started: 18 June 2021

Viani, A., Condom, T., Sicart, J.-E., Rabatel, A., Gascoin, S., Ranzi, R., and Wimez, M.: Impact of the glacier retreat and snow melt on the seasonal cycle of streamflow of the Arve catchment since the 1960s (Northern French Alps), EGU General Assembly, Vienna, Austria, 1, 2018.

Wetter, O.: The potential of historical hydrology in Switzerland, Hydrol. Earth Syst. Sci., 21, 5781–5803, https://doi.org/10.5194/hess-21-5781-2017, 2017.

Wilhelm, B., Ballesteros Canovas, J. A., Macdonald, N., Toonen, W., Baker, V., Barriendos, M., Benito, G., Brauer, A., Corella, J. P., Denniston, R., Glaser, R., Ionita, M., Kahle, M., Liu, T., Luetscher, M., Macklin, M., Mudelsee, M., Munoz, S., Schulte, L., St. George, S., Stoffel, M., and Wetter, O.: Interpreting historical, botanical, and geological evidence to aid preparations for future floods, 6, https://doi.org/10.1002/wat2.1318, 2019.