DamaGIS: a multisource geodatabase for collection of flood-related damage data

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Abstract. The present paper introduces a new database for collection of flood-related damage and assessment at the local scale. Every year in France, recurring flood events result in several million Euros of damage, and reducing the heavy consequences of floods has become a high priority. However, actions to reduce the impact of floods are often hindered by the lack of damage data on past flood events. Even if partial data were available, data sharing within the research community is very limited and closely supervised to ensure the protection of individuals' personal information. In comparison, the growth of social and online media has provided access to broad information at the local and global scales. Therefore, the DamaGIS database offers an innovative bottom-up approach to gather and identify damage data from multiple sources, including new media. This paper also presents an easily reproducible method to assess the severity of flood damage. The DamaGIS database is available at https://doi.org/10.5281/zenodo.1186623.

1 Introduction

Floods are the most damaging natural hazard in the world. Between 1995 and 2015, they affected more than 2.3 billion people and caused about $662 billion in damage around the world (Wallemacq, Guha-Sapir, McClean, Cred, & Unisdr, 2015). Although the current situation is already alarming, different studies have estimated that the socio-economic impact of river floods will more than triple by the end of the century, due to climate change (Alfieri, Feyen, Dottori, & Bianchi, 2015; Pigeon, 2002).

To date in France, the insurance trade associations have estimated the total cost of flood-related damage at 1–1.4 billion Euros a year (Bourguignon, 2014). For example, floods in the Alpes-Maritimes area in October 2015 resulted in 20 fatalities and a total amount of estimated damage greater than 600 million Euros (Caisse Centrale de Réassurance, 2017; Saint Martin, Fouchier, Javelle, Douvinet, & Vinet, 2016). More recently, from May to June 2016, large parts of the Parisian basin were also flooded. More than 2000 municipalities were affected by this event for a total cost of damage to insured goods higher than 1.4 billion Euros (CCR, 2016; Ramos, Perrin, Andréassian, Olivier Delaigue, & Viatgé, 2017; Van Oldenborgh et al., 2016).

In 2015, the Sendai Framework for Disaster Risk Reduction defined four new priorities for action to reduce the impact of disasters around the world. On this occasion, the need to "Systematically evaluate, record, share and publicly account for

disaster losses" (UNISDR, 2015) was acknowledged as a major priority. It has been shown that the collection of loss data would help to increase knowledge on disasters, including floods, and thereby reduce their consequences (D. Molinari, Menoni, & Ballio, 2017).

1.1 Damage data collection

5 Although the word "damage" is usually defined as physical harm caused to an object, the concept of "flood damage" may refer to a wide range of items. There is a common understanding that flood damage can be described as direct or indirect as well as tangible or intangible (D. J. Parker, 2000). We may refer to the notion of direct damage if caused by contact with flood water. On the other hand, tangible damage results if damage can be measured in monetary values and thus objectively quantified (D. Parker, Green, & Thompson, 1987; Smith & Ward, 1998). This paper only focuses on direct and tangible damage data to

10 enable the assessment of damage severity.

However, the need for a comprehensive and inclusive flood damage database has been underlined by many authors over the years (Bubeck, De Moel, Bouwer, & Aerts, 2011; Dilley, 2005; Elmer, 2012; Gerl, Kreibich, Franco, Marechal, & Schröter, 2016; Mileti, 1999; NRC, 1999). The most prominent disaster-related damage databases used today are EM-DAT and NatCat (Kron, Steuer, Löw, & Wirtz, 2012). The Emergency Events Database (EM-DAT) is a free and worldwide database on

15 disaster-related damage using multiple sources (Guha-Sapir, Below, & Hoyois, 2015; Hoyois & Guha-Sapir, 2003). It contains information on fatalities and costs resulting from more than 20,000 disasters which have occurred since 1900**.** However, EM-DAT is only available at a country level and does not offer information on the type of damage. The Munich RE NatCat private database also provides information on the natural disasters that have taken place since AD 79 around the world. It also provides information on damage costs and fatalities per flood event at a regional scale, which is more precise than the EM-DAT database

20 (Guha-Sapir & Below, 2002). However, information on the type of flood damage is still lacking.

It is fair to say that the United States is years ahead of the rest of the world with regard to disaster-related damage data processing (Tschoegl, Below, & Guha-Sapir, 2006). For instance, the American National Oceanic and Atmospheric Administration (NOAA) provides a database on flood fatalities and costs caused by weather events since 1903 at a county level, called the Storm Events Database (Downton, Miller, & Pielke Jr, 2005; National Climatic Data Cente, 2015). SHELDUS

25 (Spatial Hazard Events and Losses Database for the United States) is another county-level hazard database for the United States (Hazards & Vulnerability Research Institute, 2013). Unlike NOAA's Storm Events database, which is foremost interested in weather events independently of loss, SHELDUS focuses on loss data. Between 2008 and 2010, an experiment was also conducted by one of NOAA's laboratories to collect specific data on flash floods called the Severe Hazards Analysis and Verification Experiment (SHAVE) (Calianno, Ruin, & Gourley, 2013; Gourley et al., 2013; Ortega et al., 2009).

30 In Europe, several countries have implemented their own databases on flood damage at the national scale. Germany has the HOWAS21 database (Kreibich, Thieken, Haubrock, & Schröter, 2017), Switzerland the Swiss Flood and Landslide Damage Database (Kron et al., 2012) and Italy the FloodCat database (Daniela Molinari, Legnani, di Lecco, & Di Architettura, 2013). In France today, neither an easily accessible nor a complete database on flood-related damage is available at the local scale.

However, an initiative was launched to this effect in 1976 by the French Ministry of Environment, although it did not yield a concrete outcome, as suggested in D. Molinari et al. (2017).

The French GASPAR database is available at the municipal scale. However, it only contains information on whether or not a municipality has been damaged by a flood and provides no information on damage type or severity. Although insurance companies have been collecting accurate data on flood damage, they only disseminate synthetic data at the department level (through ONRN http://www.onrn.fr/site/) or for major events only (through https://erisk.ccr.fr/faces/erisk-accueil.jsp website). The respect of privacy rights and/or commercial confidentiality makes it difficult to openly communicate information such as damage to private housing. However, even insurance companies do not have access to complete flood damage data. Their data only concern private households and business premises, excluding all information on public infrastructures.

Emergency services also have time-stamped and localised records of their operations during flood events such as rescue services or emergency pumping. However, there are no established standards on how to collect and organise those data at the national scale. This might make them difficult to aggregate but also to use and analyse from one location to another. Moreover, this heterogeneity as well as the confidentiality of these data add to the complexity of acquiring them.

This review of the existing databases on flood-related damage at different scales has made it possible to identify the shortcomings and the requirements that need to be addressed in order to implement a new database. Initiatives in other countries have appeared to fill the gap of existing databases (LLasat et al., 2013). This paper presents a new database, called the DamaGIS database, which compiles and structures flood-related damage in the South of France. It is a new approach which aims to provide fine-scale damage data and a preliminary assessment of its severity.

1.2 Structure of the paper

Although it is not fully comprehensive, DamaGIS provides an increased database for flood-related damage combined with an assessment of damage severity. This database has only been implemented in the South of France for now, but this paper initiates a new approach to characterise, organise and share flood damage data at a fine scale. This paper contains the necessary information to understand, use and continue completing the DamaGIS database.

First in Section 2, the characteristics of the DamaGIS database are introduced along with its content and organisation. Section 3 presents and explains the damage rating method used within the database. In Section 4, an analysis of the damage contents is provided. Section 5 presents the benefits, limitations and perspectives of the DamaGIS database.

2 The DamaGIS database

2.1 Sources of information

DamaGIS is a community-based and multisource database for object-specific flood damage caused by river floods. Since 2011, direct and tangible damage caused by flash floods in the South of France has been systematically collected in the DamaGIS

5 database. To this aim, numerous sources of information have been used for comprehensiveness purposes:

- Corporate website,
- Personal blog,
- Video-sharing website (Youtube, Dailymotion),
- Local authorities,
10 - Public administrations,
- On-site observation,
- Social network media (Facebook, Twitter),
- Online media.

To ensure data reliability, a direct web link to the sources of information is added to the database for each damage occurrence.

15 For now, DamaGIS data have been manually entered by a small group of people, a very time-consuming process. This bias will be corrected by means of multiple contributors. The objective for the database is to evolve into participatory functioning. However, data may also be directly bought from social media companies using keywords and an area with a given radius. In this case, substantial extra costs should be taken into consideration.

The various sources of DamaGIS damage data were analysed (**Figure 1**) to highlight the prominence of new media, accounting

20 for three-quarters of the data collected (75%). New media can be defined as the sources of information shared using digital technology such as blogs, social media, online media and websites. Using these new media makes it possible to obtain information at a fine scale where traditional media are not always present.

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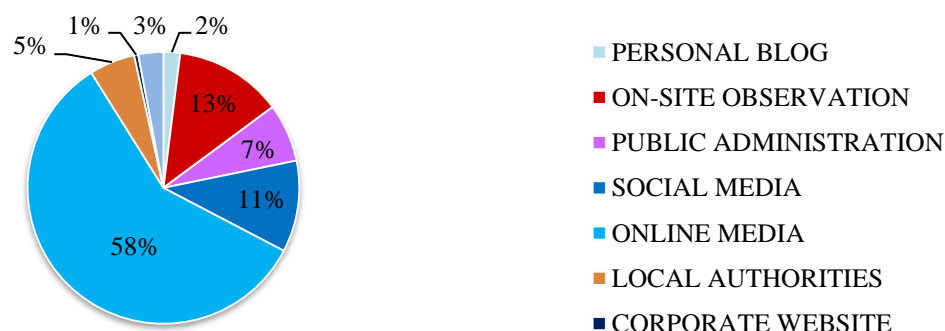


Figure 1: Distribution of data sources in the DamaGIS database for the 2011–2016 period. New media are represented in shades of blue.

Among the new media, social media hold a prominent place. They can be defined as "a group of Internet-based applications that build on the ideological and technological foundations of Web 2.0, and that allow the creation and exchange of user-generated content" (Kaplan & Haenlein, 2010). The rise of social media enables direct access to damage data from the people who are present during or after a flood event (Dashti et al., 2014) (**Figure 2**). Sources of information are therefore multiplied. This is a way to counterweigh the overrepresentation of large or more impacted cities during and after floods (Douvinet & Vinet, 2012).

Information on flood damage is collected in new media entering flood-related keywords in search engines. Then the outcomes are sorted from the most recent to the oldest to be assessed. When information is considered relevant with a precise location, it is added to the database. To obtain precise information on damage location, an extensive photographic recognition task was completed for non localised damage. This means deducing the location of a damaged element from a picture, using easily recognisable items such as road signs, store fronts, vegetation, etc.

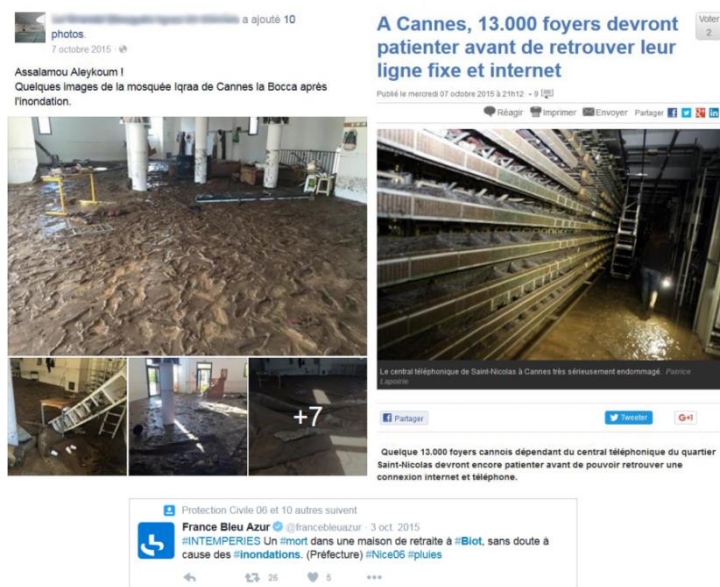



Figure 2: Example of flood-related damage information publicly available in new media (from left to right: screenshot of the Facebook page of a Mosque in Cannes, screenshot from the Nice Matin Journal website, screenshot of a tweet from the France Bleu Azur Radio).

2.2 Structure of the database

From the different sources presented in the previous section, we extract what we call "damage data". It consists of information on damaged elements, with a time-stamp and a location. Each damaged element corresponds to a single object organised within the DamaGIS database, implemented as a geodatabase in the ArcGIS software to have a vectorial format for data tables in the

form of feature classes. DamaGIS is based on a system with three feature classes interconnected by keys. The conceptual data model which organises this system is presented in **Figure 3**. Each damage entry is related to a row within the DAMAGE feature class and is connected to a single BASIN feature and a single EVENT feature. However, one EVENT feature might refer to several damage entries and one BASIN feature might be connected to several DAMAGE entries. However, there is no

5   direct connection between the EVENT and BASIN feature classes.

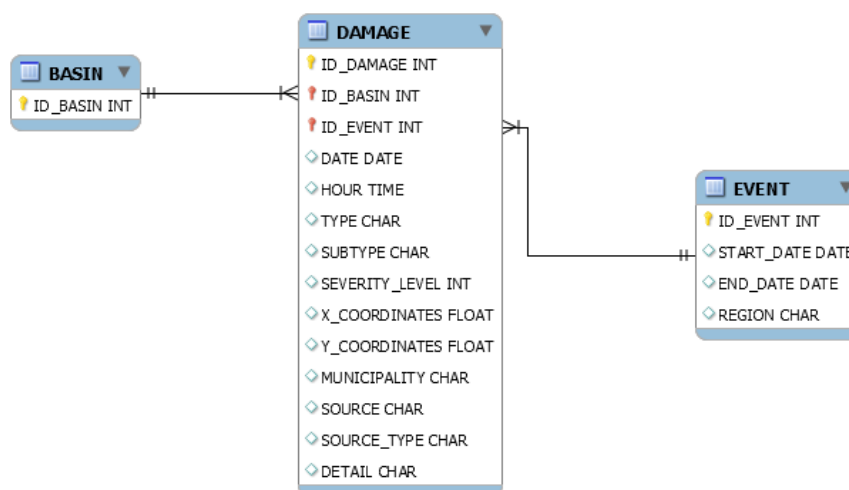



Figure 3: Data structure diagram organising the connections between the DAMAGE, BASIN and EVENT feature classes.

The first feature class is called "EVENT". It is a table with a shape field containing polygon geometries for geographic features.

10   The EVENT feature class identifies flood events that have caused damage in the South of France since 2011. Since then, 23 flood events have been recorded in the database. Each flood event corresponds to a polygon feature. It is related to a single row within the EVENT feature class and has a unique identifier. The EVENT database contains four fields in addition to the shape field.

• ID_EVENT: unique identifier of the flood event,

15   • START_DATE: starting date of the flood event,

• END_DATE: ending date of the flood event,

• REGION: areas impacted by the event.

The second feature class is called "BASIN". It is a table with a shape field containing polygon geometries for geographic features. It is related to the river basins of the area studied, which were extracted from the French Carthage database (Pella,

20   Sauquet, & Chandesris, 2006). Carthage joins a set of information layers representing geographic objects related to hydrology. It is available online as a free download (through SANDRE http://www.sandre.eaufrance.fr/). The BASIN feature class only

has one field in addition to the shape field, corresponding to the unique identifier of each basin. Each basin corresponds to a unique polygon feature and each damaged object is attached to a single basin due to its location.

Finally, the third and main feature class of the structure is the DAMAGE database, which catalogues flood-related damage. It is a table with a shape field containing point geometries for geographic features. Each damage entry in the feature class is associated with a unique identifier and connected to a single flood event and a single river basin. Since 2011, 729 damage entries have been included in the DAMAGIS geodatabase in the South of France. The DAMAGE feature class contains 12 fields besides the shape field.

- ID_DAMAGE: unique identifier of the damage entry,

- ID_BASIN: unique identifier of the river basin,

- ID_EVENT: unique identifier of the flood event,

- DATE: date of the occurrence of the damage entry,

- TYPE: type of damage (Table 1)

- SUBTYPE: sub-type of damage (Table 1)

- SEVERITY: severity of damage,

- X_COORD: X coordinates in Lambert93 of the damaged element,

- Y_COORD: Y coordinates in Lambert93 of the damaged element,

- TOWN: municipality where the damaged element is located,

- SOURCE: source of information on the damage entry,

- SOURCETYPE: type of source.

2.3 Type of damaged element

To facilitate the exploitation of this geodatabase, potential damaged elements are sorted into 14 types presented in **Table 1**. Each type of damaged element might also contain several sub-types. More detailed information on the damaged element is available in the "DETAIL" field of the DamaGIS database. These different categories of damaged elements were obtained from an adaptation of the classes used by the BD Topo® generated by the French National Geographic Institute (IGN). This vector database offers a description of geographic objects relating to land use and infrastructures.

DamaGIS does not take fatalities into account. The choice was made so as to focus only on material damage. However, information on flood-related fatalities is included in another database called the Vict-In database, which has gathered the

circumstances of death and the profiles of the flood victims in the French Mediterranean departments since 1988 (Boissier, 2013; Vinet, Boissier, & Saint-Martin, 2016).

Table 1: Types and sub-types of damaged elements within the DAMAGE feature class.

Type	Sub-type(s)				
Agriculture	Animal husbandry	Cultivation			
Crisis management	Firehouse	Town hall	Police station		
Economic activity	Store	Business	Association		
Electric network					
Road network	Small road	One-lane road	Two-lane road	Highway	Boulevard
	Avenue	Street	Passage	Bridge	Motorway interchange
School	Pre-school	Elementary	Junior-high	High-school	University
Seasonal accommodation	Camping	Hotel	Seasonal accommodation		
Government service, administration					
Transport building	Train station	Airport	Bus station		
Water network					
Health	Nursing home	Hospital			
Housing					
Parking	Underground				
Public place of recreation	Sport facility	Park	Place of worship	Museum	

Given the very wide range of damage types within the database, an appropriate rating system had to be found to assess their severity on a comparable basis. The severity assessed of each damage entry can be found within the DAMAGE feature class with the "SEVERITY" field. In the next section, this rating system is presented and explained.

3 The rating system for flood-related damage

5 Damage assessment methodologies usually focus on assessing potential future flood damage. But in this paper we chose to focus on the assessment of post-flood damage for feedback purposes. Damage assessment almost always includes the assessment of direct and tangible damage because it is easier to identify and quantify. However, although there are numerous methods to assess the severity of this type of damage, they vary greatly in their content. Indeed, there is substantial heterogeneity among damage assessment methodologies depending on their purpose (Bouwer, Crompton, Faust, Höppe, &
10 Pielke Jr, 2007).

Damage severity may be expressed in raw money values, percent loss estimates, an index value on a scale, a numerical standardised value on a scale from 0 to 1 or a range of indicators (Blong, 2003). In the literature, damage is often assessed with the replacement cost or the value of the impaired element (Jongman et al., 2012; Merz, Kreibich, Schwarze, & Thieken, 2010; Olesen, Löwe, & Arnbjerg-Nielsen, 2017). One major disadvantage of this kind of approach is that it weakens the
15 possible comparison between two flood events (Blong, 2003). Indeed, depending on where and when a flood event occurs, there might be a considerable variation in costs.

The objective of the damage assessment method presented in this paper was to easily gather and compare different types of damage regardless of the nature of the damaged element. The aim is not to obtain an economic evaluation but a functional assessment of damage. This approach also makes it possible to obtain objective information on damage severity. Different
20 studies suggest that the analysis of damage severity over time and space is made difficult by the absence or low quality of available databases on flood damage and the lack of consensus upon flood data collection (Sene, 2012). With the DamaGIS database, this type of approach is made possible by using a simple rating scale operating on a range of damage indicators. This scale enables comparison over time and space as well as for a single flood severity category; the functional consequences of a flood on an element will stay the same.

25 We use an ordinal scale, which means that the greater the damage is, the higher the value is on the scale. However, neither the value of the scale level nor the difference between two scale levels is meaningful separately (Velleman & Wilkinson, 1993). This scale is made up of four levels, shaped like a decision tree ranging from level one to level four (**Figure 4**). To illustrate this scale, we might use the example of a road whose primary function is to provide land access.

•   The first level of damage severity corresponds to the flooding of an element without the loss of its function. For
30 example, a road is flooded but cars can still drive on it.

- The second level means that the flooding caused the loss of the element's function for fewer than 3 days. For example, a road is flooded and cars cannot drive on it for a day.

- The third level of severity indicates an interruption time of the flooded element function longer than 3 days. For example, a road is flooded and cars cannot drive on it for a week.

5 • Finally, the fourth severity level is based on the destruction of the element by the flood. For example, a road is destroyed by a flood.

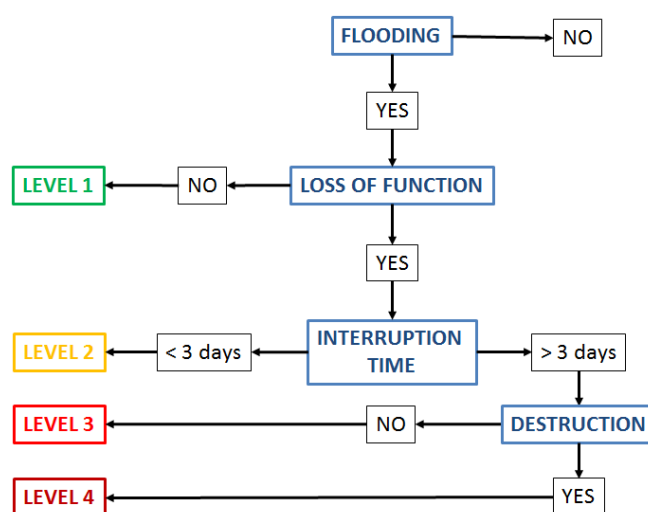



Figure 4: Illustration of the measurement scale used to assess damage severity.

10 This approach is midway between the assessment of direct and indirect damage given that we chose to express damage severity as loss of function. Direct damage is usually measured in terms of monetary loss and loss of function is commonly associated with indirect damage. However, we consider that the loss of function is a direct effect of flooding on an element because it affects the purpose for which it exists.

4 Analysis

15 Since 2011, the DamaGIS database has been completed with 729 damage entries amongst 23 flash flood events in the South of France (**Figure 5**). It might seem difficult to draw conclusions for such a reduced period of time, but the next section will attempt to provide an overview of the entire database content entered to date.

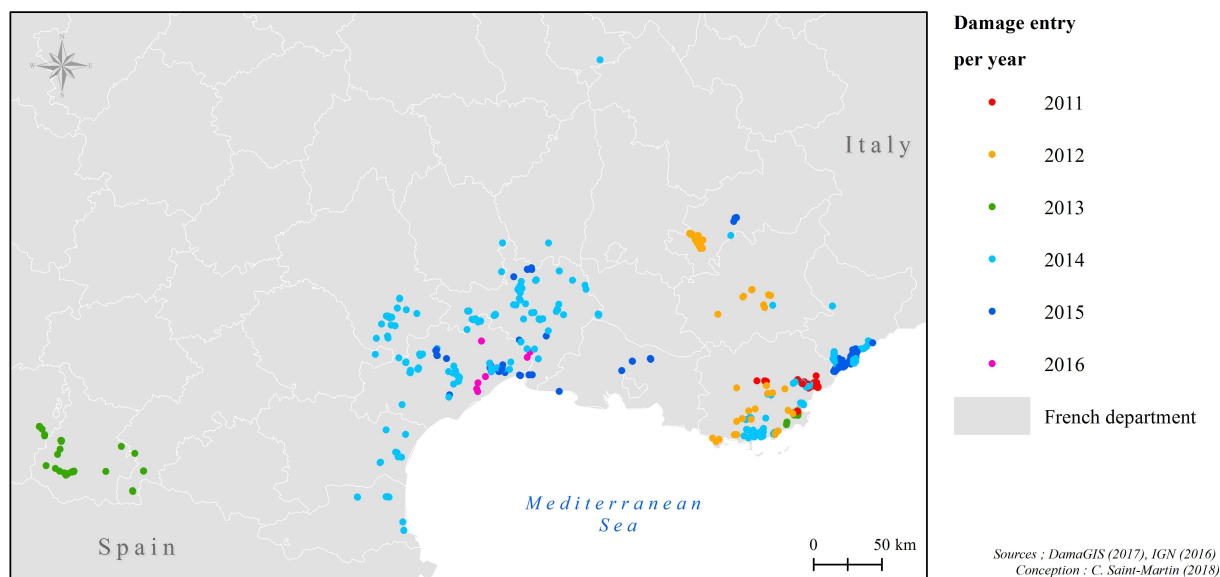



Figure 5: Spatial distribution of flood-related damage within the DamaGIS database.

5   According to the database, two main categories of damaged elements seem to be more affected by floods: 23.6% of the damage
     entries involve an economic activity while 23.5% affect the road network: each group made up one-quarter of the total (**Figure
     6**). The over-representation of these two types of elements can be explained by different factors.

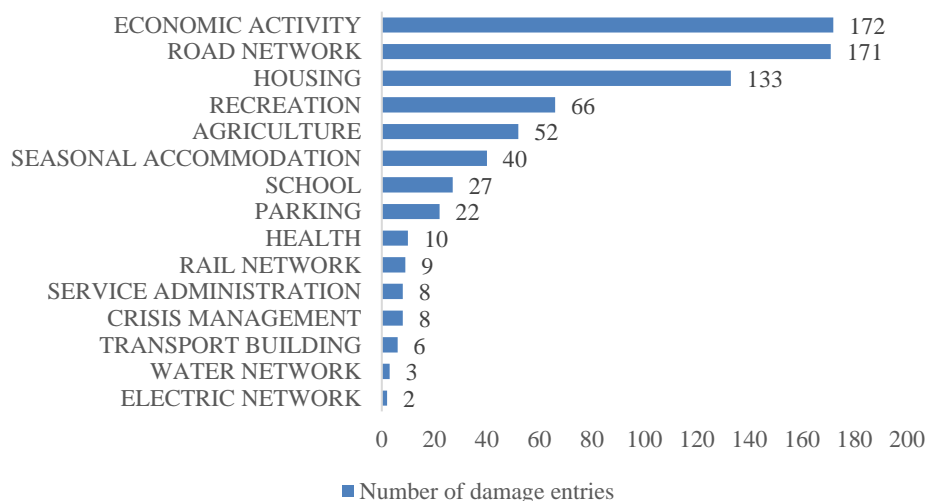



Figure 6: Number of flood-related damage events by type of element affected since 2011 in the South of France

In the case of economic activities, information is easily accessible through classic media as well as new media. It is not unusual that these entities own a webpage to advertise. Similarly, a strong presence on social media can also be highlighted. In case of a flood, numerous economic activities often contact their clients through either of these two means to update them on the situation because floods may affect their functioning. In terms of indirect input to the database, economic activities are easily recognisable on unidentified pictures because of distinctive signs such as shop signs.

Two main reasons for road network damage as recorded in the database can be cited. First of all, the road network is extensive and dense, and highly exposed to flooding (Versini, Gaume, & Andrieu, 2010). This can be illustrated by the circumstances involved in deaths related to floods. For instance, since 1982, 30% of flood-related fatalities in the South of France were caused by a vehicle driven on a flooded road (Boissier, 2013). Secondly, information on flooded roads is easily accessible by means of navigation software available to the public. Moreover, local authorities increasingly tend to monitor and share information on social media and by radio concerning the condition of the road network to keep the public informed (Bunce, Partridge, & Davis, 2012; Cheong & Cheong, 2011; Latonero & Shklovski, 2011).

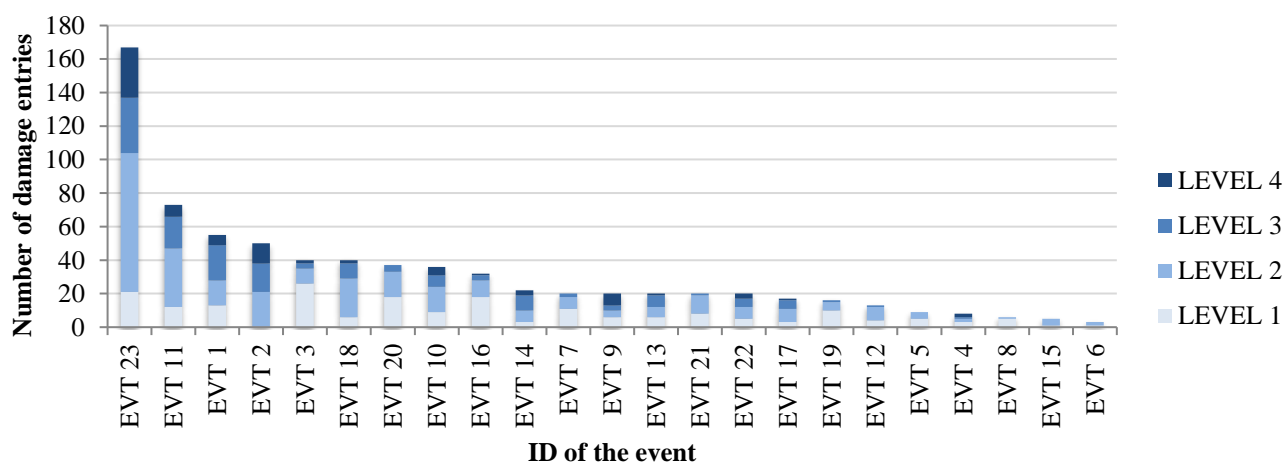



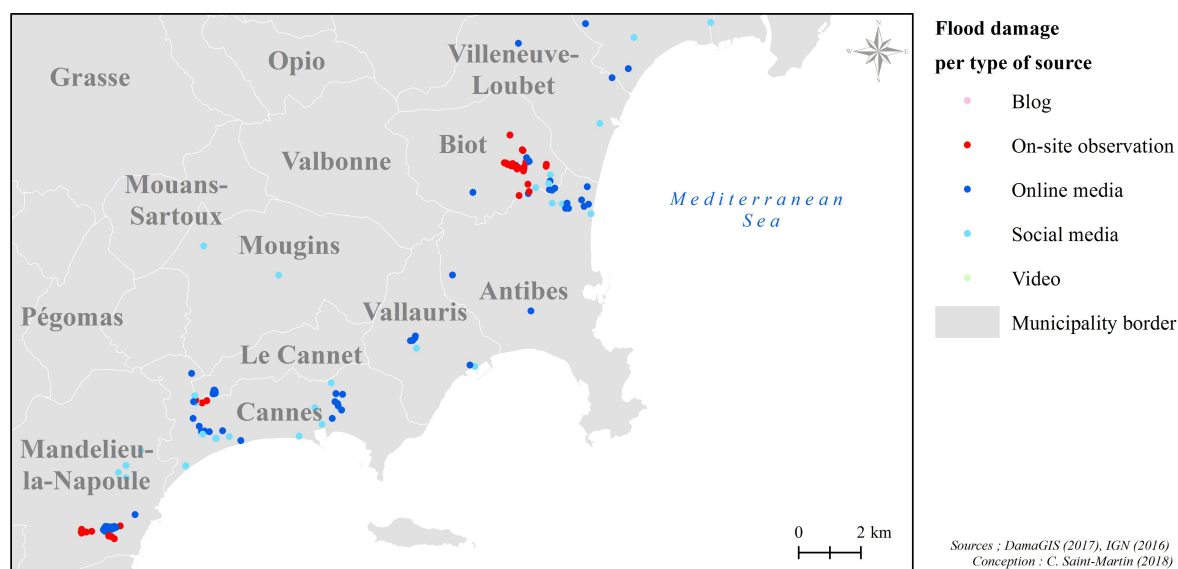
Figure 7: Severity and number of damage entries per flood event

Regarding the severity of damage, flood evens are not equally distributed among the four levels. For instance, the second level of severity is the most frequent within the database (**Figure 7**). This level comprises 302 damage entries while the first level has 194 and the third and fourth levels 151 and 82 entries, respectively. These differences may be caused by the use of a short-term series of damage data. Due to the limited size of the database, the damage data may not be fully representative. For this reason, the results of the database analysis need to be interpreted cautiously.

The 3rd of October 2015 flood event

The average number of damage entries per flood event within the database is about 32. Four of these flood events seem to stand out with more than 50 damage entries. These events took place in 2013, 2014 and 2015. However, the most damaging flood event within the database occurred on 3 October 2015 in the Alpes-Maritimes region (**Figure 7**).

5   There are as many entries associated with this event, as for the other three major floods within the database (**Figure 7**). Therefore, it seems relevant to focus on this particular event. On 3 October 2015, a storm produced more than 175 mm of rainfall in 2 h and caused significant flash floods in a short period of time on small basins in the Alpes-Maritimes region (Javelle et al., 2015). This flood event caused 20 fatalities and more than 650 million Euros of damage (Direction Territoriale Méditerranée du Cerema, 2015).

10   Within the DamaGIS database, 167 damage entries refer to this specific event. They are distributed among 14 towns and villages in the Alpes-Maritimes region. The main data sources are social networks, online media and fieldwork. The fieldwork has made it possible to obtain localised information about three specific zones in the Mandelieu-la-Napoule, Biot and Cannes municipalities, while online and social media provided information on larger zones (**Figure 8**).

15   **Figure 8: Spatial distribution of damage from the 3rd of October 2015 flood according to their sources**

Regarding the type of damage, the over-representation of damaged housing might be underlined in comparison with other flood events. Indeed, housing represents more than one-third of the damage entries within the DamaGIS database, even though it accounts for only one-tenth of the entire database. This discrepancy might be explained by the large number of damage entries obtained with fieldwork. Indeed, it is easier to obtain information about damage in residential areas on-site. This

20   example underlines why it is important to use multiple sources of data to improve the comprehensiveness and quality of data.

5 Conclusions and outlook

Benefits of the database

Amongst the main benefits of the DamaGIS database, the great accuracy of the data available within the database can be highlighted. Indeed, the use of the building scale provides significantly greater detail, notably for modelling purposes. There

5 is currently no other database offering this level of accuracy in open access.

The simplicity of use of the database as well as data entry must also be underlined. To be continued, DamaGIS depends on a wide range of contributors that must be able to easily add information to the current database. To this end, this paper has presented a new scale to assess damage severity. This scale makes it possible to compare and contrast damage data regardless of the type of information, and across time and space. In that respect, the DamaGIS database can be easily used in other areas

10 than the South of France. The implementation of this fine scale is in itself an innovative approach.

The DamaGIS database also uses multisource data including social media. This presents many advantages, notably its ability to obtain damage data rapidly after a flood without having to go on-site.

Finally, one of the main advantages of the database is also its format. As a geodatabase, DamaGIS can be used as a simple database be accessed through GIS software. The vectorial format of the feature classes within the database allows one to easily

15 visualise and represent the data these categories contain.

Limitations of the database

Despite the advantages of the DamaGIS database presented in the previous section, certain questions and concerns should be addressed. First, this database only focuses on damage caused by flood events in the South of France since 2011. Consequently, the available data time-series are relatively short and do not yet allow relevant statistical analysis.

20 Secondly, the collection of damage data can be a time-consuming process. This is why it is strongly recommended that multiple contributors participate in completing the database.

The use of new media may raise concerns about the discrepancies among the sources of information. According to a recent study, French people aged 50 and above are unwilling to use social media and do not know how to properly use the internet (Douvinet, Gisclard, Kouadio, Saint-Martin, & Martin, 2017). However, they make up 38% of the French population (INSEE,

25 2017). Nonetheless, the use of new media, particularly social media, as a source of more detailed and new information might outweigh damage data concerning people aged less than 50 years.

Finally, it must be underscored that the database is not comprehensive. Some information might be eluded during the search process. Moreover, certain required information about damage data might not be available through the data sources presented in this paper. This is why the need for collaborative work from a variety of contributors as well as a multisource approach are

30 required for the database to grow.

Perspectives

From the various benefits and limits addressed in the previous section, many prospects can be highlighted for the DamaGIS database.

As discussed above, even though the database has only focused on the South of France for now, it can easily be applied to

5 different areas given its high adaptability and simplicity of use. An online platform could then be considered to encourage collaborative work as well as the creation of multi-stakeholder working groups.

The current content of the DamaGIS database is framed at a fine spatial scale: damage data are provided at the building scale. This means that damage data available at a larger scale are not included within the database. However, to prevent the database contributors from excluding valuable but less precise data, a quality index could be provided to assess the geographic accuracy

10 of the data. For instance, a damage data available at the building scale would have a high index, while damage data at the neighbourhood scale would have a low one.

At this time, however, one of the main and most immediate prospects for the DamaGIS database would be its use for modelling purposes. Currently flood damage data are needed to calibrate and validate flood damage models at a fine scale. In this respect, this paper presents a new approach to compile and assess flood-related damage data from multiple sources in a participatory

15 type of functioning within the DamaGIS database.

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