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InunIB: Analysis of a flood database for the Balearic Islands

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Abstract

This paper presents a database that includes all the known flood events in the Balearic Islands from the 15th century to 2018. The research uses historical sources, such as chronicles, church records and public archives, while for recent events, the data is obtained from newspapers information and official reports from local and regional authorities. The result is that more than 200 floods have been identified. The next step is study the obtained data. In that sense, the temporal distribution is analysed. Some other characteristics, such as the evolution of damaged areas or the increase of events during the 20th century, are presented. The database structure allows to be updated after recent events and the data presented can be considered as a first step to gain a valuable knowledge of the flooding risk in the Balearic Islands and can contribute to provide information on future events in terms of spatial and temporal flood impact.

1. INTRODUCTION

The natural risk impact is increasing around the world as well as in Europe. One of the main hazards is flooding (Agencia Europea del Medio Ambiente, 2006; Gaume et al, 2009). The impact of the 2002 floods in central Europe and in other areas of the continent led to an EU directive which has as objective to reduce the risk of floods (2007/60/CE).

Among others provisions, article 4 in chapter 2 states that "a description of the floods which have occurred in the past and an assessment of the adverse impacts they have entailed" must be included in a preliminary flood risk assessment, moreover those significant floods "where significant adverse consequences of similar future events might be envisaged."

The literature concerning the floods affecting Europe has a wide range of topics. From compilations of data about events around the continent (Barredo, 2007; Gaume et al, 2009; Marchi et al, 2010) to research focused in single events (Bisantino et al, 2016; Majewski, 2006; Vinet, 2008; Violante et al, 2016) or with national or regional insights (Black, 1995; MacDonald et al, 2010; Petrovic et al, 2015; Petrucci et al, 2012; Ristic et al, 2012) to methodological approaches to the study of floods (Borga et al, 2008; Gaume and Borga, 2008; Koutroulis and Tsanis, 2010; Fleig and Wilson, 2013).

Spain is no stranger to the flood impact as several events in the past shown (Alcoverro et al, 1999; Grimalt, 2001; Llasat et al, 2001; Mayer, 2002). The social effects of floods are linked to casualties and economical losses. Between 1995 and 2012, 304 people died (Ministerio Medio Ambiente, 2014) and the economic impact increased year after year. Between 1987 and 2002 11921 million of euros were lost due to flooding and the estimation of losses from 2004 to 2033 is 875 million of euros each year (IGME, 2004).

The Spanish Mediterranean coast is the area most affected by floods, basically flash floods, which are related to convective precipitation (Llasat et al, 2016; Gilabert and Llasat, 2018). A combination of extreme rainfall, geological settings and the human occupation of flood-prone areas had resulted in a large number of events thorough the years (Llasat et al, 2014; Gil-Guirado et al, 2019). Other historically affected areas are the Pyrenees, where floods are the result of rainfall and snowmelt processes, central areas of the Peninsula where large rivers flow (Morales and Ortega, 2002; Arranz, 2008; Domenech et al, 2011) and even the Canaries Islands (Marzol, 2002; Mayer, 2002).

2. THE STUDY AREA

The Balearic Islands archipelago (Figure 1) is situated off the eastern coast of Spain. It is made up of five islands (Mallorca, Menorca, Eivissa, Formentera and Cabrera) with adjacent islets. The island's total surface area is 5014 square kilometres and its population in 2018 was just over 1 million (CAIB, 2019). The biggest island is Mallorca, with a surface of 3640 square kilometres, then Menorca (701.34 km^2) and Eivissa (572 km^2). The main economical activity is tourism, initially a sun and sand destination; nowadays changing to cultural, historical and nature-related activities (Minguez, 2012).

The climate is Mediterranean, with own characteristics as a result of its location and the proximity to the mountain ranges of the Iberian Peninsula and the north of Africa. Rainfall varies depending of latitude (highest amounts to the North) and altitude (increase in mountain areas). The rain amounts range between the 300 mm a year of

Formentera to over 1500 mm/year in the central areas of the Tramuntana mountain range, located in the North of Mallorca.

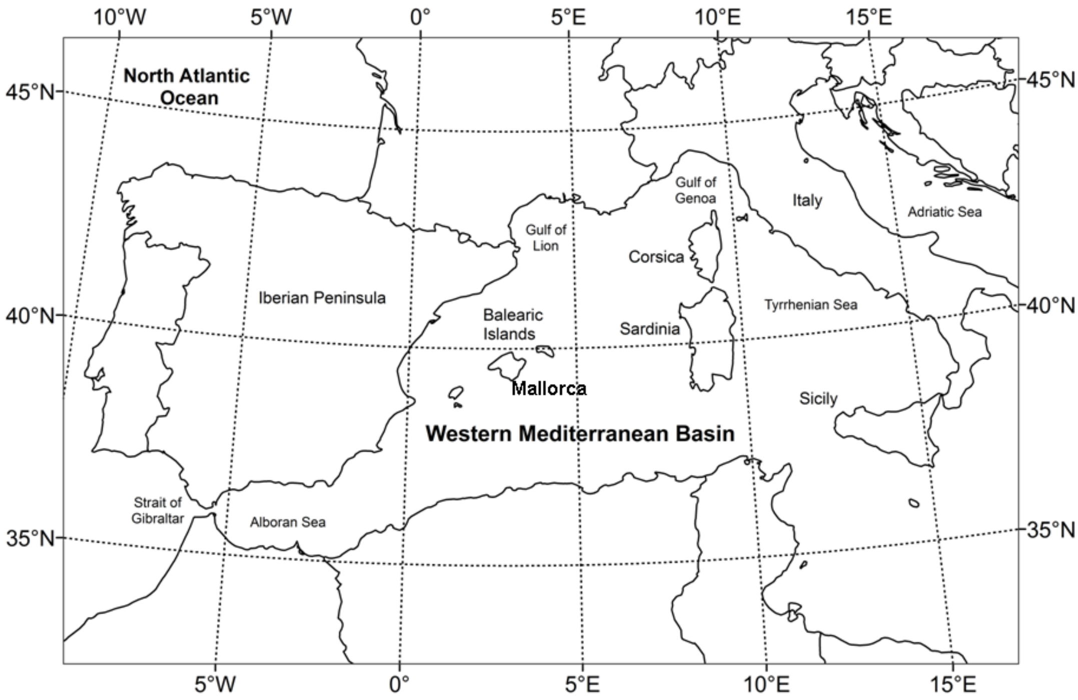

Figure 1. Location of the Baleric Islands within the Mediterranean basin- Grimalt et al, 2013.

Some local factors can contribute to increase the amounts of precipitation so, in some cases, especially at the end of the summer and autumn, the hourly precipitations can be very intense and reach important totals in 24 hours, sometimes more than 200 mm, that can suppose between 10 and 30% of the annual total recorded precipitation (Rossello, 2012).

The fluvial system of the Balearic Islands is formed by ephemeral streams, called torrents. The catchments are small, with steep slopes in the mountain areas and wide valleys in the flat parts of the islands. Only in Mallorca can be found catchments over 300 square kilometres of surface while in the other islands are smaller. The drainage system is usually dry during the year and become active as a result of the rainfall distribution, the calcareous nature of soils and anthropogenic activities.

The surface runoff is organized in two basins in Menorca and Eivissa while in Formentera only one basin is considered. Mallorca, due to its geographical complexity with mountainous areas and plains, has seven basins (Figure 2).

Men actions against erosion have had also effects in the surface runoff. A complex traditional system to regulate the water circulation (stone-dry walls in slope areas, stream channelization and runoff inhibition) have affected the islands catchments and the result is a fluvial system with long non operational periods that can last for years and sudden flood events of catastrophic effects, accentuate by human actions.

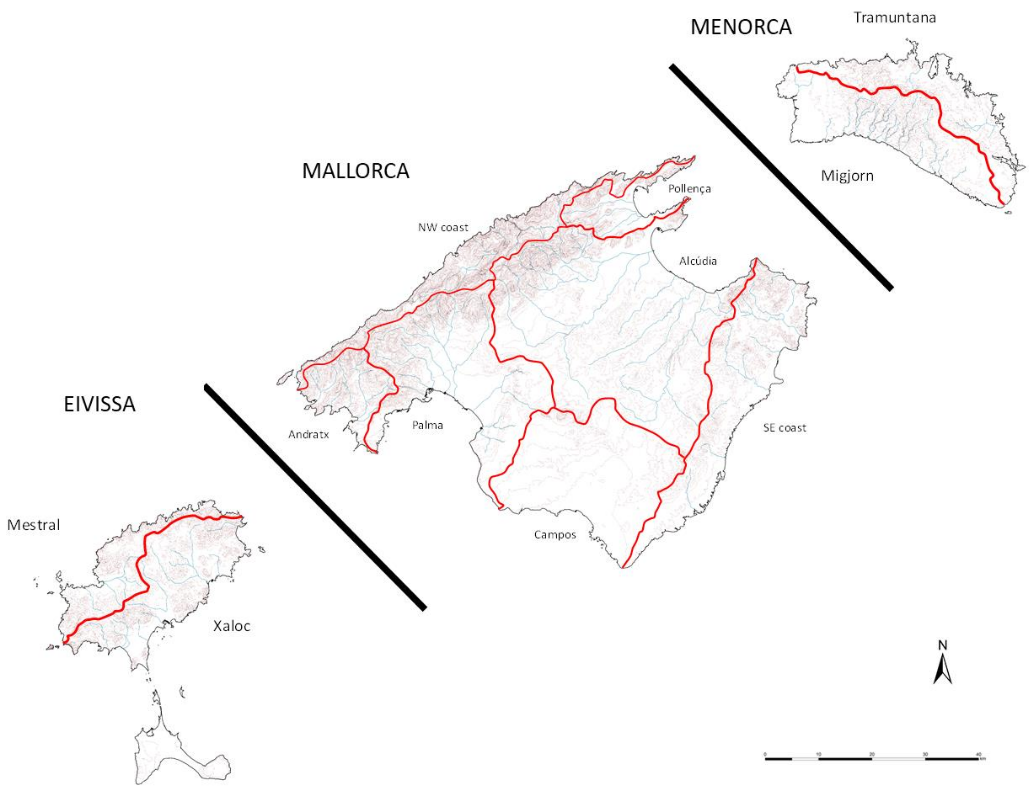

Figure 2. Basins of the Balearic Islands

3. DATABASE CONSTRUCTION

3.1 Sources

The basic approach used for this work was search for original contemporary documents from the time of the event, also known as "primary sources" (Lambert and Terrier, 2011). Historical information before the 19th century has been difficult to obtain as church and official archives are often lost or not well kept. In this case, secondary sources like compilations of information from previous centuries have been used.

The documentation obtained is mainly from historical accounts or chronicles until the 19th century. In the 19th century, the data arrive from direct witness accounts and newspapers information. Finally, the data for the 20th century is provided by eyewitness oral interviews, newspaper articles and official reports from local and regional authorities. A total of 238 books have been consulted, mainly local histories, chronicles and thematic works about risk and floods.

Since the 1960's an exhaustive research of local and regional press articles has been made. Even if some limitations can be found in the use of press data (Petrucci and Pasqua, 2012), the information provided is commonly used to research about topics such as climate change (Brulle et al, 2012; Gómez-Martín et al, 2014) as well as floods (Llasat et al, 2009a; Adhikari et al, 2010; Escobar and Demeritt, 2014).

In this study, the research has focused on the identification and dating of flood events in the Balearic Islands. Once a first list was created, more investigation was undertaken to identify exact dates, documentary references and information in terms of impact of the event.

3.2 Structure

All the information from the sources above cited has been implemented into a computerized database. In this case, the program used has been the Access® included in the Microsoft Office package.

The database methodology has followed the guidelines included in the guide developed by the Spanish Ministerio de Medio Ambiente, Medio Rural y Marino (2010) but with some changes to include the characteristics of the Balearic Islands.

The database has the following menu structure (Figure 3):

- Event data: this includes year, month and day of the event (yy/mm/dd).

- Location: basin, catchment and courses affected. The official number and name of the courses has been used even if some sources use the course's common name.

- Atmospheric data: information about the weather during events is included when available. A synoptic objective classification is used and data about precipitation (24 hours maximum, location of rain gauge, hourly intensity) are also referred.

- Hydrological trends: data about flood peak, water levels inside the bed, and water levels in the flood-plain are included in this part.

- Sources and description: includes the event direct sources and a description of the episode if enough data is available.

- Results: an explanation of the flood effects in terms of damages (roads, bridges, houses, etc) and victims as well as the economic impact are included in this field.

- Bibliography: documentary sources of information about the event.

- Present situation: a relation between the historical event incidences and the present. It relates to the possible modifications of physical characteristics of the stream and/or social adaptations between historical events and the current times.

In each field, the answers can be fixed, with a limited number of options, or free, allowing more relevant information to be included. Among the fixed categories fields, we can find:

- Basins: a classical distribution is used (Jansa, 1951). Formentera has one basin, Eivissa and Menorca two apiece and Mallorca has seven.
- Catchments: the official code number and name has been used. Toponimy has been normalized as some names are wrongly cited in the official lists.
- Weather types: using the Jenkinson and Collison classification applied to the Western Mediterranean basin (Grimalt et al, 2013), different weather types have been included. The Jenkinson and Collison is an objective classification system of the daily weather types (1977). The types included in the database are:
    a) Advective, with a flow direction N, NE, E, SE, S, SW, W and NW.
    b) Cyclonic, with a flow direction N, NE, E, SE, S, SW, W and NW.
    c) Anticyclonic, with a flow direction N, NE, E, SE, S, SW, W and NW.
    d) Undetermined.
- Kind of flood phenomena: floods could be included in three categories:
- Flash floods, when short lived rainfall (minutes, hours) originates a flood.
- Floods caused by long-time precipitation, when the rainfall total is the accumulation of various days of precipitation.

- Accidental floods, when the overflow is caused by the breaking of stone walls or other man-made structures.

Free text fields include the results of the flood event as well as the bibliography. The compiled data is included in the database following the structure show in figure 4.

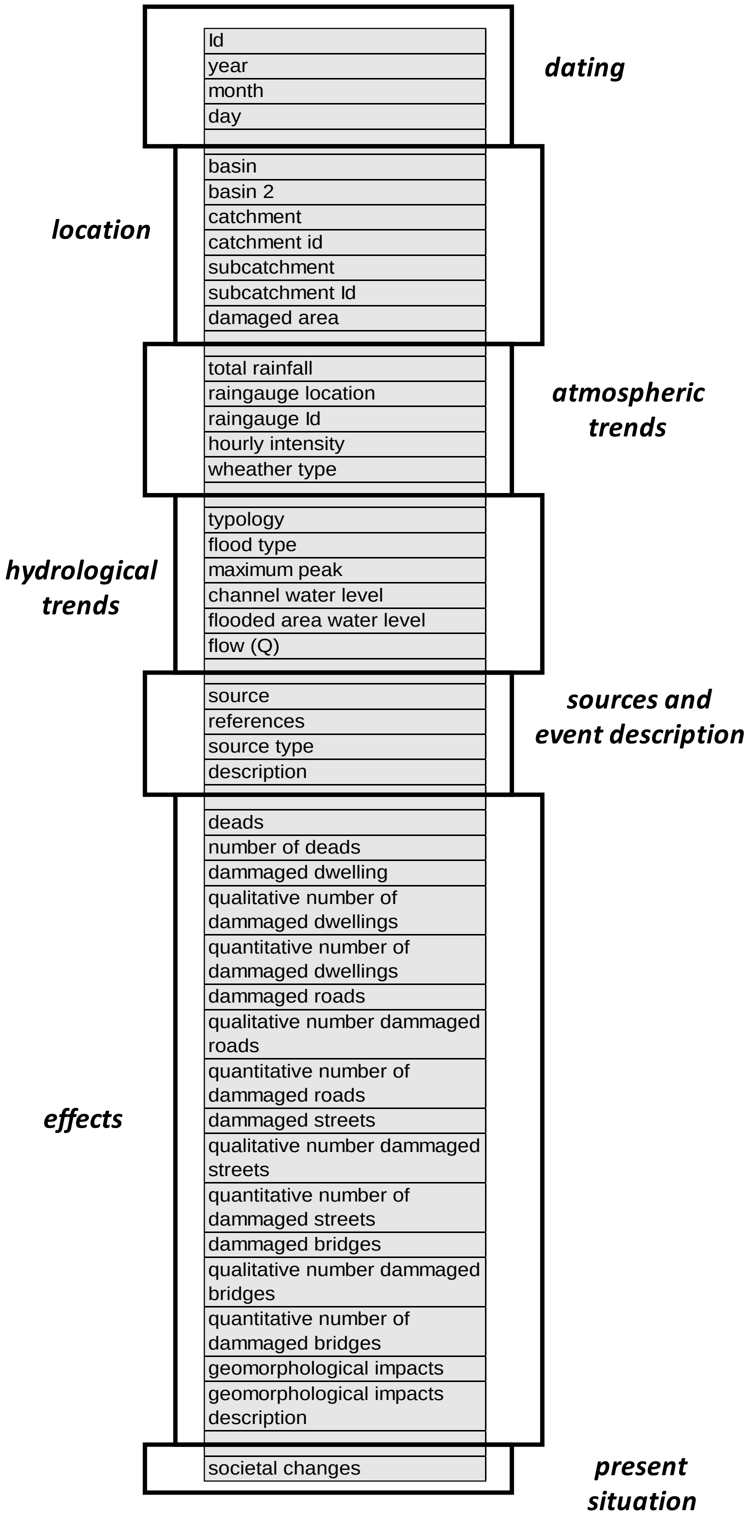

Figure 3. Design of the database

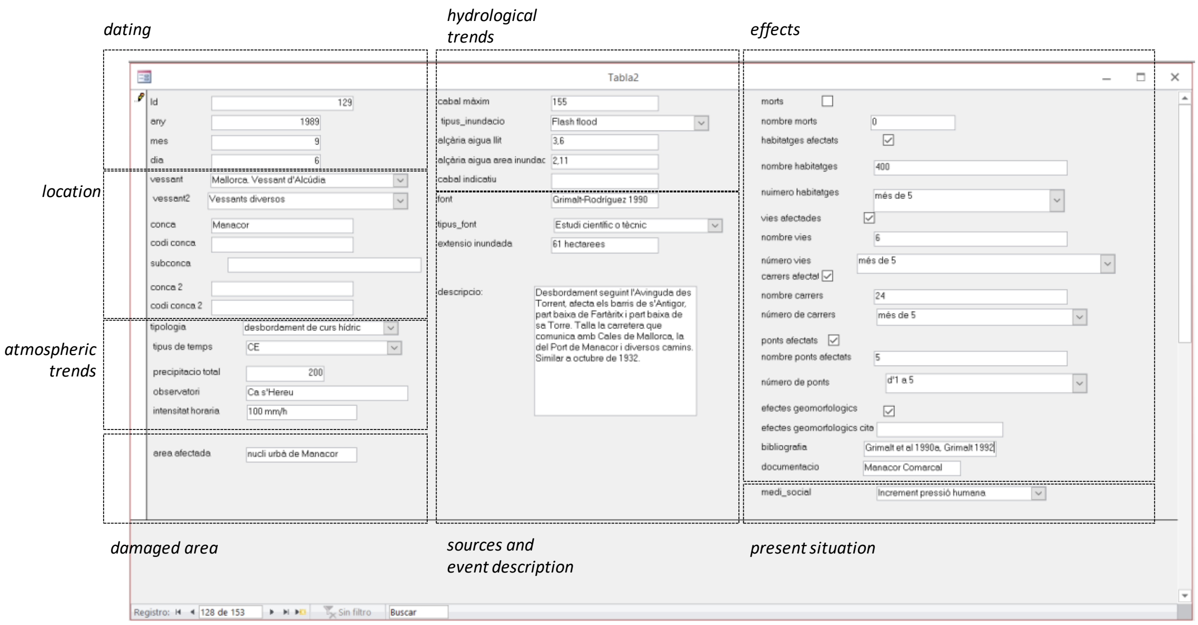

Figure 4. Screenshot of the information fields using as example the September 6th 1989 flood

4. RESULTS

A total of 246 days with flood events were recorded between 1403 and 2018. It must be taken into account that the database is structured by basins so the actual number of events is over 400 as floods can be affecting different catchments in the same day.

4.1 Temporal distribution

The daily events were divided in centuries to observe the evolution of the existing information from the 15th century to our days.

Table 1 shows the distribution of flood events among the centuries. The highest number of events, 126, is found in the 20th century while in the 10 years elapsed of 21st century 64 events have been located. From historical times, the 18th century has 10 events and the 17th 7 recorded floods. In the 20th century, official reports from various authorities helped to find more information about flooding events. In contrast, data from the 18th century and before must be found in archives and usually lacks information about aspects such as amounts of rain, affected area and so on.

The great amount of data obtained as we approach the 20th century can be linked to the use of newspapers as a source, because a great number of articles about floods are published. The increasing impact of flooding over population helps to increase the amount of information provided to the society and even minor events are recorded in contrast with previous centuries, where only high impact floods in terms of damages and human lives were recorded in official archives or subject to chronicles.

The monthly distribution of the days with floods (Table 2) shows a clear seasonal pattern related to the precipitation structure in the Balearic Islands (Grimalt et al, 2006). September is the month with more cases (61), followed by October (59) and November (37). February is the month with fewer events, only 3, for the analyzed period. March and June follow with 7 apiece.

Table 1. Distribution of flood by centuries

Century	Number of floods	Affected islands
15th	4	Mallorca
16th	0	
17th	6	Mallorca, Eivissa
18th	10	Mallorca
19th	36	Mallorca, Eivissa
20th	126	Mallorca, Menorca, Eivissa, Formentera
21st	64	Mallorca, Menorca, Eivissa

The importance of August as a flood-prone month (14 events) must be understood within the complex Mediterranean climate dynamics and the anthropogenic influence. August is often affected by rainy storms, which record not large amounts of precipitation but high intensities, thus leading to flooding in urbanized areas, where the drainage system cannot cope with the amounts of rain falling in short time.

Table 2. Monthly distribution of flood events

Month/Century	15th-19th	20th	21st
January	2	6	2
February	1	2	0
March	3	4	0
April	2	5	2
May	2	3	5
June	1	3	3
July	1	3	2
August	1	10	3
September	10	34	17
October	15	31	13
November	9	16	12
December	2	7	5

As for the seasonal distribution of floods (Figure 5), autumn is the season with more events, followed by winter, summer and spring. The fall season has more than the half of the floods, 66%, while winter and summer have an 11% of events. As suggested by the monthly distribution, spring has the smallest number of events, 26, only a 10% of the total.

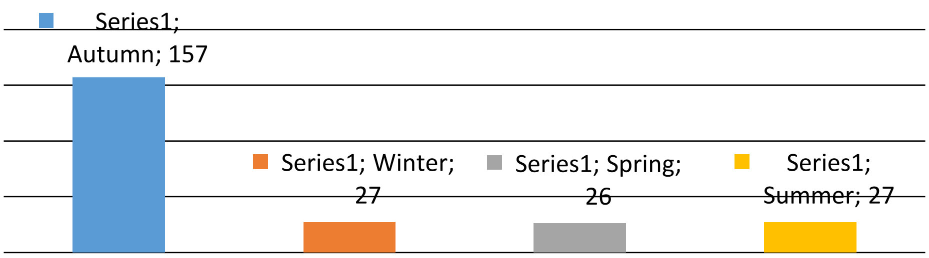

Figure 5. Seasonal distribution of flood events

4.2 Spatial distribution

Mallorca is the island most affected by flooding, followed by Eivissa. Well behind in terms of events are Menorca and Formentera.

Historically, floods affected coastal plains with an agricultural value and the oldest urban centres of Mallorca. Usually, these towns have been located away from flood-prone areas, normally in higher places (i.e. hills). Only three cities have torrents inside the city centre, Palma, Sóller and Manacor. Two other villages, Esporles and Sant Llorenç, have the stream close to the village. Another complex problem is located in Campos and Sa Pobla, which are located in alluvial plains and the city centre is crossed by paleo-channels that only work when large floods occur. Similarities can be found in Menorca and Ibiza, with events affecting the largest farming areas of both islands (Figure 6).

The reason for that spatial distribution of events was the human adaptation to the environment, avoiding dangerous flood-prone areas through the transmission of the knowledge linked to an agricultural way of life.

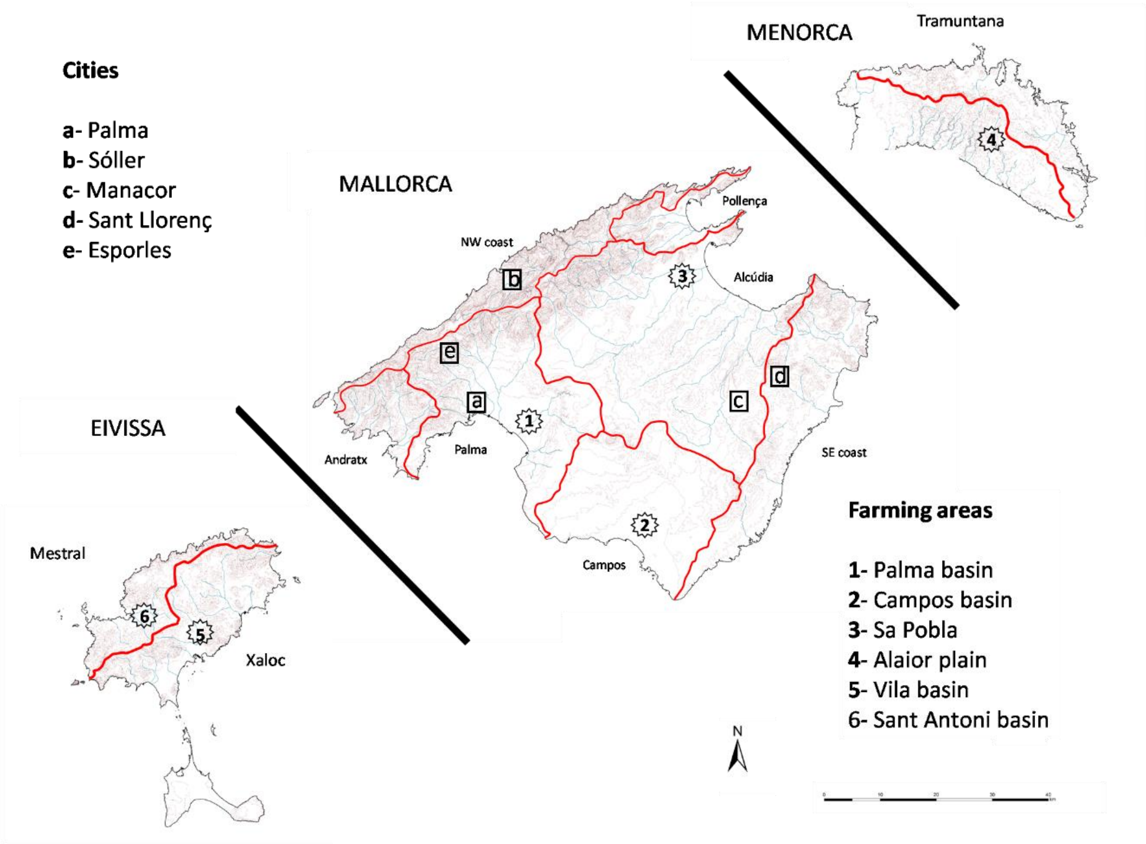

Figure 6. Spatial distribution of historical floods

From the 19th century onwards, a change on locations is found, something related to the urban expansion towards areas of risk. Initially, the expansion affected some towns located in non-coastal areas until the 1950's but afterwards, starting in the 1960's, the urbanization development is located in the coast, linked to the touristic industry (Salvà, 1990; 2002), a common occurrence with other Spanish regions such as Catalonia (Cuadrado-Ciureneta and Durà-Guimerà, 2018). Its main effect is the urban use of flood-prone coastal zones as well as the torrent's mouth, occupied by tourism-related buildings and infrastructures (Figure 7).

The same facts are identified in Eivissa. From historically flooded places like the main city, Vila, and the surrounding farming areas a shift on affected areas, mostly coastal locations and new urbanized neighbourhoods, is found after the massive arrival of tourism since the 1980's. In the case of Menorca, the late arrival of the island to the tourism industry resulted in a higher protection degree, thus reducing the expansion of touristic activities in flood-prone areas.

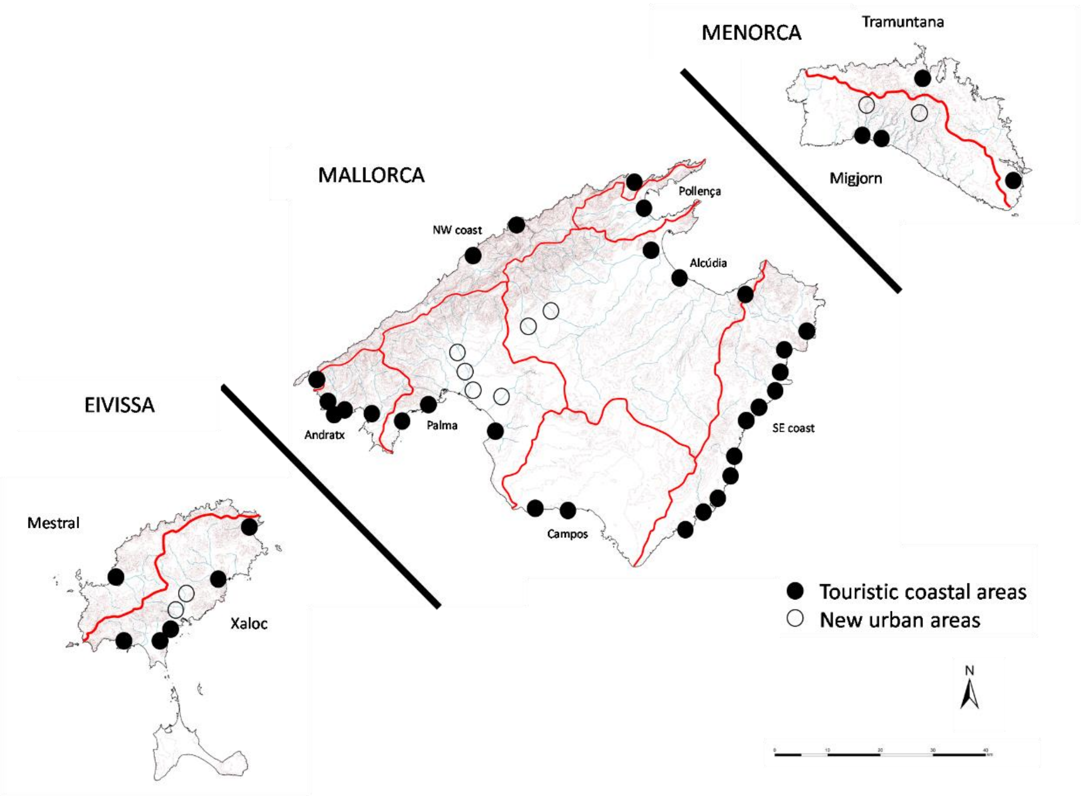

Figure 7. Spatial distribution of floods since 1950

4.3 Data analysis

Among the results reached following a geographical analysis of the data, we can consider:

1) Floods are local phenomena, affecting specific catchments or basins as a whole island has never been affected by flooding events at the same time.
2) In terms of same time events, no correlation has been found between the three main islands (Mallorca, Menorca and Eivissa). Eventually, flood-causing storms can move slowly eastwards affecting each island on consecutive days. Same day events have only been found in Eivissa and Formentera.
3) The flooding events are mainly included in the flash flood category as the territorial characteristics of the islands do not allow large floods linked to long lasting rain episodes.
4) The floods affecting the Balearic Islands are then the result of rainfall events with great quantities of precipitation, generally above 100 mm in 24 hours (Grimalt et al, 2006). Furthermore, the precipitation has to have a great hourly intensity

(higher than 30 mm/hour), generally related to convective processes. This is the reason why catastrophic floods are usually found in September and October, coincident with the maximum storm activity in the islands (Ruíz et al, 2012).

5. CONCLUSIONS

A first analysis of the flood data for the Balearic Islands is presented. A total of 246 events have been located between 1403 and 2018. The gathered information helps to depict a scenario on the distribution of flood events in the islands.

The highest number of events occurs in September, followed by October and November. February, March, June and July, are the ones with fewer floods, as a result of the shortage of precipitation during the end of the winter season and summer.

Regarding the distribution of events by century, the 20th is the one with more cases, something that can be linked to an increase of information, related with the development of the press and the existence of official reports from local and regional authorities. Another explanation can be related with the extensive urbanization of coastal and flood-prone areas as a result of the tourism activity in the Islands and the consequent increase of population.

Spatially, Mallorca is the most affected island, being the largest of the archipelago. The island has suffered a total of 202 events. It is followed by Eivissa, with 27 while Menorca (10) and Formentera (4) are the places where flooding events have had the lesser impact thorough the years. A shift from traditional flooded places, towns and farming areas, to newest locations, mainly in the coastal areas of Mallorca and Eivissa, can be found after the 1960's, as a result of the increase of urbanization related to the tourism industry. Menorca and Formentera, the islands with less population, record few flood events thorough the research period.

An analysis of the data shows that events are mainly of flash flood type, the result of extreme precipitation from convective storms. Amounts of rain exceed 100 mm in 24 hours and it is thought that hourly intensities are really high but no records from gauges are available.

The database will help to study the flood-prone areas of the Balearic Islands and allow a continuous update of events. Future research should focus on the location of more events and the analysis of the already available information in order to upgrade the knowledge of the flood risk for the Balearic Islands.

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