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Research article

Flood spatial location in a Mediterranean coastal city: Ibiza (Balearic Islands) from 2000 to 2021

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Abstract: Floods are a common occurrence in the Western Mediterranean basin, causing daily life disturbances, economic impacts and fatalities as the population living near the Mediterranean shores face a great risk. The city of Ibiza has been historically affected by floods of different magnitudes. After almost three decades without large events, with the 1977 flood being the latest, 20 floods have been identified within the city boundaries since the beginning of the 21st century, causing a great social impact. The aim of the research herein presented is to identify the locations of floods and their possible causes. The methodology is based on a comprehensive survey of newspapers articles and technical reports, thus allowing mapping of the location of the events over a city map. Among the causes, there are the lack of a runoff network and deficient infrastructure planning. Regarding the spatial distribution of floods, the most affected areas are the circumvallation freeways around the city and the neighborhoods urbanized after the 1960's. The results highlight the importance of the urban sprawl and malpractices related to flood risk areas, which increase the occurrence of floods. Moreover, the identification of the most affected areas can help city planners to create prevention measures and systems to reduce flood hazards and vulnerability.

Keywords: floods; spatial distribution; Mediterranean Sea; urbanization impact

1. Introduction

Floods are a common natural process in the Mediterranean coastal areas [1], with significant costs both in terms of damages [2,3] and in terms of fatalities [4,5]. Flooding is the result of a combination of causes. On the one side, natural ones, like the occurrence of extreme rainfall events, are usually of short duration but high hourly intensity, and their catchment characteristics include having a small size, short courses and high slopes [6,7]. On the other hand, anthropogenic factors, like the large population living around the Mediterranean Sea and the resulting high level of urbanization [8,9], increase the impact in terms of damages, fatalities and environmental risk.

Urban settlements are exposed to different types of flooding, with the fluvial one being the most common [1,3]. Nevertheless, pluvial floods are rapidly becoming important because of the increase of impervious surfaces due to urbanization, and by affecting the drainage network, canalizing streams or culverting large parts of the streams [1,10].

There is a large body of research about floods affecting urban spaces, especially since almost 56% of the world's population lives in cities [11]. From case studies to worldwide challenges, the research has focused on best practices to manage the flood risk [12,13], modeling urban floods [14,15] and the use of remote sensing to detect floods [16,17].

Despite all of the studies, the runoff processes still affect urban areas and can be caused by the overflow of the stream channels or the inadequate drainage systems in the cities [18]; their main effect is the disturbance of daily life, even if important economic damages and fatalities can also be a result of such events.

Urban floods are becoming a problem for coastal cities across the Mediterranean, but the flood affectation is not new. Former research has highlighted the impact of flood events in cities like Barcelona [19,20], Valencia [21,22], Genoa [23,24], Palermo [25] and Athens [26,27], or those affecting whole regions or basins like Catalonia [28] or the Ebro River [29]. Nowadays, special attention is given to new urbanized areas, usually with residential or tourism-related activities around the Mediterranean coast [30–34].

The Spanish Mediterranean coast is a clear example of the increase of new urban spaces, especially after the second half of the 20th century and the flood affectation of such areas [35,36].

The Balearic Islands location, within the Western Mediterranean basin, has resulted in an important development of the tourism industry since the 1960s. Such development did not take into account the flood risk that existed, with more than 200 events recorded since 1403 [37], which has thus increased the occurrence of floods affecting urban areas like the Balearic Islands capital, Palma [38]. Also heavily affected by flooding has been Ibiza, where the last large event happened in 1977, when almost all of the island streams overflowed and caused heavy damages and two fatalities. The main city, Ibiza, was briefly isolated because all roads were inundated and power lines and phone lines went down, resulting in service shortages. Even more, a mixture of rain and sewage waters flooded the city center and the harbor. From 2000 onward, 20 events have been identified as affecting the municipality of Ibiza, with floods occurring away from the traditional flooding zones and those close to the streams of the island catchments.

In that regard, the research herein presented has two objectives: (1) to identify and classify the floods affecting the city of Ibiza, and (2) to map the spatial location of the flood events.

The results can be a helpful tool for stakeholders and policymakers to develop protection plans for citizens and infrastructures.

2. Materials and methods

2.1. Research area

The island of Ibiza is located within the Balearic Islands, an archipelago off of the eastern coast of Spain (Figure 1). Comprised of five municipalities, the largest of the island in terms of population and importance, and its capital, is Ibiza, or *Vila* as it is known locally. Located on the southern coast, *Vila* has an area of 11.14 km^2 and 50,643 inhabitants [39]. The first details of human presence in the area date from the 7th century B.C., in Phoenician times, and the city shape has been transformed by successive historical epochs. *Vila* is the oldest urban settlement in the Balearic Islands that is still inhabited and located in the same area where it was built.

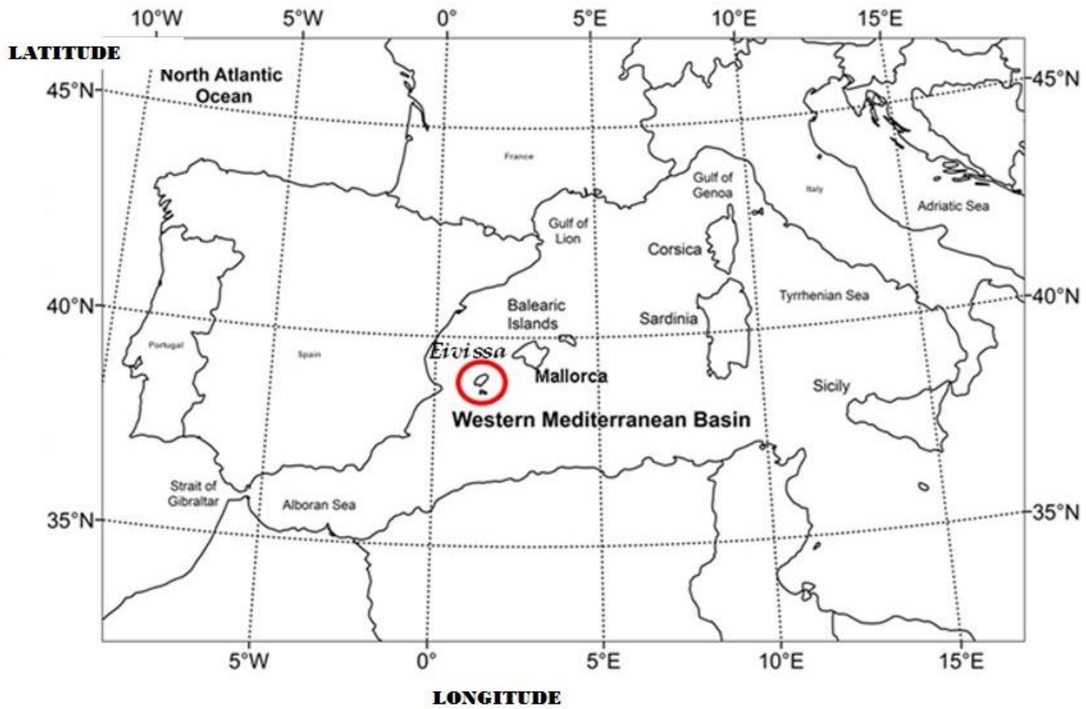

Figure 1. Location of Ibiza within the Balearic Islands and the Western Mediterranean basin.

The old city is located on a coastal hill (known as *Dalt Vila*), linked to the mainland by a tombolo, where marshlands were located (*es Pratet, es Prat de Vila* and *ses Feixes*). Those marshes were dried up for agricultural purposes and became orchards; but, they were abandoned during the urban expansion of the 20th century, when the city grew away from the hill and the enlargements were built, occupying the ancient orchards, mainly in *es Pratet* and also a large part of the *Prat de Vila* (Figure 2).

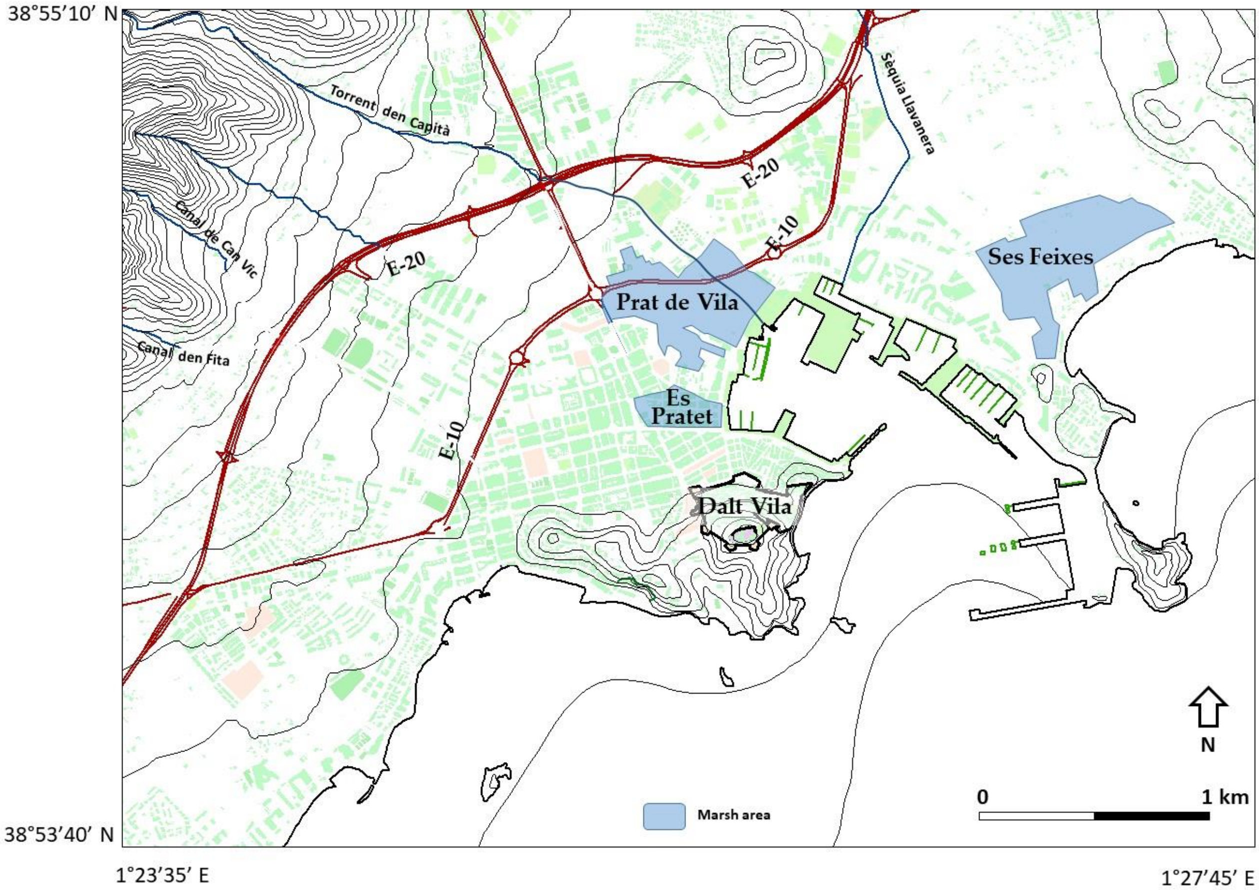

Figure 2. Location of the research area: old city (*Dalt Vila*), the marshlands *(Es Pratet, Prat de Vila* and *Ses Feixes*) and the streams ending within *Vila* boundaries. Altimetry and bathymetry equidistance: 10 meters.

The main result was an accelerated urban growth, which was larger in the second half of the 20th century when the tourism industry arrived to the island. It led to an increase of urbanized surfaces, from 4.15 km^2 in 1956 to more than 10 km^2 currently. Such expansion has generated inequalities in terms of infrastructure and urban equipment among the city neighborhoods. The lack of control, together with a large period without flooding events across the city, allowed for the construction of new residential and services areas inside flood-prone spaces, and even inside stream beds. The result has been the creation of large impervious surfaces replacing natural soil [9], which has, in turn, caused the growth of runoff coefficients and possible flood peaks, a common occurrence in urbanized environments [39,40].

Furthermore, urban planning has affected the fluvial system of the basin, which is organized by ephemeral streams, locally known as torrents (Table 1). *Vila*'s basin has an area of 55 km^2 and three catchments that end at the municipality coast, running through alluvial fans (Figure 2).

The drainage network is ephemeral due to the geological characteristics of the area (limestone and karstic features), the scarce rainfall recorded annually and the reduced surface of the catchments. Therefore, the regime is irregular, with beds that are usually dry and presenting runoff either after large rainfall events or when a spring breaks as the result of continuous rain days.

Table 1. Characteristics of the area's water network.

Stream name	Catchment surface (km^2)	Main channel length (km)	Main channel slope (%)
Sèquia Llavanera	56,5	15,24	2,24
Torrent den Capità	4,82	5,75	4,8
Canal de can Vic	0,4	1,30	12,0
Canal den Fita	0,71	1,42	5,6

The region's climate is Mediterranean, with dry summers and mild winters. The mean annual rainfall is 475 mm, which falls mostly in autumn (October and November), while the minimum rain is recorded in May and July. The mean annual temperature is 18 ºC, with a summer maximum reaching as high as 35 ºC [41,42].

The main streams are the *Torrent den Capità* and *Sèquia Llavanera*, both ending in *Vila*'s marshland, known as *Ses Feixes*. *Sèquia Llavanera* is the largest catchment of the basin—in terms of surface and channel length—and it has been extremely modified by humans who performed cross-sectional shortening, bed sealing and channel covering with roads, buildings and infrastructure. The final stretch is channelized through roads and buildings and ends at the bay in a marina, crossing underneath the seaside promenade and disappearing under concrete (Figure 3).

On the other hand, *Torrent den Capità* flows through the central area of the plain, but its bed has disappeared as the point that it reaches the city outskirts. The construction of the E10 circumvallation road first, and then the E20 in 2007, resulted in the cut of the stream, making it disappear under the industrial polygonal roads and buildings through a small concrete channel, as well as end in *ses Feixes*, where the water flow can run freely toward the sea. As stated before for the *Sèquia Llavanera*, the mouth of *Torrent den Capità* runs underneath the promenade into a marina. Both streams were modified when the marshlands became orchards and were converted in ditches to irrigate the crops. Once the tourism arrived in the 1960s, such drainage systems were abandoned, and some of those marshlands have since returned to their original state. There is also a small number of minor streams along the central area, with a total surface area of 1.2 km^2 and ending in the *Eixample* neighborhood, close to the city's main hospital.

On the western side of the basin, three creeks can be identified from the north to south: canal *de'n Vic*, canal *de'n Fita* and canal *des Xoriguer*. The first two end on an ahreic zone located across the tombolo that links *Dalt Vila* with the mainland. The last one runs from the western hills through farmland, and it is nowadays devoted to urban uses, especially close to the coast, where one of the main tourism neighborhoods, *Platja d'en Bossa*, is located; but, its channel disappears before reaching the coastline under streets and buildings.

The channel endings, within heavily urbanized areas, increase the hazard level for flooding. The main risk, according to the Balearic Islands Flood Prevention Plan [44], is the *Sèquia Llavanera* catchment, which can affect up to 8,000 people if a flood occurs.

Figure 3. *Sa Llavanera* mouth at the harbor: (a) upstream view and (b) downstream view.

2.2. Data and methods

The data were collected from different sources of information (Table 2). Daily rainfall amounts were taken from the official Spanish Meteorological Agency (AEMET) gauges, which only record 24-hour totals. There are not currently any official gauges that record data at a minor scale of time.

The daily press of Ibiza (*Diario de Ibiza* and *Última Hora*) helped to identify the affected areas and the damage to public and private properties. Once available, official reports from city authorities or public services (firefighters, local police) allowed for the identification of affected areas and the kinds of damage sustained. All the documentary data collection was manually carried out because some of the documents are not digitized and computerized search engines could not be used. Moreover, the newspapers used were the printed version, available at the Eivissa Public Library.

Finally, post-flood surveys were used to gather *in situ* information, usually days after the event. Such research allows for the measurement of water levels and gathering of material such as pictures or videos that were taken by witnesses of the event.

Regarding the methodology used, a database of events was developed by using a spreadsheet. The information included the date of the flood, the rainfall amount if known, the affected areas and the damages, which were recorded from various sources, as previously stated.

The collected data were introduced to the database and, once verified, the affected areas were located on a city map while research was done to identify the flood causes. Following a former research methodology [45], four categories have been identified:

a) Drained wetlands;
b) Overflowing natural streams;
c) Flat urban areas without a natural drainage network;
d) Poorly planned infrastructures;

Category a refers to those drained areas that were close to the coast, formerly used as farmland and nowadays serving as a physical foundation. Category b refers to when a flood takes place from the spill-off from a stream. Category c is related to the lack of runoff due to impervious surfaces and failures of the sewage system. Finally, Category d is the result of the creation of infrastructure, without taking into account the surface runoff network, and which thus increases the impervious land cover and reduces the network capacity to transport water. Flood categories take into account the physical trends of the city, as related to its location within the island, and human-made changes in the area. They are also related to similar categories that have already been used in research about Palma, another Mediterranean location within the Balearic Islands [45].

To assess the importance of flood-related damage, a qualitative classification of impacts was developed from an existing methodology that has been used in research on damage affectation in Spanish regions [46–48] and western Mediterranean countries [49]. Floods are classified as follows:

Ordinary: when water affects roads and streets but circulation can carry on. There is a small affectation to basements and ground floors of private and public buildings.

Extraordinary: when floodwaters cause the full closure of roads and streets, damage cars and goods and provoke power outages. The flooded buildings require the work of firefighters and civil protection services to drain the accumulated water.

To map the flood locations, a neighborhood list from the *Enciclopèdia d'Eivissa i Formentera* was used [50], following the suggestions of Maurici Cuesta regarding historically flood-affected areas. The neighborhoods were located on a map modified according to the above-mentioned suggestions (Figure 4).

Table 2. Sources of data used for the research.

Type	Source	Data description
Rainfall	AEMET	Rainfall amount mm/24 hours
Event location	Newspapers, official reports	Affected streets and neighborhoods
Event location	Field survey	Affected streets and neighborhoods
Public damages	Newspapers, official reports and field survey	Damage to streets, bridges, city parks and other public property
Private damages	Newspapers, official reports and field survey	Damage to buildings, shops and vehicles
Interviews	Field survey	Pictures, videos, event description (time, impact)

Figure 4. Neighborhoods cited within the text and affected by floods.

3. Results and discussion

From 2000 onward, 20 events have affected the municipality of *Vila* (Table 3).

An average of 63.6 mm/24 hours is enough to flood parts of the city. Such amounts are common in the Mediterranean basin [51–54], where quantities between 30 and 80 mm can produce significant floods in urbanized areas.

Regarding the spatial locations of the events (Figure 5), two areas show the largest impact over the city area, *es Pratet*, and the E-20 freeway, as both were affected by almost 80% of the cases.

Even so, there is a widespread distribution of the impact points, almost all of which occurred at the adjacent urban development along the old city, which was mostly built during the 20th century (Figure 5). The old city neighborhoods were only affected twice during the events, while the outskirts of *Vila*, i.e., between the E-10 and E-20 freeways, have not registered impacts significant enough to be cited by the daily press or official reports.

The touristic areas, located at the western and eastern areas of *Vila* and united by the *Passeig Marítim* (the front sea promenade), have been affected eight times by flood events that were similarly distributed into ordinary and extraordinary in terms of damages.

City swamps, *ses Feixes* and *prat de Vila*, did not have a single recorded flood event during the research period. Nevertheless, close urbanized areas such as *Passeig Marítim* or *Talamanca* have been affected by floods, which can be due to water flows being unable to reach the sea via the pathway cut by buildings, roads and infrastructure because of the draining process undertaken in the 20th century.

Two more critical points are the poorly planned infrastructural developments located along the road network that surrounds the city, i.e., freeways E-10 and E-20, where a large number of underpasses and crossings are flooded after rainfall events. The main causes are the lack of rainwater collectors and the burial under the concrete of the natural runoff channels.

Table 3. List of floods.

Id	Date	Rainfall amount (mm/24h)	Affected areas	Type of flood
1	15–11–2005	87.4	Es Pratet, Platja de'n Bossa	b, c
2	09–08–2007	48.7	E-20 freeway	d
3	13–10–2010	95	Es Pratet, E-10 and E-20 freeways	c, d
4	14–11–2012	112	Es Pratet, E-20 freeway	c, d
5	28–04–2013	65.8	Es Pratet, Eixample, E-10 and E-20 freeways	c, d
6	25–09–2014	94	Es Pratet, E-10 and E-20 freeways	c, d
7	18–08–2015	37.4	Dalt Vila, Es Pratet, Figueretes, E-10 and E-20 freeways	a, c, d
8	02–09–2015	32.8	Es Pratet, Botafoc, E-20 freeway	a, c, d
9	20–10–2015	30.3	Es Pratet, E-20 freeway	c, d
10	24–09–2016	29.7	Es Pratet	c
11	19–12–2016	159	Es Pratet, Talamanca, E-20 freeway	a, c, d
12	10–08–2017	69	Botafoc, E-10 and E-20 freeways	a, c, d
13	06–09–2017	33.9	E-20 freeway	d
14	17–08–2018	44.6	E-10 and E-20 freeways	d
15	18–11–2018	70	Es Pratet, La Marina, E-10 and E-20 freeways	a, c, d
16	27–08–2019	33.8	Es Pratet, Eixample, Figueretes, E-10 and E-20 freeways	c, d
17	12–09–2019	50.8	Es Pratet, Eixample and E-10 freeway	c, d
18	22–10–2019	51.8	Es Pratet, E-10 freeway	c, d
19	07–09–2020	61.8	Platja de'n Bossa and E-20 freeway	c, d
20	23–10–2021	94	Es Pratet, Eixample, Passeig Marítim and E-20 freeway	c, d

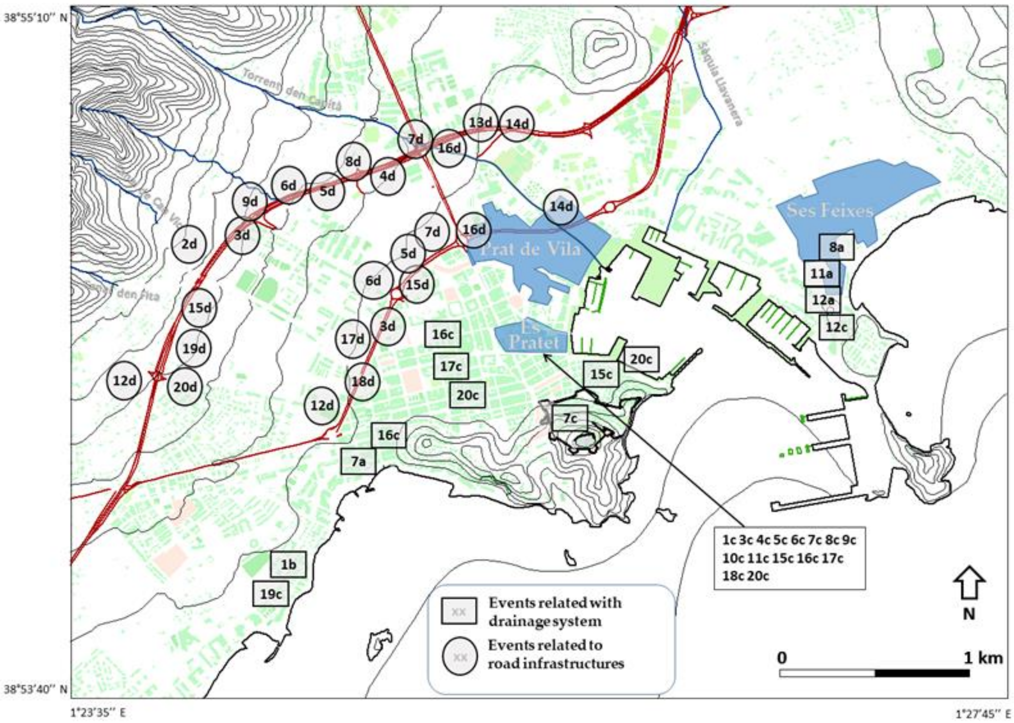

Figure 5. Location of events according to flood categories.

Taking into account the four flood categories defined in Section 2.2, the highest occurrence pertains to Category d, i.e., poorly built infrastructure (flooded on 18 of 20 events), followed by Category c, i.e., flat surfaces without natural drainage, which were affected 16 times out of 20. It must be highlighted that, since the start of the 21st century, there has been only one event linked to the overflow of a stream, i.e., the 2005 flood of *Platja d'en Bossa*.

Thus, the flooding problem of the city can be related to the urban development that originated at the start of the 20th century with the creation of the *Eixample* neighborhood and its progressive expansion toward the north first, and then westward and eastward following the coastal line. Such development modified the land use from agricultural to urban, narrowed and covered the ephemeral watercourses, thus eliminating water flows within the beds, and urbanized the swamps for tourism purposes. Furthermore, the construction of circumvallation roads around the city to connect *Vila* with the other municipalities and the airport resulted in the disruption and covering of the natural water pathways, which leads to the flooding of road sections. The case of *Vila* shows the same causes as other flood-prone cities across Spain [35,36,38,55] that have been affected by large uncontrolled urbanization processes and are usually related to the tourism industry, which has led to the increase of impervious surfaces and the occupation of historically flood-prone areas.

Moreover, another aspect of the flooding impact within the city is related to the sewage system incapacity to cope with intense rainfall events. The historical lack of maintenance, coupled with the increase of human pressure in the area, has caused the rainwater to mix with the sewage water and drains such that the accumulation of water on the surface is unavoidable, thus flooding roads, sidewalks, ground floors and basements.

In relation to the damages caused by the episodes, nine of them are classified as extraordinary because they caused large disturbances of traffic, with the closure of streets and the main roads, power failures of undetermined duration and affected buildings that were flooded until public services could drain the water. Eleven events are defined as ordinary, with damages ranging from boardwalks that were briefly impassable, large puddles on streets and roads that hindered traffic and minor damages to residential and business ground floors that could be cleared by the citizens themselves. Figure 6 shows how the temporal distribution of events highlights the increase of extraordinary events, with five happening in the six final years of the research period.

In terms of the locations of the damage, there is a widespread distribution throughout the municipality, although the areas of the *Es Pratet* neighborhood and the E20 road have been more affected. The latest extraordinary events, i.e., those on August 28th 2019 and October 23rd 2021, were the ones with the largest spatial affectation.

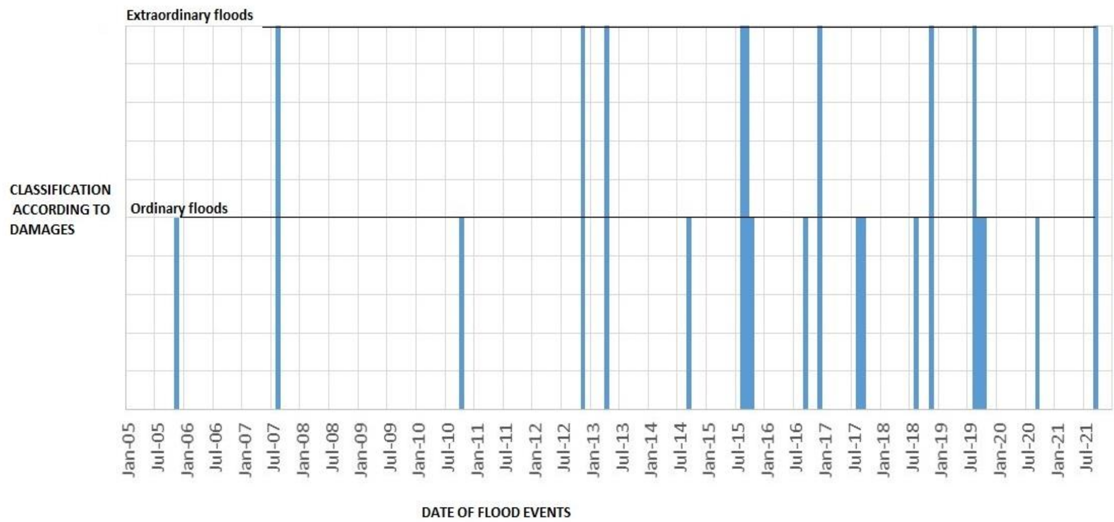

Figure 6. Temporal distribution of flood events according to their category.

4. Conclusions

This study analyzed the spatial distribution of floods affecting the city of *Vila* in the 21st century and the probable causes of such a distribution.

Four different categories of floods have been identified; but, two of them, i.e., flat urban areas and poorly planned infrastructure, cause the main impacts and disturbances to daily life. Such floods can be included within the pluvial floods classification, which are currently affecting a large number of cities in the Mediterranean area [18].

Regarding the sources of information, the daily press proves to be a valuable source when combined with official reports and field research. It must be taken into account that the press could not reference minor impacts in some locations, so not all damage locations are known for some events. However, information about the affected neighborhoods, types of damage to public and private property, water levels above the surface and times of closure of roads and streets can provide useful knowledge about the spatial distribution and affectation of the flood events. Official data (i.e., police and firefighters reports, city council damages evaluation) complement the press information, but they are difficult to obtain and it takes more time because those reports become public months after an event.

On the other hand, photos and videos, as well as oral information from witnesses of the flood, are helpful tools to study and classify urban floods, but this data should be handled with care to avoid misleading information due to the possible personal affectation of the witness.

The spatial distribution is influenced by the expansion of urban land, mainly those areas built from the 1960s and first years of the 21st century. Such expansion resulted in an increase of impermeable land cover and has led to a failure of the sewage system, which has made it unable to absorb the amounts of rain, thus causing localized flooding.

Therefore, floods are the result of a combination of natural and human-related causes. On the one hand, the city was built over marshes and flooding in *es Pratet* is due to the lack of a drainage network, which was destroyed by men. On the other hand, the road infrastructure builders did not take into account the surface water network that ran across an alluvial fan toward the sea.

In terms of future research, an important point to observe is the seasonal distribution of the events, as the season of occurrence seems to be shifting. Floods of the past, defined as riverines, usually happened during autumn, while, nowadays, even if autumn is the dominant season of flooding, there is an increasing presence of events during the summer months, especially in August. Another aspect of research is the spatial distribution of rainfall, which clearly influences the flood location. In that sense, the few available gauges can hamper such research, as well as the fact that only 24-hour values are recorded even though the research states that short-duration rainfall influences flooding more than large time-step events [56]. Improving the availability of hourly data could help the study of the influence of precipitation intensity on the origin of floods. Finally, it is considered that valuable data can be obtained from other sources, such as social media platforms including Facebook, Twitter and YouTube [57], and the insurance claims by affected people, which allow us to know the economic damage caused by the events [58,59]; such venues should be explored in future investigations.

To conclude, flooding in *Vila* has become a recurring natural risk since the start of the 21st century. Large cases, such as the one that happened in 1977, are nowadays unusual; the current events can be defined as low-level–high-damage cases resulting in the disruption of daily life (traffic and transportation system congestion; flooded houses, business and streets; electric system failures) and large economic impacts, which can increase when during the tourism season. An unanswered question is what could happen if a flood like the one of 1977 occurs today given the increased human pressure, especially during the tourism season, and all of the anthropic modifications built across the entire city basin.

Finally, this paper points out the flood-prone areas in the urban landscape of *Vila*, with the hope of increasing the level of awareness of public administration and stakeholders as related to the effects of a poor urban policy. Furthermore, it can improve measures to avoid future flood impacts through better spatial planning.

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Conflict of interest

The authors declare no conflict of interest.

References

1. Faccini F, Luino F, Paliaga G, et al. (2021) Flash flood events along the West Mediterranean coasts: Inundations of urbanized areas conditioned by anthropic impacts. *Land* 10: 620. https://doi.org/10.3390/land10060620
2. Gaume E, Bain V, Bernardara P, et al. (2009) A compilation of data on European flash floods. *J Hydrol* 367: 70–78. https://doi.org/10.1016/j.jhydrol.2008.12.028
3. Gaume E, Borga M, Llasat MC, et al. (2017) Mediterranean extreme floods and flash floods. *The Mediterranean region under Climate Change. A scientific update*, Paris, 133–144.
4. Petrucci O, Papagiannaki K, Aceto L, et al. (2019) MEFF: the database of Mediterranean Floods Fatalities (1980 to 2015). *J Flood Risk Manag* 12: e12461. https://doi.org/10.1111/jfr3.12461
5. Papagiannaki K, Petrucci O, Diakakis M, et al. (2022) Developing a large-scale dataset of flood fatalities for territories in the Euro-Mediterranean region, FFEM-DB. *Sci Data* 9: 166. https://doi.org/10.1038/s41597-022-01273-x
6. Llasat MC, Llasat-Botija M, Prat MA, et al. (2010) High-impact floods and flash floods in Mediterranean countries: the FLASH preliminary database. *Adv Geosci* 23: 47–55. https://doi.org/10.5194/adgeo-23-47-2010
7. Faccini F, Luino F, Paliaga G, et al. (2018) Role of rainfall intensity and urban sprawl in the 2014 flash flood in Genoa city, Bisagno catchment (Liguria, Italy). *Appl Geogr* 98: 224–241. https://doi.org/10.1016/j.apgeog.2018.07.022
8. Brauch HG (2003) Urbanization and natural disasters in the Mediterranean. Population growth and climate change in the 21st century, *Building safer cities: the future of disaster risk*, Kreimer A, ed., The World Bank: New York, 149–164.
9. Konrad CP (2016) Effects of urban development on Floods. *US Geological Survey Fact Sheet 076-03*.
10. Houston D, Werrity A, Bassett D, et al. (2011) Pluvial (rain-related) flooding in urban areas: the invisible hazard. Joseph Rowntree Foundation; University of Dundee, Scotland. Available from: https://www.jrf.org.uk/report/pluvial-rain-related-flooding-urban-areas-invisible-hazard.
11. UN-Habitat, World Cities Report, 2022. Available from: https://unhabitat.org/sites/default/files/2022/06/wcr_2022.pdf.
12. Hampshire A, Sipes JL (2019) From disaster to sustainability: breaking the cycle of floods in Houston. *AIMS Geosci* 5: 899–920. https://doi.org/10.20944/preprints201904.0275.v2
13. Barbaro G, Gomes Miguez M, Martins de Sousa M, et al. (2021) Innovations in Best Practices: Approaches to managing urban areas and reducing flood risk in Reggio Calabria (Italy). *Sustainability* 13: 3463. https://doi.org/10.3390/su13063463
14. Wu X, Wang Z, Guo S, et al. (2018) A simplified approach for flood modelling in urban environments. *Hydrol Res* 49: 1804–1816. https://doi.org/10.2166/nh.2018.149
15. Padulano R, Costabile P, Costanzo C, et al. (2021) Using the present to estimate the future: A simplified approach for the quantification of climate change effects on urban flooding by scenario analysis. *Hydrol Processes* 35: e14436. https://doi.org/10.1002/hyp.14436
16. Bohorquez P, Del Moral-Erencia JD (2017) 100 years of competition between reduction in channel capacity and streamflow during floods in the Guadalquivir river (southern Spain). *Remote Sens* 9: 727. https://doi.org/10.3390/rs9070727
17. Dang ATN, Kumar L (2017) Application of remote sensing and GIS-based hydrological modelling for flood risk analysis: a case study of district 8, Ho Chi Minh city, Vietnam. *Geomat Nat Haz Risk* 8: 1792–1811. https://doi.org/10.1080/19475705.2017.1388853

18. Pumo D, Arnone E, Francipane A, et al. (2017) Potential implications of climate change and urbanization on watershed hydrology. *J Hydrol* 554: 80–90. https://doi.org/10.1016/j.jhydrol.2017.09.002
19. Cortès M, Llasat MC, Gilabert J, et al. (2018) Towards a better understanding of the evolution of flood risk in Mediterranean urban areas: the case of Barcelona. *Nat Hazards* 93: 39–60. https://doi.org/10.1007/s11069-017-3014-0
20. Martin-Vide JP, Llasat MC (2018) The 1962 flash flood in the Rubí stream (Barcelona, Spain). *J Hydrol* 566: 441–454. https://doi.org/10.1016/j.jhydrol.2018.09.028
21. Carmona P, Ruíz JM (2000) Las inundaciones de los ríos Júcar y Turia. *Serie Geográfica* 9: 49–69.
22. Nuñez Mora JA (2018) Crónica de las catastróficas riadas del Turia en Valencia (I). *Tiempo y Clima*, 5. Available from: pub.ame-web.org/index.php/TyC/article/view/1476/1510
23. Acquaotta F, Faccini F, Fratianni S, et al. (2019) Increased flash flooding in Genoa Metropolitan Area: a combination of climate changes and soil comsumption? *Meteorol Atmos Phys* 131: 1099–1110. https://doi.org/10.1007/s00703-018-0623-4
24. Faccini F, Luino F, Sacchini A, et al. (2015) Geohydrological hazards and urban development in the Mediterranean area: an example from Genoa (Liguria, Italy). *Nat Hazards Earth Syst Sci* 15: 2631–2652. https://doi.org/10.5194/nhess-15-2631-2015
25. Francipane A, Pumo D, Sinagra M, et al. (2021) A paradigm of extreme rainfall pluvial floods in complex urban áreas: the flood event of 15 July 2020 in Palermo (Italy). *Nat Hazards Earth Syst Sci* 21: 2563–2580. https://doi.org/10.5194/nhess-21-2563-2021
26. Diakakis M, Deligiannakis G, Katsetsiadou K, et al. (2017) Mapping and classification of direct flood impacts in the complex conditions of an urban environment. The case study of the 2014 flood event in Athens, Greece. *Urban Water J* 14: 1065–1074. https://doi.org/10.1080/1573062X.2017.1363247
27. Papagiannaki K, Kotroni V, Lagouvardos K, et al, (2017) Urban area response to flash-flood triggering rainfall, featuring human behavioral factors: the case of 22 October 2015 in Attica, Greece. *Weather Clim Soc* 9: 621–638. https://doi.org/10.1175/WCAS-D-16-0068.1
28. Llasat MC, Barriendos M, Rodríguez R, et al. (1999) Evolución de las inundaciones en Cataluña en los últimos 500 años. *Ing Agua* 6: 257–266.
29. Balasch JC, Pino D, Ruíz-Bellet JL, et al. (2019) The extreme floods of the Ebro river basin since 1600 CE. *Sci Total Environ* 646: 645–660. https://doi.org/10.1016/j.scitotenv.2018.07.325
30. Caloiero T, Petrucci O (2014) The impact of hydrogeological events in urbanized sectors: the case of 19th November 2013 in Catanzaro (Italy). *Proc 3rd IAHR Europe Congr*. Available from: https://www.iahr.org/library/infor?pid=10751.
31. Esposito G, Matano F, Scepi G (2018) Analysis of increasing Flash Flood frequency in the densely urbanized coastline of the Campi Flegrei Volcanic Area, Italy. *Front Earth Sci* 6: 63. https://doi.org/10.3389/feart.2018.00063
32. Gil-Guirado S, Pérez-Morales A, Barriendos M (2014) Increasing vulnerability to flooding in the southern Spanish Mediterranean coast (1960–2013). *Hydrol Extreme Events Hist Prehistoric Times*, 9.
33. Olcina-Cantos J, Hernández M, Rico A, et al. (2010) Increased risk of flooding on the coast of Alicante (Region of Valencia, Spain). *Nat Hazards Earth Syst Sci* 10: 2229–2234. https://doi.org/10.5194/nhess-10-2229-2010
34. Vinet F (2008) Geographical analysis of damage due to flash floods in southern France: the cases of 12–13 November 1999 and 8–9 September 2002. *Appl Geogr* 28: 323–336. https://doi.org/10.1016/j.apgeog.2008.02.007

35. Pérez-Morales A, Gil-Guirado S, Olcina Cantos J (2015) Housing bubbles and increase of the exposure to floods. Failures in the floods management in the Spanish coast. *J Flood Risk Manag* 11: 302–313.
36. López Martínez F, Pérez Morales A (2017) Influencia del turismo residencial sobre el riesgo de inundación en el litoral de la región de Múrcia. Scripta Nova XX: 577. https://doi.org/10.1344/sn2017.21.18166
37. Grimalt M, Rosselló J (2020) InunIB: Analysis of a flood database for the Balearic Islands. *Eur J Geogr* 11: 6–21.
38. Rosselló-Geli J, Grimalt-Gelabert M (2021) Mapping of the Flood Distribution in an Urban Environment: The Case of Palma (Mallorca, Spain) in the First Two Decades of the 21st Century. *Earth* 2: 960–971. https://doi.org/10.3390/earth2040056
39. IBESTAT. Padró Municipal d'Eivissa. Available from: ibestat.caib.es.
40. Feng B, Zhang Y, Bourke R (2021) Urbanization impacts on flood risks based on urban growth data and coupled flood models. *Nat Hazards* 106: 613–627. https://doi.org/10.1007/s11069-020-04480-0
41. Pasquier V, Vahmani P, Jones AD (2022) Quantifying the city-scale impacts of impervious surfaces on groundwater recharge potential: an urban application of WRF-Hydro. *Water* 14: 3143. https://doi.org/10.3390/w14193143
42. Guijarro JA (1984) The climate of Eivissa and Formentera. *Biogeography and Ecology of the Pityusic Islands*, Monographic Biologicae, 119–135. https://doi.org/10.1007/978-94-009-6539-3_5
43. Jansà A (2014) *El clima de les Illes Balears*, Muntaner L, Editor, Palma de Mallorca.
44. CAIB, Pla de Gestió del Risc d'Inundació de les Illes Balears. Direcció General de Recursos Hídrics, 2016. Available from: https://www.caib.es/sites/aigua/ca/pla_de_gestio_del_risc_dinundacio_de_la_demarcacio_hidrografica_de_les_illes_balears/
45. Grimalt M, Rosselló J (2018) Inundaciones en la ciudad de Palma de Mallorca: distribución de los episodios y tipos de tiempo asociados, *El Clima: Aire, Agua, Tierra y Fuego*, Montavez JP, ed., Asociación Española de Climatología: Cartagena, Spain, 245–258.
46. Barnolas M, Llasat MC (2007) Metodología para el estudio de inundaciones históricas en España e implementación de un SIG en las cuencas del Ter, Segre y Llobregat. *CEH-CEDEX, Monografias M-90, Ministerio de Fomento*. Madrid.
47. Llasat MC, Marcos R, Llasat-Botija M, et al. (2014) Flash-flood evolution in north-western Mediterranean. *Atmos Res* 149: 230–243. https://doi.org/10.1016/j.atmosres.2014.05.024
48. Rosselló-Geli J, Cortès M (2021) La prensa local, fuente para el estudio de las inundaciones: el semanario Sóller (Mallorca) de 1900 a 2000. *Ería, Revista de Geografía* 41: 207–222.
49. Llasat MC, Llasat-Botija M, Petrucci O, et al. (2013) Towards a database on societal impact of Mediterranean floods within the framework of the HyMeX project. *Nat Hazards Earth Syst Sci* 13: 1337–1350. https://doi.org/10.5194/nhess-13-1337-2013
50. Cuesta Labèrnia M, Eivissa, Ciutat d'-estructura urbana. *Enciclopèdia d'Eivissa i Formentera*. Available from: http://www.eeif.es/veus/Eivissa-ciutat-d'-Estructura-urbana/#.
51. Papagiannaki K, Lagouvardos K, Kotroni V, et al. (2015) Flash flood occurrence and relation to the rainfall hazard in a highly urbanized area. *Nat Hazards Earth Syst Sci* 15: 1859–1871. https://doi.org/10.5194/nhess-15-1859-2015
52. Candela A, Aronica GT (2016) Rainfall thresholds derivation for warning pluvial flooding risk in urbanized areas. *E3S Web Conf* 7: 18016. https://doi.org/10.1051/e3sconf/20160718016

53. Tian X, Ten Veldhuis MC, Schleiss M, et al. (2019) Critical rainfall thresholds for urban pluvial flooding inferred from citizen observations. *Sci Total Environ* 689: 258–268. https://doi.org/10.1016/j.scitotenv.2019.06.355
54. Thieken AH, Mohor GS, Kreibich H, et al. (2022) Compound flood events: different pathways-different impacts-different coping options? *Nat Hazards Earth Syst Sci Discuss* 22: 165–185.
55. Arranz Lozano M (2008) El riesgo de inundaciones y la vulnerabilidad en áreas urbanas. Análisis de casos en España. *Estudios Geográficos* 69: 385–416.
56. Diakakis M (2012) Rainfall thresholds for flood triggering. The case of Marathonas in Greece. *Nat Hazards* 60: 789–800. https://doi.org/10.1007/s11069-011-9904-7
57. Brouwer T, Filander D, Van Loenen A, et al. (2017) Probabilistic flood extent estimates from social media flood observations. *Nat Hazards Earth Syst Sci* 17: 735–747. https://doi.org/10.5194/nhess-17-735-2017
58. Cortés M, Turco M, Llasat-Botija M, et al. (2018) The relationship between precipitation and insurance data for floods in a Mediterranean region (northeast Spain). *Nat Hazards Earth Syst Sci* 18: 857–868. https://doi.org/10.5194/nhess-18-857-2018
59. Gil-Guirado S, Pérez-Morales A, Lopez-Martinez F (2019) SMC-Flood database: a high-resolution press database on flood cases for the Spanish Mediterranean coast (1960–2015). *Nat Hazards Earth Syst Sci* 19: 1955–1971. https://doi.org/10.5194/nhess-19-1955-2019