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ORIGINAL PAPER

Chronicle of a forecast flood: exposure and vulnerability on the south-east coast of Spain

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Abstract

In recent years, floods have become one of the natural hazards that generate the greatest economic and human losses on the planet. As is well known, torrential rainfall events are the triggering factor for flooding processes; nevertheless, it is worth examining the responsibility of the human factor, such as urban development, in the occurrence of these potential natural disasters. To this end, rainfall observations obtained during different precipitation events have been analysed. The evolution and urban development from the growth of the number of buildings was also examined. The information obtained has been crossed with the digital cartography of flooded areas (National System of Flood Zones Cartography, SNCZI in Spanish acronym). The results obtained show that the last two extraordinary rainfall events (December 2016 and September 2019) that occurred in the municipalities of Los Alcázares and San Javier (Region of Murcia, SE Spain) exceeded 200 mm, and quantified very high hourly intensities (> 50 mm/h). On the other hand, the number of buildings constructed and the built-up area in both municipalities has increased notably, with an evolution between 1950 and 2019 from 1057 to 15,969 buildings constructed, increasing from 16.09 ha. to 450.06 ha. occupied. This real estate development has caused the number of buildings exposed to flooding to reach 3840 in 2019 for a 10-year RP (return period) and 5941 for a 500-year RP. It can be concluded by indicating the clear influence of territorial transformation on the increase of exposure and economic losses generated by flood events.

Keywords Torrential precipitation · Floods · Exposure · Building Construction · Induced hazards

1 Introduction

In recent decades, the Mediterranean coast has experienced an increase in vulnerability and exposure to the danger of torrential rains (Olcina Cantos 2017; Insua Costa et al. 2021). Within this coastal strip, these meteorological phenomena have reached their greatest magnitude in Italy, France, Spain and North Africa (López Martínez et al. 2017; Ribas et al. 2020; Furlan et al. 2021; Satour et al. 2021). Consequently, there has been an increase

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in economic losses related to floods associated with rainstorms (Marchi et al. 2010; Spekkers et al. 2013; López Martínez 2019). However, Barredo (2009) notes that there is no evidence of a clear positive trend in standardised flood losses in Europe over the period 1970–2006. Paprotny et al. (2018) analyse trends in flood losses in Europe over the last 150 years, showing that there has been an increase in the area flooded and the number of people affected annually, which contrasts with a substantial decrease in flood fatalities. One of the main causes of extraordinary risk insurance cover in Spain is flooding. It occupies first place when measured against other causes in the total cost of compensation (Barredo et al. 2012). Flooding represents 72.3% of the total over the period 1987–2019 (Insurance Compensation Consortium 2019).

When social issues come into play, it is very difficult to assess the contribution of the vulnerability factor due to the fact that there is still no fully agreed definition in the scientific field (Gil-Guirado et al. 2016). In this sense, the concept of vulnerability provides an excellent analytical tool both for assessing the susceptibility to damage, defencelessness or marginality of physical and social systems, and for improving human well-being by reducing risk (Adger 2006). Vulnerability should therefore be understood as an overarching concept that includes multilateral aspects of exposure, sensitivity and adaptive capacity to external natural changes or hazards (Polsky et al. 2007; Cho and Chang 2017). In Birkmann (2013), an integration of concepts from different authors is carried out in a way that integrates global vulnerability into six major groups: physical, ecological, social, economic, cultural and institutional. In this respect, institutional vulnerability has been extensively studied, due to its territorial implications, on the Spanish Mediterranean coast by different authors (Olcina Cantos 2010; Olcina Cantos et al. 2017; Pérez Morales et al. 2018). As established by López Martínez et al. (2017) and Papathoma-Köhle et al. (2021), this "institutional vulnerability" factor can manifest the ineffectiveness of the governmental authorities in charge of managing the effect of natural hazards on people or property, increasing their exposure. In relation to this, exposure to risk (in this case flooding) is considered to be the total number of people or the total amount of material goods that may be affected by a given event (torrential rainfall). In this regard, as stated by Jongman et al. (2012), a considerable increase in the population exposed to floods is estimated up to 2050.

The significant increase in the number of floods and their consequent damage in the Spanish coastal strip, according to pluviometric records, is related to a multiplication of exposure and vulnerability to these phenomena, rather than to an increase in extreme rainfall events (hazard) (López Martínez et al. 2017; Pérez Morales et al. 2018). Regionalised climate change projections do not show a significant increase in the frequency and magnitude of floods in Mediterranean regions (Kundzewicz et al. 2006; Rajczak et al. 2013; Madsen et al. 2014; Alfieri et al. 2015). Furthermore, according to the IPCC (2018), there is little confidence that anthropogenic climate change increases the frequency of floods on a global scale. In this line, the regionalised climate change projections for the twenty-first century for Spain do not show significant changes in intense precipitation in any of the different emission scenarios (RCPs) analysed. In the case of the Region of Murcia, a slight upward trend is shown in terms of the change in intense precipitation (%), especially in the RCPs 8.5.

On the other hand, over the last decades there has been an intense urbanisation process on the Spanish Mediterranean coast, especially between 1997 and 2007, which experienced the greatest real estate boom (Burriel De Orueta 2008). The great expansion experienced by new residential areas and agricultural crops has led to the improper occupation of the fluvial channels and floodplains (Rico Amorós et al. 2010; Gil-Guirado et al. 2014; Ibarra Marinas et al. 2017; García Ayllón 2018). Spatial planning at the local scale is an effective tool for flood risk reduction (Merz et al. 2007; Zapperi and Olcina 2021). In this respect, structural measures (hydraulic engineering works) were initially the most widely used tool to try to control or minimise the effects caused by floods (López Martínez 2019). However, their relative inadequacy in the face of large-scale events (Serra-Llobet et al. 2013) led Spanish regions (Autonomous Communities) to begin to include non-structural measures in their land-use planning regulations based on studies of the involvement of different land uses in floods. Thus, considered as a set of criteria established in different regulations, plans or programmes that legislate the development of activities (urban planning, economic, etc.) on land, land-use planning is one of the best and most effective instruments for mitigating this type of natural risk (floods). These land-use planning processes integrate different scales of work, from the international level (guidelines) to the local level (General Municipal Land-use Plans, PGMO), registering a regulatory regulation which exercises over its protection (Olcina Cantos 2004, 2021). The PGMO is an essential tool for municipal planning and is responsible for representing on the territory the conditions established in terms of land use. With regard to flooding, these planning instruments have found a great ally in the regional (INUNMUR Plan, in the case of the Region of Murcia) and national (National Floodplain Mapping System, SNCZI) instruments when it comes to delimiting the most vulnerable areas (López Martínez 2015). Flood maps are essential in spatial planning, and according to Olcina and Díez-Herrero (2021), risk mapping must improve and overcome some weaknesses to be more efficient and effective in territorial planning processes.

Figure 1 shows a comparative land-use analysis between 1990 and 2018. At present, this land cover comparison shows the following spatial distribution: 52.1% permanently irrigated land cover, 23.5% urban areas, 20.5% other agricultural areas, 1.5% forest areas and 2.4% water bodies. This means that more than 75% of the territory is occupied by urban and permanently irrigated agricultural areas, land uses that have a great impact on soil sealing processes and that favour runoff (Romero Díaz et al. 2017). Over the last three decades, there has been an incessant increase in the urban area, land cover which has doubled in size, from 1034 ha. (10.9% of the territory) in 1990 to 2234 ha. (23.5% of the territory). Due to this increase, there has been a decline in other land uses.

The traditional presence of tourists has been reinforced by the development of new residential areas. The spread of these real estate areas is both a cause and a consequence of the progressive increase in tourist arrivals, so there is greater exposure of the population to torrential rainfall events (Romero Díaz et al. 2017; Meseguer-Ruiz et al. 2021).

With regard to the study area, the work carried out by Pérez Morales et al. (2016b) reveals the magnitude of the construction of second homes during the real estate boom, which is associated with a high degree of soil sealing. This study attempts to analyse aspects very similar to those investigated in this research. However, it lacks an assessment of the precipitation accumulated in the last two torrential rainfall events (over 200 mm) in the area studied. These episodes are subsequent to the publication dates of the aforementioned work, so this document can serve as an update to the data shown in the previous work, with information on buildings up to the year 2019, compared to 2011.

Based on the basic premise of the notable increase in the impact of torrential rains in the coastal municipalities of Los Alcázares and San Javier, the main objective of this study is to analyse the causes that have led to this territorial problem. The data collected after the floods indicate that these are the areas with the highest number of economic losses, compared to other Spanish territories (Consorcio de Compensación de Seguros 2019). In this sense, the research attempts to assess the responsibility that corresponds to the natural and human factor in the perpetration of these catastrophes. Thus, the specific objectives seek to

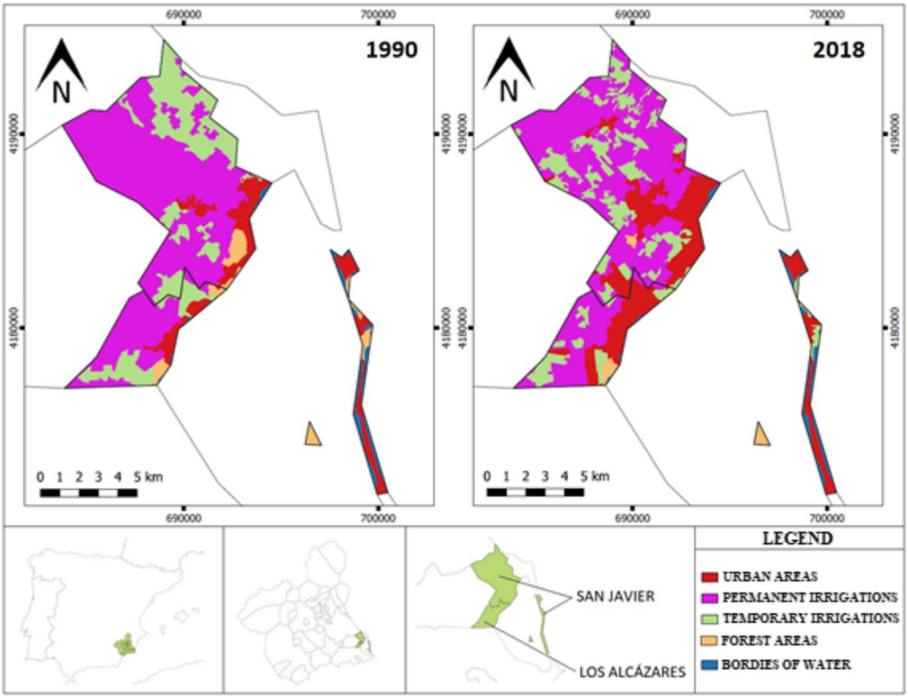

Fig. 1 Changes in land cover and land use between 1990 and 2018 (Los Alcázares and San Javier). Source: own elaboration, data obtained from Corine Land Cover

consider both the relevance of the natural factor by analysing the intensity of the two torrential rainfall events that have occurred in the last 5 years (December 2016 and September 2019), and the weight corresponding to the human factor by studying the process of real estate growth and the degree of exposure of buildings to the possibility of suffering flooding events in different return periods.

2 Methodology

2.1 Study area

The territorial scope of this research study is located in the coastal area of the Region of Murcia (South-east of the Iberian Peninsula). Unlike most municipalities located on the Mediterranean coastline, the administrative boundaries being studied are surrounded by the brackish lagoon of the Mar Menor (Fig. 2). It is a hypersaline coastal lagoon with a surface area of 135 km^2 and a perimeter of 60 km, constituting an ecosystem that for decades has been undergoing profound changes generated by the strong human pressure on its immediate surroundings (Pérez Ruzafa et al. 2005; Caballero Pedraza et al. 2015). There are two towns whose spatial extension is as follows: 2005.2 hectares in Los Alcázares, and 7518.04 hectares in San Javier. Both municipalities are located in the watersheds of the Albujón and Maraña Ramblas (ephemeral channels), which

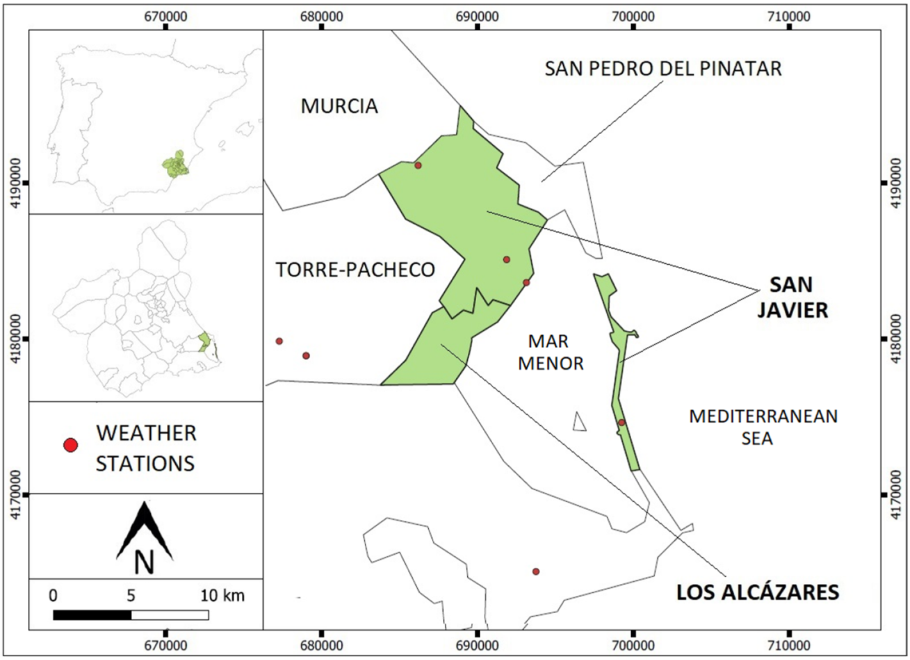

Fig. 2 Location map of municipalities analysed in the Region of Murcia (Los Alcázares and San Javier). Source: Own elaboration

together comprise some 104,800 hectares. As mentioned above, these are the municipalities most exposed to flooding and those with the highest number of damages and economic losses. In addition, the perimeter of the Mar Menor includes part of two other municipalities (Cartagena and San Pedro del Pinatar), which have a lower degree of exposure and vulnerability to this phenomenon. This territorial area exhibits a semi-arid climate, with an average annual rainfall of 300 mm. Although these precipitations show a notable torrential nature (Castejón Porcel et al. 2018). These are episodes of rainfall with a high hourly intensity, for example in the case of the events analysed, 52.8 mm/h on 18 December 2016 and 91.8 mm/h on 13 September 2019 in Santiago de la Rivera-San Javier (Agricultural Information System of Murcia). This area also holds the record for daily rainfall in the Region of Murcia, with 330 mm at the San Javier observatory (4 November 1987).

The territorial peculiarities (high insolation and thermal bonanza, among others) which characterise this territory have boosted its traditional consideration as an outstanding tourist and second-home destination, especially within the national tourist scene. The boom in this sector of activity has caused an increase in the demand for accommodation (tourist and residential), which has had a significant impact on an intense building process that has filled a large part of its territory, including areas less suitable for the construction of dwellings, such as the alluvial plains that make up the aforementioned ephemeral channels. The improper execution of urban processes in these sectors has increased the exposure and vulnerability of the territory under analysis, creating residential areas with a high risk of flooding.

The Segura Hydrographic Demarcation, the area in which the territorial space analysed is located, has a flood risk control system, the Flood Risk Management Plan. The main objectives of this Plan are the preliminary assessment of flood risk, the identification of areas of significant potential flood risk under the premise of the impact of climate change and the preparation of flood hazard and risk maps for different return periods. In addition, the Autonomous Community of the Region of Murcia has a Special Civil Protection Plan for floods (INUNMUR). The purpose of this second plan is to establish the organisation and procedures for action by the public resources and services that intervene in the event Of an emergency.

2.2 Material and methods

The following analysis is based both on the combination of data obtained from different sources, as well as the use of various spatial component techniques that allow contrasting georeferenced information arranged on the earth's surface. In this sense, the pluviometric observations obtained in different precipitation events have been counted, mapped and analysed through the official meteorological stations of AEMET (State Meteorological Agency) or SIAM (Agricultural Information System of Murcia), as well as meteorological amateurs who are individuals made up of associations: Meteoclimatic and AMETSE (South-east Meteorological Association). The precipitation data have been homogenised (Ruiz Álvarez 2020) and interpolated using the technique known as Ordinary Kriging (Vicente Serrano et al. 2003; Moral 2010). The pluviometric analysis is carried out in two phases. Firstly, an analysis of the evolution of the number of episodes exceeding 100 mm is carried out, as this amount of precipitation is considered the threshold that distinguishes torrential rainfall (López Martínez et al. 2016; Olcina Cantos 2017). In this work, an episode is considered to be the accumulation of precipitation in 5 days, although in most episodes, most of the precipitation is collected in a few hours. For the evaluation of the temporal evolution, 7 pluviometric stations located in the study area and its surroundings (from the AEMET database) were used, 3 of which have been observed for more than 80 years (San Javier, Pozo Estrecho and Fuente Álamo), as they are the longest-lived series in the study area. Secondly, the spatial distribution of the accumulated precipitation during the two precipitation events that have exceeded 200 mm in the last 5 years is analysed. For this purpose, rainfall stations located in the study area and its surroundings have been used in order to obtain a better result in the spatial interpolation process.

Together with the analysis of the natural component (precipitation), the social implication in the evolution of the flooding processes will be ascertained. For this, the evolution and development of the real estate portfolio is studied through the use of alphanumeric data (represented graphically on the territory) provided by the General Directorate of Land Registry. This official body belonging to the Ministry of Finance (Government of Spain) discloses current and detailed information on the multitude of variables that characterise the national building complex. The information obtained from this database has been crossed with digital cartography of floodplains of fluvial origin propagated by the National System of Flooding Zones Cartography (Ministry for the Ecological Transition and the Demographic Challenge). The contrast of both variables allows the degree of vulnerability and the amount of buildings and constructed land area that remain exposed to possible flooding processes in different periods of return or occurrence to be studied (Fig. 3).

However, although the data used have a high degree of quality and reliability, it should be mentioned that they also have a number of limitations. In this regard, as Pérez

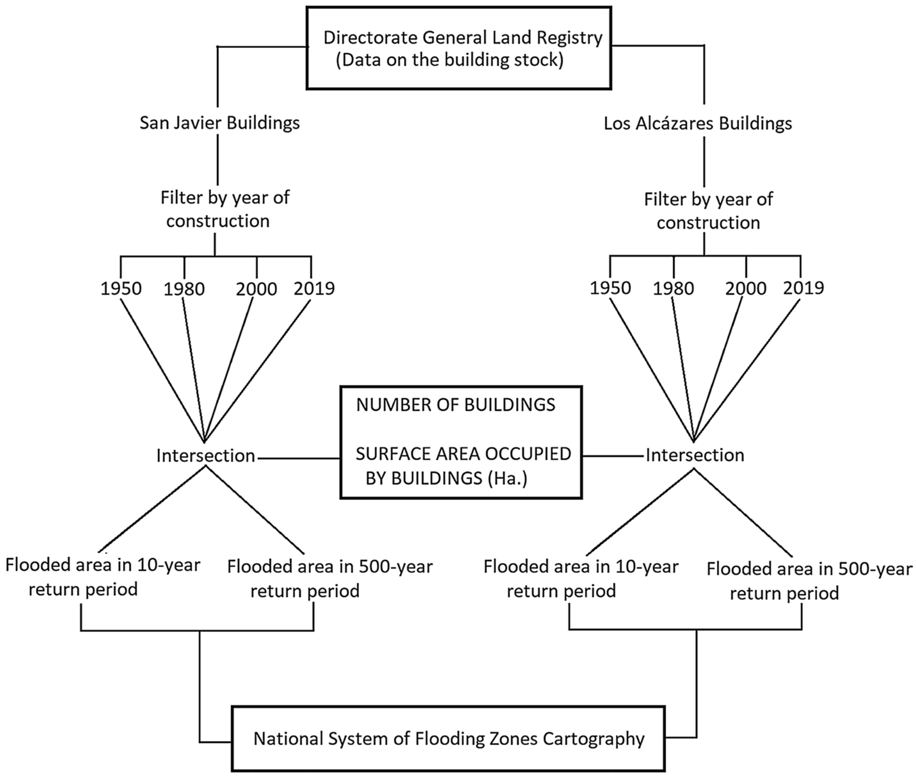

Fig. 3 Flow chart followed in the collection of data processed in the work. Source: Own elaboration

Morales et al. (2018) state, the increase in the accuracy and updating of hydrological data means that the areas with the possibility of flooding are adapted to the delineation of the communication routes of the urban space. This fact means that the intersection between the information on flood zones (National System of Flooding Zones Cartography) and cadastral data (General Directorate of Land Registry) sometimes does not overlap correctly, so that the process is not generated properly. To overcome this problem, as the study area is relatively small, a manual sweep has been carried out with the selection of buildings that have been considered to be affected as they are located in affected areas or close to flood zones. Furthermore, as Pérez Morales et al. (2016a) point out, another of the limitations that the use of these data from the cadastre may have is the consideration of different buildings (built in different years) within the same plot. The present study, as it does not work with plots but with individual data for each building, does not have this problem, as each building shows a single value corresponding to its date of construction.

Although this methodology has been used by several authors (Maantay and Maroko 2009; Fuchs et al. 2015; Koks et al. 2015; López Martínez et al. 2020), it is one of the most reliable and current techniques for this type of analysis. In this sense, the data used in it come from official sources (Government of Spain) and are renewed every 6 months. In this way, their detailed treatment can reveal the degree of responsibility that corresponds to the natural factor (magnitude of torrential rainfall events) and the human factor (land management and planning) in the development and increase of the risk posed by a natural hazard that has become a catastrophe in the areas examined in recent years.

3 Results and discussion

3.1 Pluviometric analysis

Firstly, the evolution of the pluviometric episodes with a precipitation greater than 100 mm (Fig. 4) that occurred in the territorial scope of the slopes of the Albujón and Maraña ephemeral channels is shown. The selected time slot is 1934–2020. During this period, a total of 51 episodes were recorded, the majority during the autumn (28.55% of the total) and winter (16.30% of the total) months. Over the last decades, a slight upward trend has been seen, as is the case in other parts of the Mediterranean coast (Olcina Cantos 2017). In the reference period 1961–1990, a total of 16 episodes of abundant rainfall were recorded, and in the current reference period: 1991–2020, a total of 21 episodes. Simultaneously, there has also been an increase in their magnitude. The greatest increase is observed in the winter months. Likewise, there is an evident transfer of the month of greatest occurrence of these rainfall events from October to September. In the period 1961–1990, 7 events were recorded in October and 2 in September. In contrast, during the last three decades (1991–2020), there have been 6 events in September and 1 in October. This could be induced by changes in the general atmospheric circulation leading to an increase in the frequency of cut-off lows due to the weakening of the polar jet and a consequent strengthening of the Central European anticyclone (Muñoz et al. 2020). Similarly, a clear increase in the temperature of the Mediterranean Sea has been observed in recent decades (Skliris et al. 2011; Shaltout and Anders 2014).

In the entire period analysed, a total of 4 episodes have occurred with a record greater than 200 mm. All of them have been recorded since the 1970s: October 1972, November

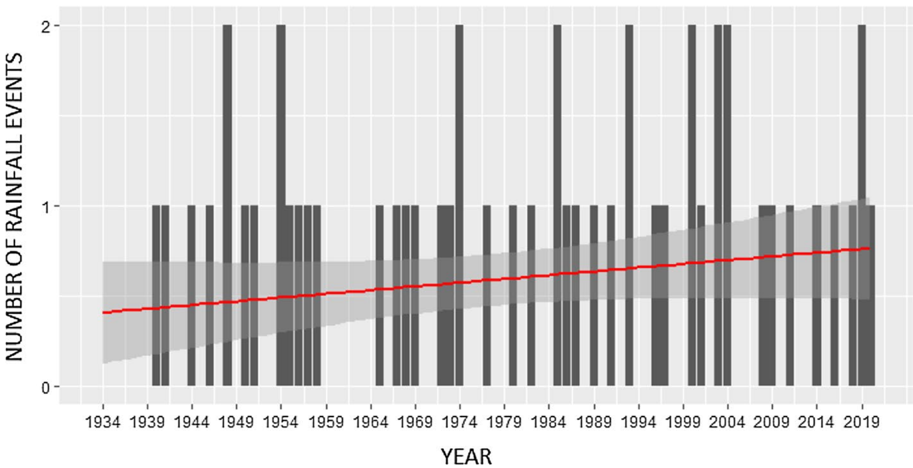

Fig. 4 Evolution of the number of precipitation episodes ≥ 100 mm. Source: Own elaboration, data obtained from AEMET and SIAM

1987, December 2016 and September 2019. The last two recorded which occurred over the last 5 years are, without a doubt, the episodes which have caused the greatest amount of damage and economic loss in the analysed territory (Espín Sánchez et al. 2017; García et al. 2020; Martí Talavera et al. 2021). In both episodes, 200 mm (accumulated over the entire rainfall event) was exceeded in large areas of the analysed territory, the most affected area being the mouths of the Albujón and Maraña ephemeral channels, where the municipalities of San Javier and Los Alcázares are located. These two rainfall events were characterised by high torrentiality and hourly intensity (> 50 mm/h).

On the other hand, in order to analyse the evolution of very intense precipitation events, Fig. 5 shows the evolution of the number of days of very intense precipitation in the San Javier series in the period 1934–2020. The threshold of very intense precipitation has been calculated from the 99th percentile of the precipitation days in the San Javier series during the reference period 1991–2020. The resulting value is 63.2 mm. There is a slight upward trend in this parameter, with 2019 being the first time that the threshold has been exceeded for 3 days. In addition, it is worth noting that during the period 2016–2019 the days of very intense precipitation accounted for more than 65% of the total annual precipitation, which shows a clear trend towards an increase in the hourly concentration of precipitation on the Mediterranean slope (Olcina Cantos 2017).

Figure 6 shows the spatial distribution of the accumulated precipitation in the watersheds of the Albujón and Maraña ephemeral channels, in the pluviometric episodes of 2016 and 2019. The first of them, which occurred between December 15th and 19th, 2016, was caused by an intense east wind flow from a long maritime route favoured by the strengthening of the Central European anticyclone. In the south-east of the Spanish peninsula, losses were estimated at 67.4 million euros, with the municipality of Los Alcázares being the most affected (Consorcio de Compensación de Seguros 2019), as it accounted for 25% of all compensation claims in the south-east of the peninsula (Espín Sánchez et al. 2017). The second episode, which occurred between September 11th and 15th, 2019, was caused by an Isolated Depression at High Levels (DANA), which caused the formation of mesoscale convective systems (Martí Talavera et al. 2021). During this event, the economic losses were much greater than in the 2016 episode, estimated at 479 million euros (Consorcio

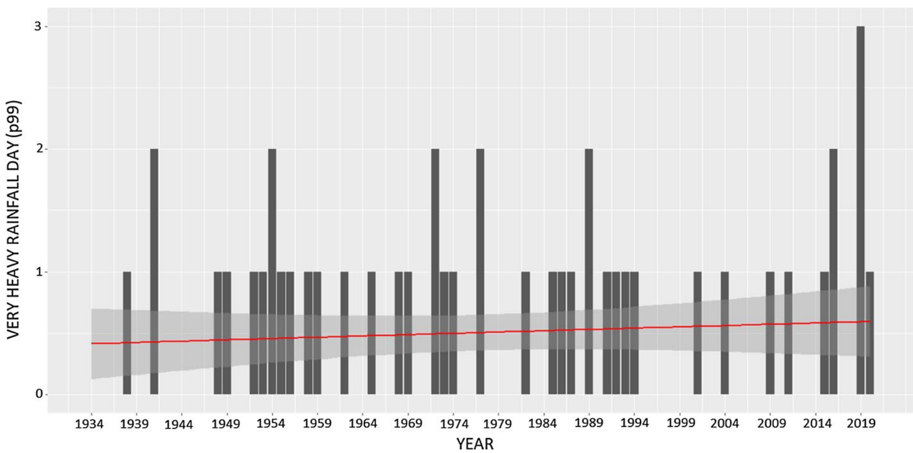

Fig. 5 Evolution of the number of days with very heavy rainfall in San Javier Weather Station (1934–2020). Source: Own elaboration, data obtained from AEMET and SIAM

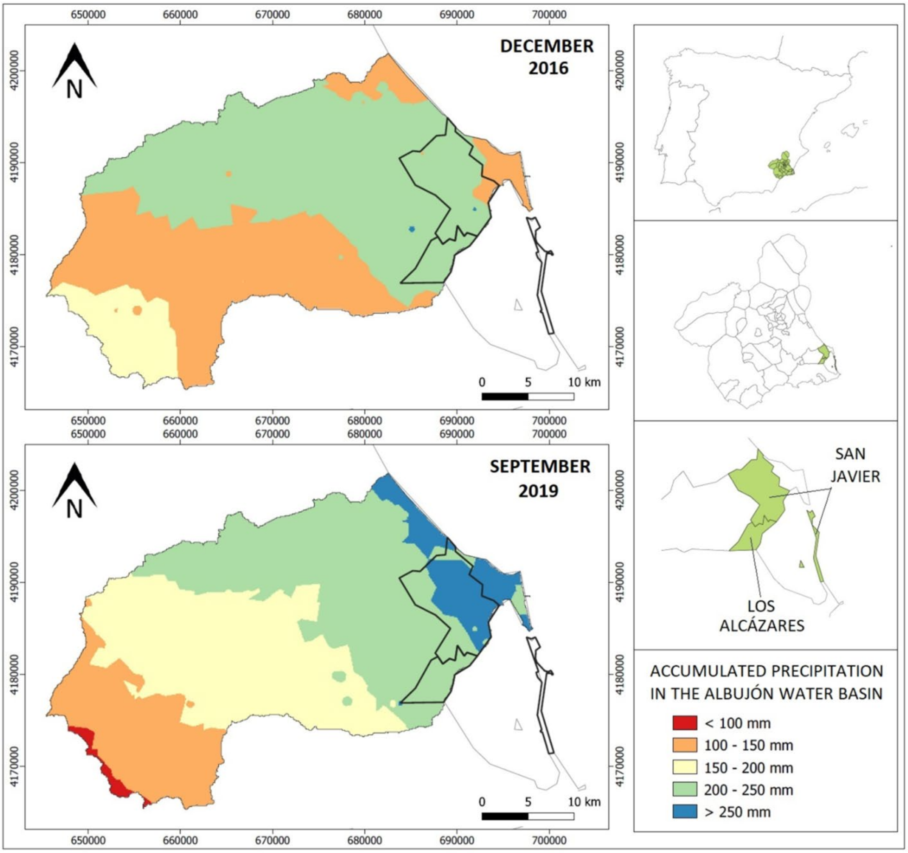

Fig. 6 Spatial distribution of accumulated precipitation during the events of December 2016 and September 2019. Source: Own elaboration, data obtained from AEMET and SIAM

de Compensación de Seguros 2019). The event was widely reported and followed in the regional media (Romero Díaz and Pérez Morales 2021). This is the fourth most serious event in terms of compensation by the Insurance Compensation Consortium since 1971, just behind the 1983 floods in the Cantabrian Sea (Ollero Ojeda et al. 2000), the atypical cyclonic storm “Klaus” in 2009, which particularly affected the far north of the Iberian Peninsula (Gomarra et al. 2010), and the 2011 Lorca earthquake (Ruiz Álvarez 2016). Again, the municipality of Los Alcázares was the most affected municipality, in this case together with the neighbouring town of Orihuela in Alicante (Nuñez Mora 2019).

Figure 7 shows the synoptic configuration of the December 2016 and September 2019 episodes. Both show the atmospheric situation at the 500 pHa geopotential at the time of the highest rainfall intensity. Both episodes were characterised by the presence of cut-off lows over North Africa and the Alboran Sea, which together with the presence of a very strong central European anticyclone favoured the presence of a clear easterly wind corridor. The low-level wind map clearly shows the configuration of long-distance Mediterranean atmospheric rivers that impacted directly on the coastline of the study area (SE Spain). This situation is one of the main factors triggering heavy rainfall on the

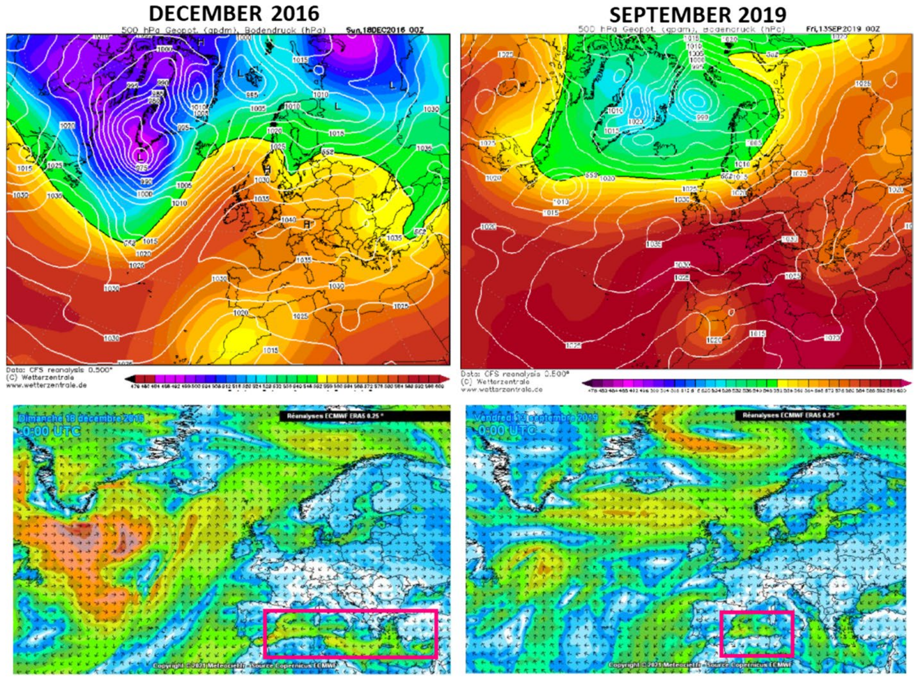

Fig. 7 Synoptic configuration of the December 2016 and September 2019 episodes (geopotential map at 500 hPa and low-level winds). Source: Wetterzentrale and Meteociel

Spanish Mediterranean coast. This intense and very humid flow, which is transported from the central Mediterranean to the Spanish coasts, has recently been denoted as a Mediterranean atmospheric river. The presence of an abrupt orography next to the coast favours, with the presence of this very humid easterly wind flow, convective developments. This configuration is one of the most recurrent situations that generate heavy rainfall on the Mediterranean coast of the south-east of the peninsula (Gil-Guirado et al. 2021).

With respect to the soil moisture parameter existing at the moments prior to the torrential rainfall events, it is worth noting that the previous conditions were notably opposite in both episodes. On the one hand, in the December 2016 event the antecedent conditions presented a very dry soil state (Espín Sánchez et al. 2017), as a consequence of one of the most severe droughts of the last 150 years (Ruiz Álvarez et al. 2021). On the other hand, the situation prior to the September 2019 event was the opposite, as the SE peninsular was immersed in one of the wettest interannual periods of the last decades (Martí Talavera et al. 2021). Recent studies, such as those by Ruiz-Sinoga and Romero Diaz (2010) and Sillero-Medina et al. (2021), show a downward trend in soil water availability over the last two decades in the southern peninsular basins, as well as an increase in torrential rainfall, which has a high impact on soil hydrodynamics. In this sense, and despite the fact that antecedent soil moisture analyses must be taken into account in flood projections (Sánchez García et al. 2019), some studies suggest that the more extreme a flood event is, the less dependent it is on soil moisture changes (Wasko and Nathan 2019). Although the decrease in soil moisture appears to be an important factor in reducing the intensity of floods, some recent research results warn that the observed increase in vulnerability to floods in recent decades is mainly due to human factors, such as increased urbanisation and population growth, rather than factors of a climatic and hydrological nature (Tramblay et al. 2019).

3.2 Land registry analysis: increase in buildings

Over the last few decades, the earth's surface has been subjected to an unprecedented artificialisation process (Lois González et al. 2016). This boom in anthropizing is motivated by building expansion, which has clearly proliferated on the Murcian coast (Pérez Morales et al. 2018). The excessive urbanisation phenomenon encourages vulnerability and increased exposure to the risk of flooding (Olcina Cantos 2004).

The towns of Los Alcázares and San Javier have experienced a drawn-out increase in their real estate portfolio. Overall, the number of constructions registered by the General Directorate of Land Registry (in both locations) has gone from accounting for just over a thousand blocks of flats and houses built in 1950, to close to 16 thousand in 2019. The area occupied by these constructions has evolved parallel to the total number of buildings (Table 1).

Since the middle of the twentieth century, land obstructed by construction has increased by almost 2700% (from 16.09 ha. to 450.06 ha.). This figure exceeds the percentage of development observed by the number of infrastructures built (1410%). Now, the construction development carried out individually by each municipality shows different rhythms and intensities. In this context, the number of buildings and land occupied in San Javier is, at all times, higher than that registered in Los Alcázares. In this regard, in the starting year of the series, San Javier had 586 buildings (55.44%) occupying 9.28 ha. (57.70%), values that exceed the figures published by Los Alcázares (471 buildings and 6.81 occupied hectares).

Over the years, the evolution of these indicators tends to increase, expanding the existing building gap between both local municipalities. Consequently, over the last seven decades, the number of buildings in San Javier has increased by 1723% (10,687 in 2019) and the area occupied by them by 3137% (300.69 ha. in 2019). On the other

Table 1 Evolution of the number of buildings and built-up area by municipality. Source: Own elaboration, data obtained from the General Directorate of Land Registry

	1950	1980	2000	2019
Los Alcázares				
Number of buildings	471 (44.56%)	1903 (28.45%)	4595 (33.82%)	5282 (33.08%)
Surface area occupied by buildings (Ha.)	6.81 (42.30%)	36.86 (27.41%)	111.88 (34.99%)	149.37 (33.19%)
San Javier				
Number of buildings	586 (55.44%)	4785 (71.55%)	8990 (66.18%)	10,687 (66.92%)
Surface area occupied by buildings (ha.)	9.28 (57.70%)	97.64 (42.59%)	207.91 (66.18%)	300.69 (66.92%)
Total				
Number of buildings	1057	6688	13,585	15,969
Surface area occupied by buildings (ha.)	16.09	134.50	319.79	450.06

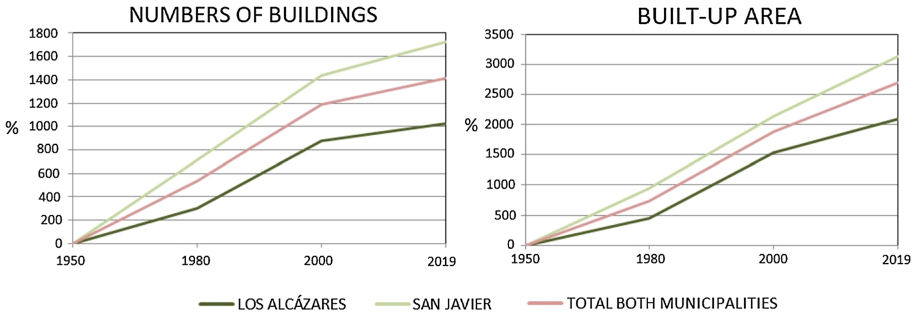

Fig. 8 Evolution of the number of buildings and built area by municipality (1950, 1980, 2000 and 2019). Source: Own elaboration, data obtained from the General Directorate of Land Registry

hand, in the same period of time, the buildings and cemented land accounted for in Los Alcázares increased by 1021% and 2,095% (5282 constructions and 149.37 ha. in 2019), respectively (Fig. 8).

The cartography shown in Fig. 9 shows the intensity of the construction process registered in both municipal areas. The presence of real estate infrastructures in 1950 is scarce, with an urban area partially concentrated in Los Alcázares and a scattered settlement in San Javier. Two decades later, the top of Los Alcázares expands and a new settlement begins to sprout north-east of it, which is named Los Narejos. Meanwhile, San Javier consolidates its central nucleus and experiences the development of a large residential area (Santiago de La Rivera), which sits on the coastline located to the east of the main urban area. The rise in tourism has caused the urban complexes located on the Mediterranean coast at the beginning of the 2000s (and Mar Menor) (Serrano Martínez 2007), driven by the expansion of traditional population centres and the development of "resort"-type residential complexes with recreational, leisure and entertainment spaces (golf courses) (François 2010).

From the beginning of the twenty-first century to the present, the urban phenomenon has undergone two phases clearly marked and influenced by the economic context the country is going through. Until 2008, the national complex and, fundamentally, the coastal areas, saw one of the most notable building drives in their history. However, from then until now, the bursting of the real estate bubble encouraged by the economic recession has caused the stagnation of construction development (Górgolas 2019). In addition, the spatial field that our research focuses on has been heavily weighed down by the environmental problems that arose around the Mar Menor and the impact caused by successive extreme meteorological events and related floods (León et al. 2017).

If the evolution of real estate and the area occupied by buildings is analysed according to the established time periods, the relevance of the construction process carried out over the last two decades of the twentieth century can be verified. The building dynamics carried out between the years 1980 and 2000 is of great magnitude with more than 210 properties being built a year in San Javier and about 135 in Los Alcázares. The area occupied by these buildings, in the same period of time, stands out above the amount of land obstructed by constructions in the rest of the temporary spaces (5.51 ha. in San Javier and 3.75 ha. in Los Alcázares). Nevertheless, between 2000 and 2019, despite constituting the phase with the lowest average annual number of constructions (89 in San Javier and 36 in Los Alcázares), the proposed building typology (mainly single-family homes) occupies a larger surface (Fig. 10).

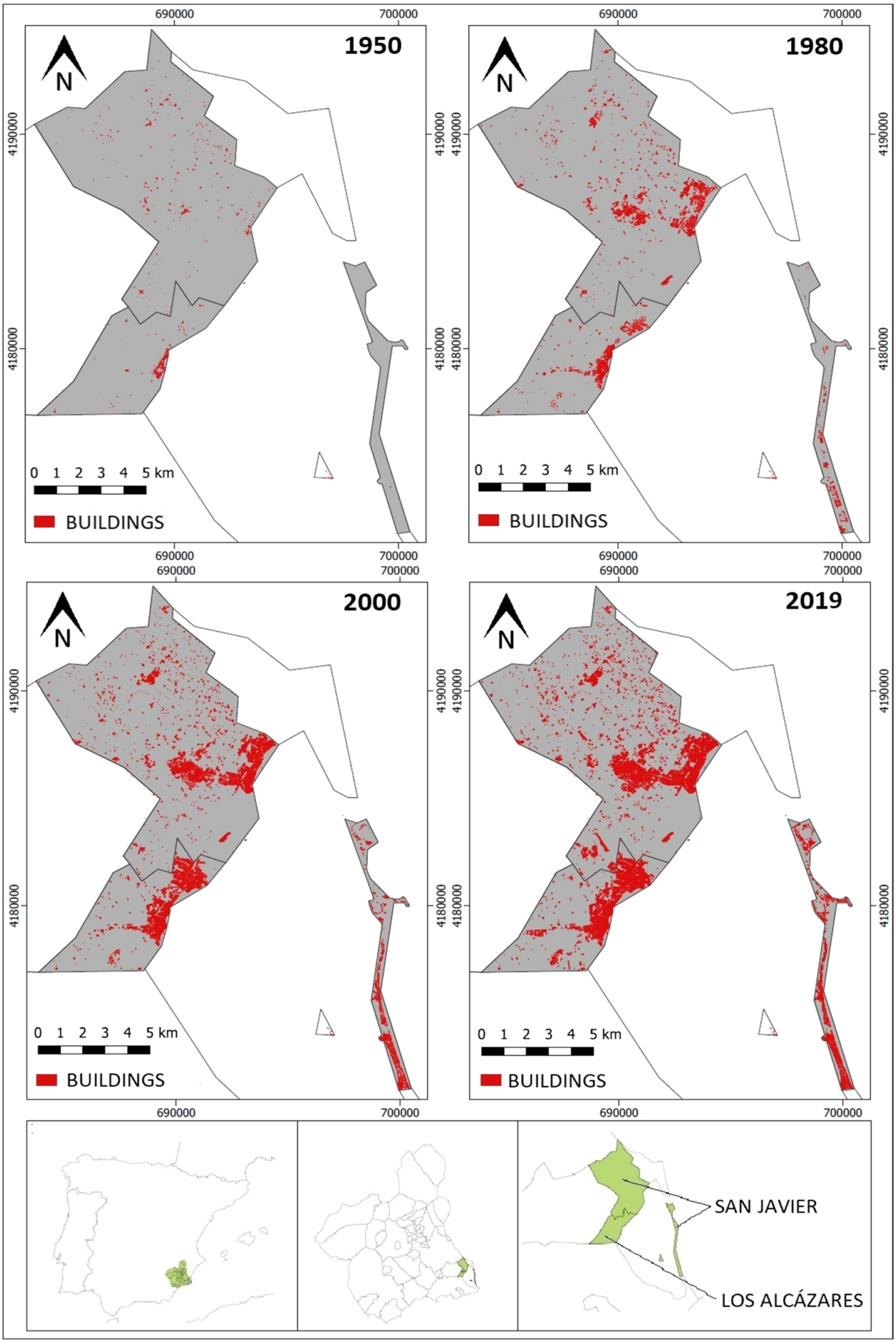

Fig. 9 Map showing the evolution of the built-up area in Los Alcázares and San Javier (1950, 1980, 2000 and 2019). Source: Own elaboration, data obtained from the General Directorate of Land Registry

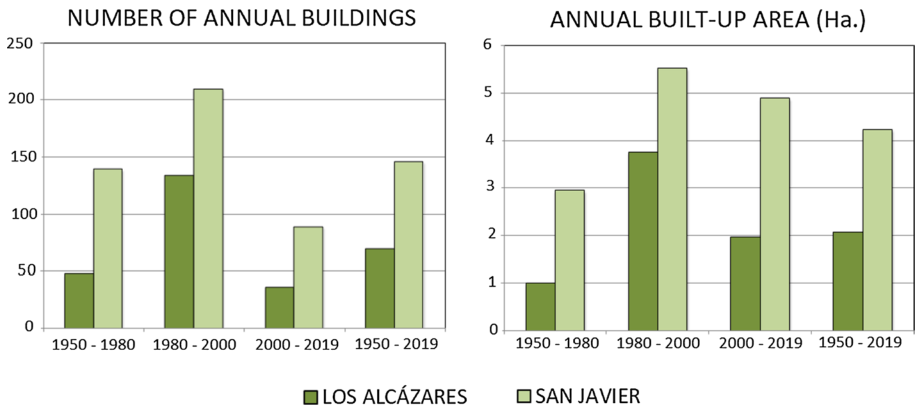

Fig. 10 Number of buildings and area built annually in Los Alcázares and San Javier for different time periods (1950–1980, 1980–2000, 2000–2019 and 1950–2019). Source: Own elaboration, data obtained from the General Directorate of Land Registry

The average number of completed properties annually in the series as a whole (146 in San Javier and 70 in Los Alcázares) was only exceeded in the 1980–2000 period. The number of buildings erected between 1950 and 1980 is also higher than those between 2000 and 2019. In spite of this, due to their placement in terms of height, the ground occupied by the finalised infrastructure between the first dates has caused them to spread over less surface area than those recently outlined.

3.3 Areas of exposure

Once the dynamics of real estate production have been analysed, the exposure of buildings built in different time periods to events of ephemeral channels will be estimated. To do this, the land registry data shown above are contrasted with territorial information on areas at risk of flooding obtained from the National System of Flood Zones Cartography (SNCZI). This project developed by the Ministry for the Ecological Transition and the Demographic Challenge of Spain (MITECO) provides georeferenced documentation on the probability of a flood in a territory in different periods of time (López Martínez 2019). In this respect, it differs between areas with high risk of flooding (return period of 10 years), frequent (return period of 50 years), medium or occasional (return period of 100 years) and low or exceptional (return period of 500 years).

Among these four river overflow scenarios, this study focuses its attention on the most extreme episodes, trying to investigate the possible effect caused on the housing portfolio by a meteorological event in the return periods (RP) of 10 and 500 years. As is evident, the reason that supports the analysis of the first context of occurrence lies in the fact that it is the most likely situation (RP 10 years). For its part, the choice of the most anomalous return period (500 years) incurs that, as can be seen in Fig. 11, the last precipitation event that occurred in the area being studied (September 2019) exceeded the established perspectives by the state agency in charge of delimiting the Hydraulic Public Domain (DPH) areas in its studies. In the work by García Ayllón and Radke (2021), the effects of the floods that have occurred in the last 5 years are analysed in much greater depth through the analysis of satellite images.

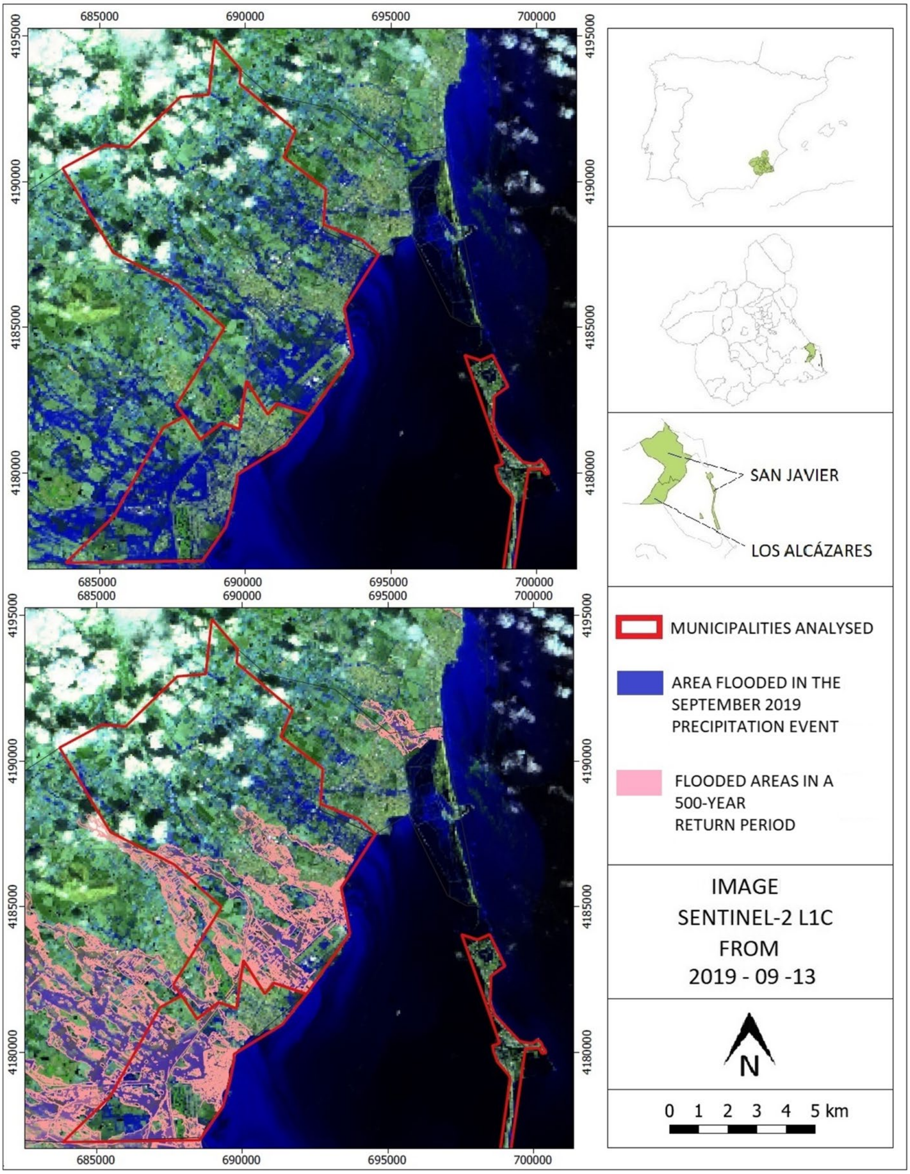

Fig. 11 Satellite image of the flooded area after the torrential rainfall event in the territory under analysis (September 2019). Source: Own elaboration, data obtained from Sentinel and SNCZI

3.3.1 Return period of 10 years (RP10)

The flood scenario with the highest occurrence level reveals the probability of river overflows occurring once every 10 years, that is, a 10% contingency. The effect of this return period on buildings is much more contained than that of 500 years, logically.

However, its impact on the housing stock of the municipalities analysed in this study shows a level of affectation to take into account (Table 2).

Although San Javier has undergone a more dispersed urbanisation process than the municipality of Los Alcázares (as reflected in Sect. 3.2), the exposure of the group of buildings in Los Alcázares is notably greater, due to the presence of ephemeral channels of the Maraña. Changes upstream of the ephemeral channels of the Maraña and Albujón may have increased the vulnerability parameter. The evolution of the percentage representation of the buildings and the surface area occupied, in relation to the total number of municipal buildings in the two municipalities, evolves in the opposite way. In this sense, while the locality of Los Alcázares decreases the exposure of its blocks of flats in percentage terms, San Javier reveals an increase in vulnerability caused by its greater exposure, so that between 1950 and 2019 the affected surface area doubled. In contrast, between the beginning and the end of the time series studied, the percentage of exposed land in Los Alcázares is reduced by half. However, the land area affected by floods in a 10-year return period in Los Alcázares increased significantly, from 3.56 ha. in 1950 to 38.49 ha. in 2019. The reason for this increase is based on the fact that not all the urban expansion process carried out in the municipalities is located in areas with a probability of flooding every 10 years, but that urban development is taking place in non-flood zones, as is the case of Los Narejos (Fig. 12).

In the same way, the percentage representation of total buildings affected by this return period drops from 60.93 to 42.22%. Nonetheless, the absolute value reveals that the number of buildings exposed to a flood every 10 years goes from 28 buildings in the middle of the twentieth century, to about 2230 at the end of the second decade of the twenty-first century. At the beginning of the new millennium, this number exceeds two thousand buildings with a high risk of flooding. Something similar, although at a lesser level, takes place in San Javier, a municipality in which 1282 buildings exposed to river overflows were counted in 2000. This is a figure that in the total computation of the series has increased by more than 1500 buildings.

Altogether, 24.04% (3840) of the properties and 18.95% (85.28) of the territory occupied by them in 2019 may present a risk of flooding at least once every 10 years.

Table 2 Absolute evolution and percentage representation of the number of buildings and the area occupied by them at very high risk of flooding (10-year PR)

	1950	1980	2000	2019
Los Alcázares				
Number of exposed buildings	287 (60.93%)	889 (46.72%)	2035 (44.29%)	2230 (42.22%)
Surface area occupied by exposed buildings (ha.)	3.56 (52.25%)	15.78 (42.81%)	32.78 (29.30%)	38.49 (25.77%)
San Javier				
Number of exposed buildings	54 (9.22%)	631 (13.19%)	1282 (14.26%)	1610 (15.07%)
Surface area occupied by exposed buildings (ha.)	0.69 (7.44%)	1.41 (11.44%)	31.26 (15.04%)	46.79 (15.56%)
Total				
Number of exposed buildings	341 (32.26%)	1520 (22.73%)	3317 (24.42%)	3840 (24.04%)
Surface area occupied by exposed buildings (ha.)	4.25 (26.40%)	17.19 (12.78%)	64.04 (20.03%)	85.28 (18.95%)

Source: Own elaboration, data obtained from the General Directorate of Land Registry and SNCZI

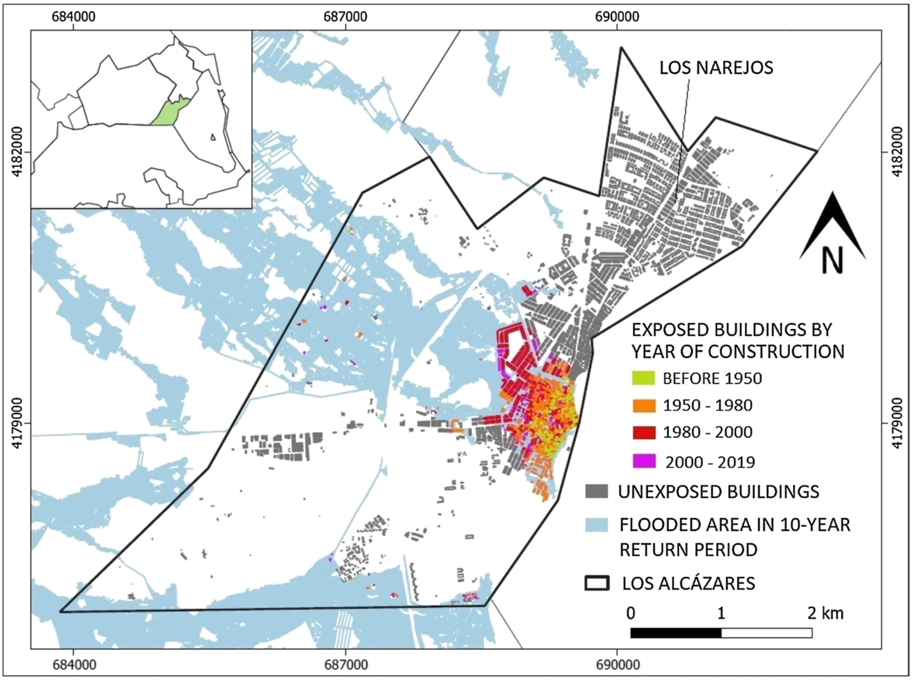

Fig. 12 Buildings exposed to floods in a 10-year RP (Los Alcázares). Source: Own elaboration, data obtained from the General Directorate of Land Registry and SNCZI

The percentage of these buildings and land area occupied in 2019 has decreased considerably since the first year it was observed (Fig. 13).

It is interesting to mention that when focusing the research on floods of fluvial origin, the territorial spit corresponding to La Manga del Mar Menor (included in the municipality of San Javier) is not to be considered due to the lack of surface hydrographic currents.

If the existing exposure factor between time periods is analysed, it is possible to see the number of buildings and the land occupied in areas at risk of flooding during different construction cycles. To this end, during the time series examined, in the two municipalities as a whole, 3499 buildings were erected with a very high risk of flooding (RP 10 years), which represents 23.46% of all buildings built in this area within the temporary parenthesis. Los Alcázares stands out, with more than 40% of the buildings built in the last seven decades (4,811), with a very high probability of flooding (Fig. 14). This threshold of representation of properties exposed to ephemeral channels is also exceeded, by this same municipality, in the building phases 1950–1980 (620) and 1980–2000 (1146).

On the other hand, the percentage of surface area exposed to this natural risk of climatic origin only exceeds 40% (12.23 ha.) of all the land occupied in the first urban development cycle (1950–1980). During this period of time, the amount of properties showing vulnerability in San Javier is very small, not even reaching one hectare (0.81% of all built-up land). In contrast, in the two subsequent time phases (1980–2000 and 2000–2019), San Javier has a higher percentage of built surface area at risk of flooding than Los Alcázares (Fig. 15).

This representation of land built in San Javier and at risk of flooding once every decade shows greater strength in the area occupied between 1980 and 2000 (more than

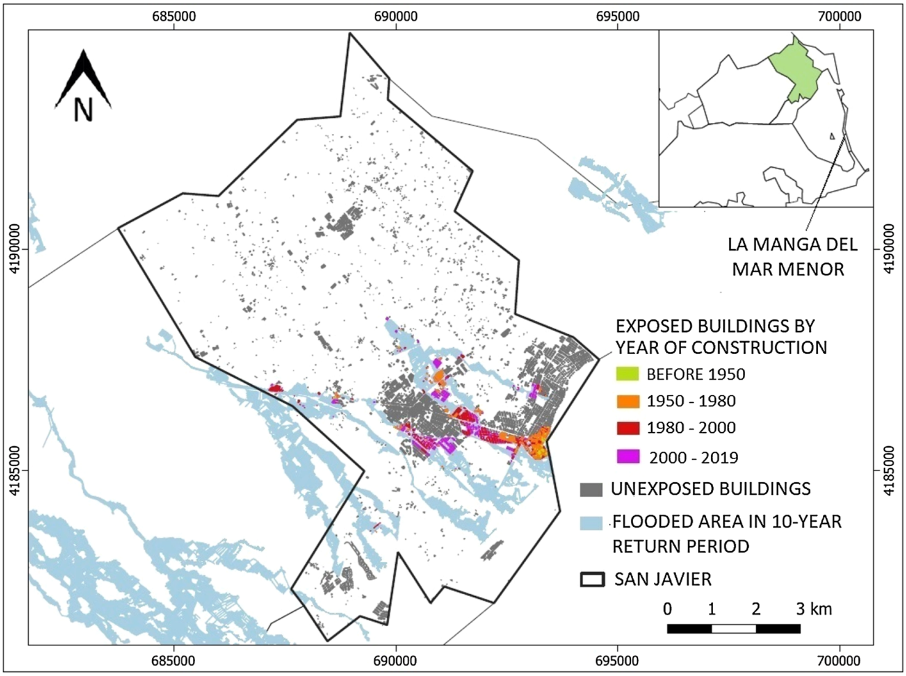

Fig. 13 Buildings exposed to floods in a 10-year RP (San Javier). Source: Own elaboration, data obtained from the General Directorate of Land Registry and SNCZI

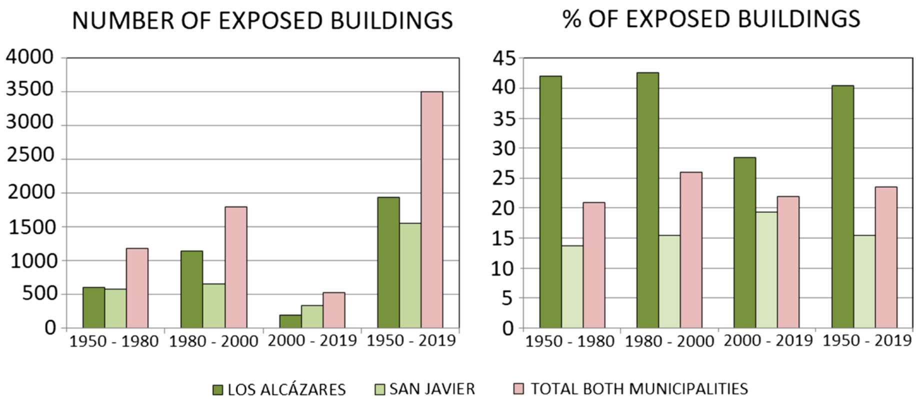

Fig. 14 Number and percentage representation of buildings exposed to flooding in a 10-year RP by temporal phases. Source: Own elaboration, data obtained from the General Directorate of Land Registry and SNCZI

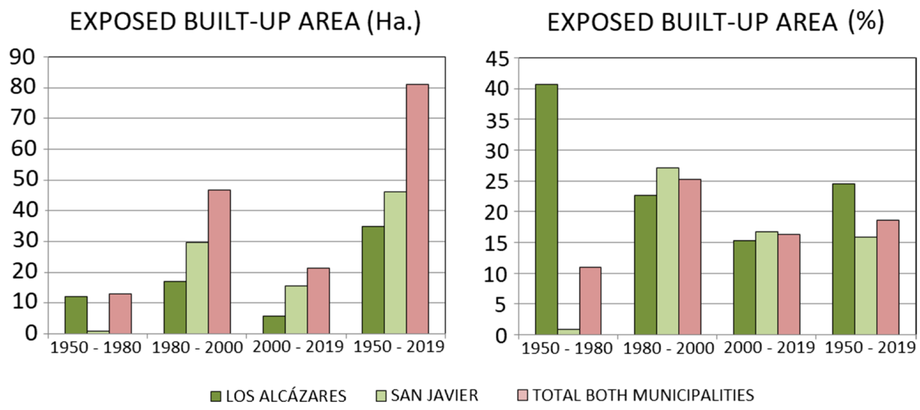

Fig. 15 Number and percentage representation of constructed area exposed to flooding in a 10-year RP by temporal phases. Source: Own elaboration, data obtained from the General Directorate of Land Registry and SNCZI

a quarter of the built area). In addition, it is the period of time in which the largest number of hectares with high flood risk is built in each of the spatial areas examined.

3.3.2 Return period of 500 years (RP500)

The impact exerted by floods in the period of least probable occurrence (RP 500 years) is much more prominent than in the one previously analysed. In this sense, the amount (absolute and percentage) of buildings exposed to the danger of this phenomenon is very high.

As in the case of 10-year-old RP, the influence exerted by the Albujón ephemeral channel in Los Alcázares increases the vulnerability of its housing portfolio. In this regard, 9 out of 10 buildings built in this municipality before 1950 may be affected by an ephemeral channel. The excessive representation of buildings exhibited until the middle of the last century tends to decrease as we approach the present day. Now, in 2019, the percentage of buildings and surface exposed to ephemeral channels for a RP of 500 years remains very high, comfortably affecting more than half of the real estate portfolio (Table 3). This value is almost double that set by the two municipalities as a whole and three times higher than that expressed by San Javier.

The historic centre or urban centre of San Javier has traditionally been less exposed to flooding. Despite this, the vulnerability exhibited by the exposure factor of its buildings and the surface area that supports them has increased over the years, due to the expansion of the city towards flood-prone areas located to the south of the original urban centre. As of today (2019), the municipality of San Javier has 2448 buildings and 66.98 ha that are exposed to this phenomenon. As can be seen in the cartography referring to Fig. 16, the southern strip of the administrative delimitation of San Javier is the area most affected by river overflows. Coincidentally, it is also the municipal area that is least clogged by urban development, which is why the impact of the floods is not so prominent.

The north-east area of Santiago de La Rivera and the historic urban centre of San Javier are practically not affected by the water level. However, the most recent constructions, located in the peripheral sector of the headwaters and areas that join the two urban centres, have greater vulnerability. This fact means that, unlike Los Alcázares, the most recent building developments have more exposure. In this sense, Fig. 17 shows how the

Table 3 Absolute evolution and percentage representation of the number of buildings and the area occupied by them at very high risk of flooding (500-year PR).

	1950	1980	2000	2019
Los Alcázares				
Number of exposed buildings	421 (89.38%)	1460 (76.72%)	3006 (65.42%)	3493 (66.13%)
Surface area occupied by exposed buildings (ha.)	5.90 (86.70%)	27.44 (74.43%)	63.77 (56.99%)	89.07 (59.63%)
San Javier				
Number of exposed buildings	96 (16.38%)	1010 (21.11%)	2017 (22.44%)	2448 (22.91%)
Surface area occupied by exposed buildings (ha.)	1.41 (15.17%)	22.72 (23.27%)	44.81 (21.55%)	66.98 (22.28%)
Total				
Number of exposed buildings	517 (48.91%)	2470 (36.93%)	5023 (36.97%)	5941 (37.20%)
Surface area occupied by exposed buildings (ha.)	7.31 (45.43%)	50.16 (37.29%)	108.58 (33.95%)	156.05 (34.67%)

Source: Own elaboration, data obtained from the General Directorate of Land Registry and SNCZI

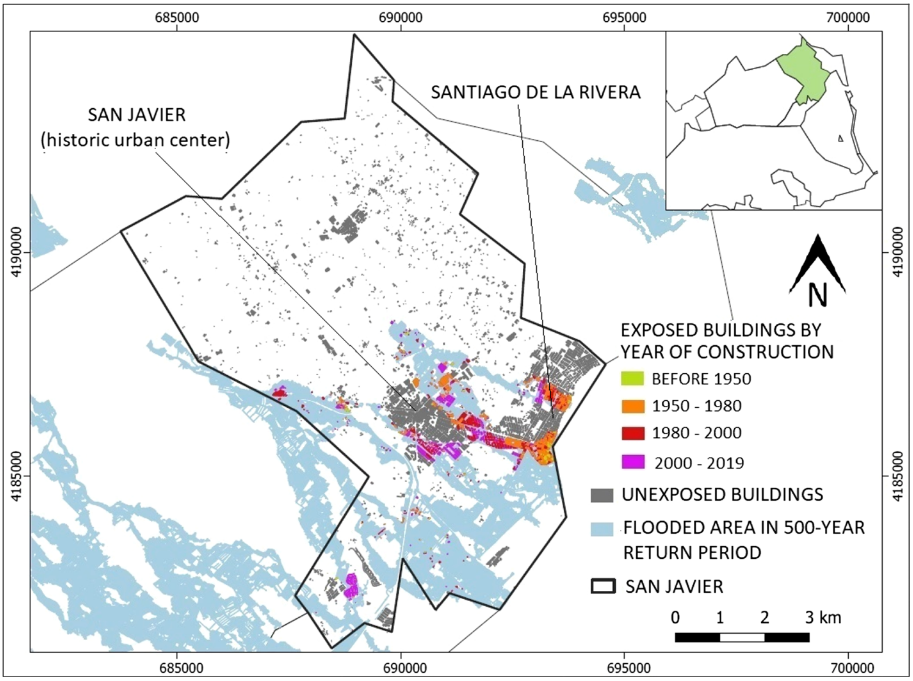

Fig. 16 Buildings exposed to floods in a 500-year-old RP (San Javier). Source: Own elaboration, data obtained from the General Directorate of Land Registry and SNCZI

central area of Los Alcázares is the area with the highest risk of flooding in a period of occurrence of 500 years.

The evaluation of properties and surface area affected by floods in a period of occurrence of 500 years shows values which should be highlighted. During the development of the complete series, the amount of infrastructure and land exposed by both municipalities amounts to 5424 properties and 148.74 ha. As is usual in this analysis, the possible impact of this phenomenon is more telling in Los Alcázares than in San Javier, with 56.64% (3,072) of these buildings belonging to the first mentioned location. The percentage of possible damage to buildings erected in the last 70 years in Los Alcázares exceeds 63%. This representation is exceeded in the periods 1950–1980 and 2000–2019, with percentage values that exceed 70% of the entire real estate portfolio (Fig. 18).

Regarding the number of buildings exposed to floods in a RP of 500 years in San Javier, it can be noted that they are much more contained in each and every one of the established time phases. Thus, the 1980–2000 construction cycle is the only one that registers more than a thousand exposed buildings. Unlike Los Alcázares, the number of total properties likely to suffer the effects of a flood with this degree of occurrence (500 years) barely exceeds 20% in each of the time periods analysed.

The percentage values of exposed land are practically similar to those observed in the analysis of buildings. Nevertheless, and unlike these, the representation of occupied land in the 1980–2000 time period in Los Alcázares is the only one that does not reach 50% (Fig. 19). Even so, it is the time period with the highest absolute number of exposed surface area (36.33 ha.).

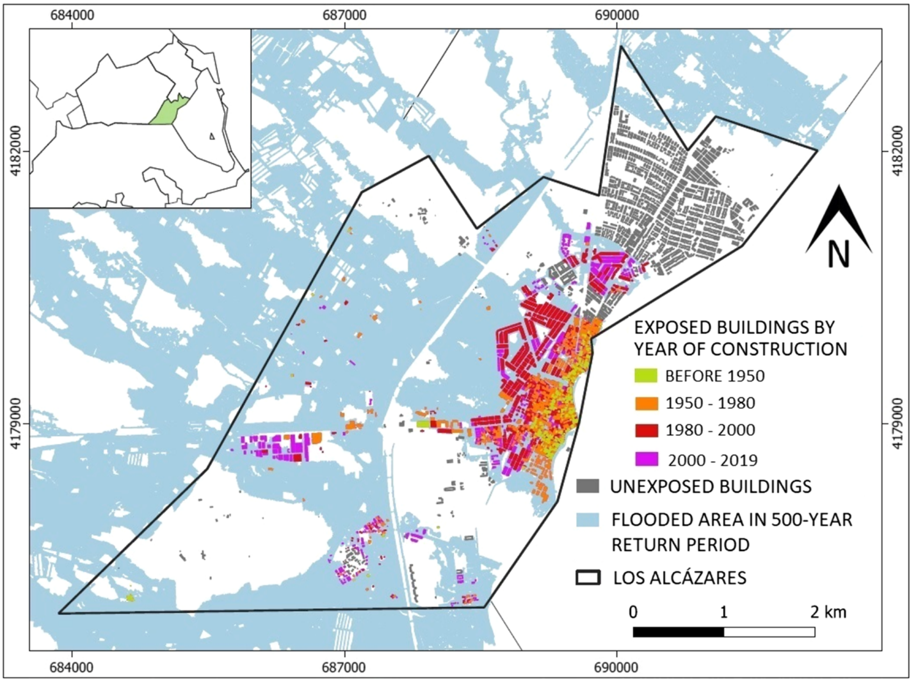

Fig. 17 Buildings exposed to floods in a RP of 500 years (Los Alcázares). Source: Own elaboration, data obtained from the General Directorate of Land Registry and SNCZI

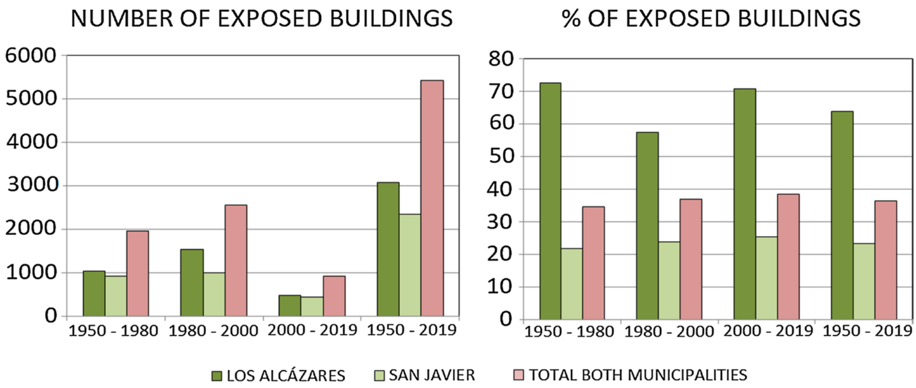

Fig. 18 Number and percentage representation of constructions exposed to flooding in a RP of 500 years by temporal phases. Source: Own elaboration, data obtained from the General Directorate of Land Registry and SNCZI

More than a third of all the land occupied by buildings in the two municipalities, during each of the periods studied, remains exposed. The total area of constructed land with the possibility of being affected by a flood every 500 years is around 150 ha.

San Javier exhibits, in all the time cycles, an area at risk of flooding slightly higher than 20 ha., which translates into a percentage value of around 20% of the entire built-up area.

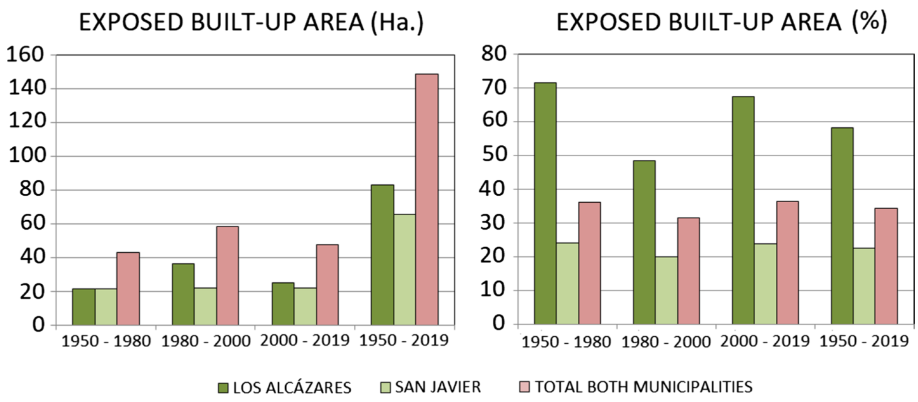

Fig. 19 Number and percentage representation of constructed area exposed to flooding in a 500-year RP by temporal phases. Source: Own elaboration, data obtained from the General Directorate of Land Registry and SNCZI

As established by Romero Díaz et al. (2017), these new constructions constitute second homes. Thus, the 2011 Population and Housing Census (latest updated data) indicates that secondary dwellings account for nearly 70% of residential buildings in Los Alcázares and 60% in San Javier, values that are well above those recorded in other neighbouring municipalities such as San Pedro del Pinatar (40%) or Torre Pacheco (10%). Finally, despite the fact that both municipalities record the total number of buildings and hectares exposed to flooding fairly evenly, the reduced total number of buildings and surface area occupied by them in Los Alcázares (in relation to San Javier) make the percentage values of buildings and land (on which they sit) at risk of flooding much higher than those exhibited in San Javier.

3.4 Towards a flood vulnerability index and mapping

Based on the spatial information obtained from the Spanish National Floodplain Mapping System (SNCZI), a preliminary assessment of flood vulnerability has been carried out for a 500-year return period. Firstly, the vulnerability of the population to flood risk was estimated by establishing the concentration of inhabitants in different flood zones (Fig. 20). In this respect, it should be noted that the highest concentration is located in the main urban area of Los Alcázares. This area has a concentration of more than 1000 inhabitants. On the other hand, the flood zones of San Javier have a lower concentration of inhabitants, so the exposure is lower. Thus, most of the area affected by the 500-year flood return period affects areas with between 101 and 500 residents. This statistic can serve as a basis for future analysis of social vulnerability.

On the other hand, Figs. 21 and 22 show an initial assessment of socio-economic vulnerability, showing on the one hand the risk posed by economic activities and on the other hand sites of special importance (social, tourist, cultural, educational, etc.).

In the face of an estimated 500-year return period flood, the socio-economic activities that are most vulnerable in the municipalities studied are those related to agricultural and urban activities. As the surface area affected is larger, the potential vulnerability to this event is higher in Los Alcázares than in San Javier.

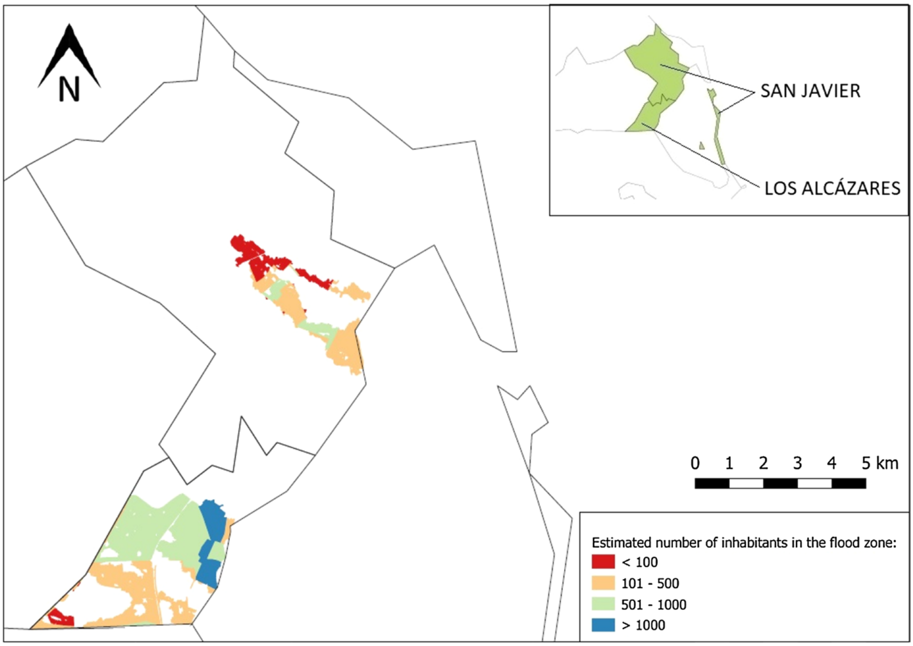

Fig. 20 Estimated number of inhabitants by flood zones. Source: own elaboration based on SNCZI data

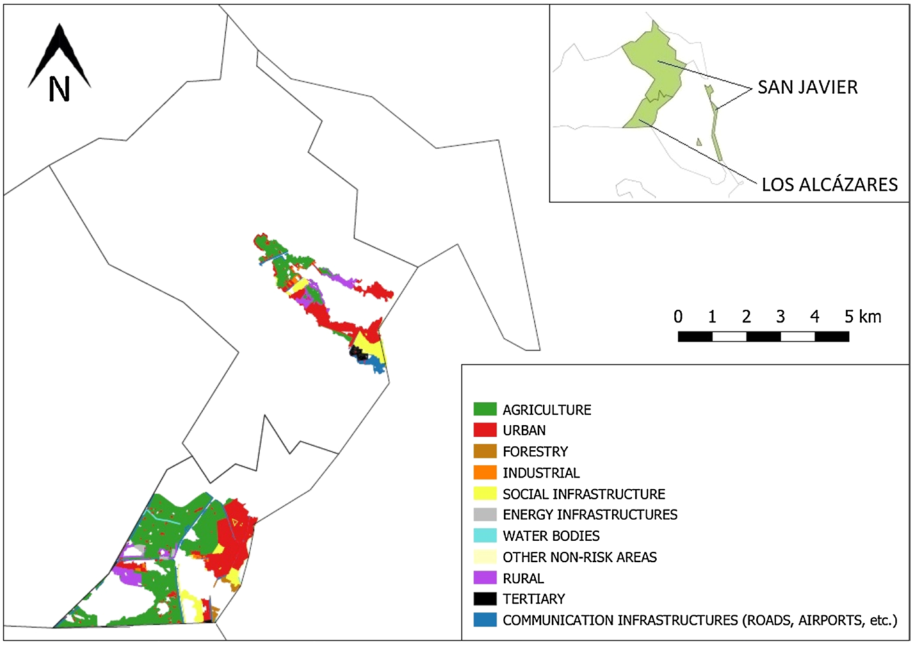

Fig. 21 Spatial distribution of economic activities affected by floods in a 500-year return period. Source: own elaboration based on SNCZI data

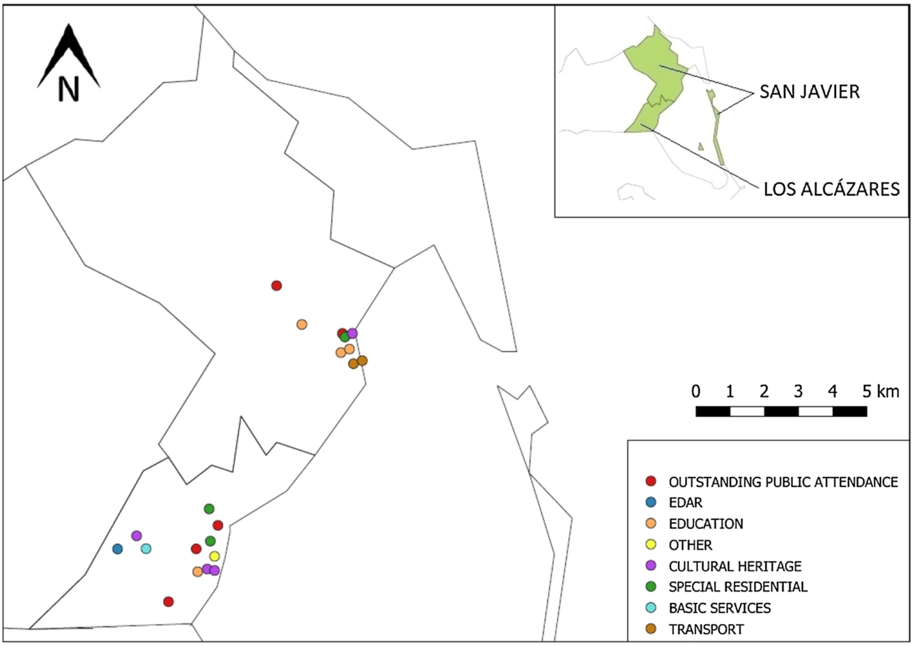

Fig. 22 Spatial distribution of points of particular importance. Source: own elaboration based on SNCZI data

Finally, Fig. 22 shows that the main points of special social importance exposed to flooding are concentrated in areas that include or are close to the urban space. These include the presence of three educational centres in San Javier and one in Los Alcázares. Other essential infrastructures are also located here, such as San Javier airport (transport). Public spaces of great concurrence, basic services, areas of special residence or infrastructures linked to cultural heritage are also relevant.

This brief analysis of population, socio-economic and essential infrastructure exposure can serve as a basis for further research into the potential vulnerability of these areas.

4 Conclusions

The flood processes make up one of the natural disasters with the greatest bearing and historical and social impact in the south-east of the Spanish peninsula. The physical and morphological particularities of the water network that irrigates the analysed territorial surface area, together with the meteorological irregularity that characterises the Mediterranean climate, stimulates the alternation of long periods of droughts with punctual and vigorous torrential precipitation events and related fluvial floods.

The occurrence of these floods is becoming increasingly serious, sometimes involving the loss of human life and considerable material damage. Against this background, two positions persist in Spain that seek to estimate the main cause that motivates the origin of these disasters. The first one, of technical-administrative orientation, attributes the origin of the floods to the regularity and greater frequency of torrential rain events. For its part, the ethical-geographical defence states that the risk and exposure to floods has been gradually increasing as a consequence of the progressive transformation of territorial coverage, the sealing of land and the unplanned proliferation of urban developments built in recent decades.

Both factors are analysed in this paper, so it is inevitable to highlight that both the natural phenomenon (torrential rains) and the social factor (inadequate construction in flood areas) contribute to the risk of flooding becoming a natural catastrophe. The two meteorological episodes analysed have prominent rainfall records. In this sense, the intense precipitation events analysed force them to be considered as triggers of the overflowing of ephemeral channels, flooding and flash floods experienced. However, while considering torrential rains as an essential factor behind floods, the responsibility of the human factor in the perpetration of potential catastrophes should not be overlooked. In fact, it is the human factor that can be corrected. In this way, it is undeniable to attribute a large part of the existing risk to the territorial transformation and to the continuous process of artificialisation of the soil recently carried out.

The study reveals how, in order to cover the growing residential needs of the tourist boom in coastal areas, San Javier saw its housing stock increase disproportionately (in relation to the buildings present up to that time), between the end of the twentieth century and the first decade of the twenty-first century. This real estate development took place in areas of obvious flood risk, which increases the exposure and vulnerability of the infrastructures and the population.

With the subsequent bursting of the real estate bubble, this real estate development slowed down, with little increase in construction. For its part, despite having urban development in a less dynamic way, the municipality of Los Alcázares has suffered the effects of the transformation of land uses and coverage carried out upstream of the fluvial channel in which it is integrated, which increased significantly increased the risk of flooding. Thus, poor management and planning in agricultural development has stimulated an increase in surface runoff, with the diversion of river channels, lowering of plots, change of orientation of ephemeral channels and waterproofing of soil. The result of these actions means that, unlike years ago, every time there is a torrential rainfall event the water network drains with greater force, overflowing the river and flooding, fundamentally, the central area of the municipality.

By way of conclusion, it can be established that despite being two urban spaces with different characteristics, both municipalities have seen a notable increase in the number of people and buildings exposed to flooding. This fact results in a clear increase in vulnerability to flooding. As a result, territorial planning and management is considered to be a fundamental and effective tool when trying to minimise or reduce the risk of flooding and its disastrous consequences.

Finally, it is worth mentioning that the methodology used in this work can be completed with an analysis of the depth of the flood plains and its effects on the damage caused. The evaluation of this aspect is essential when examining the damage caused by the flooding in more detail. On the other hand, we are also developing the estimation of the effect of urbanisation on floods, using hydrological models and the IBER software. Likewise, as a future line of work, we will estimate the number of people affected by the floods based on the number of residents per dwelling. To know these values, the number of dwellings present in each of the building blocks affected by floods in each return period must be considered. Once the number of households is known, the average number of people permanently living in each household must be estimated. This estimate is somewhat difficult because we are in one of the areas with the highest number of second homes and seasonal population in Spain (residential tourism is, along with agriculture, an essential economic activity in this territory). The processing of this information requires the use of complex databases such as Habits BigData or the contrasting of the number of households and inhabitants per building and census section.

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