



FLOODS IN SPAIN'S MEDITERRANEAN REGION: CAUSES AND EFFECTS

Inundaciones en la región mediterránea española: causas y efectos

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1. Floods in a global context

The importance of floods throughout the world is beyond doubt. According to the United Nations International Strategy for Disaster Reduction (UNISDR), Hydrometeorological risks are the most important natural risks in the world, and floods are the risk that affects the greatest number of people and property. Different databases corroborate this statement.

The international database Munich-Re (2018), indicates that during the last ten years floods have become the most recurrent natural risk, so much so that throughout 2017 345 events were registered worldwide, the consequences of which resulted in 6,505 deaths and damages worth approximately €30 billion.

The 2020 Annual Report of the Weather Climate & Catastrophe Insight reveals that floods are currently the second most economically lossy natural hazard in the world after tropical cyclones. In 2020, the number of extraordinary flood events has been 167, costing 76 billion dollars.

Detailed flood data is reported in more than 89 countries in the worldwide datasets of Sendai. For Spain, this database for the period 1416-2010 includes 19,751 floods, in which 24,318 deaths have occurred and 113,710 houses have been damaged.

The International Disaster Database (EM-DAT), which compiles worldwide data on natural hazards that have affected the world from 1900 to the present, shows how flood records rise to 5,386 and they constitute the largest of the natural risks, representing 35% of the total risks, followed by storms with 26.5%. Regarding Europe, floods are the second most important risk, behind mass movements with 648 events, and represent 24.4% of total risks. For Spain, there are only 38 records from 1950, but it should be mentioned that this database only collects the most important events.

Environmental change, together with the greater exposure of goods and people, is causing a disconnect between human groups and their environment. As evidenced by the trends in the data, there is an accentuation of the effects of the climate on societies, in the form of greater economic losses. If we consider the IPCC projections, the current scenario is very likely to worsen. Given that risk is increasing and will continue to do so, if such predictions are materialized by intensifying the severity of the hazard, it seems necessary to pay more attention to human factors issues to achieve adaptation strategies that reduce this trend as for losses.

In this sense, the first step is to consider floods as complex multidimensional and connected dynamic systems that integrate human and environmental variables. There is a consensus around the idea that the risk of a natural event, such as floods, is determined by the sum of three basic factors that make up this dynamic system: (i) natural hazards, (ii) the vulnerability of the communities, and (iii) the exposure of goods and people. Therefore, the condition of the above is only explained if that society is vulnerable. This is an assessment of special interest, since, in the case of floods, the occupation of floodplains can reveal a high global vulnerability.

On this basis, historical studies of flood episodes acquire singular importance, since they allow showing the evolution produced in terms of vulnerability, measured in terms of adaptation to climatic changes, as well as exposure to danger. The results of these works are very useful for the improvement of hydrological studies and derived planning and spatial planning. Some relevant examples of this type of work are included in this special issue.

With regard to risk management, research is currently incipient, but the need has arisen for tools and mechanisms capable of assessing the risk of societies to floods with greater precision, to establish measures of adaptability. For this, it is essential to carry out interdisciplinary studies. In recent years, this has been one of the great challenges and the work on the physical factor or danger and the human factor or vulnerability seem to have been quite separate. However, in special issues, such as the one presented here, it is intended to bring together the interests of the disciplines dedicated to one or another factor to achieve better results.

Evidence of the interest that floods arouse in the world are the review publications that have been made in recent years (Ologunorisa *et al.*, 2005; Cheng *et al.*, 2010; Salman and Li, 2018; Lindersson *et al.*, 2020; Díez-Herrero and Garrote, 2019, 2020). The bibliometric analysis on a world scale by Díez-Herrero and Garrote (2020), using the Web of Science database, to evaluate the historical evolution and future perspectives of the flood risk assessment, shows how the scientific production on the analysis of flooding has increased considerably in the last 25 years. In this study, despite the limitations derived from both the data sources and the analysis methodology used, the number of references found is remarkable and is expected to continue growing. With the keywords “Flood” and “Risk” these authors (as of June 22, 2020, for the period 1996-2020) found 22,934 references. Regarding the main research focuses detected, the following stand out: (i) the impact of global change and its components, (ii) coastal flooding and its economic consequences, (iii) studies of multiple risks and the interactions between the risk of flooding and other types of natural hazards and (iv) incorporation of the psychosocial aspects of flood risk. In the opinion of these authors, in the future, there will be a significant increase in publications due to factors such as population growth, increased urbanization, deterioration of infrastructure, and the potential impact of climate change.

For Spain, Díez-Herrero and Garrote-Revilla (2019) performed the same bibliometric analysis. In this case, with the keywords “Flood” and “Spain”, the number of references obtained was 3,857 for the period 1996-2019, showing, like the publications at a global level, a very notable increase in recent decades especially in the publications referring to flood risk. These authors consider that, in the future, interdisciplinary studies that combine aspects of the natural sciences and the social sciences, focused on non-structural mitigation measures, will prevail.

In the Mediterranean area, it is noteworthy that, both in the Sendai database and in the EM-DAT, the highest number of floods collected have occurred in this territory. On the Mediterranean coast, in general, and in Spain in particular, throughout history there have been numerous and important flood episodes, thus testifying to this: (i) the historical flood catalogs (CNIH); (ii) the analysis of historical documentation (Barriendos *et al.*, 2003; Llasat *et al.*, 2005; Blöschl *et al.*, 2020); (iii) the different databases such as FLOODHYMEX (Llasat *et al.*, 2013a and b), HIDREXMED, SHERE (Gilabert *et al.*, 2014), European Flood Database (Hall *et al.*, 2015), Munich-Re (2018), EUFF (Petrucci *et al.*, 2019), MEDIFLOOD (Barriendos *et al.*, 2019), SMC-Flood database (Gil-Guirado *et al.*, 2019); (iv) reconstruction of paleo-floods (Benito and Thorndycraft, 2005); (v) or the various studies carried out on

different Mediterranean basins, such as those of the Ter rivers (Ribas Palom, 2008) Llobregat (Llasat *et al.*, 2001) Ebro (Ollero Ojeda, 2000, 2007; Espejo Gil *et al.*, 2008; Ollero Ojeda and Sánchez Fabre, 2016), Turia (Almela, 1957; Sánchez Fabre and Ollero Ojeda, 2017) Júcar (Butzer *et al.*, 1983; Mateu, 1988; Carmona González and Ruiz Pérez, 2000), Segura (Romero Díaz and Maurandi Guirado, 2000; Romero Díaz, 2007; Castejón Porcel and Romero Díaz, 2014), Andalusian basins that flow into the Mediterranean sea (Capel Molina, 1987; Sánchez Ramos, 2010; Rodríguez Martínez and Mesa Garrido, 2016), and the Balearic islands (Grimalt and Rosello, 2011; Torrens Calleja *et al.*, 2016).

But floods are not history, according to Petrucci *et al.* (2019), in their study on “Flood Fatalities in Europe, 1980-2018”, these continue to be a major threat to people, despite considerable advances in forecasting, management, defense and rescue, and the number of victims is expected to continue to rise in the coming years.

Along the same lines, other investigations carried out show very worrying data. Predictions indicate that, as floods and damage to people and property increase, they will increase considerably. According to the international study, coordinated by Blöschl (2020), in which 34 research groups from all over Europe have participated, and in which floods in Europe between 1500 and 2016 have been studied, it has been found that floods now cause damage worth more than € 100 billion annually, and the general trend of heavy flooding is increasing. The last three decades are among the most important periods in terms of frequency and magnitude of floods in Europe.

Another recent study, conducted by the World Resources Institute (WRI), estimates that the number of people affected by floods will double worldwide by 2030, reaching 147 million people, compared to the 72 million that were affected 10 years ago. In terms of economic costs, damage to cities will rise from \$ 174 billion to \$ 712 billion each year. But in 2050 it will be even worse because according to this report a total of 221 million people will be at risk and the losses will be 1.7 trillion dollars a year.

In Spain, the study published in Nature Communications (Kulp *et al.*, 2019) concludes that more than 200,000 people will be periodically exposed to coastal flooding caused by climate change and, in the worst-case scenario, the number rises to 340,000 in the year 2100. And in the Mediterranean region, due to its topographic and thermal characteristics, which contribute to presenting intense rainfall in short periods, the existence of numerous torrential basins that favor flash floods, or human settlements in flood areas (increasing exposure to risk), are factors that can favor the increase in catastrophic events.

The evidence mentioned on the growing problem of floods reveals a profound lack of adaptation, as the main aggravating factor, regardless of what may happen to the climate in the future. The study of flood risk in the Mediterranean area, which this issue covers, is especially revealing about this trend and what it may hold in the future to the rest of the world. The challenge is open and it is urgent and necessary to redouble efforts in the study and knowledge of the causative agents, especially vulnerability, in order, as far as possible, to establish preventive strategies and measures, supported by a level of certainty that only the results of research, such as these, provide us.

2. The contributions included in this number of CIG/GRL

Although we are aware of the number of publications that have been and are being made on floods, it is enough to cite just two of the most recent: the monographic issue of the Water magazine “Flood Risk Assessments: Applications and Uncertainties” (Diez-Herrero and Garrote -Revilla, 2020) or the book *Riesgos de inundación en España: análisis y soluciones para la generación de territorios resilientes* (López Ortiz and Melgarejo Moreno, 2020), derived from the congress on floods that was held in 2020, we considered that more of this type of event has to be analyzed, both from the point of view of their causes and their effects and future predictions. That is why *Cuadernos de Investigación Geográfica* has considered it appropriate to also dedicate a special issue to “Floods in Spain's

Mediterranean region” which, as has been shown in different studies, is one of the regions most affected by them and it is expected that in the near future it will also be.

The twelve articles that are collected here deal with different aspects of floods in a spatial scope that extends throughout the entire Spanish Mediterranean area from Catalonia to Andalusia, including the Balearic Islands. Ten of the articles have a regional dimension, while another two cover a larger space.

The monographic issue begins with a valuable contribution by M.C. Llasat, with the title “Floods evolution in the Mediterranean region in a context of climate and environmental change”. This work analyzes the floods in various areas of the Mediterranean (Catalonia, southern France, and Italy, Greece, and Turkey) in a context of climate and environmental change, considering a holistic perspective that also includes adaptation measures. The author reaches important conclusions such as that: (i) there is insufficient evidence to affirm that river floods are increasing in the Mediterranean; (ii) flash floods in small non-gauged basins are increasing due to increased vulnerability and exposure; (iii) future projections point to an increase in heavy rains, especially in Mediterranean Europe, and an increase in the southern Mediterranean; (iv) by the end of the 21st century, a decrease in flood risks is likely to take place in some Mediterranean rivers in southern Spain and an increase in others (for example, the Ebro river); (v) the probability of high impact flooding will increase as the temperature increases; or that (vi) flood management should be approached from an integrated and holistic point of view that includes greater awareness of the risks among the population and their participation in the formulation of mitigation strategies.

In the second work, signed by A. Pérez Morales, A. Romero Díaz, and S. Gil Guirado, “Structural measures against floods on the Spanish Mediterranean coast. Evidence for the persistence of the “escalator effect”, almost the entire scope is analyzed space of the Spanish Mediterranean, except for Andalusia. It has been carried out by cataloging the structural works (dams, channeling, and storm tanks) built in the basins of the Mediterranean from the beginning of the 20th century to the present. It has been observed how in the first half of the century the actions were mainly limited to the construction of rolling reservoirs and it was from 1950 on that growth in defense infrastructures for the new urban areas was observed. Through the mapping carried out, a differentiated spatial distribution is also verified between the types of infrastructures and basins. The authors conclude by stating that, in the Spanish Mediterranean, despite the construction of a huge number of infrastructures aimed at mitigating the risk of flooding, flood damage has not diminished, so it is necessary to reflect on the validity of these actions and it is necessary to consider other prevention measures.

Following a north-south structure of Spain in the appearance of works of a more regional nature, in this monograph, A. Ribas Palom and D. Saurí Pujol focused their attention on the Ter river basin with their study “What can we learn from the past? A century of changes in vulnerability to floods in the Ter river basin”. Its objective has been to analyze, from a historical perspective, what have been the impacts of flooding in this basin in the period 1900-2020, focusing its attention on the three factors that, according to the approach to vulnerability proposed by the IPCC, intervene on the impact of floods: exposure, susceptibility, and adaptability. The results obtained indicate that, although exposure to floods has increased and damage has followed an upward trend, the vulnerability has decreased as a result of the decrease in susceptibility and, especially, a significant increase in adaptive capacity. Both in terms of victims and relative economic losses, the impacts of the floods would show a downward trend that, among other factors, tends to correlate positively with the increasing levels of economic development and well-being that this basin has experienced. Progress in flood forecasting and warning, together with emergency planning which helped to explain why large-scale events such as storm “Gloria” in January 2020 (an event associated for the first time with climate change) did not cause human casualties.

The authors A. Ollero, J.H. García, A. Ibisate, and M. Sánchez Fabre, with extensive research experience on this subject, propose an update of knowledge with the title “Updated knowledge on floods and risk management in the middle Ebro river: the Anthropocene context and river resilience”. This is

because the recent floods in the middle course of the Ebro have made it necessary to rethink and update the forecasting and management systems. In this research, the new maximum flow data modified in 2019 by the Ebro Hydrographic Confederation have been applied for the first time; trend changes have been observed (decreasing until 1996 and slightly increasing since 1996); variations in the frequency of events (longer and more complex, which can lead to greater damage); variations in seasonality (now concentrating floods in winter and spring); and the correction of the data and the expansion of the series has made it necessary to update the return periods, reducing the flow forecast for the reference periods. According to its authors, the present work marks a starting point or inflection, laying the foundations: i) towards new analyzes that must be developed when the revised hydrological series is prolonged in time, ii) towards the follow-up and adaptive evaluation of the new ones. risk management measures that are being implemented, so that they are sustainable and achieve the resilience of the river, and iii) a greater knowledge of floods and the risk, which should be transmitted to the population so that they increase their memory, their awareness, and with it, their resilience.

In the Valencian Community, with a different scale of work, A. Cerda *et al.* have carried out the work “Rainfall and water yield in Macizo del Caroig, Eastern Iberian Peninsula. Event runoff at plot scale during a rare flash flood at the Benacancel ravine”. These authors undertake a study on a slope and pedon scale, which is where the runoff is generated and the origin of the water discharge, which will later produce floods. These investigations are especially important in Mediterranean areas with dry riverbeds (“Ramblas”), such as the Ramblas of the Coroig Massif that is analyzed here. From the experimental studies carried out, after eleven years of direct measurements in the field, it is concluded that, from a spatial point of view, there is a decrease in the runoff coefficient along the slope; and from a temporal point of view, runoff is concentrated in few rain events, which are precisely those that cause floods. Only one rain event (in eleven years of follow-up) of 140 mm day^{-1} connected the runoff from the plots with the Benacancel ravine.

Continuing in the Valencian community, A. Camarasa-Belmonte has developed his research entitled “Flash-flooding of ephemeral streams in the context of climate change”. By analyzing the different databases, it is possible to observe how many of the floods occur in dry riverbeds suddenly. For this reason, it is not surprising that the author of this work considers that the Mediterranean boulevards imply a significant risk of flooding, historically underestimated due to their intermittent flow and the general ignorance about their hydrogeomorphological functioning. This article addresses key issues of rain-flow conversion and flood generation in boulevards, as well as their evolution in the current context of environmental change. Based on cincominutal data (SAIH-Júcar), the work has been carried out in two phases: (i) in the period 1989-2018, in four boulevards, the generation of floods at the basin scale has been determined, based on 138 events; and (ii) in the period 1989-2016, on a more general scale, the evolution of 698 rain episodes in the Júcar River Basin District has been analyzed, to infer what consequences environmental changes could have for the formation of floods in Ramblas. The results obtained suggest that the episodes tend to increase in intensity and decrease the accumulated precipitation. Climate change could lead to an increase in intense flash floods, which are increasingly difficult to manage with the usual flood control instruments, and secondly, there is a tendency towards progressive aridification of these Mediterranean basins. It is necessary to increase the hydrogeomorphological knowledge of ephemeral streams to develop solutions to current and future problems.

The causes that produce intense rainfall in the provinces of Alicante and Murcia have been studied by J. Martín-Vide, M.C. Moreno-García, and J.A. López-Bustins, under the title “Synoptic causes of torrential rainfall in South-Eastern Spain (1941–2017)”. The work has determined the synoptic types of 68 dates in which torrential precipitation greater than 200 mm/day was recorded in the period considered, in any station in the provinces of Alicante and Murcia, representative of the southeast of the peninsula. For the same dates, the surface pressure, and the value of the Western Mediterranean Oscillation index (WeMOi) have also been considered. The results show the percentage importance in torrential rainfall in the Southeast of Spain of the eastern advection with DANA (isolated high-altitude

depression) or 'cold drop' type, present in more than 50% of cases, followed by troughs in 500 hPa and dynamic or cold storms. Except for the latter type, the mean atmospheric pressure is close to or higher than normal. In all cases, the WeMOi was negative, which is consistent with the nature of this teleconnection pattern.

The episodes of intense rains that produce floods in the Segura basin, in general, and in the province of Murcia in particular, in recent years, have been frequent and with catastrophic effects. One of these episodes took place in September 2019 and A. Romero Díaz and A. Pérez Morales have carried out a study of this episode, using the press as a source for information. The objective of the work, entitled "Before, during, and after the DANA of September 2019 in the region of Murcia (Spain), as reported in the written press", was to analyze this episode through a follow-up of all the news published in two newspapers regional for 52 days. A total of 816 articles were analyzed and grouped into 26 topics. The database created made it possible to organize the information in different aspects and sequences: (i) prevention tasks and alerts before the materialization of a risk situation; (ii) rescue, relief, and assistance to people, and (iii) response, rehabilitation and reconstruction. From the analysis carried out, it cannot be concluded that the news that appeared in the press directly motivated response from the administration, but it is considered that they may have had a great influence. One year after the DANA episode, the panel of experts formed immediately after the event, has finally proposed a series of measures, intending to minimize the impact of the floods.

Another source of information, such as historical documentation, is that used by S. Gil-Guirado, J. Olcina-Cantos, A. Pérez-Morales and M. Barriendos in their study carried out in the city of Murcia, "The risk is in the detail: historical cartography and a hermeneutic analysis of historical floods in the city of Murcia". In this work, a hermeneutical analysis of the three most catastrophic floods that occurred in Murcia in the last 400 years is carried out and the analysis is completed with a quantitative historical cartographic reconstruction. Among the main conclusions reached by its authors, the fact that Murcian society had strategies for overcoming disasters that involved the whole of society and that advocated comprehensive management of emergencies stands out. However, the state of hardship before a flood is a determining factor to explain the resilience capacity of the social system. It is found that pre-industrial Murcian society used the mechanisms available to it to adapt to floods less efficiently. A hermeneutical analysis is important to transcend the mere description of the events that occur during a disaster and to highlight the problems and potentialities of each period in a historical key. The historical cartographic analysis has allowed a better understanding of the internal flooding processes, as well as a better characterization and contextualization of the complexity of the study area. Thanks to the use of old maps, it has been possible to delimit a historical region such as the Huerta de Murcia, which due to its complexity and internal structures escapes a simple administrative delimitation.

In the Andalusian Mediterranean region, J.M. Senciales-González and J.D. Ruíz Sinoga also try to know the climatic causes that produce recurrent floods. With their work "Features of weather types involving heavy rainfall along the southern Spanish Mediterranean", they propose a systematic comparison of synoptic conditions with events of heavy rainfall in southern Mediterranean Spain, evaluating the types of weather responsible for the meteorological risk in specific locations in this mountainous region. To do this, they analyze the maximum intensity of precipitation since 1943 in an observation period of 10 minutes to 24 hours, using an extensive database of 132 meteorological stations. Subsequently, heavy rain has been associated with the type of weather that triggers it. The study came to identify a pattern of intense rains different from that previously known in the Mediterranean area. Thus, the maximum number of intense rain events is usually caused by low pressures associated with front systems and winds from the East-Northeast, but the maximum volumes are usually associated with Cold Drops and the same winds. In the Alboran Sea, in southern Spain, a pattern of heavy rainfall was found that differs from that previously reported for the Mediterranean area. This was due to its geographical position, very close to the Atlantic Ocean, and the conjunction of latitude and orography.

In the same geographic area as the previous work, J. Ojeda Zujar, P. Fraile-Jurado, and J. Álvarez-Francoso, evaluates the risk of flooding, but in this case due to the rise in sea level. The objective of his work “Sea level rise inundation risk assessment in residential cadastral parcels along the Mediterranean Andalusian coast” is to present the main methodological results of the evaluation of permanent flood risks associated with the rise in mean sea level according to different scenarios and models. Climate change, focusing on the assessment of the danger, exposure, and physical vulnerability of built areas, especially residential areas on the Mediterranean coast of Andalusia. The authors proposed a method of spatial analysis of the flood risk associated with each sea-level rise scenario, using a DEM of 5m spatial resolution. For the evaluation of the exposure and vulnerability of the built-up area, especially for residential areas, data from the national cadastre have been used. The superposition of the set of cadastral parcels and the flood risk maps made it possible to identify the exposure of the cadastral parcels for residential use for each chosen scenario. And using the most pessimistic scenario, the exposed parcels amount to more than 24,000 and more than 13,000 exposed residential cadastral parcels were identified for which their risks, exposure, and vulnerability were calculated to finally assess the flood risk associated with future sea levels.

The last article in this monograph is dedicated to the island of Mallorca. In it, M. Grimalt-Gelabert, J. Bauzá-Llinás, and M.C. Genovart-Rapado analyze “The flood of October 9, 2018, in the city center of Sant Llorenç des Cardassar (Mallorca)”. This population, unfortunately, has suffered since the 1940s, repeated episodes of flooding from the different tributaries of the Ca n’Amer torrent, but in 2018 the most important flood of the series occurred, which caused a large part of the population to be affected, including fatalities. The authors have analyzed the historical relationship of the town with the flooding processes, the response to them by the administration and the natural geographic environment and anthropic actions on the territory. In this work, the direct observation, the face-to-face, and graphic testimonies, and the fieldwork are to be highlighted. A detailed investigation of flows, directions, and levels has also been carried out, and exhaustive mapping of the event has been carried out, showing the sequential development of the flood. As a conclusion, it is indicated that the flood is the result of the combination of extremely important flows, natural processes of cutting in meanders, and angular sections that are combined with infrastructures that interfere with the flow of water and prevent its reintegration into the main channel. The administrative response to the floods has been the construction of artificial cemented canals, however, the canals have always been designed with a lower capacity than the registered floods. The canals have been supplemented with extremely solidly constructed, narrow-stem bridges, which has made overflows and flooding worse.

Finally, I would like to thank the editors of *Cuadernos de Investigación Geográfica* for offering to be the guest editor of this monographic issue. I also want to comment that after the proposal that I made to several authors to contribute their research to achieve a high-quality number, I have to say that the positive response was practically unanimous.

Due to the contents, results, and conclusions so interesting that, on different aspects related to the floods in the Spanish Mediterranean, which can be found in each of the articles presented here, a detailed reading is highly recommended. Our gratitude to all the authors who have contributed to this special issue of *Cuadernos de Investigación Geográfica* sees the light, both for their time and effort and for the extraordinary work they have done.

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