MORE EXPOSED BUT ALSO MORE VULNERABLE? CLIMATE CHANGE, HIGH INTENSITY PRECIPITATION EVENTS AND FLOODING IN MEDITERRANEAN SPAIN

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Abstract

Purpose – This paper examines the role of high intensity precipitation events in increasing ~~enhancing~~ the vulnerability to flood~~ssing~~ in Mediterranean Spain. Precipitation intensity in this area appears to have augmented ~~increased~~ in the last two decades in association with warming trends of the Mediterranean Sea. At the same time, intense urbanization processes, occupying and transforming flood prone land, have produced an important increase in exposure. Our main objective is to assess whether higher intensity precipitation and ~~-~~changing patterns in exposure aggravate ~~increase~~ vulnerability to floods.

Design / Methodology/ Approach - In this paper, vulnerability is understood as the result of the interrelationships between exposure, sensitivity, impacts, and adaptive capacity. Consequently, methods used involved the compilation and analysis of published and unpublished precipitation data; population and land use data; data on insurance claims, and media sources related to those variables.

Finding - Changes towards episodes of more intense precipitation in the expanding urban areas of Mediterranean Spain increase exposure but not necessarily vulnerability, at least in terms of human deaths. However, adaptative capacity needs to be formulated. Actions that attempt to absorb and eventually reuse flood flows (as the flood park in Alicante) appear to be more effective than traditional hydraulic solutions (as in Majorca).

Originality/value – The article provides a systematic and coherent approach to vulnerability analysis taking into account the changing dynamics of its components. Especially it signals the limits of current adaptive approaches to flooding and advocates for changes towards a more circular and less linear approach to urban drainage.

Keywords: Precipitation, Intensity, Floods, Exposure, Adaptation, Mediterranean Spain

Article classification: Case study

Introduction

According to the United Nations Office for Disaster Risk Reduction and the Center for Research on the Epidemiology of Disasters, between 1995 and 2015, 157,000 people died as a result of floods and 2.3 billion US dollars or 56 percent of all damages of~~caused by~~ weather-related disasters, were caused by flooding (UNISDR and CRED, 2019). Flood impacts respond to a combination of trends in the magnitude and frequency of natural events and trends in the human occupation and transformation of areas subject to periodic inundation. Increasingly however, flood occurrence and impacts are becoming more associated with the human component of the hazard equation. For instance, the recent emergence of pluvial flooding as a major risk obeys to an important extent to the rise of cities and the parallel expansion ~~increase~~ in sealed surfaces altering natural drainage and facilitating the concentration of water (Houston *et al.*, 2011). Additionally, dense built environments multiply the potential for economic and infrastructural losses (Rosenzweig et al., 2018).

Tendencies in flood losses, especially in the long term, remain difficult to estimate with accuracy due to poor or missing records and disparities in measurement criteria. Nevertheless and for the European case, a major recent study focusing on the period 1870-2016 (Paprotny *et al.*, 2018) concludes that floods affect more people and more areas now than in the 19th century, reflecting the changes in population and land use~~s~~ that have occurred in the continent. A report by the European Environment Agency ~~(EEA, 2019)~~ analyzing flood events between 1980 and 2010 (EEA, 2019), found that during that period 37 European countries had suffered some ~~more than~~ 3,500 flood episodes with the highest number (more than 300) recorded precisely in ~~the same~~ 2010. However, occurrence and impacts do not appear to translate into greater losses at least in relative terms. Tanoue *et al.* (2016) covering the period 1960-2013 for river floods, found that both global mortality and global losses had decreased. According to Prapotny *et al.* (2018) ~~show that~~ flood fatalities show a consistent downward trend during the last decades (up to 4.3 percent annually since 1950) which is probably explained by technological advances in flood protection structures and by flood warning and preparedness actions. Regarding monetary losses, the picture emerging from long term analyses is more complex. In general, it can be argued that economic losses increase in absolute terms but when “normalized” (that is, considered in the context of the evolution of GDP and GDP per capita) may remain stable or even decrease (Neumayer and Barthel, 2011).

Trends also differ according to the different types of flooding. For river floods, European and North American exposure may have diminished (Rojas *et al.*, 2013) but for coastal floods in the form of storm surges the reverse might be true. It is likely that exposure to riverine flash floods and pluvial, diffused floods have ~~both~~ increased especially in Western and Southern Europe. Prapotny *et al.* (2018), however, argue that, while exposure may now be greater than it was in the past, both in terms of fatalities and (relative) economic losses the impacts of floods in Europe show a downward signal since at least 1950. Regarding future trends, the EEA study anticipates that flood losses in the continent would increase fivefold by 2050 and an astonishing seventeen fold by 2080. According to this study however, climate change, often pointed at as the main responsible for the increase in the impacts of extreme events, plays only a relatively marginal role in the growth ~~increase~~ of flood losses despite projections of higher intensity rainfall episodes. In fact, the largest responsibility (70 to 90 percent according to the report) of losses will lie in socioeconomic development. Other studies agree in singling out exposure as the main cause of disaster impacts but advice not to rule out climate change. Rather, exposure combined with more virulent episodes may push losses upward especially in countries undergoing rapid socioeconomic transformations (Visser *et al.*, 2014).

Exposure therefore appears to be a major factor in the increase of flood occurrence and impacts but past trends do not seem to indicate that human and economic losses due to flooding are increasing especially if normalized losses are considered (Barredo, 2009). However, due to major shifts expected in the characteristics of extreme rain and flood events (Lehmann *et al.*, 2015) and also to trends in the human occupation and transformation of flood prone land, it may be pertinent to reexamine the interplay between these phenomena and the human and socioeconomic contexts in which they occur with regard to both exposure and vulnerability.

Vulnerability is a multidimensional, complex term open to many different conceptualizations each one endowed with specific causal chains and increasingly concerned with longer term social and economic dimensions rather than in shorter term ~~more~~ physical dimensions (Wisner, 2016). In the emerging field of Disaster Risk Science, the approach to vulnerability tends to align with the more social view, noting the separation between exposure and vulnerability and making the latter perhaps the most significant aspect in the occurrence of disaster risks (Kelman, 2018). In a similar vein, the FORIN (Forensic Investigations on Disasters) approach developed by Oliver-Smith et al (2016) insists on not decontextualizing disaster occurrence and on paying more attention to underlying causes rather than to impacts. There is a clear interest in unraveling the underlying causes of exposure and vulnerability to hazards which, as in the previous work by Hewitt (1983) and Blaikie et al (2005), are better understood as processes and not simply as isolated events. All these approaches stress the uneven manifestations of vulnerability according to class, gender, race, ethnicity, and other social variables thus questioning ~~correcting~~ the more simplistic idea that vulnerability can be reduced to the measurement of monetary damages alone.

The theoretical and methodological approach followed in this paper, already used in a previous work (Olcina et al 2016), is based on Cutter (2006) in the conceptualization of vulnerability as the product of the interplay between four basic components:~~,~~ 1) Physical exposure to the natural event; 2) Sensitivity to damages, 3) impacts, or the combination between exposure and sensitivity, and 4) adaptive capacity. In a previous study (Sauri *et al.*, 2013) this conceptual approach was applied to study the effects of climate change on the water resources of Mediterranean Spain. By "hazard" we will refer to the characteristics of the natural event, in this case flood water, in terms of magnitude, frequency, spatial extent and temporal frame. Exposure basically involves the relative position or location of elements population, tangible and intangible assets, etc. regarding the natural event; sensitivity to damages refers to internal characteristics or properties of the elements exposed, in terms of their biological, physical, social, economic and cultural characteristics which may exacerbate or attenuate the effects of exposure and therefore of impacts. Finally, adaptive capacity would refer to the capacity to absorb impacts without major upheavals in the human environmental context experiencing the hazard.

The paper attempts to illustrate the interplay between these components for three recent flood episodes in Mediterranean Spain. The main hypothesis is that exposure to flooding has increased in this area due to changes in precipitation patterns leading to more high intensity events and to changes in the human occupation and transformation of flood prone land. An attempt will also be made to show how this increase in exposure has not necessarily led to an increase in vulnerability in what concerns human casualties and possibly normalized economic losses. Hence ~~as well implying~~ ~~that~~ adaptive capacity may have ~~has~~ improved, although in this case, lack of reliable data at appropriate scales makes difficult to fully sustain the argument. However, and in order to stress the dynamic nature of vulnerability and of its multiple, changing conditions the paper is also aware of the need to move beyond vulnerability assessments exclusively based on economic damages and explore other vulnerabilities appearing in the case studies out of dynamic pressures or risk drivers for which adaptive capacity may not be ready or may be difficult to implement.

The paper is organized as follows. After this introduction a section on data and methods used is provided ~~esented~~. Next, new trends in precipitation and precipitation intensity in Mediterranean areas are presented. This is followed by a section on recent land use changes in Mediterranean Spain and particularly the urbanization process of the last decades. The last section of this more contextual part of the paper focusses on the human and economic impacts of floods in this area also during the period 1998-2018 with the idea of discerning vulnerability patterns. In the second part of the paper we study three recent flood episodes: the flood of the city of Alicante in March 2017; the flash flood of Sant Llorenç d'Escardassar (Majorca) in October 2018, and the flood affecting the city of Girona in June 2017. For each case the characteristics of the natural event are examined, especially with regard to its possible differences with past episodes, and the characteristics of the human environment in terms of exposure and vulnerability. The main findings of the three studies are then discussed and the paper concludes contrasting the changing nature of the physical event with exposure and vulnerability and offering some policy recommendations .

Data and methods

Precipitation data

For the analysis of changes in precipitation episodes, statistically treated rainfall data from official sources (AEMET) and for several Spanish Mediterranean cities (Girona, Barcelona, Valencia, Palma de Mallorca, Alicante, Murcia and Malaga) was used. For the three case studies of Girona, Alicante and Sant Llorenç d'Escardassar, intensity data (mm/h) of precipitation from meteorological stations in Girona, Alicante and Colonia de San Pere was the main variable considered. The assessment of temperature trends in the Western Mediterranean Sea is derived from ~~has been based on~~ information provided by the Centro de Estudios Ambientales del Mediterráneo (CEAM) (Pastor *et al.*, 2017), which records sea surface temperature series (NOAA) since 1982.

Population Growth and Urban Land Use data

For the analysis of population growth we have used ~~drawn on~~ population censuses of 1998 and 2018 for~~in~~ the eight provinces of the Mediterranean peninsula (Girona, Barcelona, Tarragona, Castellón, Valencia, Alicante, Murcia and Almeria) facilitated by the Spanish National Institute of Statistics (INE). For the analysis of urban land use changes in the same period, the lack of aggregate information for the area of study required to use as a proxy the land area under ~~with~~ urban brightness within a 50 km radius form provincial capitals (1992 and 2012, in km2) estimated by the Grup d'Estudis sobre Energia, Territori i Societat of the Universitat Autònoma de Barcelona (GURB, 2019).

Insurance compensation data

Data on economic losses due to flood episodes and compensation figures resulting from extreme events during the period covered in the study, come from the database of the *Consorcio de Compensación de Seguros* (CCS), a Spanish public entity participated by private capital which provides direct compensation in case of extreme natural events or reinsurance funds for private insurance companies that include extreme natural events in their insurance. After the occurrence of an extreme event, the CCS processes loss adjustments, appraisals, and the payment of compensations directly to the policyholder under the same conditions established in the original ('ordinary') contract ~~policy contracted~~ with the private insurance company. Appraisals are based on the extent of damages and on the average values of goods at the moment of the event (for example, cars). Data was given to us in the format of spreadsheets of individual claims that were consequently elaborated to produce aggregate tables and figures.

Press Sources

The description of the main characteristics and impacts caused by each of the three case studies has benefitted from an extensive content analysis of local and regional media sources, mostly Diario Información (Alicante), Diari de Mallorca, Diari de Ibiza and La Vanguardia (Sant Llorenç d'Escardassar), and Diari de Girona (Girona).

Context

New patterns of precipitation intensity

For the purposes of the present study, "intense" rainfall is defined as rainfall ~~values~~ between 20 and 150 mm. accumulated in a maximum of two hours, while "torrential" rainfall would be limited to volumes above 150 mm in 24 h. with possibly more moderate hourly intensities. For the analysis of episodes of heavy rain it is necessary to have rain gauges able to record hourly intensities while for torrential rain accumulated daily values suffice. In hourly intensity values, the design in terms of capacity of the urban drainage networks is critical. It should also be borne in mind that, if the predictions of climate models are confirmed, the increase in hourly intensity of precipitation will be a prominent feature of precipitation in Eastern Spain during the coming decades (IPCC, 2019; AEMET, 2019).

The flooding episodes recorded in the Spanish Mediterranean coast during the recent years show at least two features of interest. First, these events, preceded with very copious amounts of rain, do not necessary cause high losses of human lives or even large economic losses. Second, events observe a significant change in the period of occurrence since important episodes have taken place outside the autumn months, traditionally the period of the year associated with heavy rains and floods in Eastern Spain~~Iberia~~.

Several studies (CEDEX, 2012; Marcos-García and Pulido-Velázquez, 2017; Serrano Notivoli, 2017) have examined recent changes in precipitation occurred in the Iberian Peninsula. A declining trend in precipitation has been identified although it is neither uniform nor of equal dimension in the area. Other studies also highlight the notorious increase in precipitation intensities in the Mediterranean coast (Barrera-Escoda et al 2014; Hogar et al 2010; Serrano et al 2017; Ribes et al 2019)

The most important flood episodes, with significant economic losses and human victims, occurred since 1950 have been caused by torrential rainfall, ~~with very high values of precipitation~~ intensities of ~~y,~~ generally~~ over~~ 200 mm. in 24 hours. Records of rain in 24 h in Spanish Mediterranean coast often exceed values of 300 or even 400 mm. The town of Sueca (Valencia) has the highest precipitation intensity recorded in Spain for an interval of 2 hours and 30 minutes (296 mm, 23 September 2008). On the 1st August 1993, the ~~station of the~~ Automatic Hydrological Information System (SAIH) station , located in the Valencian town of Manuel, captured 90.6 mm of rain in just 20 minutes. For a 1 minute period, the highest intensity recorded in Spain corresponds to the town of Montserrat (Valencia) on the 10th of October 2008 (10.2 mm).

Serrano Notivoli (2017), in his study on rainfall in Spain, noted a significant negative trend in maximum annual rainfall in one day in the Iberian Peninsula for the period 1950-2012. This means that less precipitation accumulates in the most extreme events. However, he also found a positive trend in the contribution of intense precipitation to cumulative annual totals indicating that episodes of heavy rain are more frequent, although the amount accumulated in them is smaller. Closely related to the recent behavior of precipitation in the Mediterranean coast, is the temperature of sea water which showed a consistent warming trend between 1985 and 2007 (Shaltout and Omstedt, 2014).

(figure 1)

Several localities of the Spanish Mediterranean coast have recorded flood episodes in recent years caused by the development of very heavy rainfall, ranging between 50 and 150 mm. precipitated in just 60-90 minutes (Figure 1). However, this trend is not uniform for the whole of the area~~Spanish Mediterranean coast~~. The increase occurred in the last decade in the central sector (Valencia Murcia, and Balearic Islands) but for the northern (Catalonia) and southern (Mediterranean Andalucia) coasts no discernible trend has been found. The explanation of these differences may be lie in the erratic character of rains in the Mediterranean coast of Spain. The general tendency appears to indicate a decrease of annual amounts of rain and an increase of rainless days (Serrano Notivoli, 2017). Moreover, the influence of local mountains, encouraging the occurrence of intense rainfall in certain areas above others and, as said before, the remarkable increase of sea water temperatures, especially in the central sector (Balearic Sea and Algiers Sea) may be important factors to consider in the explanation. In this regard, Shaltout and Omstedt (2014) have found that, between 1982 and 2012, the sea near the Balearic Islands experienced the highest temperature increase of the Western Mediterranean of~~r~~ 0.033 º C / year. On the other hand, Miró Pérez (2014), using satellite data of the NOAA / NASA AVHRR Oceans Pathfinder database, calculated the thermal increase in the coastal waters near the Valencian coast for the period 1985-2007, estimating an annual increase per decade of 0.26 ºC. More recently, Pastor *et al.*, 2017) calculated the temperature increase of the Western Mediterranean Sea since 1982, which they estimated in 1.19ºC.

At a more detailed scale, the analysis of rainfall in the Palma de Mallorca observatory shows a clear trend of increase in intense rains, of short duration during the last decade (Figure 2). Similar results are recorded in the observatories of Valencia and Alicante (Olcina, 2017).

The predictions of the last reports by the Spanish Meteorological Office (AEMET), following the calculation parameters of the IPCC report (2014), point that precipitation extremes (droughts and floods) in the Iberian peninsula will tend to be more pronounced and severe while the number of rainy days would decrease so that annual rainfall will accumulate in fewer days. In the Mediterranean coast, this trend will be exacerbated by the effect of accumulated heat of ~~the~~ sea water and its role in increasing rainfall intensities.

(figure 2)

A very rapid urbanization process

The period 1998-2018 was a crucial time for urbanization in Spain, with two clearly differentiated stages. First, the years between ~~period~~ 1996 and ~~-~~2007 were~~as~~ marked by economic growth and accelerated urban development (Burriel, 2008; Mateo Tome, 2014). Second, the period that began with the economic crisis of 2008, lasting until approximately 2017-2018, entailed a massive failure of the housing market and a severe slowdown in urban expansion (Albertos and Sánchez, 2014; Méndez *et al.*, 2015).

During the last two decades, most urban growth in Spain has occurred in the coastal Mediterranean provinces, including the Balearic Islands. Demographic and urban magnitudes derived from these transformations are presented in tables 1 and 2. Between 1998 and 2018 the population of the Mediterranean coast increased by more than three million people. Growth was especially intense in the Balearic Islands and in the provinces of Girona, Almería, Alicante, Tarragona and Murcia (Table 1). Most of this growth occurred before 2008, coinciding with the economic bonanza and the massive arrival of immigrants (both Europeans and from outside the continent) and went hand in hand with the so-called "urbanizing tsunami" affecting the area (Gaja, 2008). One of the most noticeable effects of urbanization was the artificialization and sealing of soil. More than 40 percent of the Mediterranean coastline is sealed and the urban land uses detected through the nocturnal luminosity have more than doubled (Table 2). The main reason behind accelerated urban growth was the so-called “housing bubble” fueled among other factors by permissive land use laws, both regional and local, and cheap credit attracting both European immigrants (mostly retirees from the United Kingdom, Germany and Scandinavian countries) and non–European immigrants from northern Africa and Latin America searching for jobs in the booming construction sector (Jiménez, 2009; Rullán, 2011). All in all, the Spanish Mediterranean coast became the most dynamic region of Spain after Madrid.

(table 1)

(table 2)

The spectacular growth in urban land increased exposition to flooding along a coastline and hinterlands mostly dominated by small, ephemeral and highly dangerous streams ~~highly dangerous~~ ~~regarding flash flood potential~~ in a process that could be defined as the “littoralization of risk” (Olcina, 2009). In Catalonia between 2000 and 2009 more than 210,000 new housing units were built in municipalities classified as of “high risk of flooding” (Departament de Territori i Sostenibilitat. Generalitat de Catalunya, 2019; Departament d’Interior. Generalitat de Catalunya, 2015). In Valencia, areas exposed to floods increased to over 1,440 km2 in 2013, with almost a million people potentially affected (Generalitat Valenciana, 2013). In the coastal municipalities of Alicante and Murcia, between 1994 and 2013, almost 7 million square meters of new housing were built in flood prone land to reach a total of over 22 million square meters (Pérez-Morales *et al.*, 2016). Along with the traditional effects on inundation and the alterations in the hydrological cycle caused by land use changes, the urban frenzy of that period also made pluvial flooding widespread. Hence and in terms of the Press and Release Framework (Blaikie et al 1994; Wisner et al, 2012), the dynamic pressures on land brought about by the urbanization process unleashed exposure both indirectly by modifying local hydrological cycles making them more susceptible to flood occurrence and directly by occupying flood prone space.

Exposure is particularly important in new urban areas in which uncertainty regarding the effects of urbanization on local streams is high while the experience with floods of the newly arrived tends to be low (Perles, 2010). This translates into ~~A fairly typical example of this are~~ cars being washed away together with their occupants by sudden flooding when trying to cross streams ~~with occasional deaths~~. To an important extent, the cause of ~~these~~ deaths in these cases is likely the unfamiliarity or overconfidence by drivers unaware of torrential rains and floods (for example, English or German residents in Alicante or Majorca). One of the most pervasive and insidious effects of urbanization of flooding patterns is that flood planning and management must not limit itself to regulate development in just traditional flood prone land but to manage all urban land because all may be potentially inundated. In urban areas, exposure continues to be chiefly concentrated in ground level and subterranean areas (parking spaces, etc.) as well as in public buildings (sports centers, schools, train and bus stations, etc.) along with all that might be in the street at the time of the event (person, vehicles) even though the characteristics of flood events continue to change as well. Pluvial flooding, for instance, rarely causes deaths but it is responsible for injuries (falls, etc.); traffic chaos, street pollution, damages to public networks (gas, water, electricity, inundation of basements, fallen trees, etc.).

Vulnerability

In the section above we have provided data showing an increase of exposure to flooding in the Spanish Mediterranean coast during the last two decades. In this section we aim to ascertain whether this increase may be ~~is~~ translated into a parallel increase in vulnerability manifested ~~as reflected~~ in human causalities and economic losses. We are aware that these metrics ~~is~~ may be considered a reductionist approach to vulnerability in that they ~~it~~ hardly take~~s~~ into account the many more factors relevant for the concept ~~behind vulnerability~~. However and no matter how crude, these two dimensions provide at least a first snapshot of the magnitude of the problem before entering into more detailed appraisals.

In our study area and regarding human casualties, between 2000 and 2018 only two episodes caused 10 human casualties or more. Although the highest number of casualties for a single episode occurred in the final year of the period considered, a discernible pattern of vulnerability increase in this category is hard to establish. Furthermore, episodes producing most victims such as that in Majorca in 2018 are highly localized events.

(table 3)

Table 3 also provides an estimation of economic losses. First, differences in amount tend to correlate with the spatial dimension of the event. Hence the relatively small figures for the episodes in Alicante and Majorca. Second, an important part of losses affect public infrastructures and facilities. Most of these infrastructures (streets, roads, sewers, urban furnishings, etc) are local with highly variable estimations of damages. Third and regarding insured economic losses, the *Consorcio de Compensación de Seguros* provides insurance against flooding and other natural hazards to all persons or organizations having home, business or car insurance. While this system has the advantage of making flood insurance available to all it does not offer subsidies or penalties according to differential flood exposition. For example, between 1998 and 2018 the *Consorcio de Compensación de Seguros* processed some 200,000 flood damage claims with a total amount of 1.273 million euro. The evolution of these compensations (Figure 3) in the period 1998-2018 reflects not so much an increase in the frequency of extreme events of nature as a greater penetration of insurance and, above all, an increasing accumulation of goods in flood prone areas (Barredo *et al.*, 2012).

(figure 3)

(figure 4)

According to Figure 4, the more affected sectors are shops, houses, manufacturing activities, office buildings and municipal facilities works. Although we cannot offer a definitive argument on this because of lack of reliable data, to an important extent, the reduction in vulnerability appears to be related to the increase in adaptive capacity and not to the reduction of exposure or sensitivity (Olcina *et al.*, 2016). However, the episodes of pluvial flooding show important differences with the more well-known fluvial and coastal flooding regarding differential vulnerabilities or the vulnerability of different persons, social groups, economic activities or city areas which, by means of their susceptibility and adaptive capacity, may be more likely to suffer the negative effects of increasing exposure to floods. Factors such as urban density; the use of the urban space by vehicles; the physical condition of individuals (children, senior citizens, persons with reduced mobility, etc.); the structure and quality of the built environment, income and possibilities to contract insurance are common in creating differential vulnerabilities. In the case of pluvial flooding we must add a new factor which is the lack of individual and collective experience with these phenomena which difficults ~~hampers~~ the adoption of appropriate adaptive actions.

Case studies

Alicante. Alicante, in Southeastern Spain, has suffered several important floods during the last decades. Of special relevance were the episodes of October 1982 and September 1997 with human victims and a heavy economic toll~~ and human casualties~~. In both cases~~events~~, more than 200 mm of rain in 24 hours were recorded. In the series of events occurred in the city since the mid-20th century it can be observed how since 1980 and with the exception of the two aforementioned events of 1982 and 1997, the city suffers from heavy flooding after episodes of about 100 mm of rain in 24 hours. Most of the rain accumulates in much shorter periods, usually 60 to 90 minutes. From the analysis of rain events above 20mm in 24 hours between 1977 and 2016 it can be noted that short but intense downpours have increased during the period 2006-2016 with some 40 episodes of rain between 20 and 50 mm (Olcina, 2017). As to the specific event of interest, on the 13 March, 2017, cold air in the upper layers of the atmosphere located towards the Southeast of the Iberian Peninsula coincided with very warm temperatures associated with Saharan winds recorded during the previous days and with sea water temperatures off the coast of Alicante of 18ºC. The storm dumped 136 mm of rain on the city in 24 hours, 83 mm of which fell in just three hours, between 6 and 9 PM. Economic losses as estimated by the *Consorcio* amounted to near 10,4 million euros and mostly occurred in garages, subterranean parking lots, commercial premises as well as in street public infrastructure.

The city is crossed by seven ravines which have been incorporated into the urban fabric since 1950. Currently, about 25 percent of the urban area is exposed to flooding for return periods of 500 years. The most exposed areas, many near the seashore, are Playa de San Juan, the urban sector of San Gabriel, the south of Benalua, and Avenida Denia. After the episode of 1997 important flood control works involving the construction of underground runoff reservoirs were built in some of the areas of the city that had been inundated in the past thus reducing the amount of people potentially exposed.

In general, flood water reservoirs responded well to the 2017 episode as did the flood pumps installed in problematic points. In particular, the Sant Gabriel reservoir, in the south of the city, was able to contain and store 60,000 cubic meters of floodwater (its maximum capacity) that otherwise would have flooded the southern neighborhoods. One the other hand, the La Marjal" public park, located in the urban sector of the San Juan beach proved also its effectiveness as flood control device since its flood pond was able to absorb 15,500 cubic meters of floodwaters or 35 percent of its total capacity during the 2017 episode, and more than 20,000 cubic meters or 50 percent of its capacity in the more recent episode of August 2019 (Figure 5).

(figure 5)

However, in 2017, the high values of accumulated precipitation throughout the day, together with the high rainfall intensities registered especially between 7 and 8 PM produced the accumulation of flood water in the low areas near San Juan beach, Avenida Denia, and Albufereta, in the vicinity of the Maldo ravine.

In summary, the episode of heavy rains of March 2017 showed how adaptive capacity under the form of relatively new approaches to hydraulic flood management (underground reservoirs and "flood parks") were able to contain excess runoff thus avoiding significant damage in the city and ~~some other~~ areas nearby. Despite the high intensity, no human casualties were recorded during the episode. Still, other city areas lacking such containment infrastructure suffered damaging inundation. In this sense, the case of Alicante may be an example of an increasingly important differential vulnerability within the city but also an example of changing adaptive capacity towards more sustainable solutions.

Sant Llorenç d'Escardassar (Mallorca). On Tuesday 10 October 2018, the municipality of Sant Llorenç d'Escardassar, in the Southeast of the island of Majorca, suffered the worst flood episode of the last 25 years in Spain. The event, a typical Mediterranean flashflood exacerbated by the enormous volume of rain falling in a short period of time and by evening commuting, caused thirteen dead and some 17.5 million euro in insured damages, including more than 300 business and houses as well as more than 300 cars (Consorcio de Compensación de Seguros, 2018; Diario de Mallorca, 11/10/2018; La Vanguardia, 11/10/2018). This event also showed the limitations of flood warning systems, even though warnings were issued in advanced regarding the possibility of heavy rainfall, and above all, the limitations of flood control works causing the well-known feedback or levee effect noted by geographers such as Gilbert White and his colleagues (Burton *et al.*, 1978), by which flood control works may decrease probability of occurrence but increase damage potential (Figure 6).

A report by the Spanish Meteorological Office (AEMET) indicated that on October 10th more than 200 mm of rain precipitated over this area in less than two hours. Although extreme rainfall episodes were not unknown (the last one, in 1989~~, which~~ left five dead), this event broke all existing records in terms of the precipitation intensity (Diario de Mallorca, 14/10/2018). Precipitation responded to the typical ocean-atmosphere interplay in the Mediterranean in autumn with warm and moist air clashing with cold air in altitude but in this case it appeared that ascendant air was warmer than normal and related to rising~~increasing~~ surface temperature in the Mediterranean Sea). The hydrological response to this amount of precipitation was also quite common. Most of the precipitation fell on a small basin dominated by a 500 meter high mountain with a wide reception area and a narrow course downstream (Lorenzo-Lacruz et al 2019). It is also known how in Mediterranean basins most rainfall turns into runoff with extremely rapid concentration times. Although no official data has been released, the peak flood may have reached the average flow of a large river such as the Ebro (600 cubic meters per second) taking some 45 minutes to reach the town.

As to causal factors of human origin, Sant Llorenç d'Escardassar also tells a fairly typical story. Originally located on high ground to avoid flashfloods, during the last decades, the town has expanded to accommodate more people and economic activities mostly linked to tourism, and this expansion, admittedly recognized in land use and urban plans, has taken place on areas highly exposed to flooding (Diario de Mallorca, 11/10/2018). The response to the episode of 1989 was the widening (up to 12 meters) and channelization of the main ravine and, under the supposed protection of flood control works, urbanization of this area increased. However and somehow fortunately, when the flood broke the hydraulic system, affected activities were mostly garages and workshops and not residential uses (20 Minutos, 10/10/2018). As to the unusually high number of deaths, flood warnings were issued by AEMET with reasonable accuracy but messages either did not reach the public adequately or the public did not take notice of them given the high number of people trapped in cars during the event (Diario de Ibiza, 12/10/2018).

(figure 6)

Girona. On ~~June~~ 30 June , 2017, the city of Girona, in the Northeast the Iberian Peninsula, suffered an episode of rain and hail that flooded ~~caused flooding in~~ the old city and the modern center (Diari de Girona, 30/6/2017). The episode originated in the accumulation of cold air in the upper layers and a surface temperature of 27ºC with rapidly ascending warm air. The high intensity of rain and hail (52.1 mm in 30 minutes), accompanied by winds close to 60 km/h, inundated streets with up to 40 centimeters of rain while more than 20 centimeters of hail accumulated in the streets and roofs of the city, blocking drains and causing the flooding of streets, shops and homes (Figure 7). One of the most prominent incidents was the flooding of the ground floor of the main commercial center of the city, which forced the evacuation of customers. The downpour occurred at the end of the warmest June in Girona since 1911. Although no human deaths were recorded, several people were injured due to falls. Losses amounted to 3 million euro in insured damages, including damages in 200 shops and offices, 250 homes, and 125 cars (Consorcio de Compensación de Seguros, 2018; Diari de Girona, 5/7/2018).

Girona, a city crossed by four rivers (Ter, Oñar, Güell and Galligants), has historically suffered the impact of fluvial floods, the last serious one in 1970 (Ribas, 2007). The constant flood threat explains the complex hydraulic system constructed over the centuries (channelization, diversions, etc.) in the city and to a great extent responsible of the lack of catastrophic episodes caused by the rivers since 1970. At the same time, however, the expansion of the urban area has reduced infiltration and also the drainage capacity of the street fabric. Hence, the traditional fluvial floods characteristic of the autumn months are giving way to the pluvial floods of the summer months, with important episodes in August 2005, June 2017 and July 2018. Among the causal factors of human origin, it is also worth highlighting the fact that the sometimes these episodes of rain and hail have occurred in the areas and times of the day or the week coinciding with high human and vehicle presence, for example, commercial areas in Friday or Saturday afternoons.

Especially problematic are episodes of intense rain accompanied by wind and hail, blocking drains ~~from the moment drains are blocked~~ either by the concentration of leaves and branches of trees or by the same hail. In addition, the population exposed to this type of episodes often does not know how to react and behave. Likewise, local authorities remain unaware of pluvial flooding and do not promote enough actions to minimize this risk, such as, for instance, the increase in infiltration capacity and ~~in the~~ number of potential sinks.~~,~~ ~~size and adequacy of sinks, public education, etc~~Also, ~~. In this sense~~, for the case of Girona we could speak of a “situational vulnerability” arising from the intersection between the spatial and temporal occurrence of the episode and the demographic characteristics of persons affected. Most of the latter were young and middle aged people (bicycle and motorcycle drivers or pedestrians) present in the streets at the moment of the event. Moreover, damages concentrated on shops and other service activities in one of the busiest times of the week (early evening of a Friday).

In summary, the episode of June 2017 as well as those of August 2005 and July 2018, were partly a product of changing patterns of precipitation intensity after days of very high temperatures. But they also showed the inability of the city to adapt and absorb intense rainfall through, for example, detention basins; spaces for infiltration or specific information to citizens regarding these relatively new type of flood events.

(figure 7)

Discussion, conclusions and policy recommendations

Precipitation patterns in the Spanish Mediterranean coast during the last two decades appear to indicate an increase of high intensity events. T~~hus t~~he number of rainfall episodes discharging quantities between 50 and 150 mm in just one hour has augmented causing mounting damages in the affected territories. The geography of intense precipitation events shows also a greater presence~~increase~~ in the central sector of the Spanish Mediterranean coast which may be related to the warming trend in SST characteristic of this area. However, ~~, although~~ the accumulation of sensible heat in the rest of the Mediterranean coast, especially in summer months, also favors the formation of localized and intense storms in any area of Eastern Spain~~ as well~~. Another observed phenomenon is that the seasonality of intense rains appears to have changed. These events can happen now during any month of the year and ~~,~~not only autumn as was usual in past decades. This will force to review warning and emergency protocols that will have to stay activated all year round for this type of episodes.

In the risk equation the human component plays a critical ~~a very important~~ part,~~ probably more important that the physical events themselves. In this sense, ~~Mediterranean Spain has experienced a spectacular increase in urbanization which not only has occupied intensively flood prone land but has also modified deeply local hydrological cycles especially through soil sealing. The most immediate effect of this process has been the increase in episodes of pluvial inundation now probably the most frequent type of flooding in the region. Despite the increase in exposure, there is no discernible pattern of an increase in vulnerability concerning human casualties. Episodes with more than 5 victims have become exceptional (Catalonia, 2000 and 2005; Málaga, Almería and Murcia, 2012; Mallorca 2018) and some remain ~~are~~ highly localized events. Economic losses can easily fall beyond ~~overcome~~ the figure of 100 million euros per episode and would probably continue to increase reflecting an increase in the accumulation of economic goods in flood prone land many of them insured due to the generous provision of insurance against floods in Spain. Although in this case we have not been able to contrast the hypothesis of increasing vulnerability (in terms of human and economic losses) due to lack of reliable data, it is likely that the Spanish Mediterranean coast follows what has been documented for Europe in general (Paprotny *et al.*, 2018). Other dimensions of vulnerability and especially of differential social vulnerability have not been examined in detail by this paper due to difficulties in accessing quality data~~ for these dimensions~~.

One question that we have been particularly interested is whether more intense episodes may affect not only exposure but also susceptibility and adaptive capacity. In this regard, the analysis of the three cases presented in the paper offers some insights worth of note. First and in terms of victims, fluvial floods and especially flash floods from ephemeral streams continue to be responsible for most of the deaths as shown by the Sant Llorenç d'Escardassar episode. In contrast, pluvial flooding would rarely produce a similar number of deaths although it probably could increase the numbers of injured persons both pedestrians and motorists, as in the case of Girona. As population in cities grows older, ~~susceptibility~~ vulnerability could also increase. Regarding adaptive capacity, the three cases show the shortcomings of traditional flood control works (especially in the Majorca case) but also the potentialities of new hydraulic approaches. In the particular case of pluvial flooding we must add a new factor that may increase vulnerability ~~susceptibility and decrease adaptive capacity~~, which is the lack of individual and collective experience with these phenomena in many cities making it difficult to design and implement appropriate adaptation measures.

In Girona or in certain Alicante neighborhoods, pluvial flooding reveals the limitation of conventional urban drainage designed to convey floodwaters out of the cities as fast as possible. More intense precipitation events on cities would add more stress to sewer capacity to absorb floodwaters and more so if maintenance tasks are not routinely performed. Adaptive capacity in this case probably requires a paradigm shift in the way urban drainage currently works. As the floodwater deposits and especially the flood park of Alicante show, preparation for more intense events will likely be more successful if based on these alternative solutions than depending solely on conventional sewers and on conventional stream channelization as in the case of Sant Llorenç d'Escardassar. Moreover, examples such as the Marjal Park in Alicante enforce the idea of a more circular approach to flood management in which hazards can become resources (Sauri and Palau-Rof, 2017; Cousins, 2018). Hence the creation of SUDS (Sustainable Urban Drainage Systems) would be one important instrument for the cities of the Spanish Mediterranean coast in the coming decades, also as a measure of adaptation to climate change.

Adaptive capacity also includes nonstructural actions such as ~~urban~~ planning regulating land uses in flood prone land. Traditionally, in Spain, urban planning has played a very minor role in flood adaptation and this is true in the three case studies examined in the paper. Urban planning in Spain is responsibility of local councils although they need to take into account under more general regional and national land use laws. As said before, in 1998, a very permissive national land use law was passed by the Spanish Parliament allowing for the acceleration of urban growth. Quite paradoxically, the law stated that land could not be developed into urban land if affected by a "natural risk". However, uncertainty and lack of data regarding risks and their occurrence precluded limitations to development. As a result, the period between 1998 and the approval of a new national land use law in 2008, saw the largest growth of urbanization if flood prone land, especially in the Mediterranean coast and also in the Canary Islands. The 2008 law required flood maps and other proof in order to control development in flood prone land and could benefit as well from the strong decline in urban projects brought about by the economic crisis starting in the same year.

Finally, and regarding policy recommendations, the physical and human layout of these areas (heavy rainfall; small but step basins with abundant and fast runoff, and important human occupation) otherwise quite common in coastal Mediterranean hinterlands makes flooding common. In this sense, flood management should change focus towards improved warning systems (and especially better transmission of messages to the population) and an attitude of "living with floods" rather than futile attempts to suppress them with more flood control works. Ravine channelization has reached its limits and new flood management actions should aim at reducing exposure and susceptibility through more stringent land use and urban plans and through the adaptation of the built environment to these phenomena. The challenge for the future will be to devise actions to absorb perhaps equal or even higher precipitation intensities with tools different than conventional hydraulic works. Adaptive capacity to new events cannot obliterate the importance of urban planning and the continuous need to limit development in flood prone land. Planning instruments as well as public education should be much more effective than in the past. Together with this new paradigm in urban drainage favoring a circular rather than a lineal approach, planning and education are now as always essential tools in making our cities more resilient to the coming climatic extremes.

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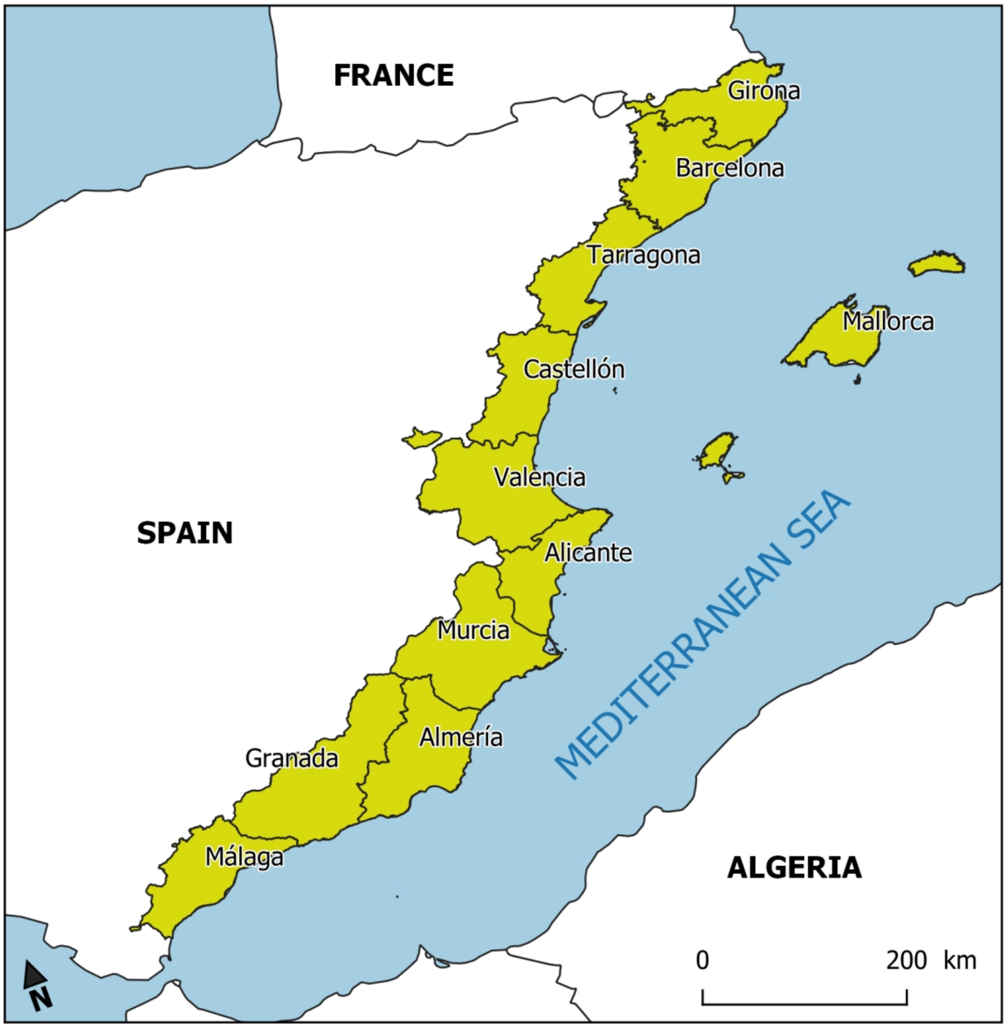
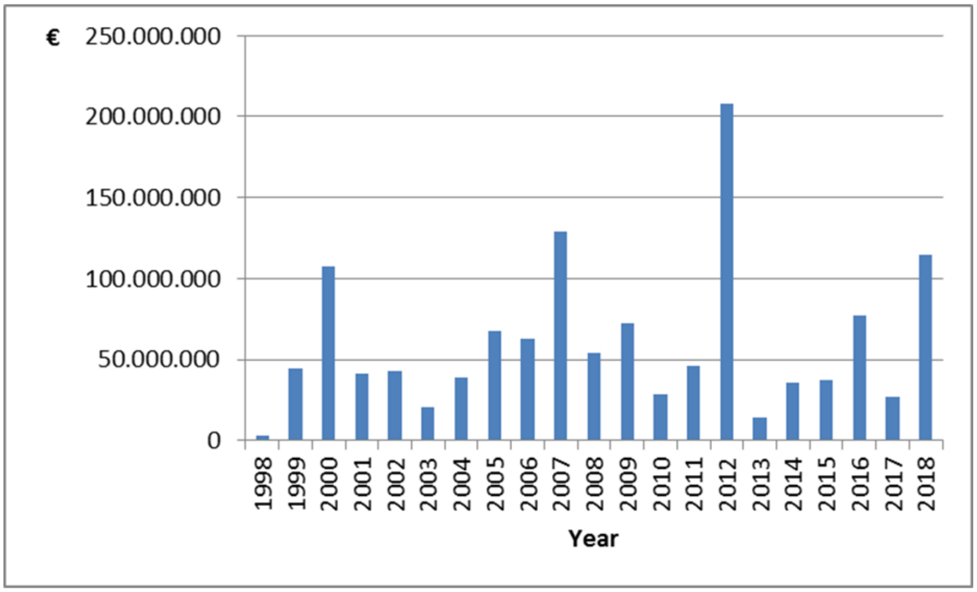
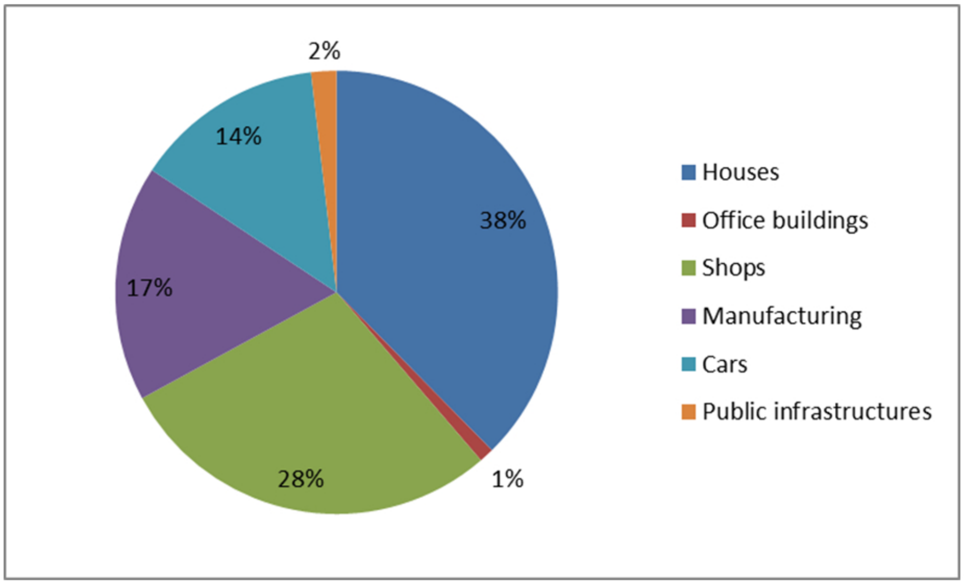


Study area. Source: Own elaboration.

140x143mm (300 x 300 DPI)



Compensations paid by the Consorcio de Compensación de Seguros (in €) (1998-2018). Source: 35. Consorcio de Compensación de Seguros (2018).



Compensacions paid by the Consorcio de Compensación de Seguros (in €) as per damages to goods in flood episodes (1998-2018). Sourde: Consorcio de Compensación de Seguros (2018).

La Marjal Flood Park (Playa de San Juan, Alicante): (a) empty, (b) with 15,000 m3 of flood water produced by the event of 13 March 2017). Source: Aguas de Alicante (reproduced with permission)

La Marjal Flood Park (Playa de San Juan, Alicante): (a) empty, (b) with 15,000 m3 of flood water produced by the event of 13 March 2017). Source: Aguas de Alicante (reproduced with permission)

Effects of the flood of October 10, 2018 in Sant Llorenç d'Escardassar. Source: Celso Garcia (UIB) (reproduced with permission).

711x533mm (72 x 72 DPI)

Effects of the flood of October 10, 2018 in Sant Llorenç d’Escardassar. Source: Celso Garcia (UIB) (reproduced with permission)

711x533mm (72 x 72 DPI)

Effects of the episode of rain and hail on June 30, 2017, in the city of Girona
Source: El Gerió Digital (reproduced with permission)

691x394mm (72 x 72 DPI)

Effects of the episode of rain and hail on June 30, 2017, in the city of Girona
Source: El Gerió Digital (reproduced with permission)

564x423mm (72 x 72 DPI)

Table 1. Population of Spanish Mediterranean provinces, 1998-2018

Province	**1998**	**2018**	**Increase (%)**
Girona	543.191	761.947	40,27
Barcelona	4.666.271	5.609.350	20,21
Tarragona	580.245	795.902	37,16
Castellón	461.712	576.898	24,94
Valencia	2.172.796	2.547.986	17,26
Alicante	1.388.933	1.838.819	32,39
Murcia	1.115.068	1.478.509	32,59
Almería	505.448	709.340	40,33
Baleares	796.483	1.128.908	41,73
Total	12.230.147	15.447.659	26,30

Source: INE

Table 2. Land area with urban brightness[1] within a 50 km radius form provincial capitals of the Spanish Mediterranean (total area, 1992 and 2012, in km^2 and change 1992-2012, in %).

Province	**1992**	**2012**	**Change (%)**
Girona	117	613	423,93
Barcelona	1.170	1.779	52,05
Tarragona	299	663	121,73
Castellón	119	553	364,70
Valencia	494	1.204	143,72
Alicante	400	1.144	186
Murcia	433	1.606	270,90
Almería	58	264	363,79
Palma	155	246	58,70
Total litoral	3.245	8.072	148,75

1. In Spain, for each km^2 of effective urban land, urban brightness occupies 2,4 km^2 (Nel·lo, 2017)

Source: Own elaboration from data provided by the Grup d'Estudis sobre Energia, Territori i Societat (GURB, 2019).

Table 3. Flood episodes in Mediterranean Spain (1998- 2018): Deaths and Economic Losses

Date	Episode	Deaths	Economic losses (million €)
2000	Catalonia (June and October) Valencia (October)	8	839.2
2002	Valencia, Alicante (April, May and September)	3	150.3
2005	Catalonia (October)	8	16.7
2006	Catalonia, Valencia, Balearic Islands (September)	1	100
2007	Valencia (October)	2	150
2009	Alicante (September)	0	193.5
2012	Málaga, Almería and Murcia. (September)	10	350
2015	Valencia, Alicante, Murcia, Almería (September)	4	165.3
2016	Valencia, Alicante, Castellón, Murcia, Almería, Balears (September) Malaga, Cádiz (December)	7	175.6
2017	Alicante (March)	0	10.3
2018	Mallorca (October)	13	16.9

Source: Compiled from Consorcio de Compensación de Seguros (2018), Ayala, F., Olcina, J. (2002) and Centre de Recherche d'Épidémologie des Disasters (CRED) (https://www.cred.be/)