International Journal of Disaster Risk Reduction 100 (2024) 104160

Contents lists available at ScienceDirect

International Journal of Disaster Risk Reduction

journal homepage: www.elsevier.com/locate/ijdrr

Uses and opportunities of emergency calls as a resource for flood risk management

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A R T I C L E I N F O

Keywords:
Risk communication
Disaster
Hazard
Mapping
Vulnerability

A B S T R A C T

Floods pose significant risks to both human lives and property, necessitating effective flood risk management strategies. One promising approach for enhancing flood risk management is the utilization of emergency calls as a valuable data source. This paper proposes two primary applications of these calls: 1) enhancing the cartography of flood risk areas and 2) improving risk communication systems. The disastrous flood event that took place in the Vega Baja region (Spain) in September 2019 is taken as a case study for this research. On the one hand, by analysing and geolocating emergency calls related to this flood event, we identify additional affected zones that are not represented in the existing cartography, leading to more comprehensive and accurate mapping. On the other hand, the analysis of the 112 calls is used to create a context-based catalogue of warning messages, tailored to address the unique requirements and challenges faced by the local population during the flood event under study. Thus, emergency calls serve as a direct link between the needs of affected population during a flood event and emergency response agencies. Overall, the outputs of this research underscore the importance of integrating emergency call data into flood management frameworks to enhance preparedness, response, and resilience in flood-prone regions in the framework of climate change.

1. Introduction

In recent years, the frequency and severity of flood events have increased globally due to the combined effects of climate change, urbanization, and environmental degradation. Floods pose significant challenges to communities, causing loss of life, property damage and economic disruptions. The increasing frequency and intensity of flood events worldwide have led to a rise in both the number of fatalities and the economic costs associated with these disasters. In the period from 1991 to 2000, insured costs related to floods amounted to 30 billion dollars. This figure more than doubled in the subsequent decade, reaching 68 billion dollars and the trend continued to escalate, with insured costs soaring to 100 billion dollars from 2011 to 2021 [1]. Also, human losses have increased, with more than 7000 deaths per year, according to the most recent data [2].

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https://doi.org/10.1016/j.ijdrr.2023.104160
Received 28 July 2023; Received in revised form 24 October 2023; Accepted 26 November 2023
Available online 30 November 2023

The Sendai Framework for Disaster Risk Reduction 2015–2030, the global agreement adopted by United Nations member states, provides a comprehensive approach to disaster risk management, emphasising the importance of understanding and addressing the underlying drivers of risk. This framework calls for a shift in focus from disaster response to prevention and mitigation, highlighting the need for both structural and non-structural measures with what has come to be known as integrated [3,4] or holistic (Vojinović et al., 2016) approaches to flood risk management. While engineering structural measures, such as levees and dams, have traditionally been the cornerstone of flood management with a strong focus on hazard control, there is a growing consensus on the importance of incorporating non-structural measures to build more resilient communities [5]. Non-structural measures encompass a range of policies, regulations, and practices aimed at reducing the potential impacts of floods without physically altering the environment, including land-use planning, risk communication and early warning systems, flood insurance, among others [6]. The more socially-oriented nature of non-structural measures requires a comprehensive understanding of local contexts [7]. In this sense, the Sendai Framework, aligned with the academic community [8,9], also underscores the importance of adopting context-specific approaches tailored to address the specific challenges and needs of diverse communities, enhancing their resilience and adaptive capacity.

The growing emphasis on context-specific and bottom-up approaches in the design of non-structural measures for flood risk management has led to the exploration and integration of new sources of information. These new sources of information, often derived from local knowledge and experiences, provide valuable insights into the diverse challenges and opportunities faced by communities in the context of flooding. Local and community-based data sources, such as participatory mapping [10,11], citizen science [12,13], and community-based monitoring [14,15], have increasingly been recognised as valuable complements to conventional top-down data collection methods. These emerging concepts are directly aligned with the demand of the Sendai framework to develop "a broader and a more people-centred preventive approach to disaster risk" [16]: 10). The inclusion of non-expert knowledge in the domain of flood analysis and management has evolved over time, seeing a significant surge in the last decade [17]. According to a literature review conducted by Ref. [15]; it is possible to identify three basic applications of citizen-based knowledge in the context of flooding. First, this type of knowledge has historically been used for data collection on flood-prone areas. The analysis of local testimonials and traditional cultural practices has historically been employed to delineate flood zones and estimate the potential intensity of these events [10,18,19]. More recent applications have utilized local population's territorial knowledge to support modelling in data-poor ungauged catchments [20]. Second, input from affected populations has also advanced damage analyses typically conducted after a flood event. The social impacts experienced by the community during a disaster can hardly be identified comprehensively and accurately if researchers do not consider the firsthand experience recounted by the affected individuals. In fact, some authors have designed methodologies to assess the social impacts of floods based on community knowledge and their disaster experiences [21,22]. Other recent studies have analyzed large volumes of publications and user comments on social networks as a method to understand the main damages, emergency situations, and areas affected by a disaster [23,24]. Thirdly, information collected among affected communities has not only been used as a source for data collection but has also been employed as a strategy for flood risk management. So much so that Article 14 of the Water Framework Directive promotes the active participation of stakeholders in the drafting, review, and updating of basin plans. This is why some national legislations of European countries establish the need to subject flood risk management plans to public information and consultation processes. These citizen-based processes incorporate aspects related to the community experience of risk and disasters, allowing for a socially strategic design of management mechanisms such as early warning systems [25,26], initiatives for awareness and understanding of self-protection measures [27,28], or protocols for community action and recovery in the face of flood disasters [29,30]. Non-expert knowledge, therefore, enhances the informational input of flood risk analyses, while positively impacting community risk management by raising awareness and equipping the local population, thus increasing their resilience to future events. Despite its utility, some authors have warned that approaches sensitive to the community aspects of flood risk still face significant reservations from technicians and researchers accustomed to classical and technocratic models of knowledge production [31]. However, there is a growing consensus on the importance of adopting holistic risk management approaches based on a combination of measures of different types and scopes, among which are included non-structural measures of a social and participatory nature [32–34].

In this context of emergence of alternative models of flood risk management that incorporate the experience of local communities as a valuable source of information, the analysis of emergency calls has arisen as a strategic resource and its applications are still in an exploratory phase. The main line of application has been that of using emergency calls to estimate disaster damages. For instance Ref. [35], analyze the damages caused by disasters in several Finnish case studies based on emergency calls, insurance company information, and meteorological radar data [36]. examined 19,680 emergency calls made during Hurricane Harvey (2017) in Houston to analyze the damages incurred during the event. [37], on the other hand, utilize emergency calls in conjunction with pluviometric and hydrological information to identify on-site problems caused by flooding on the road network of the Valencian Community (Spain). While damage estimation is the primary analytical use of emergency calls, in this paper we explore new application opportunities for this informational input. Building on the increasing recognition of the value of context-specific and bottom-up information sources in flood risk management, this research article illustrates the utility of the information provided by emergency calls received by the 112 (or 911) call centres during flooding events as a valuable resource for designing and implementing non-structural measures. As we will expose in the following sections, emergency calls serve as a real-time repository of community experiences, needs, and concerns during flood events, providing unique insights into the spatial and temporal dimensions of flood risk, as well as the coping strategies and capacities of affected populations. Also, emergency data are especially useful for risk management because it provides spatially accurate and trackable information as the disaster develops [35]; [37]. It allows the identification of spaces that are vulnerable or susceptible to hazardous events and gives valuable information about the event's impacts as they occur (i.e. the state of road infrastructures and access routes for the emergency teams) [38]. However, as this paper will demonstrate, emergency calls data is not only valuable for operative reasons during a flood event, but also for preparation and prevention measures before the event, and recovery and adaptation measures post-event. In short, emergency calls can facilitate a better understanding of the functioning of the socio-ecological dynamics of a territory during a flood event [37] [39]; which is crucial for those in charge of executing preventive and management measures in the face of an emergency.

More specifically, this research uses the information gleaned from the emergency calls received by the 112 service of the Valencian Autonomous Region's (Spain) during a severe flooding event that occurred in September 12th-15th 2019 on the southeast of Spain, and presents two different applications to enhance flood risk management by: 1) improving early warning systems by creating a catalogue of warning messages informed by the specific concerns and needs identified through the analysis of the 112 calls; and 2) enhancing emergency and risk cartography by integrating spatial and temporal data from the calls to better understand the distribution of flood impacts.

2. Case study

The selected event for this case study is the September 2019 flood that affected the Vega Baja region, located in the southern part of the Valencian Autonomous Region (Spain). This event occurred due to the formation of a cold drop that brought about a significant episode of torrential rainfall. Extreme precipitation levels were recorded in some areas, with 521.6 mm that fell in the city of Orihuela within 72 h, nearly doubling the average annual precipitation in this southeastern Spanish region [40]. The flood resulted from various factors, including the overflowing of the Segura River, the rupture of a river containment dike, and flash floods caused by the presence of ravines and gullies throughout this territory. During the episode, four people lost their lives, and damages, according to the Valencian Government, amounted to 1.5 billion euros [41]. The most significant social and economic impacts were losses in the agricultural sector and local businesses, as well as material and structural damages to housing, which were more intensely experienced in neighbourhoods with vulnerable populations. According to data from the Spanish Insurance Compensation Consortium, this flood has been the second most expensive on record in Spain, with insured damages exceeding 450 million euros [42].

The severe damages that occurred during the event were a result of the high intensity of rainfall, as well as other factors related to the exposure and vulnerability of the population. The Vega Baja territory is an alluvial plain of the Segura River basin, which, due to its geological and hydrological characteristics, has been exposed to recurrent floods over time [43]. It is also a region heavily impacted by human activity, such as agriculture, the development of secondary homes and intense urban growth. Most of the anthropized territory of this region is located in flood-prone areas. As a result of the combination of residential tourism and agriculture, the demographic landscape of this area is highly heterogeneous, with the presence of labour migrants from developing countries attracted by agricultural employment and residential migrants from EU countries motivated by the region's tourist offerings (Canales and López-Pomares, 2010). These groups often overlook the natural threats of the territory and sometimes are unaware of the preparation, response, and recovery guidelines for extreme events [44]. This sociodemographic complexity, combined with the high hazard levels previously described, make Vega Baja a high-risk territory. This elevated level of risk materialised during the September 2019 flood, which caused intense material and human damages.

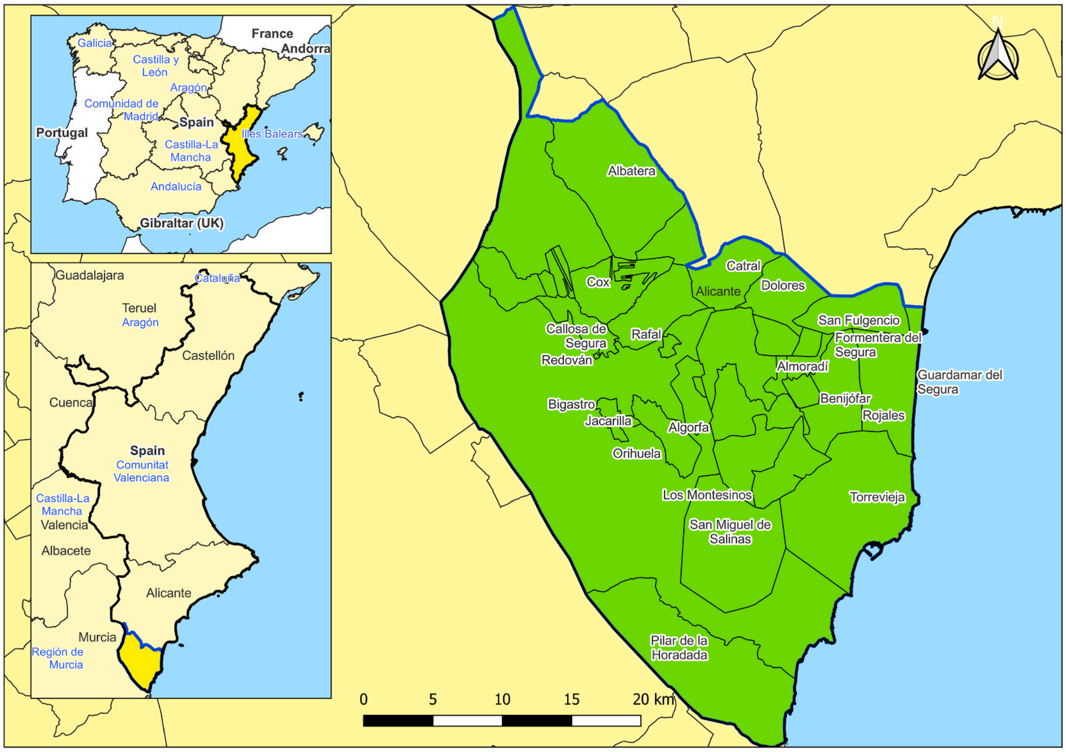

Fig. 1. Study Area: Vega Baja del Segura. Source: Valencian Cartographic Institute (ICV). Own elaboration.

Table 1
Final content structure of the flood risk warning message catalogue.

Phase 1: Forecasting	Number of messages
1. Meteorological information	7
1.1. Rainfall forecast (72 h)	1
1.2. Heavy rainfall forecast (48 h)	1
1.3. Very heavy rainfall forecast (48 h)	1
1.4. Heavy rainfall forecast (24 h)	1
1.5. Very heavy rainfall forecast (24 h)	1
1.6. Subsequent heavy rainfall forecast	1
1.7. Subsequent heavy rainfall forecast	1
Phase 2: Preparation	
1. Provision of essential resources	14
1.1. Food, medicine and other	7
1.2. Information on the event	3
1.3. Drawing up an action plan	4
2. Securing dwellings	7
2.1. Hazardous products	1
2.2. Elements exposed to the outside	1
2.3. Energy supply	2
2.4. Ducting and seepage areas	3
3. Care of dependents	4
3.1. General dependent population	1
3.2. Elderly dependents	1
3.3. Children	1
3.4. Ill people	1
4. Road traffic and circulation	5
4.1. Vehicle status	2
4.2. Road circulation	3
5. Education and services	2
5.1. Schools and education centres	1
5.2. Businesses and administrative services	1
6. Outdoor activities	5
6.1. Sports	1
6.2. Leisure activities	4
7. Animal care	2
7.1. Domestic environment	1
7.2. Urban and rural environments	1
Phase 3: Action	
1. Water infiltration into properties	4
1.1. Living areas	3
1.2. Garages and basements	1
2. Traffic emergencies	4
2.1. Vehicle parking	1
2.2. Road emergencies	3
3. Flooding and storms	5
3.1. Waterlogged areas	1
3.2. Mountain areas	1
3.3. Urban areas	1
3.4. Coastal areas	1
3.5. Thunderstorms	1
4. Landslides and rockfalls	2
4.1. Natural environment	1
4.2. Street furniture	1
5. Assistance and rescue of people	7
5.1. Social environment	1
5.2. Outdoor emergencies	4
5.3. Injured people	2
6. Evacuation of people	7
6.1. Evacuation from dwellings	2
6.2. Information	2
6.3. Guidelines for action	3
7. Animal protection	3
7.1. Household environment	1
7.2. Urban and rural environment	2
8. Essential resources and supplies	6
8.1. Food and water	2
8.2. Energy	1
8.3. Communication systems	3
Phase 4: Recovery	
1. Personal safety	5

(*continued on next page*)

Table 1 (*continued*)

Phase 1: Forecasting	Number of messages
1.1. Household environment	2
1.2. Urban and rural environment	3
2. Cleanliness and hygiene	6
2.1. Return to the home	5
2.2. Community environment	1
3. Personal injuries	2
3.1. Injured people	2
4. Insured damages and aid	2
4.1. Insurance	1
4.2. Other financial assistance	1

The study area is located in the South of the Valencian Autonomous Region, in the district of Vega Baja del Segura, comprised of a total of 27 municipalities with a population reaching 350,000 inhabitants, which can increase to a million in the summer months. (Fig. 1).

3. Method and data sources

The primary data source used in this research consists of the emergency calls received by the 112 service, recorded at the Emergency Coordination Centre of the Valencian Autonomous Region during the flood event chosen as a case study. The calls data were anonymised and provided courtesy of the Valencian Agency for Safety and Emergency Response (AVSRE) of the Valencian Regional Government.

Emergency calls serve as a research resource with vast potential for risk analysis. In this research, the emergency calls have allowed for an examination of the informational or assistance needs of the population during the event with the aim of creating a catalogue to improve risk communication. Additionally, these calls afford insight into the precise timing and location of their occurrence, two crucial elements for establishing the relationship between the calls and the timing of the hazard in question (in this case, floods), and for delineating the affected area to improve upon existing official risk maps. This research resource provides three fundamental parameters for socio-territorial risk analysis: location (space), precise timing of occurrence (time), and the reason for the call (need).

Given the particular attributes and objectives of each of the two applications that we present in subsequent sections of this paper, the sample of emergency calls varied. For the creation of a warning message catalogue that covered all phases of the event lifecycle (pre-event, event and post-event), the database comprised calls made from 00:00:00 on September 10th to 23:59:59 on September 20th. For the cartography application, the emergency call database encompasses calls received from 00:00:00 on the September 12, 2019 to 23:59:59 on the September 15, 2019. The choice of these dates is justified by their coinciding with the two significant rainfall events (12th and 13th) and the most severe flooding situation (13th–15th).

The call database provided by the emergency services, consisting of 14,194 calls, was filtered to ensure that only those calls directly and indirectly associated with the selected flood event case study were considered. Ultimately, a sample of 4078 calls from the period of September 10th to 20th was used for the first application (warning message catalogue), along with 3648 calls to the 112 service corresponding to the days between September 12th and 15th (for cartographic application).

3.1. Method for the design of the warning messages catalogue

The creation of the warning messages catalogue based on the case of the 2019 flood event in Vega Baja was guided by a methodological design that sought to fulfil three specific tasks: (1) the creation of the catalogue's content architecture, (2) the crafting of each individual message, and (3) the testing of the messages.

The initial step towards the construction of this repository entailed the design of a content structure that comprehensively encapsulated the variety of necessities that individuals face during a flood event. The identification of these categories was achieved via two distinct processes: firstly, through the analysis of the calls made to the regional government's 112 service (analogous to 911 in other countries) during Vega Baja's 2019 flood, and secondly, through the examination of warning messages disseminated by other domestic and global emergency entities.

The calls in the database provided by the AVSRE were coded according to diverse categories of information and emergency needs. A total of 4078 calls were individually coded. To carry out the coding of the calls, we considered the thematic categorization made by the emergency services when recording the call, as well as the comments included in the database as observational notes with the aim of specifying the reason for the call. During the coding process, we identified general typologies of topics - which became the basis for the main *sections* of the catalogue -, and more specific issues, which conformed the different *topic areas* within the main section. 12 sections and 32 topic areas comprised the catalogue's structure at this first stage.

Besides the analysis of the case study's emergency calls, and in order to ensure generalizability and comprehensiveness of the catalogue we reviewed 15 different sets of warning messages published by national and international emergency services (Spanish External Affairs Ministry; Spanish, General Direction of Civil Protection; Andalusia; the Basque Country; the Canary Islands; Catalonia; Murcia; Navarra; Valencian Autonomous Region; the Centre for Disease Control and Prevention, CDC, USA; the Federal Office for Civil Protection and Disaster Assistance, Germany; the Health Security Agency, UK; the National Oceanic and Atmospheric Administration, NOAA, USA; Ready.gov, USA; the Royal Society for the Prevention of Accidents, RoSPA, UK). After reviewing these catalogues, a total of 161 distinct messages were compiled, excluding repeated or very similar messages. Most of these messages were appropriately categorized within the thematic structure obtained in the previous step. However, some messages did not fit within this content structure, leading to a decision to create new sections or topic areas. Thus, we conducted a second coding process, from which the definitive thematic structure of the catalogue was derived, comprising 20 sections and 55 topic areas (refer to Table 1 in the Results section). Therefore, this analysis supplemented and finalized the list of sections and topic areas identified in the previous phase.

Regarding the drafting of the warning messages, we followed [45] message mapping proposal, which is one of the most commonly used by agencies such as the US Environmental Protection Agency (EPA) or the World Health Organisation (WHO). The main guidelines provided by this framework and that were adopted in this work refer to:

- The structuring of the message body into three sections: a header (with essential information related to the message's main objective); a supporting fact, that clarifies the content of the warning or illustrates specific actions regarding preparation, action or recovery; and additional information needed for an adequate understanding of the message by the receiver. This message structure model, based on the [45] protocol, also enabled the standardization of message writing and the organisation of its content in accordance with different communicative functions (essential information in the heading, supporting facts in the body of the message and supplementary information at the end of the message).
- The avoidance of technical jargon and use of language that is understandable by the general population. Also, the principle of economy of words was considered to establish the length of the messages, ensuring they were as short and concise as possible.
- The use of infographic elements or adequate formatting (capital letters, italics, bold font, etc.).

To tackle the drafting, the research team was divided in two: part of the team was in charge of writing the texts and the other group reviewed their work and made corrections or modifications. When writing the messages, both the style criteria and the structure described earlier were taken into consideration. A preliminary catalogue of 97 messages was elaborated following Covello's message structure.

Lastly, all the warning messages included in the catalogue were tested to ensure their technical validity, comprehensiveness and usage. Two types of pilot-testing were carried out. The first testing involved the evaluation by experts of messages with significant technical content. 26 such messages, primarily related to first aid, traffic, and rescue operations, were selected. Six experts, including two medical emergency professionals, two environmental disaster firefighters, and two members of the civil protection technical department, were consulted. They were asked to assess the technical accuracy, appropriate expression, and the need for editing in the messages. After completing this testing phase, minor changes were made to the technical aspects of some messages' wording. The second test aimed to determine if the messages were comprehensible to end-users and if the warnings were clear and useful enough to facilitate the recommended preparation, response, and recovery actions. Criteria for this evaluation included the language and terminology used, salience (message's capacity to convey the seriousness of the emergency), the adequacy of examples, the explanatory power of the message, and the feasibility of recommended actions for the general public. Three focus groups were formed with varying age demographics: young adults (18–30), adults (31–65), and seniors (over 65). Each group had nine participants from different municipalities of Vega Baja, totalling 27 participants. This diverse composition enabled participants from each age group to share their understanding of the messages, leading to balanced proposals for improvement. After collecting suggestions for improvement, the research team revised the messages accordingly. The revisions fell into five categories based on the extent of changes: typos (40); minor changes (42); moderate changes (14); major changes (1); and new messages (2).

3.2. *Method for the improvement of flood-risk cartography*

For this second application, we proceed with the geolocation of calls received by the 112 emergency service. In total, we analyzed 3648 calls received between September 12 and 15, 2019 in the study area. This database contains, for each call, information related to its location, the time it was made, and its primary reason. This information enabled us to conduct a detailed analysis of the rain event evolution, understanding more accurately the behaviour of water courses, and identifying the exact locations where flooding situations occurred.

We projected the calls in geographical coordinates (X, Y) and then transformed them to UTM Zone 30 N, EPSG:25830 projection, as required by European cartographic regulations, and transferred the information to a GIS. To accomplish this, we created a database in Excel format (.xml) and later converted the file into CSV format (comma-separated values). The GIS used was QGIS software in which the CSV file was loaded. Once added, this file was converted into a layer with shapefile (.shp) format. This conversion allowed us to geolocate the calls in the study area, thereby delineating the zones and the flood process.

The maps produced in this study were generated using the geographical location values (latitude and longitude) included in the call database provided by the 112 service. Most of the flooded areas correspond to those identified as flood-prone in the official cartography of the National System of Flood Zone Cartography (SNCZI) and the Territorial Action Plan for Flood Risk in the Valencian Community (PATRICOVA). However, there are other areas that experienced flooding in September 2019 that were not mapped in these official sources. Consequently, emergency calls (112) have allowed us to identify both the areas affected by river overflow already known in official cartography and to incorporate new areas not included in these maps.

The delimitation of the mapped areas displayed in the results section of this article has been determined using official cartography (SNCZI and PATRICOVA), the geographical location of emergency calls (112), and the mapping of existing watercourses in the study area, which were analyzed using historical aerial photographs.

The geolocation of the calls and their analysis helped the identification, among other things, of the streets in the urban environment that act as channels during the event: current channels, historical channels, and primary river courses responsible for the floods that lead individuals to use the 112 service. One of the results to be showcased in the following section is that many calls came from areas not identified in official maps or were classified with a lower risk level than suggested by actual events. The SNCZI is focused on hydrological and hydraulic modelling of main channels, and therefore does not consider minor channels. These minor channels are those that the regional mapping of the PATRICOVA considers as having geomorphological hazardousness. However, this geomorphological hazardousness layer delineates flood-prone areas but they are not identified as high-risk areas in PATRICOVA and, therefore, they are not considered in land use planning. Thanks to the analysis of the emergency service calls, it was confirmed that the areas identified as having geomorphological danger by PATRICOVA do indeed cause flooding in urban centres and rural areas, sometimes even being the primary cause of flooding at certain specific points. Hence, the analysis of emergency service calls not only verifies the presence of areas with potential risk but also pinpoints the 'hotspots' where emergencies actually took place. These 'hotspots' represent areas where the social impact was more intense, as evidenced by the higher number of emergency calls, clearly highlighting the repercussions on the local population.

4. Results

4.1. Catalogue of warning messages for flood emergencies

As a result of the previously explained methodological decisions and the analysis of the 112 services database, we compiled a final catalogue of 99 warning messages to be used by emergency services during flood events. The catalogue was structured according to two main dimensions: (1) the four main stages of a flood life cycle: forecast, preparation, action and recovery. Different sections and thematic areas were organised within each of these chronological stages, derived from the evaluation of calls made to the regional 112 service and the review of warning messages from various national and international emergency organisations (Table 1).

Each individual message card is presented in an editable slide with an internal organisation that includes:

- Chronological and Thematic Codes: each card incorporates details regarding the temporal phase (forecast, preparation, action, and recovery), the section, and the topic area of each message. Every message has been assigned a numerical identifier ranging from 1 to 99.
- Informational Content: the content of the messages aligns with [45] tripartite structure, comprising a headline (bold text), a supporting fact (the initial bullet point beneath the headline), and supplementary details (the second bullet point beneath the headline).
- Supplementary Resources: an "Other resources" section is located at the base of each card, offering links to websites that can provide additional information as required by emergency personnel. Moreover, a "keywords" section has been included to expedite message location for emergency staff.

Herein, we provide a synopsis of the primary aims and content corresponding to each phase of the event, as well as a selection of messages from each of them, presented in their translated version into English, as the original version is in Spanish.

Phase 1. Forecasting: This phase comprises alert messages delivering weather forecast updates issued by emergency services 72, 48, and 24 h prior to the rainfall. Messages in this category relay information sourced from central meteorological services and the formal declaration of the alert status (yellow, orange, or red) as rain approaches (Fig. 2).

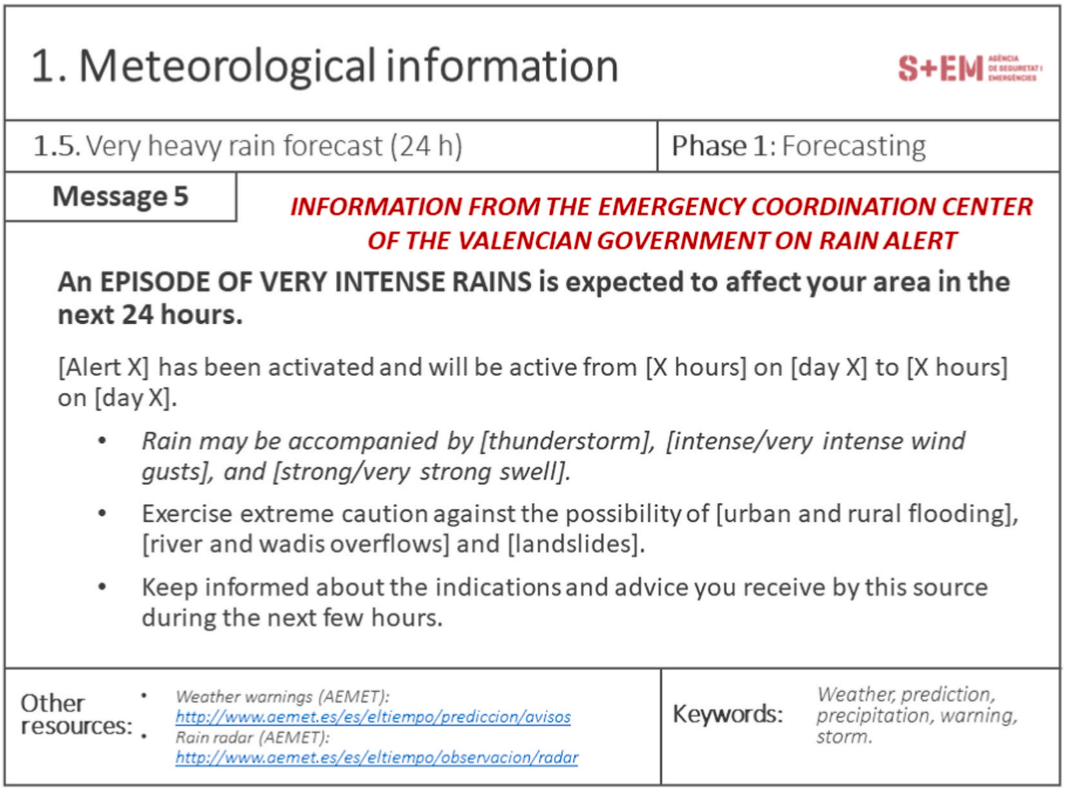

Fig. 2. Example of message card for phase 1: Forecasting.

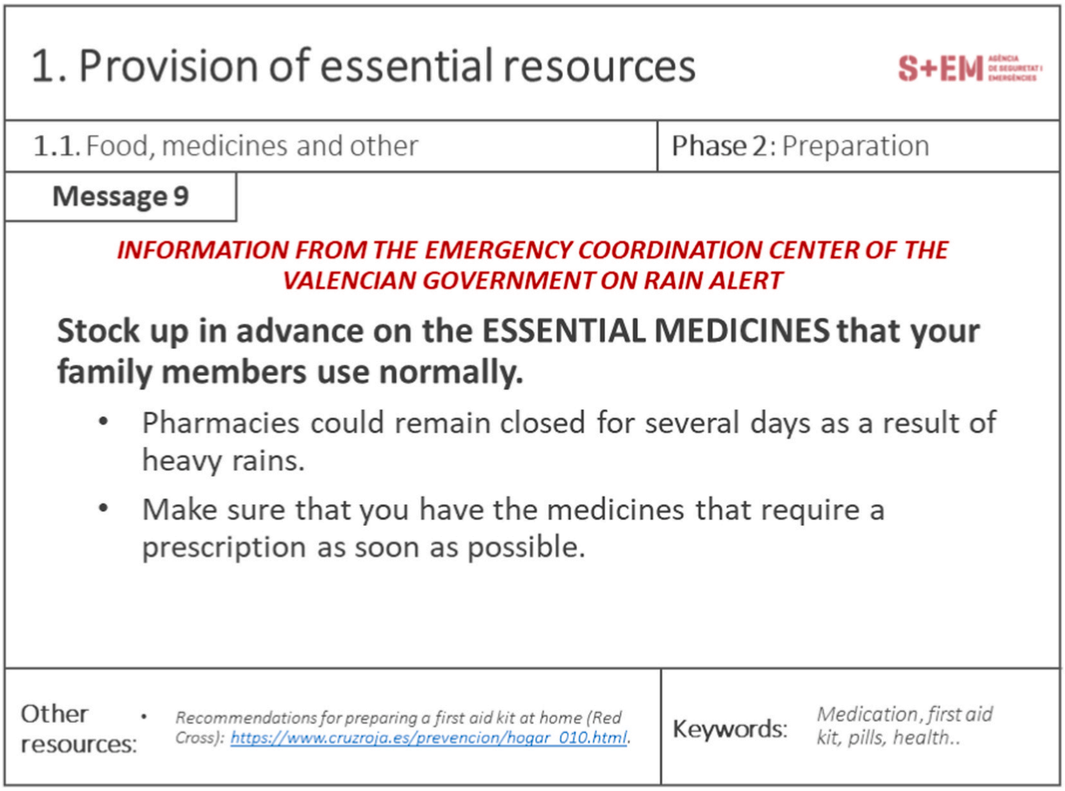

Fig. 3. Example of message card for phase 2: Preparation.

Phase 2. Preparation: This phase involves messages intended to ready the public for the impending rainfall and potential emergencies. The information provided assists at-risk populations in preparing for the likely event by gathering critical resources (food, medicine, water, etc.), safeguarding their homes against water intrusion or power failure, and avoiding exposure to dangerous substances or potential accidents. This phase also includes messages concerning special care for dependent demographics (elderly, children, ill individuals) and animals (pets or livestock), as well as preventive guidance on behaviour while driving, participating in outdoor activities, and staying updated on educational activities and other public services (Fig. 3).

Phase 3. Action: Messages in this phase are designed to clarify and illustrate specific actions and behaviours during the active disaster or emergency. Communication during this stage will supply information and suggestions beneficial for various circumstances that may arise during the flood event, such as how to act if water enters homes, garages, or basements, or if the recipient becomes trapped in traffic, a flooded outdoor area (mountains, coast, urban areas), or situations involving landslides or rock falls. This phase's messages also include pertinent information concerning vehicle usage, roadside emergencies, assistance, rescue, or evacuation of individuals or animals (Fig. 4).

Phase 4. Recovery: In this concluding phase of the emergency, sections consist of messages offering advice for a secure and efficient return to normalcy, like health guidelines, safe behaviours or information on insurance and financial aid to manage the economic impact of the damages (Fig. 5).

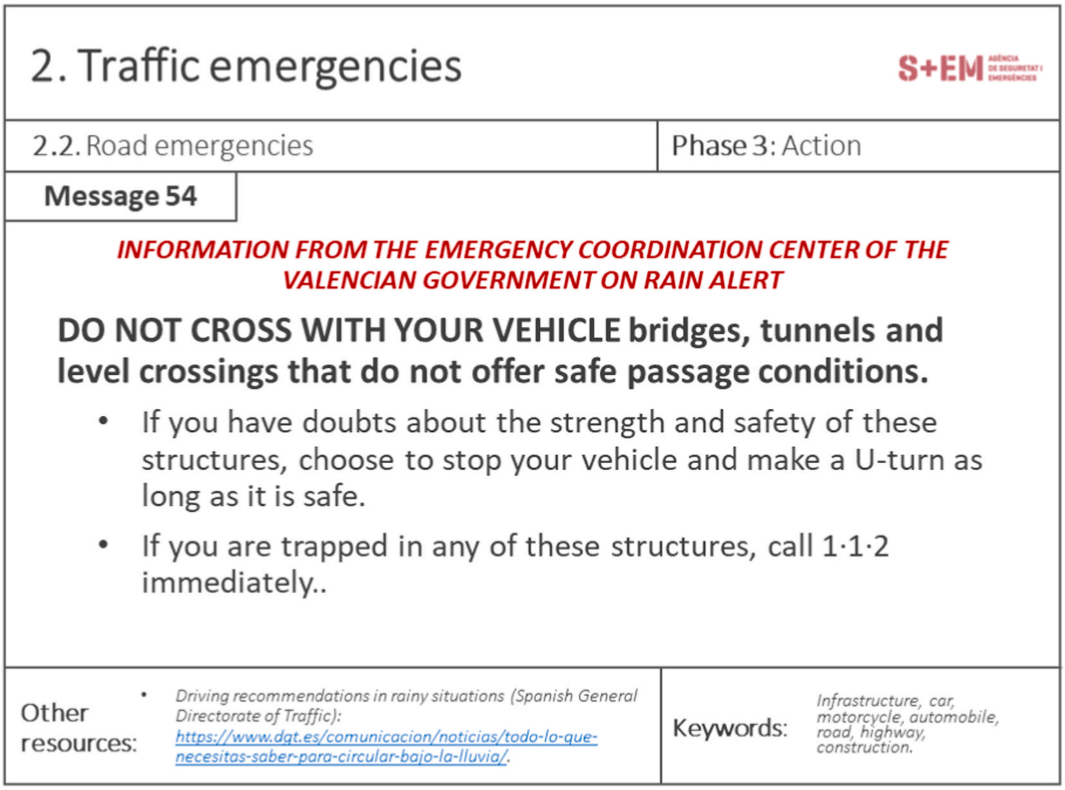

Fig. 4. Example of message card for phase 3: Action.

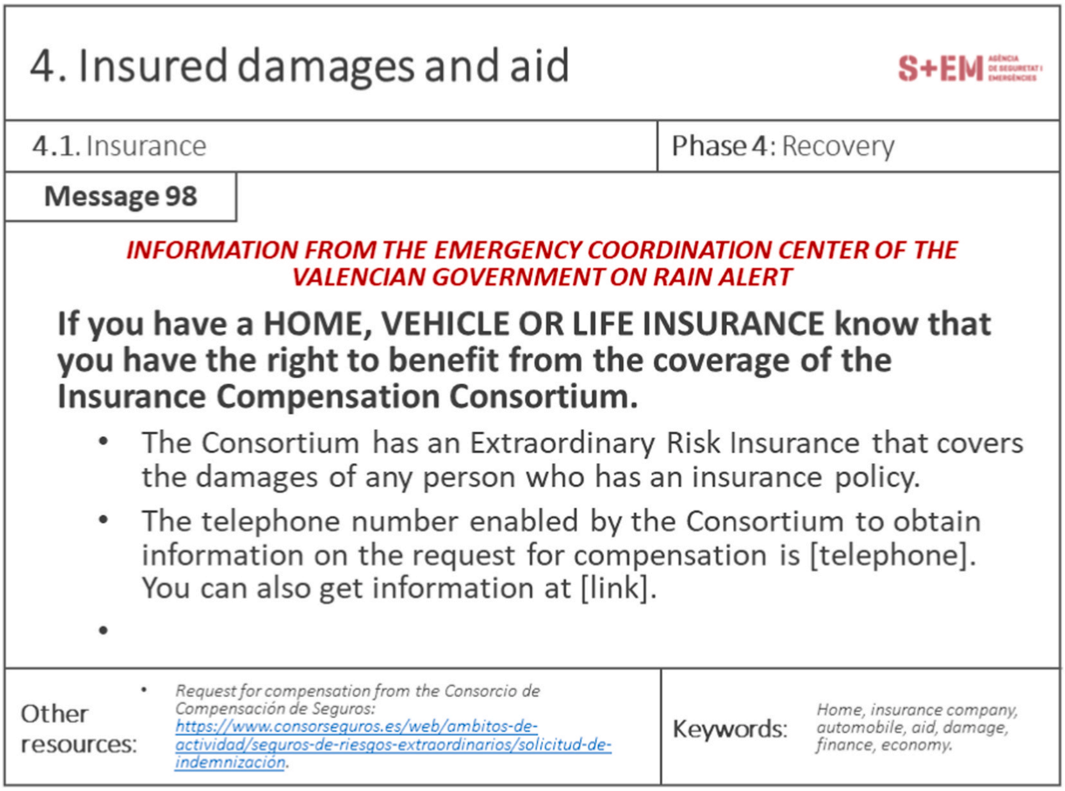

Fig. 5. Example of message card for phase 4: Recovery.

4.2. Improvement of flood-risk cartography

The utilization of emergency call data has allowed us to analyze and understand the dynamics of watercourses in the Vega Baja del Segura region, stemming from the 2019 flood episode. The analysis carried out has enabled the spatio-temporal distribution of flood emergencies and their evolution throughout the event. The maps shown in this section summarise all the calls received by the 112 service during the four-day event (from September 12 to 15, 2019).

As illustrated below, the flooded areas during the event under review have been mapped into large polygonal patches. In this regard, this work has allowed us to identify two main general groups of floods for this event (Figs. 6 and 7):

a) Group 1: floods caused by main channels (for example, Segura river, Abanilla ravine, Salada ravine, among others). These channels are named after the channel and the affected area.
b) Group 2: areas flooded due to the presence of a minor channel, multiple channels, or areas flooded by rainfall, among others, are named after the municipality where they are located.

The first group consists of those main channels in the region that flooded large land areas. Notable within this first group are: floods caused by breaches and overflows of the Segura River, the floods of the Abanilla ravine, the overflow of the Azarbe Mayor de Hurchillo irrigation ditch, the reactivation of gullies and flooding of the watercourse between Jacarilla-San Miguel de Salinas-Los Montesinos, the reactivation of the Algueda ravine, and the floods of the Salada ravine. The second group highlights the floods that occurred in different municipalities due to various watercourses.

The study also takes into account water courses from neighbouring towns whose overflowed waters affect sectors and municipalities of the study area. The calls recorded on the 12th mainly (blue points in Fig. 8) refer to pluvial-type floods due to the discharge of high amounts of rainfall and torrentiality (>250–300 mm). For this reason, most of these calls occur at the foothills of the Orihuela and Callosa de Segura mountain ranges, belonging to group 2 (Fig. 8). That is, the towns located at the foothills of the Orihuela and Callosa mountain ranges register numerous calls due to the reactivation of torrents that descend sharply from the elevated areas of the mountain range, causing floods and landslides. Meanwhile, the number of calls coming from the towns of Rafal, Almoradí, or Torrevieja reflect problems associated with sewer system deficiencies and significant flooding issues caused by intense rainfall.

On September 13 (green points), a further 250–300 mm rainfall was recorded, nearly reaching the historical record of over 500 mm in the study area. This day was the most significant of the event, as it saw the reactivation of numerous water courses and the rupture of several banks of the Segura River, completely flooding its floodplain (Fig. 8).

After the episode of torrential rains, during September 14 and 15 (red and pink points, Fig. 8), the 112 service continued recording calls. These calls were predominantly focused on issues arising from flooding, water drainage, or rescue operations. These calls were located in municipalities that lie at the lowest point and closest to sea level, on the left bank of the Segura River floodplain (Dolores, Daya Vieja, San Fulgencio, and Guardamar del Segura). In some of these points, the water remained stagnant for up to a month, due to the gentle slope and the presence of two barriers perpendicular to the natural flow of waters: the national road 332 and the breakwater or wall separating the old bed of the Segura River from the new channel, which hindered the drainage of the overflowed waters.

Fig. 8 represents all the calls received by the emergency services during the period from September 12 to 15, 2019. The collective set of calls and their spatio-temporal distribution have helped refine the flood zone mapping in the Vega Baja del Segura region.

To corroborate all this information, we compared the results with the official SNCZI cartography, associated with a low hazardousness level, corresponding to a flood of a recurrence or return period of 500 years. This mapping accurately reflected the flooding in the floodplain of the Segura River, but lacks information regarding other minor channels. Additionally, we have used the mapping developed by the Copernicus satellite that identifies the sectors that were flooded or where the water flowed. As can be seen in Fig. 9, much of the Copernicus vector mapping aligns with the SNCZI modelling, although there are areas identified by Copernicus that SNCZI does not account for (see Fig. 10).

Emergency calls from the 12th and 13th, which coincide with the waterspouts and the most significant effects of the September 2019 flood episode, have been added to this combined mapping. As can be seen in Fig. 8, most emergency calls are located in the zones marked by Copernicus and SNCZI. However, calls are also observed in areas not depicted in these maps. For instance, there are a large number of calls located in areas of geomorphological hazardousness where there were situations of very high risk and significant socio-economic damage. As seen on the maps, the 112 service received numerous calls in urban centres like Orihuela, Redován, Callosa de Segura, Cox, or Bigastro, which suffered significant flooding with the reactivation of water courses representing geomorphological hazardousness. Similarly, in areas like San Miguel de Salinas, Los Montesinos, Orihuela Costa, and Pilar de la Horadada, among others, historical channels or paleochannels were reactivated in the 2019 flood episode, flooding spaces not considered geomorphologically hazardous by PATRICOVA [38]. Similarly, PATRICOVA assigns a hazard level 2 to the entire municipality of Catral. However, during the 2019 flood, only the agricultural areas of the municipality (west, southwest, south, southeast, and east) were affected. Therefore, this new mapping allows the completion of the official maps, identifying and corroborating affected zones not considered in them.

Below, we provide some local scale examples that facilitate a better appreciation of the utility of this application of 112 calls to improve flood cartography. Fig. 11 refers to the town of Orihuela, characterized by the presence of a mountain on the north and the Segura River dividing the city into two parts. As shown in the image, there are various reasons for flooding in Orihuela concerning the division of groups made before. Regarding Group 1, it can be observed that part of the city of Orihuela is submerged due to the Segura River overflowing at the lowest point of the city. Additionally, a small area in the upper right, indicated in green, refers to the area flooded by the Abanilla ravine. Smaller ravines also affect the northeastern sector of Orihuela, such as the Cruz de la Muela ravine or the San Antón ravine, affecting the palm grove of Orihuela. The floods indicated by the red areas refer to ravines or torrents in the Sierra de Orihuela, which flooded the lower sector of the city. As can be seen in the Figure, dots corresponding to 112 emergency calls

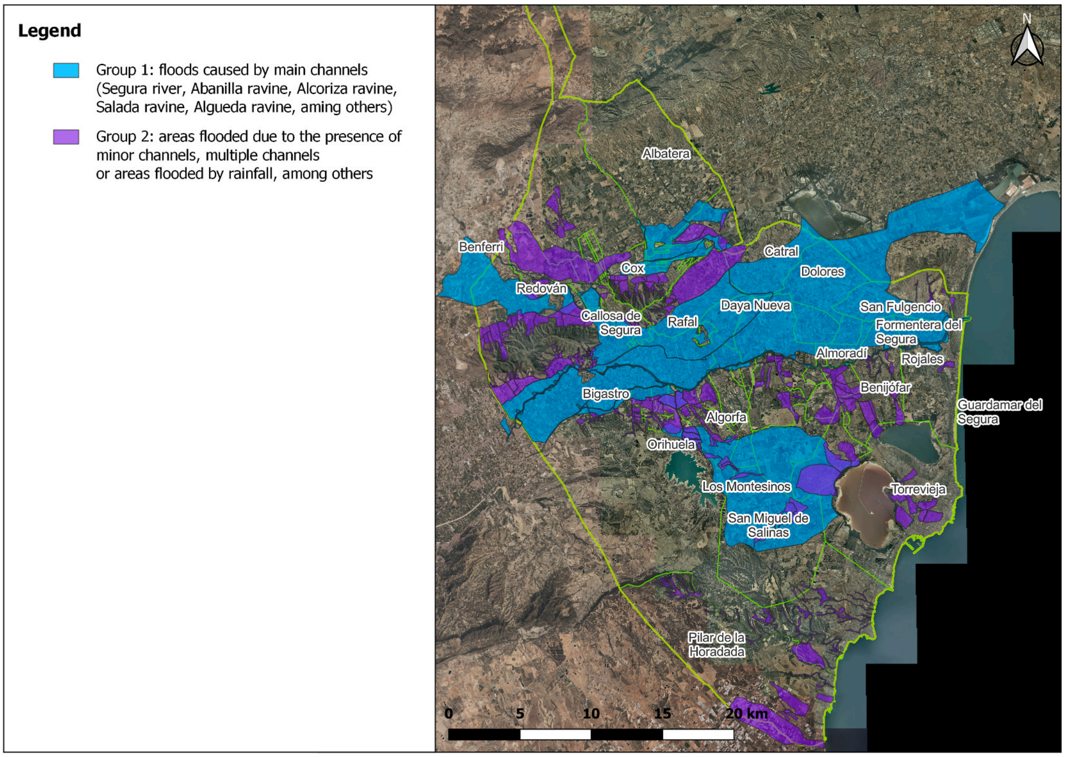

Fig. 6. Main groups of flooded areas in September 2019, according to the entity of the water channels. Source: Valencian Cartographic Institute (ICV). Own elaboration.

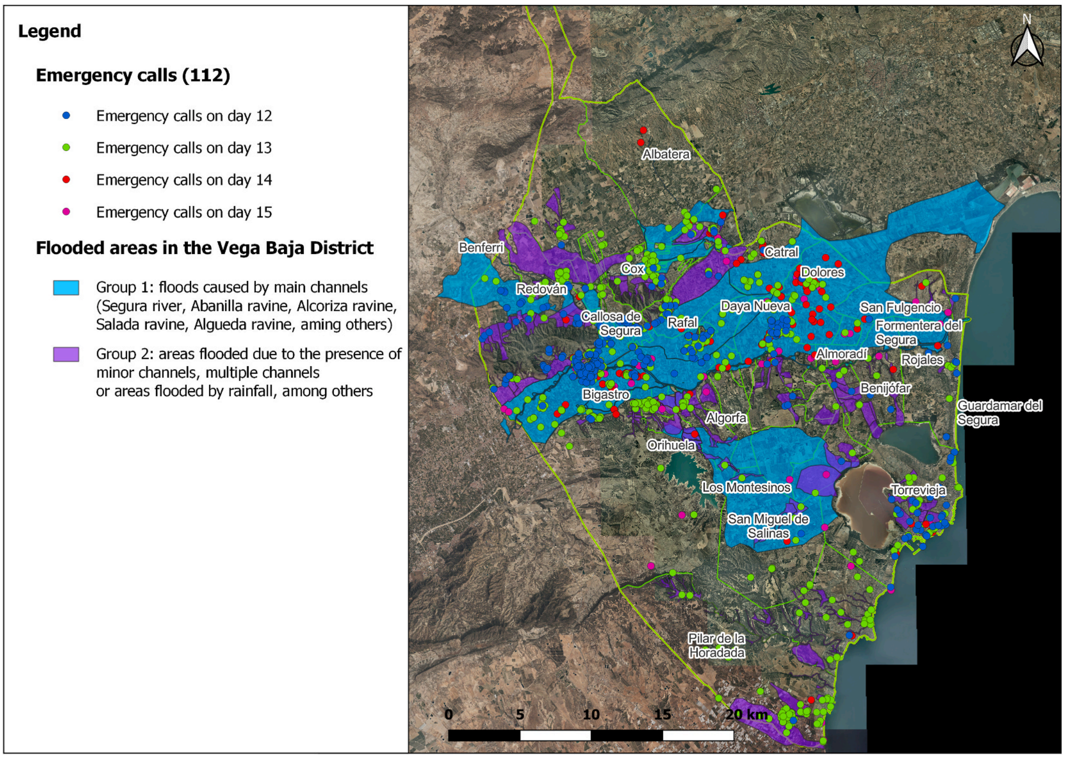

Fig. 7. Main groups of flooded areas in September 2019, according to the entity of the water channels and geolocation of the calls received by the 112 service (September 12–15, 2019). Source: ICV. Own elaboration based on calls to the Valencian 112 service.

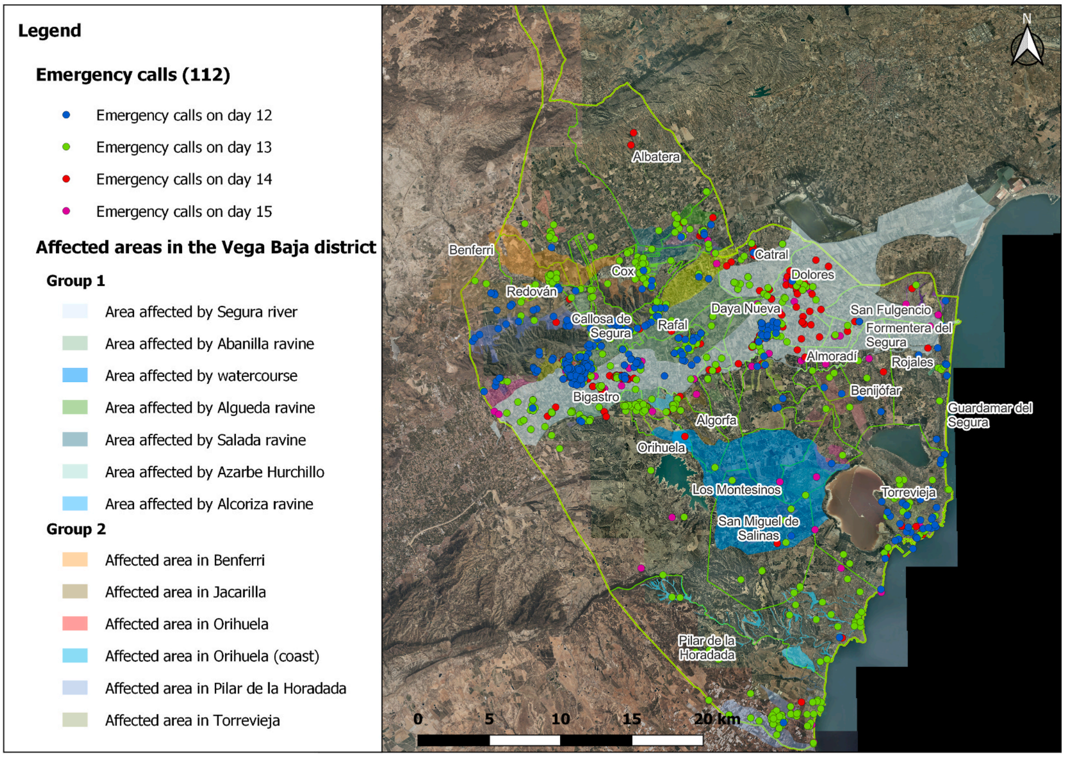

Fig. 8. Flooded areas flooded and emergency calls received by 112 on September, 12–15, 2019. Source: Own elaboration based on calls to the Valencian 112 service. AVSRE.

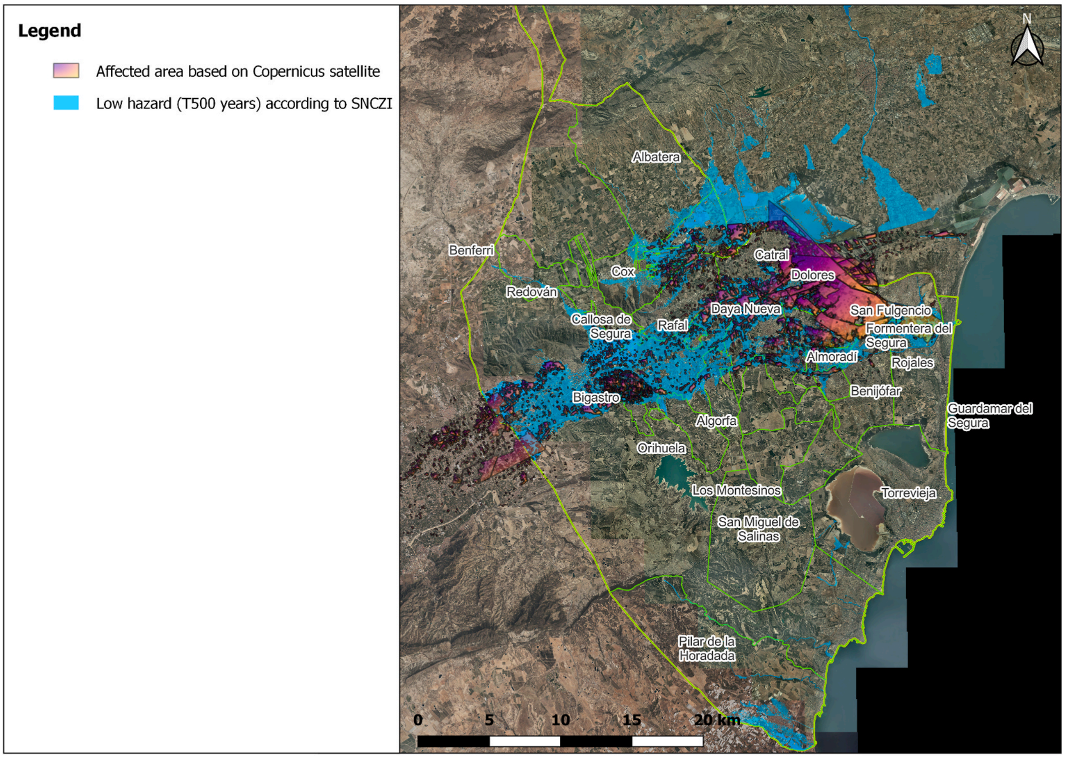

Fig. 9. Comparison of flooded areas in September 2019 according to SNCZI and Copernicus satellite. Source: SNCZI. Copernicus satellite (September 2019), Valencian Cartographic Institute (ICV) and National Geographic Institute (IGN). Own elaboration.

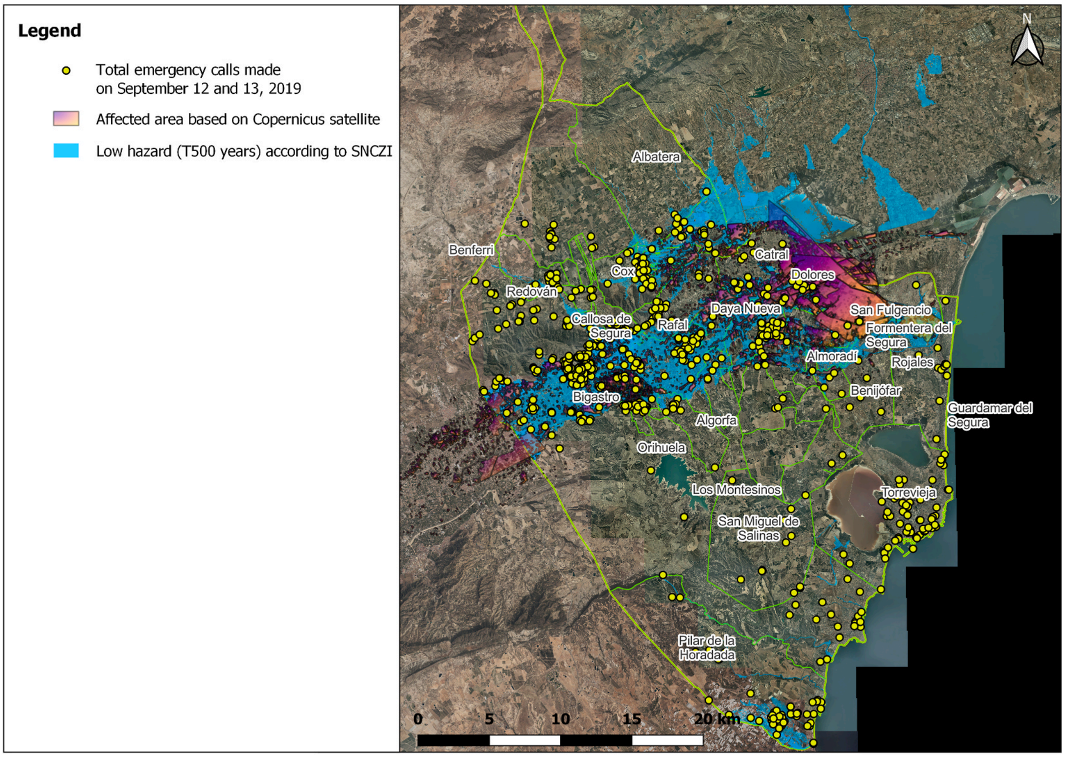

Fig. 10. Flooded areas according to SNCZI and Copernicus satellite, and emergency calls received by 112 services on September 12–13, 2019. Source: Valencian Security and Emergency Response Agency (AVSRE) (112), Copernicus satellite (September 2019), Valencian Cartographic Institute (ICV) and National Geographic Institute (IGN). Own elaboration.

received from Orihuela are not included in the cartography because they were related to pumping or leaks due to the intensity of the rainfall, but not directly related to river-type flooding.

This methodology is also applicable in coastal areas, whether for riverine flooding or maritime storms. Fig. 12 represents the case of the coastal town of Pilar de la Horadada and the areas inundated due to the reactivation of canyons (dry channels that become active during heavy precipitation but are characterized by having wide and shallow channels). In this case, diffuse currents occur until they flow into some channel or accumulate in the AP-7 tunnel (an infrastructure running perpendicular to the water flows and located below ground level). To the south of Pilar de la Horadada, the Cañada de las Siete Higueras suffered significant flooding in the entire area of irrigated crops, and the Pilar ravine, which runs through the urban centre of Pilar de la Horadada, also overflowed at the bend and start of the channelization of the ravine, inundating some sectors of the urban area.

In conclusion, the geolocation and analysis of the emergency calls have allowed for the reconstruction and completion of the flood map for the September 2019 event, identifying the channels and the flooding they caused. This analysis reaches a local level of detail, by neighbourhoods and even by streets, allowing for a more comprehensive and detailed understanding of flood risk areas. This knowledge, based on the experience of the flood, does not replace official maps, but serves as a strategic resource to complement them in the effort to achieve as realistic an understanding as possible of flood risk.

5. Discussion and conclusions

This research has demonstrated the potential and utility of emergency calls as a strategic data source for improving flood risk management. The results presented in this study are extremely useful to guide and enhance the efficiency of flood response mechanisms by institutions and the affected population, mainly in two aspects: 1) improving the accuracy of existing flood risk cartography; 2) enhancing emergency communication by identifying a wide range of topics to provide guidance to the population on how to act during the preparation, response, and recovery phases of a flood event.

On one hand, concerning the mapping made from the record of 112 calls, the results of this study confirm and address some of the limitations present in the national (SNCZI) and regional (PATRICOVA) flood-risk cartography. The information provided by the calls received by the emergency services has allowed for a much more detailed and accurate flood mapping, which complements the information from official maps by identifying the functioning of water channels and minor rivers that are generally not delineated in official maps. These latter ones focus only on the main water courses, not covering some secondary channels that cause significant material and human damage.

This analysis has also made it possible to understand the influential hydrographic factors in the flood process, distinguishing

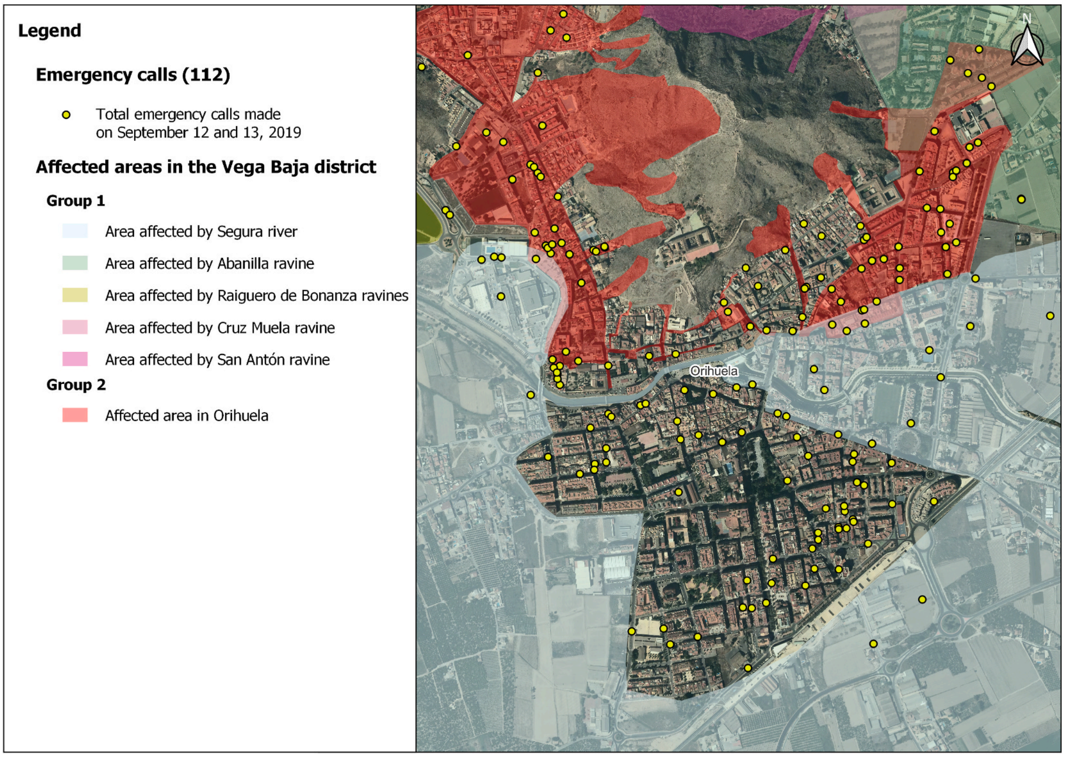

Fig. 11. Flooded areas flooded and emergency calls received by 112 on September 12–13, 2019 in the case of Orihuela. Source: Valencian Security and Emergency Response Agency (AVSRE) (112) and ICV. Own elaboration.

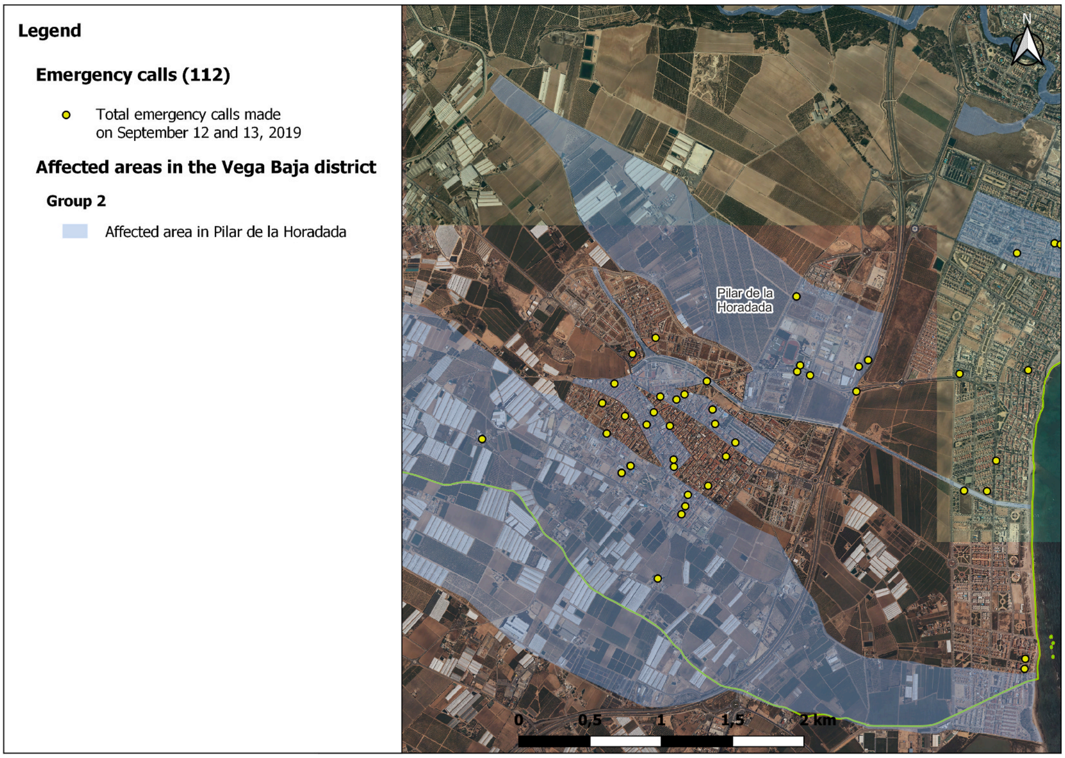

Fig. 12. Flooded areas and emergency calls received by 112 service September 12–13, 2019 in the case of Pilar de la Horadada. Source: Valencian Security and Emergency Response Agency (AVSRE) (112) and ICV. Own elaboration.

different forms of flooding across the studied territory. From this information, management measures can be identified that are adapted to the specific forms of flood risk that occur in different points of the territory. Likewise, the cartographic analysis of emergency calls also has the potential to identify vulnerable areas within the territory. While official maps are created considering only the variable of flood hazardousness, the analysis presented in this work allows us to detect areas where material and human damage occurs, indicating the presence of vulnerable areas. Although a vulnerability map would require a detailed study of the social and economic conditions of the population, this analysis becomes an effective resource to obtain basic knowledge of the critical points that a territory exposed at the population and residential level presents, indicating the presence of vulnerable areas not identified in official mapping. It also allows us to understand the problem and the consequences of the existence of conflictive points in a river flood. For example, paths and roads that act as channels, road or railway infrastructures that act as retaining walls or dams, pontoons with insufficient hydraulic spaces that divert flooding to urban centres, or lack of height of roads that cross powerful flash flood river courses.

Finally, this analysis is also capable of identifying the main types of emergencies and needs experienced by the population during a flood event. This analysis does not replace the assessments of social and economic effects that must be carried out to obtain detailed knowledge of the impacts of an event [22], although it is a useful tool to have preliminary knowledge about the spatial and temporal distribution of the main types of problems that can occur in a risk-prone territory.

The analysis presented for the improvement of risk maps, however, shows some limitations worth noting. First, it is necessary to consider the possibility that there may be points in the territory affected by a flood where no calls are made to emergency services (e.g., due to temporary absence of people in affected homes or the interruption of telephone lines). These areas would not be represented in this proposed cartographic analysis. Second, it is important to bear in mind that this analysis identifies the flood process of a specific event. Flood processes in the same territory can vary between events as a result of the spatial and temporal distribution of rainfall, the state of the channels, or specific contingencies that may occur during each episode (e.g., the rupture of a river channel wall). This variability obliges caution when extrapolating the results to other flood events that may occur in the future. Lastly, it is important to consider some technical difficulties related to the cartographic analysis of calls, such as the conversion of geographical coordinates to projected coordinates, which can cause precision errors in the geolocation of the affected points.

On the other hand, regarding the catalogue of flood warnings, the analysis of calls received by emergency services represents a valuable resource. This analysis allows us to identify an extensive array of emergency types that occur during a real flood event. This knowledge, based on case experience, ensures appropriate coverage of the topics that should be included in the warning catalogue to properly respond to the various needs that arise during the preparation, response, and recovery phases of an event. This classification, which reflects the importance of each theme and its temporal distribution throughout the event cycle, offers the possibility of designing strategies for sending selective warnings that can enhance the effectiveness of emergency communication. These strategic advantages represent an opportunity to develop warning systems with greater population reach and more effective communication. Recent changes in European legislation on emergency alert communication open a key opportunity for the development of this field of knowledge, within which the analysis of emergency calls presented in this work represents a key resource. Additionally, this analysis can be replicated for other types of natural and technological hazards, such as forest fires, earthquakes, or chemical disasters.

The analysis of 112 emergency calls also presents some limitations for the creation of warning catalogues that need to be considered. Firstly, it's important to note that the scope of identifying themes for warning catalogues directly depends on the magnitude of the emergencies and damage of the event under study. In this sense, it can be established that the greater the intensity of the event, the greater the number of emergencies occurring among the population, which ultimately translates into the identification of a larger number of themes that can be part of the content structure of the warning catalogue. The variability in the magnitude of different events and the social, demographic, and economic differences between territories represent a factor of uncertainty for the exhaustive identification of warning themes. Therefore, for this research, a disastrous event was chosen in which the volume of emergencies and, therefore, calls to the 112 service, ensured a thorough observation of the various situations that can occur during a major flood. However, it is advisable that the analysis of calls be complemented with other sources, such as the review of specialized literature or consultations with experts in the analysis and management of the risks examined in each case study. Also, it is worth noting the existence of structural barriers in emergency communication. These barriers depend not only on the quality of the warning systems but also on fundamental aspects such as the social perception of flood risk, the population's memory of the flood, or the trust in the institutions responsible for emergency management. Thus, emergency communication occurs along a continuum that includes the technical quality of warning systems and the risk culture of the population and institutions. Finally, concerning the limitations associated with analyzing emergency calls to create warning catalogues, it is important to consider the possibility that not all the population's needs and emergencies are reported to the 112 service. Moreover, emergency services do not always provide detailed reasons for the emergencies they handle over the phone and individuals may choose not to report some emergencies related to domestic matters, believing that their resolution depends on individual action rather than assistance from emergency services. Therefore, when analyzing emergency calls, it is necessary to take into account the possibility of hidden information or the need for more detailed explanations from the callers. For this reason, this research conducted a testing with the local community to supplement and contextualize the information included in the alert messages.

In conclusion, despite the limitations exposed thus far, this research has highlighted that the analysis of calls to emergency services represents a novel informational resource with great potential for application in different areas of risk analysis and management. Beyond providing contextualized information that will strengthen risk management in the study area, this work paves the way for two powerful tools for analysing 112 calls, using a bottom-up approach. The capacity of this resource to improve the reach and effectiveness of risk planning tools for various types of threats is of enormous importance considering the challenges arising from climate change and its specific effects on the increase of disaster risk on a global scale.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:Guadalupe Ortiz reports financial support was provided by Agencia Valenciana de Seguridad y Respuesta a las Emergencias (AVSRE). Generalitat Valenciana.

Data availability

The data that has been used is confidential.

Acknowledgements

The authors wish to express their gratitude to the Valencian Agency for Safety and Emergency Response (AVSRE) and the Emergency Coordination Centre of the Valencian Government (112), for providing the information and data used in the development of this research. In particular, we want to acknowledge the support of Jorge Suárez Torres (Deputy Director General of Emergencies of the Valencian Agency for Safety and Emergency Response) and José María Ángel Batalla (Director of the Valencian Agency for Safety and Emergency Response). Also, we would like to acknowledge the support of Josep Tur in the analysis of the database.

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