



OPEN

DATA DESCRIPTOR

Developing a large-scale dataset of flood fatalities for territories in the Euro-Mediterranean region, FFEM-DB

Katerina Papagiannaki¹✉, Olga Petrucci², Michalis Diakakis³, Vassiliki Kotroni¹, Luigi Aceto², Cinzia Bianchi⁴, Rudolf Brázdil^{5,6}, Miquel Grimalt Gelabert⁷, Moshe Inbar⁸, Abdullah Kahraman⁹, Özgenur Kılıç¹⁰, Astrid Krahn¹¹, Heidi Kreibich¹¹, Maria Carmen Llasat¹², Montserrat Llasat-Botija¹², Neil Macdonald¹³, Mariana Madruga de Brito¹⁴, Michele Mercuri¹⁵, Susana Pereira^{16,17}, Jan Řehoř^{5,6}, Joan Rossello Geli⁷, Paola Salvati⁴, Freddy Vinet¹⁸ & José Luis Zêzere^{16,17}

This data paper describes the multinational Database of Flood Fatalities from the Euro-Mediterranean region FFEM-DB that hosts data of 2,875 flood fatalities from 12 territories (nine of which represent entire countries) in Europe and the broader Mediterranean region from 1980 to 2020. The FFEM-DB database provides data on fatalities' profiles, location, and contributing circumstances, allowing researchers and flood risk managers to explore demographic, behavioral, and situational factors, as well as environmental features of flood-related mortality. The standardized data collection and classification methodology enable comparison between regions beyond administrative boundaries. The FFEM-DB is expandable, regularly updated, publicly available, and with anonymized data. The key advantages of the FFEM-DB compared to existing datasets containing flood fatalities are its high level of detail, data accuracy, record completeness, and the large sample size from an extended area.

Background & Summary

Despite significant improvements in managing flood risk and the numerous initiatives governments and institutions undertake, floods threaten human life and health. According to Munich Re¹, flooding accounted for 40% of all global loss-related natural catastrophes since 1980. In 2020, there were 23% more floods resulting in fatalities and 18% more flood-related deaths compared to the annual average calculated for the previous 20-year period (2000–2019)². In recent decades, Europe has experienced catastrophic floods^{3,4}, causing substantial loss

¹Institute for Environmental Research and Sustainable Development, National Observatory of Athens, Athens, 15236, Greece. ²CNR-IRPI National Research Council-Research Institute for Geo-Hydrological Protection, Rende, 87036, Italy. ³National and Kapodistrian University of Athens, Faculty of Geology and Geoenvironment, Panepistimioupoli, Zografou, GR15784, Greece. ⁴CNR-IRPI National Research Council-Research Institute for Geo-Hydrological Protection, Perugia, 06128, Italy. ⁵Department of Geography, Faculty of Science, Masaryk University, Brno, 61137, Czech Republic. ⁶Global Change Research Institute, Czech Academy of Sciences, Brno, 60300, Czech Republic. ⁷Grup de Climatologia, Hidrologia, Riscs i Paisatge, Universitat Illes Balears, Palma de Mallorca, 07122, Spain. ⁸Department of Geography and Environmental Studies, University of Haifa, Haifa, 33000, Israel. ⁹School of Engineering, Newcastle University, Newcastle upon Tyne, NE1 7RU, United Kingdom. ¹⁰Department of Meteorological Engineering, Faculty of Aeronautics and Astronautics, Samsun University, Ondokuzmayis, Samsun, 55420, Turkey. ¹¹GFZ German Research Centre for Geosciences, Potsdam, 14473, Germany. ¹²Department of Applied Physics, University of Barcelona, Barcelona, 08028, Spain. ¹³Department of Geography and Planning, School of Environmental Sciences, Roxby building, University of Liverpool, L69 7ZT, Liverpool, United Kingdom. ¹⁴UFZ Helmholtz Centre for Environmental Research, Leipzig, 04318, Germany. ¹⁵National Research Council of Italy - Institute for Agricultural and Forest Systems in the Mediterranean (ISAFOM), Rende, CS, Italy. ¹⁶Centre of Geographical Studies, Institute of Geography and Spatial Planning, University of Lisbon, 1600-276, Lisbon, Portugal. ¹⁷Associated Laboratory TERRA, Lisbon, Portugal. ¹⁸University Paul Valéry Montpellier 3, Montpellier, 34090, France. ✉e-mail: katpap@noa.gr

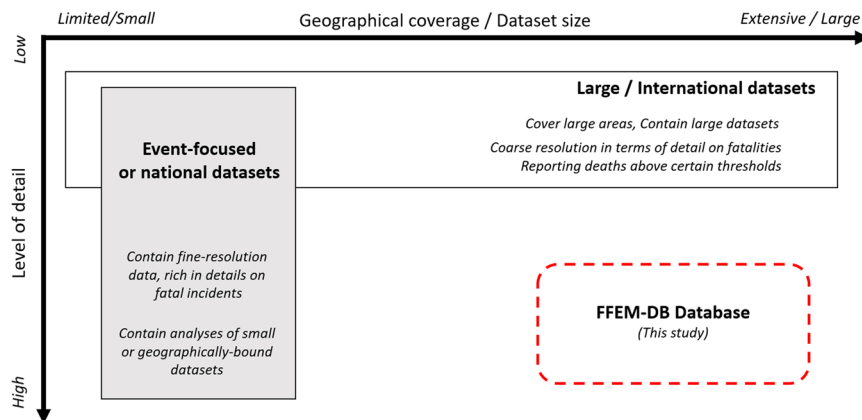


Fig. 1 Conceptual model showing the advantages and limitations of existing flood mortality databases and the trade-off between dataset size and detail level, in comparison to the intended position of the FFEM-DB database proposed by the present study.

of human life⁵, with the river floods of July 2021 resulting in more than 200 fatalities⁶, which demonstrates this problem remains unsolved.

Insights on how people die from floods usually derive from the study of flood fatality accounts. However, existing studies and databases on flood fatalities (FFs) face important limitations, such as (1) small sample size; (2) narrow geographic extent; (3) low level of detail on FFs; and (4) lack of information concerning the circumstances surrounding fatal incidents (Fig. 1). Regarding the first two limitations, studies tend to focus predominantly on national datasets⁷ or event-focused datasets^{8–10}, usually containing a relatively small number of FFs in a specific area. However, examining small samples within narrow geographic boundaries produces results that are hardly transferable to other regions. Such results may be influenced by traditions and cultural factors^{11–14}, infrastructure typology¹⁵, types of environments or settings¹⁶, housing types¹⁷, and the population's quality of training or education. Methodological differences, such as using different systems to classify flood death conditions, are also a major problem for cross-study comparisons (see, for example, Ashley and Ashley¹⁸ and Fitzgerald *et al.*¹⁹). A significant challenge for researchers is comparing information for different regions or countries based on common criteria and standards to gain a general, transferable understanding of the drivers of flood mortality.

In addition to these limitations, currently available international databases, such as the Emergency Events Database EM-DAT²⁰, provide a useful accounting of fatality numbers but lack details on the circumstances of actual incidents. At the same time, many of them are multihazard-oriented, making the attribution of fatalities to specific hazards, such as flooding, complex, as they often occur in conjunction with other hazards, e.g., wind or landslides. In addition, some international databases include events only if they exceed a minimum threshold of fatalities. Such thresholds lead to a potential miss of fatalities, which, especially within Europe, can be an important portion of the total number of fatalities as a result of a large number of low-mortality events²¹.

To address these gaps, we propose the Database of Flood Fatalities from the Euro-Mediterranean region, FFEM-DB, a multinational database comprising 2,875 FFs from territories in Europe and the Mediterranean region, from 1980 to 2020. FFEM-DB presents an extensive geographical area (covering 12 study areas, nine of which are entire countries) addressing the sample size issue repeatedly acknowledged in the literature^{9,22,23}. It provides a high level of detail for each fatality, precise demographic and geographic location data, and details of the circumstances leading to a fatality. Therefore, it enables the comprehensive cross-regional study of FF circumstances, identifying commonalities and differences between particularly vulnerable groups and hazardous situations that lead to fatal accidents, and considering regional socio-economic characteristics. Furthermore, FFEM-DB creates the foundation for studying the association of FF mortality with cross-border variables, such as geomorphological and hydrometeorological features and risk mitigation initiatives and policies. Such cross-regional and cross-border learning can support improved risk communication and better preparedness to help avoid accidents. In this light, FFEM-DB is valuable in evaluating the impact of the EU Flood Directive (2007/60/EC) on flood risk management in Europe and relevant to the Sendai Framework for Disaster Risk Reduction target of reducing disaster mortality between 2020–2030.

FFEM-DB brings together the best information available at the regional/national level, ensuring that the data are standardized, verified, and quality controlled. Moreover, FFEM-DB is publicly accessible, and it is scalable as it has been developed with a clearly defined methodology that permits the addition of new regional/national datasets. With these characteristics, the FFEM-DB database is globally unique.

Methods

Data sources. The FFEM-DB database draws data from local, high-resolution databases (or datasets) to ensure high accuracy, data quality, and completeness. These databases have been developed and published individually (online-only Table 1) by local research teams or are included here for the first time (e.g., UK) to support mortality studies at national or regional levels. A common denominator of these local databases is the detailed recording of FFs profiles and circumstances of death through multiple sources, namely (1) national authorities, (2) reports from bodies implicated in risk management such as the police and fire department, and (3) local or

Study area (acronym)	Area (km ²)	Area (% of total)	NUTS 2 (number of units)	Population (inhabitants)	Population (% of total)	Population density (inh./km ²)
BAL	4,993	0.2%	1	1,188,220	0.3%	238
CAT	32,113	1.5%	1	7,566,431	2.2%	236
CYP	9,256	0.4%	1	875,899	0.3%	95
CZE	78,873	3.7%	8	10,649,800	3.0%	135
SFR	53,194	2.8%	3	8,343,000	2.4%	157
GER	357,661	16.8%	38	83,019,213	23.7%	232
GRE	131,759	6.2%	13	10,724,599	3.1%	81
ISR	22,159	1.0%	N.A.	9,054,100	2.6%	409
ITA	324,764	15.2%	21	60,359,546	17.2%	186
POR	91,909	4.3%	5	9,779,826	2.8%	106
TUR	780,376	36.6%	26	82,003,882	23.4%	105
UK	244,545	11.5%	41	66,647,112	19.0%	273
Total	2,131,602	100.0%	158	350,211,628	100.0%	—

Table 1. Description of the study areas. Notes: Source: <https://ec.europa.eu/eurostat/>, data 2019. For SFR: French Statistical Service, 2021. For ISR: CBS (2020).

FFEM-DB tables					
FATALITIES		LOCATION		NUTS 3	
FATALITY_ID ^A	Int	FATALITY_ID ^A	Int	NUTS_3_ID ^{A,B}	Varchar
NUTS_3_ID ^B	Varchar	COUNTRY	Varchar	NUTS_3_NAME	Varchar
DATE	Date	FFEM_STUDY_AREA	Varchar	NUTS_2_ID	Varchar
AGE_STRING	Enum*	STUDY_AREA_ACRONYM	Varchar	NUTS_2_NAME	Varchar
GENDER	Enum*	TERRITORIAL_LV1	Varchar	NUTS_1_ID	Varchar
RESIDENCY	Enum*	TERRITORIAL_LV2	Varchar	NUTS_1_NAME	Varchar
VICTIM_CONDITION	Enum*	TERRITORIAL_LV3	Varchar	NUTS_0_ID	Varchar
VICTIM_ACTIVITY	Enum*	LATITUDE	Decimal	NUTS_0_NAME	Varchar
ACCIDENT_PLACE	Enum*	LONGITUDE	Decimal	NUTS_3_AREA	Decimal
ACCIDENT_DYNAMIC	Enum*	LOC_ACCURACY	Enum*	NUTS_3_POPULATION	Int
DEATH_CAUSE	Enum*	NUTS_3_ID ^B	Varchar	NUTS_3_POP_DENSITY	Decimal
PROTECTIVE_BEHAVIOR	Enum*			NUTS_3_MALES	Int
HAZARDOUS_BEHAVIOR	Enum*			NUTS_3_FEMALES	Int
				NUTS_3_AGE_0-14_MAL	Int
				NUTS_3_AGE_0-14_FEM	Int
				NUTS_3_AGE_15-29_MAL	Int
				NUTS_3_AGE_15-29_FEM	Int
				NUTS_3_AGE_30-49_MAL	Int
				NUTS_3_AGE_30-49_FEM	Int
				NUTS_3_AGE_50-64_MAL	Int
				NUTS_3_AGE_50-64_FEM	Int
				NUTS_3_AGE_OVER64_MAL	Int
				NUTS_3_AGE_OVER64_FEM	Int
				POP_AGE_NOTE	Varchar

Table 2. Structure of the relational FFEM-DB database. *String objects, ^APrimary key, ^BForeign Key.

national media from which detailed information is drawn. Secondary control sources include historical catalogs of damaging flood events/fatalities and scientific publications.

Of the aforementioned data sources, news media were particularly relevant as they are deemed as a reliable source of societal information. They have been previously used to analyze FFs^{24–26}, indicate the impact of damaging weather events on a local scale^{27–31}, explore the evolution of perception of natural hazards^{24,32}, and validate hazard maps^{33–35}. The period covered by the FFEM-DB, 1980–2020, can be divided into two time periods based on the availability and ease of access to press information. Roughly, the 1980–2000 period is based on printed archived newspaper material. After 2000, digital newspapers and archives became more abundant, and, most importantly, there is greater access to local newspapers that often provide detailed accounts of particular events. Online-only Table 1 presents the main sources of primary data on fatal flood events and the associated FFs for each study area.

Data collection and reporting standards. Consistency and accuracy were ensured throughout the data collection process. Securing these criteria concerns two main steps: (1) collecting data from the individual research teams and (2) merging the derived data into FFEM-DB.

Regarding data collection in each study area, various and multiple sources have been used by each independent research team, as shown in the online-only Table 1. All the sources used were specified to ensure high transparency and confidence in the derived information. Despite the variety of sources that may have been used depending on availability, a prerequisite was set that data should be verified by at least two independent sources. We can distinguish different combinations of sources for verifying the data, with the following being the most prevalent among the involved research teams:

- Press and media combined with field research.
- Documentary records, including the press, combined with official authorities' reports.
- Various media sources using text-mining tools.

To ensure reporting standards were the same for all 12 regions, each research group used a standardized form that enables homogeneity of information imported into the database. This standardized form was developed through a trial period of use by five research groups involved in capturing, designing, and initiating FF data collection³⁶ to ensure that it could accommodate their data. The basic form adjustments made during the trial period were as follows:

- Adjust field categorization to cover all distinct sub-cases.
- Introduce new fields and their categorization.
- Revise fields considering the availability and accessibility of the requested information.

The derived data were consistently checked before entering the standard fields of the database. The following were primarily checked concerning the suitability of the reported FFs:

- Each reported FF corresponds to the type of floods the database deals with (see section Data Records).
- Each reported FF is directly associated with rainfall-induced flooding (see section Data Records).

The data collected in the standardized form also included fields for assessing the accuracy of specific information difficult to collect or confirm, namely the approximate hour when the fatality took place and the geographical coordinates. Data was also quality controlled for errors, duplicate entries, and missing data. The identification of duplicate entries was undertaken by computing the Jaccard similarity coefficient³⁷. Geographical coordinates were checked in the GIS environment (QGIS 3.10). When needed, coordinates were adjusted based on auxiliary spatial information provided, with either a reverse geocoding process or manual geolocation through Google Maps or OpenStreetMap services. Fatality data were anonymized.

History and updates of the database. The FFEM-DB is an expandable database that is periodically updated^{36,38}. The update occurs on average every two years. It was developed in its original composition in 2017 (MEFF version³⁶ with data exclusively from Mediterranean countries or regions for the 1980–2015 period. It included five territories from four countries (France, Greece, Italy, and Spain). In 2019 it evolved to include FFs from new territories in Europe and neighboring non-European countries of the Mediterranean region, covering 1980–2018 (EUFF version³⁸). Specifically, the EUFF version also included FFs from the Czech Republic, Israel, Portugal, and Turkey. The FFEM-DB is the latest version, covering a larger area of the Euro-Mediterranean region and a more extended period (1980–2020). Compared to the EUFF version, it also includes FFs from Cyprus, Germany, and the UK. Most importantly, FFEM-DB has been developed into a structured and publicly accessible database, available in 4TU Centre for Research Data³⁹. We should note that the standards for collecting, reporting, and controlling data were the same in all database versions.

Data Records

Definitions and key concepts. The basic concepts of the FFEM-DB database are defined in the following:

Study period: Currently, FFEM-DB covers 41 years, from 1980 to 2020.

Flood fatality (FF): A person killed by the direct impact of a flood. It encompasses people killed from short-term clinical causes, such as drowning, collapse/heart attack, poly-trauma, poly-trauma & suffocation, hypothermia, suffocation, and electrocution. People missing and presumed dead are included only if more than one source refers to eyewitness testimonies that, for example, the missing person was swept away by a torrent. FFs resulting from storm surges, dam breaks, and accompanying landslides are not included in the FFEM-DB. Additionally, indirect losses associated with long-term health effects are not included.

Fatal flood event (FE): A flash flood or river flood that has caused one or more deaths in a specified region. Flash floods are caused by sudden, short-lived, and usually heavy rainfall over relatively small basin/watershed, while overflowing rivers and streams cause river floods, usually resulting from long-lasting rainfall/snowmelt. Floods caused by the accumulation of rainwater due to lack of drainage, such as urban floods, are also included. The FEs are aggregated at the NUTS 3 spatial level⁴⁰.

Geographical coverage. Nine of the study areas (Fig. 2) represent entire countries: Cyprus (CYP), Czech Republic (CZE), Germany (GER), Greece (GRE), Israel (ISR), Italy (ITA), Portugal (POR), Turkey (TUR), and the United Kingdom (UK). The other three study areas are the Spanish regions of Catalonia (CAT)

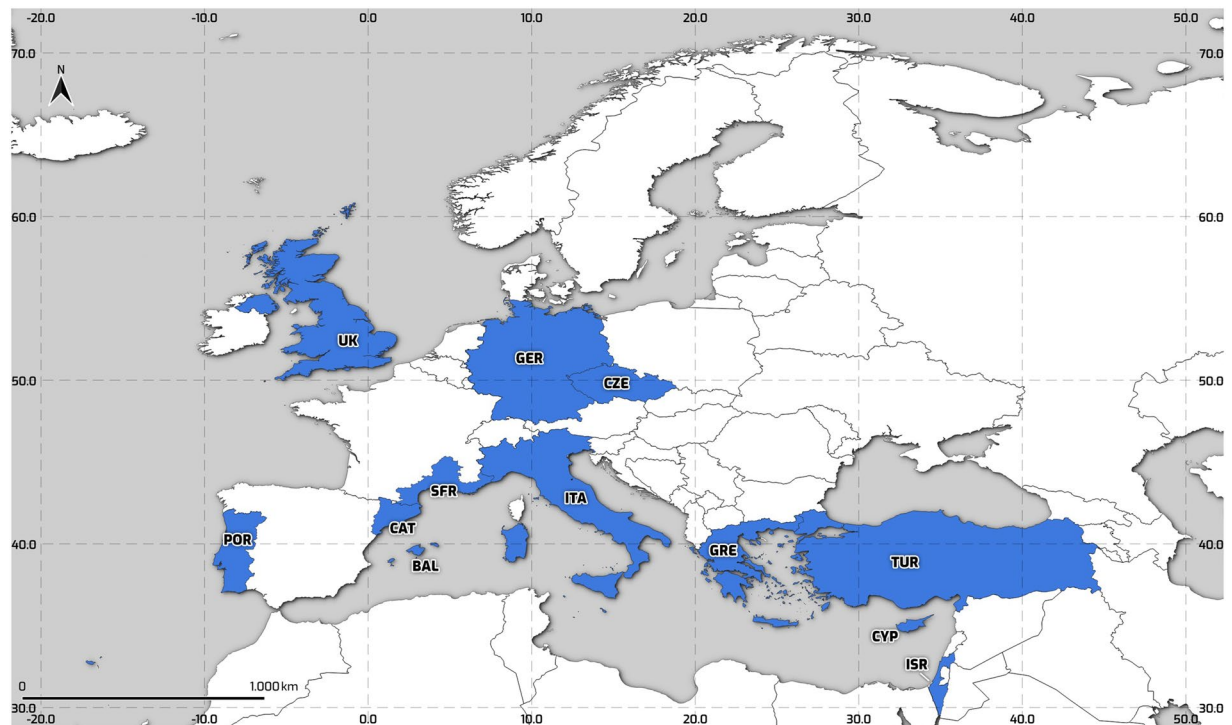


Fig. 2 FFEM-DB study areas, in blue. BAL: Balearic Islands; CAT: Catalonia; CYP: Cyprus; CZE: Czech Republic; SFR: Southern France; GER: Germany; GRE: Greece; ISR: Israel; ITA: Italy; POR: Portugal; TUR: Turkey; and UK: United Kingdom.

and Balearic Islands (BAL), as well as the southern French regions bordering the Mediterranean coast (SFR: Languedoc-Roussillon and Provence-Alpes-Cote d'Azur). Table 1 presents information about the area and population of each study area, as well as the number of the representative administrative units at the NUTS 2 level.

Database structure and content. Data are stored in a relational MySQL database, using phpMyAdmin administration tool, which consists of three tables: (A) FATALITIES table, (B) LOCATION table, and (C) NUTS 3 table with information on the administrative level, as shown in Table 2. The fields of the table FATALITIES are filled in by selecting from a predefined menu of options, shown in Table 3.

A. FATALITIES table: It contains the date when the fatality occurred, the fatality profile (gender, age, and residency), and circumstances (victim's condition and activity, the place and dynamics of the accident in terms of the particular circumstances that led to death, clinical cause of death, protective or hazardous behaviors). The ID-Fatality is the primary key connecting this table to the LOCATION table, while NUTS_3_ID works as a foreign key connecting to the table NUTS 3.

B. LOCATION table: It contains administrative and geographical information on where the fatality occurred (country name and acronym, territorial levels from 1 to 3 according to the country administrative subdivisions, latitude and longitude, the accuracy of location). The accuracy of geographical coordinates is considered high if the place of death is precise. Otherwise, it is considered low, and the coordinates correspond to the center of the relevant smaller known administrative unit, e.g., at the territorial_LV3 level.

C. NUTS 3 table: This table allows the downscaling of the location of death from the NUTS 0 (country level) to NUTS 3 level. Geographical and demographic information (area, population, population density, population by gender, and age category) on the NUTS 3 level is also provided^{40,41}.

The predefined categories in the fields of the FATALITIES table resulted from extensive research in the existing literature. Previous works have highlighted among FFs the role of demographics^{12,42} and victim activity²², infrastructure, the use of vehicles^{23,43,44} and vehicle types¹⁵, the victim's residence⁴², and the cause of death²². In addition, previous studies have shown the influence of environmental factors^{16,45,46} and the victim's hazardous behavior^{47,48}.

Spatial data visualization. Figure 3 shows the number of FFs at the NUTS 3 level for the examined period. The geographical distribution can indicate various environmental, climatic, and societal factors of vulnerability to flooding. Indeed, analyses published on a previous version of the database³⁶ present handy conclusions on the role of the geographical location and demographic features on flood mortality across the studied areas.

Technical Validation

Evaluation of completeness and coverage indicators. Based on several indicators, the database is evaluated regarding data completeness and coverage of FFs. The evaluation is undertaken internally, i.e., by evaluating the completeness of the data of each field and study area, and the evolution of completeness within the examined period, as well as externally, by comparing cumulative data against external sources.

FATALITIES TABLE			
DATE	VICTIM_CONDITION	ACCIDENT_PLACE	PROTECTIVE_BEHAVIOR
Year (yyyy)	By bicycle	Public/private building	Climbing trees
Month (mm)	By boat	Bridge	Driving to avoid danger
Day (dd)	By bus	Campsite/tent	Getting on roof/upper floor
AGE_STRING	By car	Riverbed/riverside	Getting out of the car
Child: 0–14 years	By caravan	Tunnel/underpass	Getting out of buildings
Boy/Girl: 15–29 years	By tractor	Countryside	Grabbing onto someone/something
Young adult: 30–49 years	By van	Ford	Moving to a safer place
Adult: 50–64 years	By other	Recreation area	Getting on the car roof
Elderly: >65 years	Laying	Road	HAZARDOUS_BEHAVIOR
GENDER	Standing	Bungalow	Check damage during the flood
M: Male	VICTIM_ACTIVITY	ACCIDENT_DYNAMICS	Driving on roads closed by police
F: Female	Traveling	Blocked in a flooded room	Fording rivers
RESIDENCY	Recreational activities	Caught in a bridge collapse	Refuse evacuation
Resident	Rescuing someone	Caught in a road collapse	Trying to rescue animals
Not resident	Sleeping	Caught in a building collapse	Refuse warnings
Tourist	Working	Dragged by water/mud	Staying on bridges
	Hunting	Fallen into the river	Staying on river banks
	Fishing	Surrounded by water/mud	Trying to save vehicles
		Hit	Trying to save belongings
		DEATH_CAUSE	
		Collapse/hearth attack	
		Drowning	
		Hypothermia	
		Electrocution	
		Poly-trauma	
		Poly-trauma and suffocation	
		Suffocation	

Table 3. Predefined drop-down menus for the FATALITIES table compilation.

Internal evaluation is intended to measure data completeness at various levels and dimensions, to indicate interannual changes, differences between the study areas, and parameters associated with low data availability.

Field completeness. Table 4 shows the percentages of missing data for each field of the FATALITIES table per study area. The following fields were excluded from the evaluation: (1) the date, which is 100% complete as it is a mandatory field, and (2) the fields of protective and hazardous behaviors, as this information is only available in cases where someone witnessed the accident. Therefore, it is unknown whether the absence of data in these fields is related to the lack of information or the non-manifested behavior.

Among the evaluated fields, the lowest percentages of missing data correspond to gender (20%), accident dynamic (20%), and cause of death (20%), while the highest is associated with victim's activity (61%). The study area of Turkey exhibits the highest proportion of missing data for the selected fields (52%), while those of Catalonia and Greece have the lowest (10%). Temporal change of field completeness

Table 5 shows the annual evolution of missing data (%) in the fields of the FATALITIES table for the total FFEM-DB area. Overall, there was a decreasing trend in missing data, which reduced from 47% in 1980 to 23% in 2020. The improvement of completeness over time reflects increased access to information, suggesting even better recording of such data in the future.

As the level of description of the FFs within FFEM-DB is very high, with 11 parameters required for the overall description of death conditions (FATALITIES table), missing values are expected. The percentage of missing values is quite large for some fields, especially at the beginning of the study period. Nevertheless, we consider all fields essential for analyzing the FF circumstances. Moreover, given the large sample, we do not consider that studies addressing the vulnerability of citizens to floods would be undermined. Regardless the acknowledged completeness trends, FFEM-DB creates an extensive dataset that allows study of flood mortality from multiple aspects (related to the different variables included), addressing the limitations mentioned in the introductory section of this study. Finally, we also expect more opportunities to fill these fields in the future through focused research and better information means.

External evaluation is based on the comparison with international databases and literature regarding the FFs coverage achieved. Finally, an evaluation through specific events that have been well-documented is performed.

FFEM-DB fields (FATALITIES table)	BAL	CAT	CYP	CZE	GER	GRE	ISR	ITA	POR	SFR	TUR	UK	FFEM-DB
Missing data (%)													
Age	0	13	29	36	42	15	52	2	38	9	65	12	39
Gender	26	7	12	7	32	2	26	2	6	3	35	3	20
Residency	26	17	100	46	58	12	42	40	29	18	31	20	33
Victim's condition	26	11	24	80	50	20	38	21	26	18	90	23	57
Victim's activity	35	23	24	70	73	25	44	33	55	44	82	38	61
Accident place	26	6	24	32	36	6	30	4	12	7	64	12	36
Accident dynamic	30	3	35	49	45	3	28	4	16	24	20	13	20
Death cause	0	1	47	10	34	0	11	3	88	1	31	0	20
Total missing data (%), per study area	21	10	37	41	46	10	34	14	34	16	52	15	36

Table 4. Percentages (%) of missing data for each field of the FATALITIES table per study area.

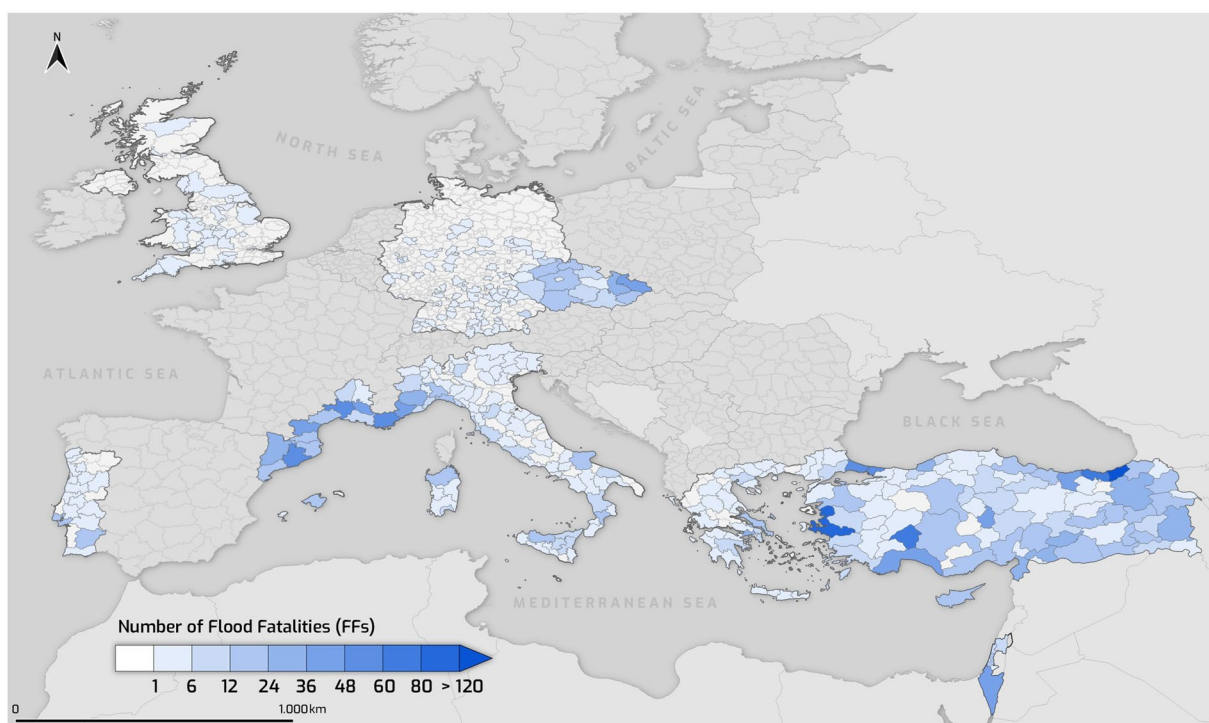


Fig. 3 Flood fatalities (FFs) at the NUTS 3 level across the FFEM-DB study areas.

Overall coverage. Comparative analysis and evaluation of FFEM-DB in relation to other disaster databases require the high spatial density of FFs data to be adapted to the spatial levels used within other study areas to ensure comparability between reported FEs among databases.

Four independent publicly accessible disaster impact databases were considered for the evaluation of FFEM-DB completeness as to the total number of FFs: the Emergency Events Database (EM-DAT)²⁰, the Dartmouth Flood Archive (DFA)⁴⁹, the European Past Floods (EPF)⁵⁰, and the Historical Analysis of Natural Hazards in Europe-HANZE-Events database (HANZE-E)⁵¹. The respective specifications are presented in online-only Table 2.

When comparing FFEM-DB with these databases, the following issues should, however, be considered:

- The external databases used for the comparison focus on catastrophic events irrespective of the occurrence of FFs, while the FFEM-DB focuses only on fatal events regardless of the overall induced societal impact of each case. Also, the information that the aforementioned databases provide about FFs is limited to the number of deaths, with no reference to the circumstances of each death.
- Each of the external databases refers to a different study period. EM-DAT is the only one covering the entire 1980–2020 period, which coincides with the FFEM-DB study period. DFA starts later (in 1985), while EPF and HANZE-E finish earlier (in 2015 and 2016, respectively).

Missing values (%)	BAL	CAT	CYP	CZE	GER	GRE	ISR	ITA	POR	SFR	TUR	UK	FFEM-DB
1980						0	40			25	48		47
1981	0		75	25	100			10			51		47
1982		29		25				17			59	25	42
1983		0			100			13	59		64		60
1984		13	50	50				6					39
1985				38		0					50		38
1986		13		38	100			16		25	44		43
1987		13		43			19	13	0		43		31
1988		5		75	52	6				22	49		42
1989	75	0				0		4	17		54	25	38
1990	75	13		31	71	24	100	13	13	25	70		60
1991		19		13	25		29	11			54		40
1992				25			34	15		12	46		16
1993		38		25	73			17		22	54		29
1994		8	100	25	100	21	88	22	19	8	53	0	29
1995		13		31	60			14		0	71		65
1996		13	13	44		10	88	12	29	16	44		36
1997		63	88	55	6	13	38	19	30		41	13	43
1998		13		48	38			19		13	67	25	59
1999		0			33			14		15	43		22
2000		2		50	8	13		13	25	25		27	15
2001			25	13	0	3	75		34	29	40		35
2002				33	67			23		20	64		49
2003		0	13	38	8	7		9		33	70	0	31
2004		0						13	19	0	37	0	26
2005		4		38	27	13		11		16	51	8	31
2006	75	0	13	23	3		21		15	6	39		30
2007	75	13		13	13	0	25		38		41	23	26
2008					16	0		8	25	0	30	17	16
2009			25	51		2		21			38	2	33
2010				47	18	0	6	16	13	13	30	0	23
2011					25			15	25	9	44	13	25
2012		0		50	13	19		13		6	41	6	27
2013				39	28	6	21	10		0	23	13	19
2014		0			29	0		12		18	46		25
2015		0		38	13	6	0	6	38	15	49	0	23
2016		0			33	5	88	8			41	0	29
2017		0			50	18		11	25		39		20
2018	2	6	13	25	25	0	3	8	25	7	38	0	12
2019		8		13		0	25	8		1	70	0	18
2020	4	5		20		15	16	22		28	33	42	23

Table 5. Percentage (%) of missing data in the fields of the FATALITIES table for each study area and the total FFEM-DB area. Note: empty cells denote years without FFs.

- The external databases report on different geographical coverage and administrative level resolutions. This characteristic affected the comparison for the FEs in BAL, CAT, and SFR as data are not available at this administrative level in the other four impact databases, although basic information on the regions that the event affected within a country is always reported. An analysis of the FEs and associated FFs for these study areas is possible with EM-DAT and HANZE-E, after a thorough study of the reported events in Spain and France.

Figure 4 shows the number of FFs in FFEM-DB and the respective estimates of the four disaster databases. Only FFs corresponding to common periods and territories are considered in each case.

As demonstrated in online-only Table 2, the disaster databases also include fatalities from phenomena other than floods but related to them, such as landslides. However, it should be noted that where possible, based on analysis of published articles, extreme landslide events included in disaster databases have been excluded from the list of the events used in the comparative analysis. For example, for ITA, three extreme landslide events were

Study area	Number of FEs with 10 or more FFs		Number of associated FFs		Difference % of FFEM-DB FFs from EM-DAT FFs
	FFEM-DB	EM-DAT	FFEM-DB	EM-DAT	
BAL	1	1	13	13	0
CAT	1	0	12	0	100
CYP	0	0	0	0	—
CZE	3	3	63	60	5
GER	1	1	22	27	−19
GRE	2	1	37	11	236
ISR	1	2	14	27	−48
ITA	7	5	123	137	−10
POR	2	1	29	19	53
SFR	8	8	192	201	−4
TUR	28	17	706	533	32
UK	0	0	0	0	—
Total (1980–2020)	54	39	1211	1028	18

Table 6. Number of high-impact FEs (with 10 or more FFs) and associated FFs in FFEM-DB and EM-DAT, for the 1980–2020 period.

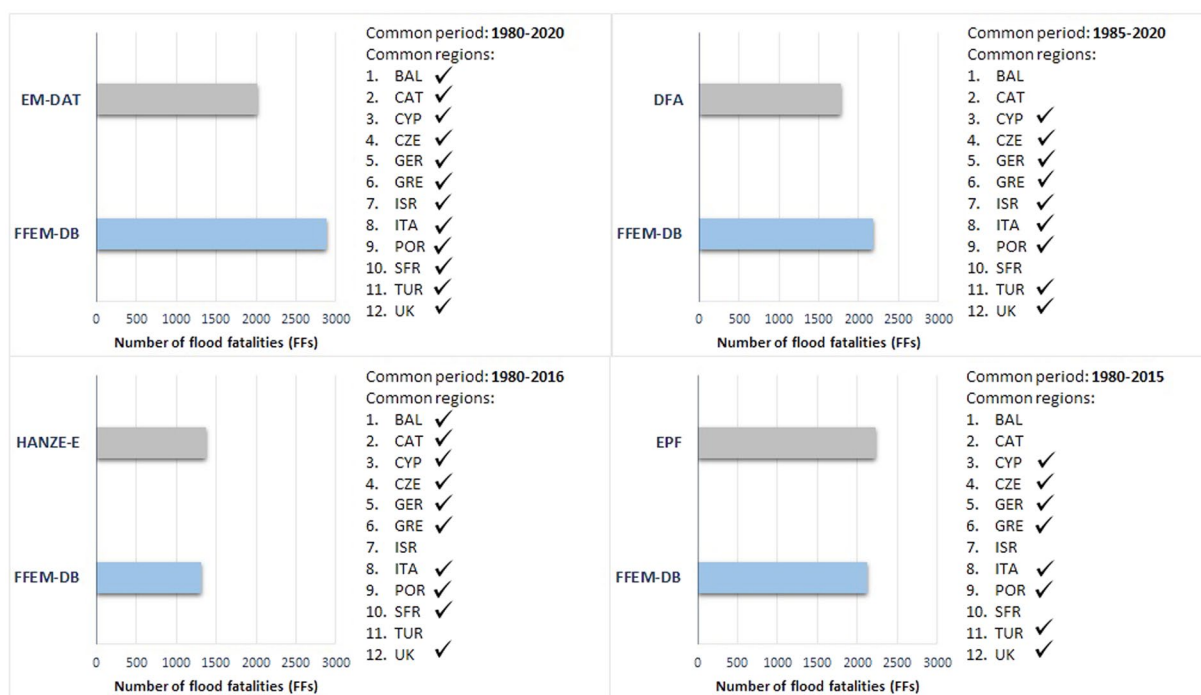


Fig. 4 Number of flood fatalities (FFs) in FFEM-DB and the respective estimates of the four disaster databases (EM-DAT, DFA, EPF, and HANZE-E).

excluded, namely the Cavalese-Stava mudflow in July 1985 that caused 329 fatalities⁵², the Giampileri landslides in October 2009 that caused 37 fatalities⁵³, and the landslide in May 1998 in Southern Italy⁵⁴ that caused 148 fatalities.

Apart from the landslide fatalities, FFEM-DB did not consider FFs resulting from storm surge, coastal water, and infrastructure failure, such as dam break. For all the above reasons, the numbers of fatalities shown in Fig. 4 are not entirely comparable. However, the results indicate the level of FFs coverage reported by FFEM-DB. In particular, FFEM-DB contains 48% and 22% more FFs than EM-DAT and DFA, respectively, which is most likely related to the non-inclusion by the latter of small-scale fatal floods. The lower number of FFEM-DB FFs compared to EPF (−5%) and HANZE-E (−4%) is a result of the inclusion of losses of life from other phenomena (e.g., rain-induced landslides), but which cannot be easily distinguished. It has to be noted that currently, FFEM-DB is available for a more extended period than HANZE-E and EPF and more territories (i.e., Turkey, Israel).

High-impact events coverage. Table 6 presents the results for the number of high-impact FEs and associated FFs per study area, derived by the two databases, FFEM-DB and EM-DAT. The EM-DAT was selected for

this comparative analysis, as it covers the whole study period and geographical area of the FFEM-DB. Choosing events with 10 or more FFs eliminates the threshold bias associated with EM-DAT's mandatory event entry criteria. The events that were specified in EM-DAT as landslides, dam breaks, or storm surge events were excluded from the comparison. Out of the 48 flood events recorded within EM-DAT (with 10 or more FFs), which concern the examined areas, 11 (23%) were excluded for the reasons mentioned above.

Overall, FFEM-DB contains 18% more FFs than EM-DAT for the FEs with 10 or more FFs. In particular, at the study area level, the comparison reveals different FF numbers for nine out of the 12 study areas. FFEM-DB includes more FFs for CAT, CZE, GRE, POR, and TUR, and less for GER, ISR, ITA, and SFR than EM-DAT. For CYP and UK, there were no FEs with more than 10 FFs; thus, they are not included in the comparison.

In the EM-DAT database, the affected Spanish regions are mentioned descriptively in each event, so it is possible to export events by region. Therefore, CAT was found to be included among other regions for two events with more than 10 FFs in June 2000 and October 2018. However, according to the literature, the June 2000 event caused five deaths in CAT⁵⁵, thus it was excluded from comparison for CAT. In the October 2018 event, all the FFs took place in Mallorca (BAL)⁵⁶. In addition, CAT was not included in the affected areas of EM-DAT in the November 1982 event, in which 14 FFs were recorded in CAT as reported by FFEM-DB and documented in relevant scientific articles^{57,58}.

For CZE, both databases include three FEs that took place during the period under review, with FFEM-DB having 5% more FFs^{59,60}.

For GER, only one FE is reported by both databases; however, the number of FF differs, 27 in EM-DAT compared to 22 in FFEM-DB (22). Careful analysis of the literature^{61,62} indicates that 20 FFs occurred, so the additional FFs in the EM-DAT are likely to reflect fatalities arising from other hazards.

For GRE, FFEM-DB includes more high-impact events, resulting in a higher number of FFs by a factor of two. The Greek FEs and FFs included in FFEM-DB have been validated through scientific publications focusing on the analysis of FFs in the country^{16,63}.

For ISR, EM-DAT includes one more high-impact FE in October 1997, when most of the 13 fatalities occurred in car accidents caused by hazardous driving conditions resulting from heavy rainfall, as reported by local media⁶⁴. According to the sources of FFEM-DB, only four FFs resulted from flooding, and therefore this FE is considered to have less than 10 FFs and is excluded from the comparison.

For ITA, FFEM-DB includes more high-impact FEs (seven) than EM-DAT (five), but a lower by 10% number of FFs. Inconsistencies were, however, found regarding the number of FFs provided by EM-DAT for some FEs. In the September 2000 flood event, EM-DAT reported 16 FFs in Soverato, Calabria, while the exact number of FFs was 13⁶⁵. In addition, the November 1994 event is classified as a river flood, when in fact, landslides occurred and were responsible for several deaths⁶⁶. Finally, the Versilia event in 1996 caused many fatalities, and while almost all of which resulted from debris flows⁶⁷, in EM-DAT they were attributed to floods.

For POR, it should be noted that the FFEM-DB only contains FEs and FFs for Portugal mainland, excluding Madeira and the Azores archipelagos. This is why the February 2010 landslide/flash flood event in Madeira⁶⁸ was excluded from this comparison. Another two events in December 1981 and January 1996 were excluded from the comparison, as both caused deaths attributed to landslides^{69,70}. Beyond that, FFEM-DB includes two high-impact FEs, with only one of them listed in EM-DAT. The number of FFs for this event is comparable among the two databases.

For SFR, FFEM-DB and EM-DAT include the same FEs, while FFEM-DB reports nine fewer FFs (−4%) than EM-DAT.

For TUR, FFEM-DB includes 29% more FFs than EM-DAT. Out of the 28 Turkish high-impact FEs included in FFEM-DB, only 13 (46%) are also reported in EM-DAT, which, however, includes four events of which the number of FFs in FFEM-DB is marginally less than 10. All TUR high-impact FEs have been cross-referenced with local databases^{71,72}.

Accuracy evaluation through specific events. To evaluate further the accuracy of FFEM-DB, the number of FFs for specific well-documented flood events was compared against those reported in international databases. For the validation, the actual number of fatalities was derived from scientific publications and/or governmental reports describing these well-known events. In online-only Table 3, we present the comparison and relevant documentation of all the notable flood events that occurred in the FFEM-DB area and study period causing more than 15 FFs, showing that FFEM-DB has more accurate values than other existing databases with regard to the number of FFs.

Comparisons with international databases showed that the FFEM-DB achieves high coverage of FFs caused by flash floods, urban floods, and river floods while giving special attention to the quality, immediacy, and reliability of the sources it draws the information from. This is supported by the variety of sources used in each country/region included in FFEM-DB and the local character of information. The closeness of the information source to the actual flood events and the cross-checking between different sources enhance the completeness, accuracy, and reliability of the overall dataset.

Usage Notes

The FFEM-DB database can be easily accessed and downloaded from the 4TU Centre for Research Data³⁹, and data can be directly used for analysis (<https://doi.org/10.4121/14754999.v2>). This database is intended to act as a large pool of publically accessible data for analysis of death circumstances over territories within the Euro-Mediterranean region. The relational structure of the database allows for analyses at the FF, study area, country, territorial, and NUTS levels. The FATALITIES table provides granular data on the FF profiles and circumstances. Each FF is further linked to geographical data (LOCATION table) and demographics at the NUTS levels (NUTS 3 table).

The data and their structure allow easy integration into databases intended to assess and analyze the societal impacts of disasters related to weather and climate. To this end, we provide, in the following, specific examples of analyses that can be applied. The extensive geographical area of the FFEM-DB dataset offers the opportunity to:

- Compare flood mortality in different geomorphological settings (e.g., flat areas of Germany or the Czech Republic against the high-inclination areas of Greece or Italy), as well as in different landcover and urbanization settings.
- Compare flood mortality and death circumstances among areas with different policies and measures aiming to address flood risk mitigation, such as through driving education, road network management, risk signage, and the adaptation of impact-based warnings.
- Examine the impact of risk mitigation policies and initiatives on flood mortality. For example, our dataset can be used to compare an area/country that uses a “turn around don’t drown” – type of awareness campaign⁴⁸ with an area/country that does not, in terms of vehicle-related flood fatalities, as a complementary criterion on the efficiency of such campaigns.

Data availability

FFEM-DB is available in the 4TU Centre for Research Data³⁹, <https://doi.org/10.4121/14754999.v2>. It includes the following files:

- a comma-separated values (csv) file, named “Fatalities.csv” that contains the structure and data of the FATALITIES Table (Table 3);
- a comma-separated values (csv) file, named “Location.csv” that contains the structure and data of the LOCATION Table (Table 2);
- a comma-separated values (csv) file, named “NUTS 3.csv” that contains the structure and data of the NUTS 3 Table (Table 2);
- the readme (txt) file, containing the description of the database structure.

Code availability

No custom code was used to generate or process the data described in the manuscript.

Received: 22 December 2021; Accepted: 23 March 2022;

Published online: 12 April 2022

References

1. Munich Re. Risks from floods, storm surges and flash floods. Underestimated natural hazard. *Munich Re* 1 (2021).
2. CRED & UNDRR. *Global trends and perspectives Executive Summary*. file:///C:/Users/asadzadeh/ISBK/Desktop/2020_The Non-COVID Year in Disasters.pdf (2021).
3. Gaume, E., Livet, M., Desbordes, M. & Villeneuve, J. P. Hydrological analysis of the river Aude, France, flash flood on 12 and 13 November 1999. *J. Hydrol.* **286**, 135–154 (2004).
4. Delrieu, G. *et al.* The catastrophic flash-flood event of 8–9 September 2002 in the Gard Region, France: A first case study for the Cévennes-Vivarais Mediterranean Hydrometeorological Observatory. *J. Hydrometeorol.* **6**, 34–52 (2005).
5. European Environment Agency. Deaths related to flooding in Europe. <https://www.eea.europa.eu/data-and-maps/figures/people-per-million-population-affected-4> (2020).
6. Cornwall, W. Europe’s deadly floods leave scientists stunned. *Scienc* 372–373, <https://doi.org/10.1126/science.373.6553.372> (2021).
7. Špitalar, M., Brilly, M., Kos, D. & Žiberna, A. Analysis of flood fatalities-Slovenian illustration. *Water (Switzerland)* **12** (2020).
8. Ruin, I., Creutin, J.-D., Anquetin, S., Grunfest, E. & Lutoff, C. Human vulnerability to flash floods: Addressing physical exposure and behavioural questions. in *Flood Risk Management: Research and Practice* 1005–1012 (2009).
9. Vinet, F., Lombroso, D., Defossez, S. & Boissier, L. A comparative analysis of the loss of life during two recent floods in France: The sea surge caused by the storm Xynthia and the flash flood in Var. *Nat. Hazards* **61**, 1179–1201 (2012).
10. Yale, J. D. *et al.* Motor Vehicle — Related Drowning Deaths Associated with Inland Flooding After Hurricane Floyd: A Field Investigation Motor Vehicle – Related Drowning Deaths Associated with Inland Flooding After Hurricane Floyd: A Field Investigation. **4**, 279–284 (2003).
11. Ahern, M., Kovats, R. S., Wilkinson, P., Few, R. & Matthies, F. Global Health Impacts of Floods: Epidemiologic Evidence Global Health Impacts of Floods: Epidemiologic Evidence. *Epiemiol Rev* **27**, 36–46 (2005).
12. Alderman, K., Turner, L. R. & Tong, S. Floods and human health: A systematic review. *Environ. Int.* **47**, 37–47 (2012).
13. de Brito, M. M., Evers, M. & Höllermann, B. Prioritization of flood vulnerability, coping capacity and exposure indicators through the Delphi technique: A case study in Taquari-Antas basin, Brazil. *Int. J. Disaster Risk Reduct.* **24**, 119–128 (2017).
14. Shimi, A., Parvin, G. A., Biswas, C. & Shaw, R. Impact and adaptation to flood A focus on water supply, sanitation and health problems of rural community in Bangladesh. *Disaster Prev. Manag. An Int. J.* **19**, 298–313 (2010).
15. Gissing, A., Opper, S., Tofa, M., Coates, L. & McAneney, J. Influence of road characteristics on flood fatalities in Australia. *Environ. Hazards* **18**, 434–445 (2019).
16. Diakakis, M. *et al.* How different surrounding environments influence the characteristics of flash flood-mortality: The case of the 2017 extreme flood in Mandra. *Greece. J. Flood Risk Manag.* **13**, 1–16 (2020).
17. Diakakis, M. & Papagiannaki, K. Characteristics of indoor flood fatalities: Evidence from Greece. *Sustain.* **13** (2021).
18. Ashley, S. T. & Ashley, W. S. Flood fatalities in the United States. *J. Appl. Meteorol. Climatol.* **47**, 805–818 (2008).
19. Fitzgerald, G., Du, W., Jamal, A., Clark, M. & Hou, X. Flood fatalities in contemporary Australia (1997–2008). *Emerg. Med. Australas.* **22**, 180–186 (2010).
20. Guha-Sapir, D., Below, R. & Hoyois, P. *EM-DAT: The CRED/OFDA International Disaster Database*. www.emdat.be (2021).
21. Hoyois, P. & Guha-sapir, D. *Three decades of floods in Europe: a preliminary analysis of EMDAT data*. (2003).
22. Jonkman, S. N. & Kelman, I. An analysis of the causes and circumstances of flood disaster deaths. *Disasters* **29**, 75–97 (2005).
23. Diakakis, M. & Deligiannakis, G. Vehicle-related flood fatalities in Greece. *Environ. Hazards* **12**, 278–290 (2013).
24. Llasat, M. C., Barnolas, M., López, L. & Altava-Ortiz, V. An analysis of the evolution of hydrometeorological extremes in newspapers: the case of Catalonia, 1982–2006. *Nat. Hazards Earth Syst. Sci.* **9**, 1201–1212 (2009).
25. Pereira, S., Zêzere, J. L., Quaresma, I., Santos, P. P. & Santos, M. Mortality Patterns of Hydro-Geomorphologic Disasters. *Risk Anal.* **36**, 1188–1210 (2016).

26. NWS. Preliminary US Flood Fatality Statistics. *National Weather Institut* <https://www.weather.gov/arx/usflood> (2021).
27. Llasat, M. C. *et al.* Towards a database on societal impact of Mediterranean floods within the framework of the HYMEX project. *Nat. Hazards Earth Syst. Sci.* **13**, 1337–1350 (2013).
28. Papagiannaki, K., Lagouvardos, K. & Kotroni, V. A database of high-impact weather events in Greece: a descriptive Atmospheric impact analysis for the period 2001–2011. *Nat. Hazards Earth Syst. Sci.* **13**, 727–736 (2013).
29. Pereira, S., Diakakis, M., Deligiannakis, G. & Zêzere, J. L. Comparing flood mortality in Portugal and Greece (Western and Eastern Mediterranean). *Int. J. Disaster Risk Reduct.* **22**, 147–157 (2017).
30. Grimalt, M. & Rosselló, J. InunIB: Analysis of a flood database for the Balearic Islands. *Eur. J. Geogr.* **11**, 6–21 (2020).
31. de Brito, M. M., Kuhlicke, C. & Marx, A. Near-real-time drought impact assessment: a text mining approach on the 2018 / 19 drought in OPEN ACCESS Near-real-time drought impact assessment: a text mining approach on the 2018 / 19 drought in Germany. *Environ. Res. Lett.* **15**, 1040a9 (2020).
32. Salvati, P., Bianchi, C., Rossi, M. & Guzzetti, F. Perception of flood and landslide risk in Italy: A preliminary analysis. *Nat. Hazards Earth Syst. Sci.* **10**, 2589–2603 (2014).
33. Salvati, P., Bianchi, C., Rossi, M. & Guzzetti, F. Societal landslide and flood risk in Italy. *Nat. Hazards Earth Syst. Sci.* **10**, 465–483 (2010).
34. Guzzetti, F. & Tonelli, G. Information system on hydrological and geomorphological catastrophes in Italy (SICI): a tool for managing landslide and flood hazards. *Nat. Hazards Earth Syst. Sci.* **4**, 213–232 (2004).
35. Petrucci, O. & Polemio, M. The use of historical data for the characterisation of multiple damaging hydrogeological events. *Nat. Hazards Earth Syst. Sci.* **3**, 17–30 (2003).
36. Petrucci, O. *et al.* MEFF: The database of Mediterranean Flood Fatalities (1980 to 2015). *J. Flood Risk Manag.* **12** (2019).
37. Niwattanakul, S., Singthongchai, J., Naenudorn, E. & Wanapu, S. Using of Jaccard Coefficient for Keywords Similarity. in *Proceedings of the International MultiConference of Engineers and Computer Scientists 2013 Vol I, IMECS 2013 I 1–4* (2013).
38. Petrucci, O. *et al.* Flood Fatalities in Europe, 1980–2018: Variability, Features, and Lessons to Learn. *Water (Switzerland)* **11**, 1682 (2019).
39. Petrucci, O. *et al.* FFEM-DB Database of Flood Fatalities from the Euro-Mediterranean region. *4TU.ResearchData* <https://doi.org/10.4121/14754999.v2> (2021).
40. Eurostat. *Nomenclature of Territorial Units for Statistics*, Eurostat. (2020).
41. CBS. *Population by population group, religion, sex and age*. (2020).
42. Terti, G., Ruin, I., Anquetin, S. & Gourley, J. J. A situation-based analysis of flash flood fatalities in the United States. *Bull. Am. Meteorol. Soc.* **98**, 333–345 (2017).
43. Drobot, S. D., Benight, C. & Grunfest, E. C. Risk factors for driving into flooded roads. *Environ. Hazards* **7**, 227–234 (2007).
44. Ahmed, M. A., Haynes, K., Tofa, M., Hope, G. & Taylor, M. Duty or safety? Exploring emergency service personnel's perceptions of risk and decision-making when driving through floodwater. *Prog. Disaster Sci.* **5**, 100068 (2020).
45. Vinet, F., Boissier, L. & Saint-Martin, C. Flash flood-related mortality in southern France: First results from a new database. *E3S Web Conf.* **7** (2016).
46. Papagiannaki, K., Diakakis, M., Kotroni, V., Lagouvardos, K. & Papagiannakis, G. The role of water depth perception in shaping car drivers' intention to enter floodwaters: Experimental evidence. *Sustain.* **13**, 1–14 (2021).
47. Hamilton, K., Peden, A. E., Pearson, M. & Hagger, M. S. Stop there's water on the road! Identifying key beliefs guiding people's willingness to drive through flooded waterways. *Saf. Sci.* **89**, 308–314 (2016).
48. Hamilton, K., Peden, A. E., Keech, J. J. & Hagger, M. S. Changing people's attitudes and beliefs toward driving through floodwaters: Evaluation of a video infographic. *Transp. Res. Part F Traffic Psychol. Behav.* **53**, 50–60 (2018).
49. Brakenridge, G. R. *Global Active Archive of Large Flood Events*. <http://floodobservatory.colorado.edu/Archives/> (2021).
50. European Environment Agency. *Flood phenomena. European past floods*. <https://www.eea.europa.eu/data-and-maps/data/european-past-floods/flood-phenomena> (2015).
51. Paprotny, D., Morales-nápoles, O. & Jonkman, S. N. HANZE: a pan-European database of exposure to natural hazards and damaging historical floods since 1870. *Earth Syst. Sci. Data* **10**, 565–581 (2018).
52. Luino, F. & Graff, D. J. V. The Stava mudflow of 19 July 1985 (Northern Italy): A disaster that effective regulation might have prevented. *Nat. Hazards Earth Syst. Sci.* **12**, 1029–1044 (2012).
53. Ardizzone, F. *et al.* Landslide inventory map for the Briga and the Giampilieri catchments, NE Sicily, Italy. *J. Maps* **8**, 176–180 (2012).
54. Cascini, L., Cuomo, S. & Guida, D. Typical source areas of May 1998 flow-like mass movements in the Campania region, Southern Italy. *Eng. Geol.* **96**, 107–125 (2008).
55. Llasat, M. D. C., Rigo, T. & Barriendos, M. The 'Montserrat-2000' flash-flood event: A comparison with the floods that have occurred in the Northeastern Iberian Peninsula since the 14th century. *Int. J. Climatol.* **23**, 453–469 (2003).
56. Grimalt-gelabert, M., Rosselló-Geli, J. & Bauzá-Llinàs, J. Flood related mortality in a touristic island: Mallorca (Balearic Islands) 1960–2018. *J. Flood Risk Manag.* **13**, 1–13 (2020).
57. Trapero, L., Bech, J., Duffourg, F., Esteban, P. & Lorente, J. Mesoscale numerical analysis of the historical November 1982 heavy precipitation event over Andorra (Eastern Pyrenees). *Nat. Hazards Earth Syst. Sci.* **13**, 2969–2990 (2013).
58. Llasat, M. C. *et al.* Flash flood evolution in North-Western Mediterranean. *Atmos. Res.* **149**, 230–243 (2014).
59. Brázdil, R., Chroma, K. & Dolák, L. Rehor, J., Reznichova, L., Zahradníček, P. & Dobrovolný, P. Fatalities associated with the severe weather conditions in the Czech Republic, 2000–2019. *Nat. Hazards Earth Syst. Sci.* **21**, 1355–1382 (2021).
60. Brázdil, R. *et al.* Potential of Documentary Evidence to Study Fatalities of Hydrological and Meteorological Events in the Czech Republic. *Water (Switzerland)* **11** (2019).
61. Weichselgartner, J. & Breiviere, E. The 2002 Flood Disaster in the Elbe Region, Germany: A Lack of Context-sensitive Knowledge. in *Dynamics of Disaster: Lessons on Risk, Response, and Recovery* (ed. Rachel A., Dowty, B. L. A.) 141–157 (Earthscan, 2011).
62. DKKV. *Flood Risk Reduction in Germany Lessons Learned from the 2002 Disaster in the Elbe Region*. (Deutsches Komitee für Katastrophenvorsorge e.V. (DKKV), 2004).
63. Diakakis, M. & Deligiannakis, G. Flood fatalities in Greece: 1970–2010. *J. Flood Risk Manag.* **10**, 115–123 (2017).
64. The Jewish News of Northern California. Flash floods claim 11 lives in Israel during Sukkot. <https://www.jweekly.com/1997/10/24/flash-floods-claim-11-lives-in-israel-during-sukkot/> (1997).
65. Aceto, L., Pasqua, A. A. & Petrucci, O. Effects of damaging hydrogeological events on people throughout 15 years in a Mediterranean region. *Adv. Geosci.* **44**, 67–77 (2017).
66. Luino, F. & Padano, B. The Flood and Landslide Event of November 4–6 1994 in Piedmont Region (Northwestern Italy): Causes and Related Effects in Tanaro Valley. *Phys Chem Earth* **24**, 123–129 (1999).
67. Hungr, O., Leroueil, S. & Picarelli, L. The Varnes classification of landslide types, an update. *Landslides* **11**, 167–194 (2014).
68. Haque, U. *et al.* Fatal landslides in Europe. *Landslides* **13**, 1545–1554 (2016).
69. Zêzere, J. L. *et al.* DISASTER: a GIS database on hydro-geomorphologic disasters in Portugal. *Nat Hazards* **72**, 503–532 (2014).
70. Pereira, S., Ramos, A. M., Rebelo, L., Trigo, R. M. & Zêzere, J. L. Advances in Water Resources A centennial catalogue of hydro-geomorphological events and their atmospheric forcing. *Adv. Water Resour.* **122**, 98–112 (2018).
71. Koc, G. & Thielen, A. H. The relevance of flood hazards and impacts in Turkey: What can be learned from different disaster loss. *Nat Hazards* **91**, 375–408 (2018).

72. Koç, G., Petrow, T. & Thieken, A. H. Analysis of the most severe flood events in Turkey (1960–2014): Which triggering mechanisms and aggravating pathways can be identified? *Water (Switzerland)* **12** (2020).
73. Llasat, M. C., Marcos, R., Turco, M., Gilabert, J. & Llasat-Botija, M. Trends in flash flood events versus convective precipitation in the Mediterranean region: The case of Catalonia. *J. Hydrol.* **541**, 24–37 (2016).
74. Inbar, M. Natural Hazards in Israel, 1948–2004: A Temporal and Spatial Analysis Author (s): Moshe Inbar Contemporary Israeli Geography / תב נמז י תב נמז ו אג ת י ל א ר ש י תב נמז ; (2004 - ד - ס ש ת) , Stable <https://www.jstor.org/stable/23712691> Natural Hazards in. in *Contemporary Israeli Geography* (eds. Maos, J. O., Inbar, M. & Shmueli, D. F.) 139–146 (2004).
75. Salvati, P. *et al.* Gender, age and circumstances analysis of flood and landslide fatalities in Italy. *Sci. Total Environ.* **610–611**, 867–879 (2018).
76. Antoine, M. J., Desailly, M. B. & Gazelle, M. F. Les crues meurtrières, du Roussillon aux Cévennes. *Ann. Geogr.* **622**, 597–623 (2001).
77. Geoscience Consultants. *Mise en sécurité des populations exposées à des risques de crues et d'inondations.* (Ministere de l'Aménagement du territoire et de l'Environnement, 1995).
78. Boissier, L. La mortalité liée aux crues torrentielles dans le Sud de la France: une approche de la vulnérabilité humaine face à l'inondation. (Université Paul Valéry - Montpellier III, 2013).
79. Rezáč, F., Rezáč, M. & Nekovář, T. State aid following natural disasters. *Acta Univ. Agric. Silvic. Mendelianae Brun.* **LIX**, 411–420 (2011).
80. Kreibich, H. & Merz, B. Elbe floods 2002 - Interdisciplinary Lessons Learned study. in *Workshop on Integrated Water Research and Water Management* (2004).
81. Diakakis, M. *et al.* An integrated approach of ground and aerial observations in flash flood disaster investigations. The case of the 2017 Mandra flash flood in Greece. *Int. J. Disaster Risk Reduct.* **33**, 290–309 (2019).
82. Inspector General of Public Administration. *Findings of Inspector's General of Public Administration investigation on the flood of Mandra (15-11-2017).* (2017).
83. Cossu, A., Waele, J., De, Sanna, F. & Sanna, L. Preliminary estimation of the peak discharge at the Su Gologone spring (Central-East Sardinia) during the flood event of November 18th, 2013. *Geophysical Research Abstracts* **16**, 15708 (2014).
84. Righini, M. *et al.* Geomorphic response to an extreme flood in two Mediterranean rivers (northeastern Sardinia, Italy): analysis of controlling factors. *Geomorphology* **290**, 184–199 (2017).
85. Regione Piemonte. *Eventi Alluvionali in Piemonte. 2–6 novembre 1994, 8 luglio 1996, 7–10 ottobre 1996.* (1998).
86. Trigo, R. M. *et al.* The deadliest storm of the 20th century striking Portugal: Flood impacts and atmospheric circulation. *J. Hydrol.* **541**, 597–610 (2015).
87. Prakash, N. & Manconi, A. Rapid Mapping of Landslides Triggered by the Storm Alex, October 2020. in *IEEE International Geoscience and Remote Sensing Symposium* 1808–1811, <https://doi.org/10.1109/igarss47720.2021.9553321> (IEEE, 2021).
88. Caumont, O. *et al.* The heavy precipitation event of 14–15 October 2018 in the Aude catchment: A meteorological study based on operational numerical weather prediction systems and standard and personal observations. *Nat. Hazards Earth Syst. Sci.* **21**, 1135–1157 (2021).
89. Saint-Martin, C., Fouchier, C., Javelle, P., Douvinet, J. & Vinet, F. Assessing the exposure to floods to estimate the risk of flood-related damage in French Mediterranean basins. *E3S Web Conf.* **7** (2016).
90. Ruin, I., Creutin, J. & Anquetin, S. Human exposure to flash floods – Relation between flood parameters and human vulnerability during a storm of September 2002 in Southern France. *J. Hydrol.* **361**, 199–213 (2008).
91. Vinet, F. Flood risk assessment and management in France: the case of Mediterranean basins. in *WIT Transactions on State of the Art in Science and Engineering* **50** 105–132 (WIT Press, 2011).
92. Anisimov, A. Exploring vulnerability to disaster risks and attributing responsibilities for the consequences: Revisiting the Xynthia storm coastal floods and public trial in France. (Institut Polytechnique de Paris (ED IP Paris), 2020).
93. Gilbert, C. & Gouy, C. Flood management in France. in *Flood Response and Crisis Management in Western Europe: A Comparative Analysis* (eds. Rosenthal, U. & Hart, P. T.) 15–56 (Springer, 1998).
94. Turkoglu, N. Analysis of floods occurred on October 31–November 1, 2006 in Southeast Anatolia region. *Nat Sci* **4**, 243–254 (2009).
95. Kömüscü, A. Ü. & Çelik, S. Analysis of the Marmara flood in Turkey, 7–10 September 2009: An assessment from hydrometeorological perspective. *Nat. Hazards* **66**, 781–808 (2013).
96. Turoglu, H. İstanbul'da Meydana Gelen Sel ve Taşkınlar. *Fiz. Coğraf. Aras, tirmaları, Sist. ve Bolgesel, Turk Coğraf. Kurumu Yayınları* **5**, 411–430 (2011).
97. Ceylan, A., Alan, I. & Ugurlu, A. Causes and effects of flood hazards in Turkey. in *International congress of river basin management* 22–24 (2007).
98. Yüksek, Ö., Kankal, M. & Üçüncü, O. Assessment of big floods in the Eastern Black Sea Basin of Turkey. *Environ. Monit. Assess.* **185**, 797–814 (2013).
99. Sahin, K. *Carsamba Ovası ve yakın çevresinde sel afeti (27 Mayıs 2000).* <http://dergipark.ulakbim.gov.tr/tcd/article/download/1074000194/1074000187> (2002).
100. Ozden, A. T. Evaluation of post-disaster housing in Senirkent. (Istanbul Teknik Üniversitesi, 2004).

Acknowledgements

This work has been funded by project EXCLIMATE-GR (Grant Agreement: G-2111-63060) financed by the European Climate Foundation. Dr. Neil Macdonald was supported by an AHRC grant (AH/V003569/1).

Author contributions

Katerina Papagiannaki: Coordination, original manuscript writing, data handling, data collection. Olga Petrucci: Original manuscript writing, database management, data handling, data collection. Michalis Diakakis: Original manuscript writing, data collection, literature review. Vassiliki Kotroni: Manuscript review, data collection. Luigi Aceto: Manuscript review, data collection. Cinzia Bianchi: Manuscript review, data collection. Rudolf Brázdil: Manuscript review, data collection. Miquel Grimalt Gelabert: Manuscript review, data collection. Moshe Inbar: Manuscript review, data collection. Abdullah Kahraman: Manuscript review, data collection. Özgenur Kılıç: Manuscript review, data collection. Astrid Krahn: Manuscript review, data collection. Heidi Kreibich: Manuscript review, data collection. Maria Carmen Llasat: Manuscript review, data collection. Montserrat Llasat-Botija: Manuscript review, data collection. Neil Macdonald: Manuscript review, data collection. Mariana Madruga de Brito: Manuscript review, data collection. Michele Mercuri: Database management, manuscript review, data collection. Susana Pereira: Manuscript review, data collection. Jan Řehoř: Manuscript review, data collection. Joan Rossello Geli: Manuscript review, data collection. Paola Salvati: Manuscript review, data collection. Freddy Vinet: Manuscript review, data collection. José Luis Zêzere: Manuscript review, data collection.

Competing interests

The authors declare no competing interests.

Additional information

Correspondence and requests for materials should be addressed to K.P.

Reprints and permissions information is available at www.nature.com/reprints.

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.



Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this license, visit <http://creativecommons.org/licenses/by/4.0/>.

© The Author(s) 2022