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

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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 floods3,4, causing substantial loss

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of human life\(^5\), with the river floods of July 2021 resulting in more than 200 fatalities\(^6\), 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 datasets\(^7\) 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 typology\(^15\), types of environments or settings\(^16\), housing types\(^17\), 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 Ashley\(^18\) 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-DAT\(^20\), 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 events\(^21\).

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\(^5\)–\(^22\),\(^23\). 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
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 FFs24–26, indicate the impact of damaging weather events on a local scale27–31, explore the evolution of perception of natural hazards24,32, and validate hazard maps33–35.

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.

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).

| Study area (acronym) | Area (km²) | Area (% of total) | NUTS 2 (number of units) | Population (inhabitants) | Population (% of total) | Population density (inh./km²) |
|----------------------|------------|-------------------|--------------------------|--------------------------|-------------------------|-----------------------------|
| 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 2. Structure of the relational FFEM-DB database. *String objects, **Primary key, ***Foreign Key.
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 collection 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 coefficient. 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. The update occurs on average every two years. It was developed in its original composition in 2017 (MEFF version 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 version). 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 Data. 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 level.

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)
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.

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 and victim activity, the use of vehicles and vehicle types, the victim’s residence, and the cause of death. In addition, previous studies have shown the influence of environmental factors and the victim’s hazardous behavior.

**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 database 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.
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.

### FATALITIES TABLE

| VICTIM_CONDITION | ACCIDENT_PLACE | PROTECTIVE_BEHAVIOR |
|------------------|----------------|----------------------|
| DATE             |                |                      |
| 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       |                |                      |
| Child: 0–14 years| By caravan     | Riverbed/riverside   | Getting out of the car |
| Boy/Girl: 15–29 years | By tractor | Tunnel/underpass | Getting out of buildings |
| Young adult: 30–49 years | By van | Country side | Grabbing onto someone/something |
| Adult: 50–64 years| By other       | Recreation area      | Getting on the car roof |
| Elderly: >65 years| Laying         | Road                 | HAZARDOUS_BEHAVIOR |
| GENDER           |                |                      |
| M: Male          | VICTIM_ACTIVITY | ACCIDENT_DYNAMICS   |
| F: Female        | Traveling      | Blocked in a flooded room | Fording rivers |
| RESIDENCY        |                |                      |
| Resident         | Recreational activities | Caught in a bridge collapse | Refuse evacuation |
| 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              |                |                      |
| 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.
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 FFs 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)\textsuperscript{20}, the Dartmouth Flood Archive (DFA)\textsuperscript{49}, the European Past Floods (EPF)\textsuperscript{50}, and the Historical Analysis of Natural Hazards in Europe-HANZE-Events database (HANZE-E)\textsuperscript{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 HANZ-E finish earlier (in 2015 and 2016, respectively).

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

| 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                | 28  | 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   | 38  | 1   | 31  | 0   | 20     |
| Total missing data (%) per study area | 21  | 10  | 37  | 41  | 46  | 10  | 34  | 14  | 34  | 16  | 52  | 15  | 36     |

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

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.

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

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
excluded, namely the Cavalese-Stava mudflow in July 1985 that caused 329 fatalities, the Giampilieri landslides in October 2009 that caused 37 fatalities, and the landslide in May 1998 in Southern Italy 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 the 1980–2020 period.

| Study area | Number of FEs with 10 or more FFs | Associated FFs | Difference % of FFEM-DB FFs from EM-DAT |
|------------|-----------------------------------|----------------|----------------------------------------|
| BAL        | 1                                 | 13             | 0                                      |
| CAT        | 1                                 | 12             | 0                                      |
| CYP        | 0                                 | 0              | —                                      |
| CZE        | 3                                 | 63             | 5                                      |
| GER        | 1                                 | 22             | −19                                    |
| GRE        | 2                                 | 37             | 236                                    |
| ISR        | 1                                 | 14             | −48                                    |
| ITA        | 7                                 | 123            | −10                                    |
| POR        | 2                                 | 29             | 53                                      |
| SFR        | 8                                 | 192            | −4                                      |
| TUR        | 28                                | 706            | 32                                      |
| UK         | 0                                 | 0              | —                                      |
| Total (1980–2020) | 54                                | 1211           | 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).
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 FFs 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 CAT, thus it was excluded from comparison for CAT. In the October 2018 event, all the FFs took place in Mallorca (BAL). 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.

For CZE, both databases include three FEIs that took place during the period under review, with FFEM-DB having 5% more FFs. 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 indicates that 20 FFs occurred, so the additional FFs in the EM-DAT are likely to reflect fatalities arising from other hazards.

For ITA, FFEM-DB includes more high-impact events, resulting in a higher number of FFs by a factor of two. The Greek FEIs and FFs included in FFEM-DB have been validated through scientific publications focusing on the analysis of FFs in the country. 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 media. 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 POR, it should be noted that the FFEM-DB only contains FFs and FEIs for Portugal mainland, excluding Madeira and the Azores archipelagos. This is why the February 2010 landslide/flash flood event in Madeira 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. Beyond that, FFEM-DB includes two high-impact FEIs, 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 FEIs, 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 FFIs 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 FFIs have been cross-referenced with local databases.

**Accuracy evaluation through specific events.** To evaluate further the accuracy of FFEM-DB, the number of FFIs 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 FFIs.

Comparisons with international databases showed that the FFEM-DB achieves high coverage of FFIs 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 Data, and data can be directly used for analysis. 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 campaign 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 Data, https://doi.org/10.4121/14754999.v2). It includes the following files:

a) a comma-separated values (csv) file, named “Fatalities.csv” that contains the structure and data of the FATALITIES Table (Table 3);

b) a comma-separated values (csv) file, named “Location.csv” that contains the structure and data of the LOCATION Table (Table 2);

c) a comma-separated values (csv) file, named “NUTS 3.csv” that contains the structure and data of the NUTS 3 Table (Table 2);

d) 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.

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Competing interests
The authors declare no competing interests.

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