Application of precision technologies in geomorphology: analysis of the flash flood occurred in Sant Llorenç des Cardassar, Mallorca, October 2018

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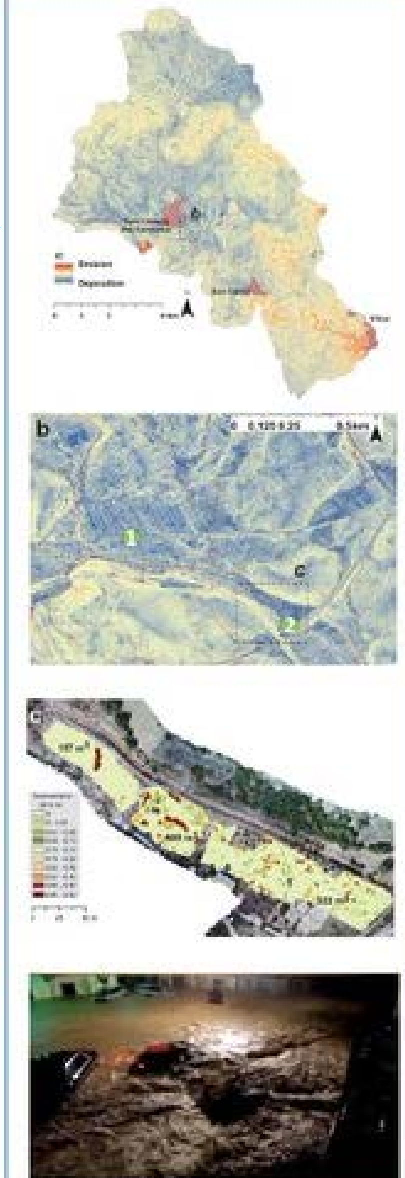

EGU General Assembly 2020

Vienna | Austria | 3–8 May 2020

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Introduction

- Flash floods. High-intensity precipitation, mainly of convective origin and with a restricted spatio-temporal occurrence.

- Mediterranean is a flash-flood prone environment due to the interaction between geomorphology, climate and vegetation:

  - The abrupt reliefs surrounding the Mediterranean Sea are very closeness to the coastline:

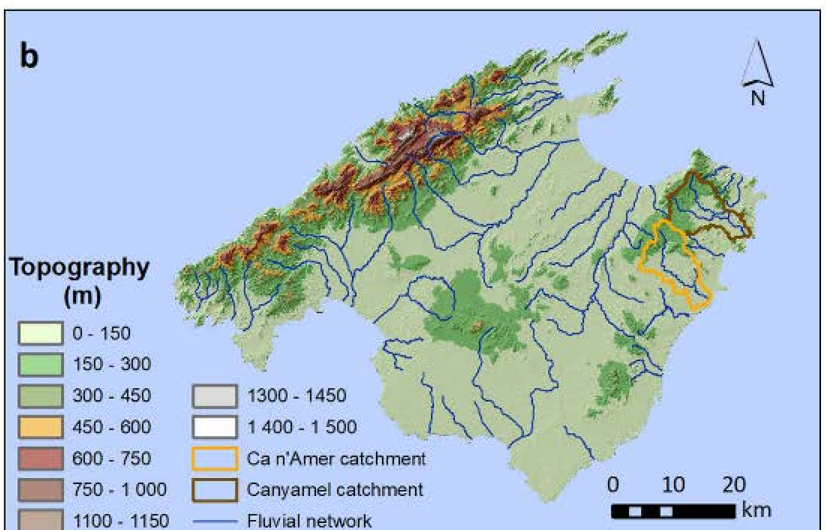
    ✓ Small and torrential catchments.
    ✓ Convergence of low-level atmospheric flows and the uplift of warm wet air masses drifting from the Mediterranean Sea to the coasts generate heavy downpours in very short periods.

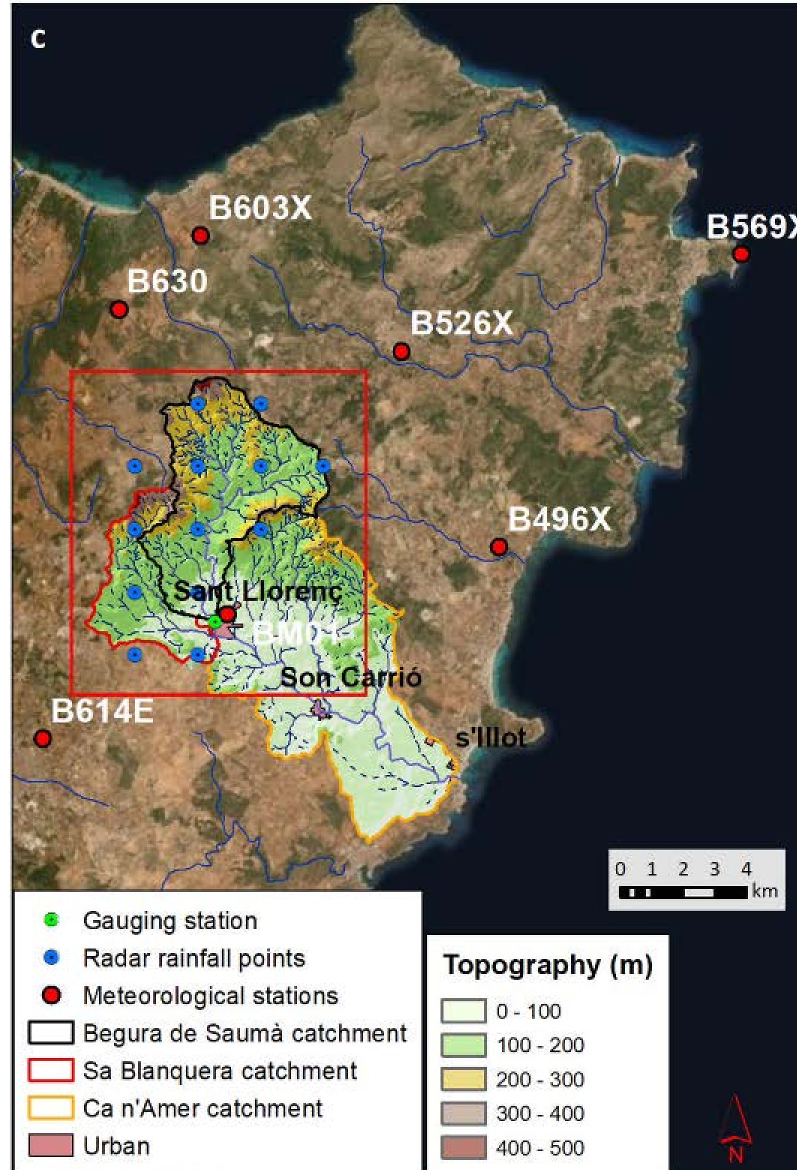
- The small spatial and temporal scales of flash-floods make these events particularly difficult to monitor and document.

    ✓ Q data are crucial to obtain representative hydrometric values and to characterize the runoff response of such extreme flash-flood events.

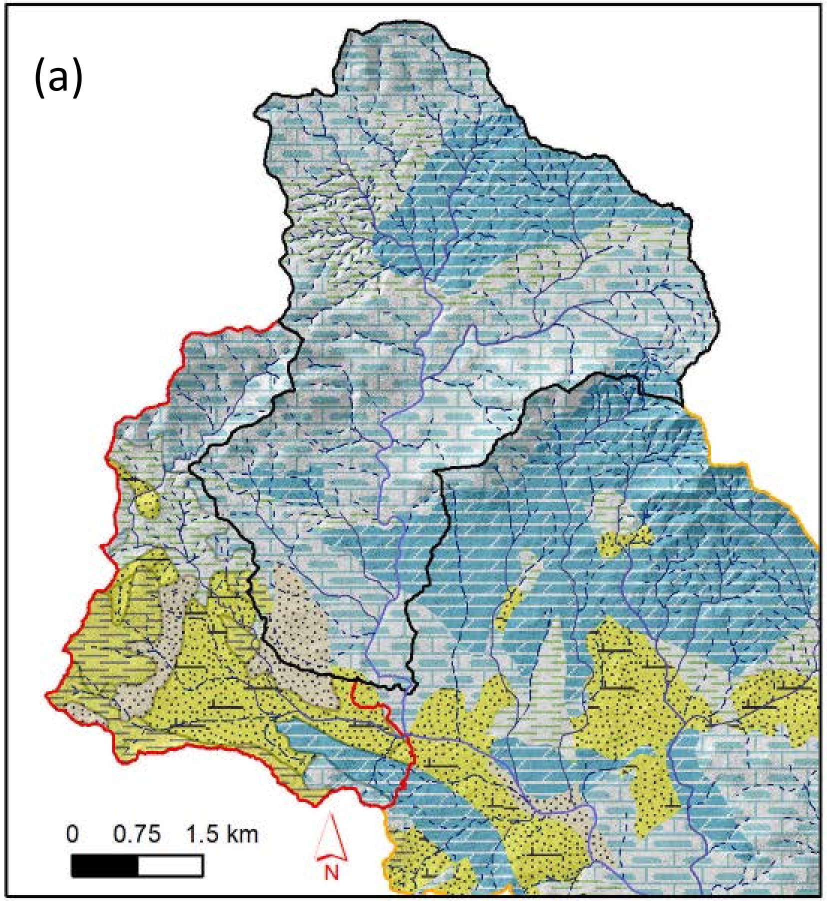
✓ A comprehensive understanding of the Sant Llorenç des Cardassar flash flood event occurred in the 9th October 2018 by means of an integrated approach with a meteorological, hydrological, geomorphological, damage and risk data analysis. It was a catastrophe that caused 13 casualties, huge economic damages and an unprecedented human resources mobilization in the Balearic Islands Region.

Study area Mallorca Island, Ca n'Amer River catchment

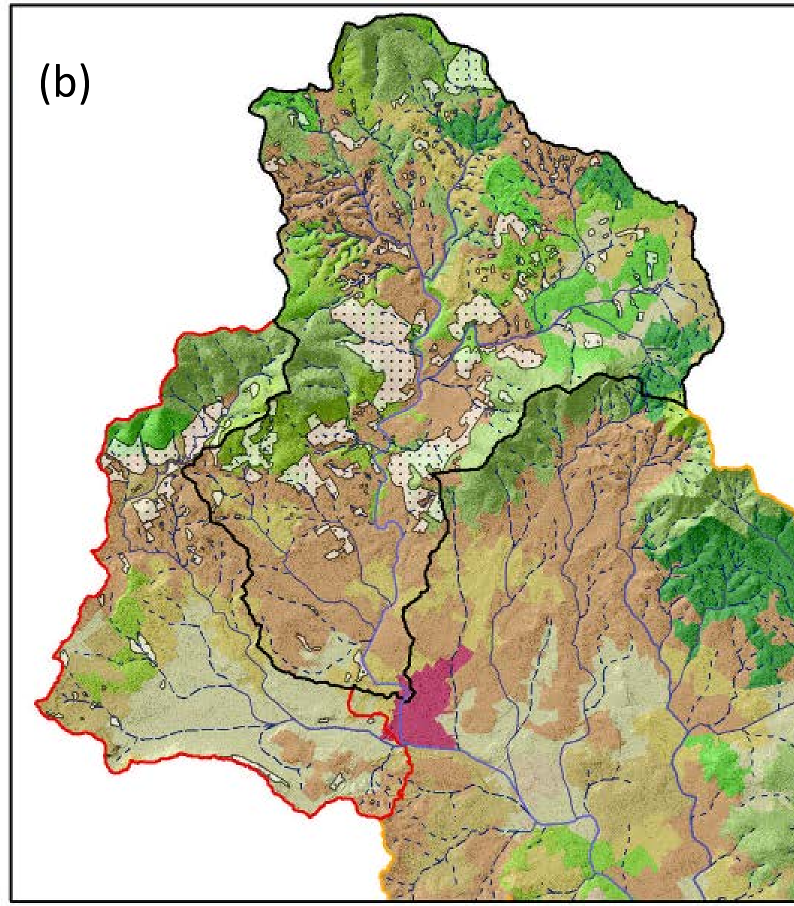




Study area Begura de Sauma River catchment: (a) lithology & (b) land uses

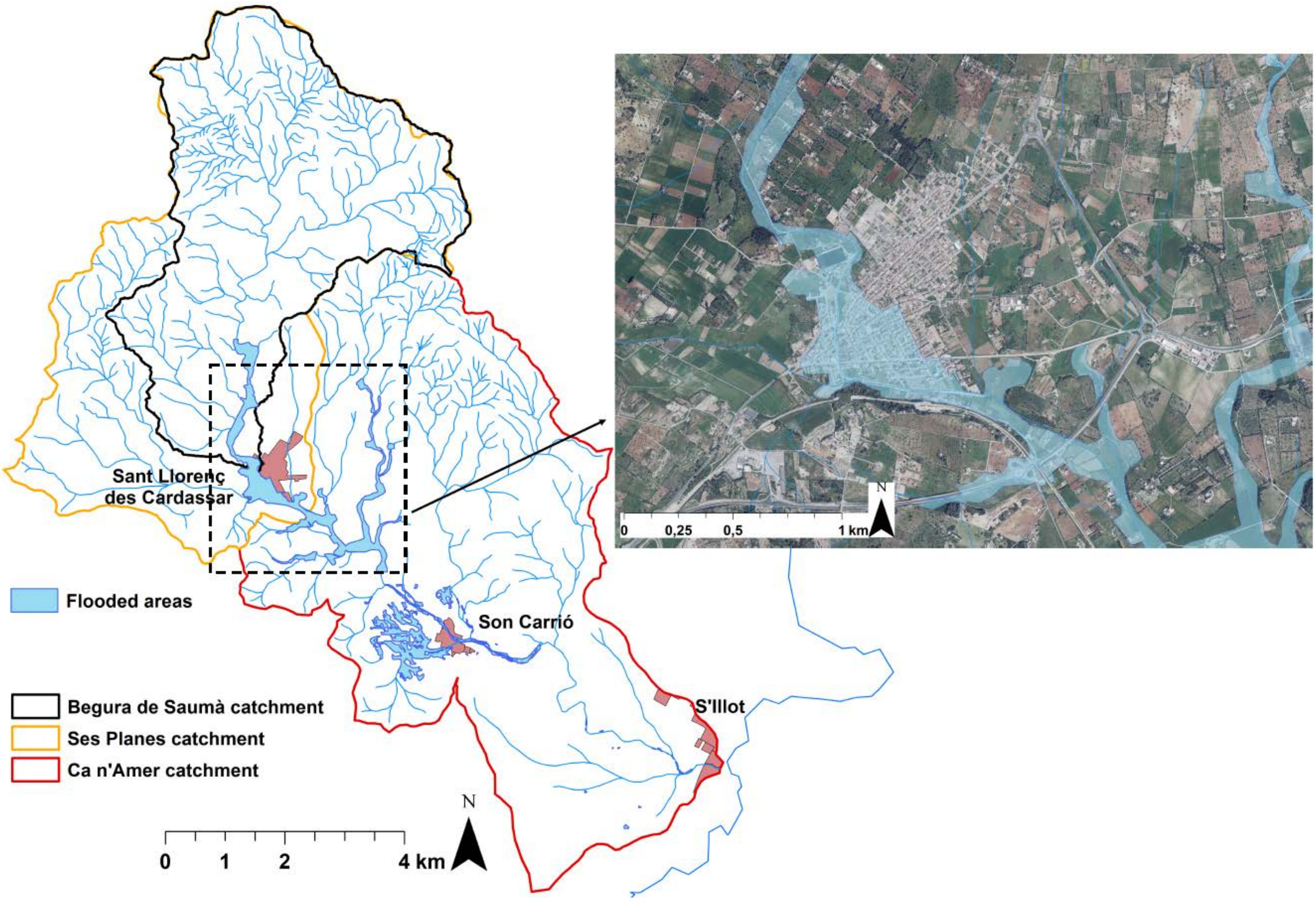


- Quaternary
- Lower Pliocene
- Upper Miocene
- Middle Miocene (Langhiense)
- Lower Miocene (Burdigaliense)
- Oligocene
- Eocene (Bartoniense)
- Lower - middle Cretaceous
- Upper Jurassic
- Middle - upper Jurassic - Cretaceous
- Lower Jurassic
- Triassic (Rhetiense)
- Triassic (Keuper)
- Middle - upper Triassic (Muschelkalk)
- Lower - middle Triassic (Buntsandstein)



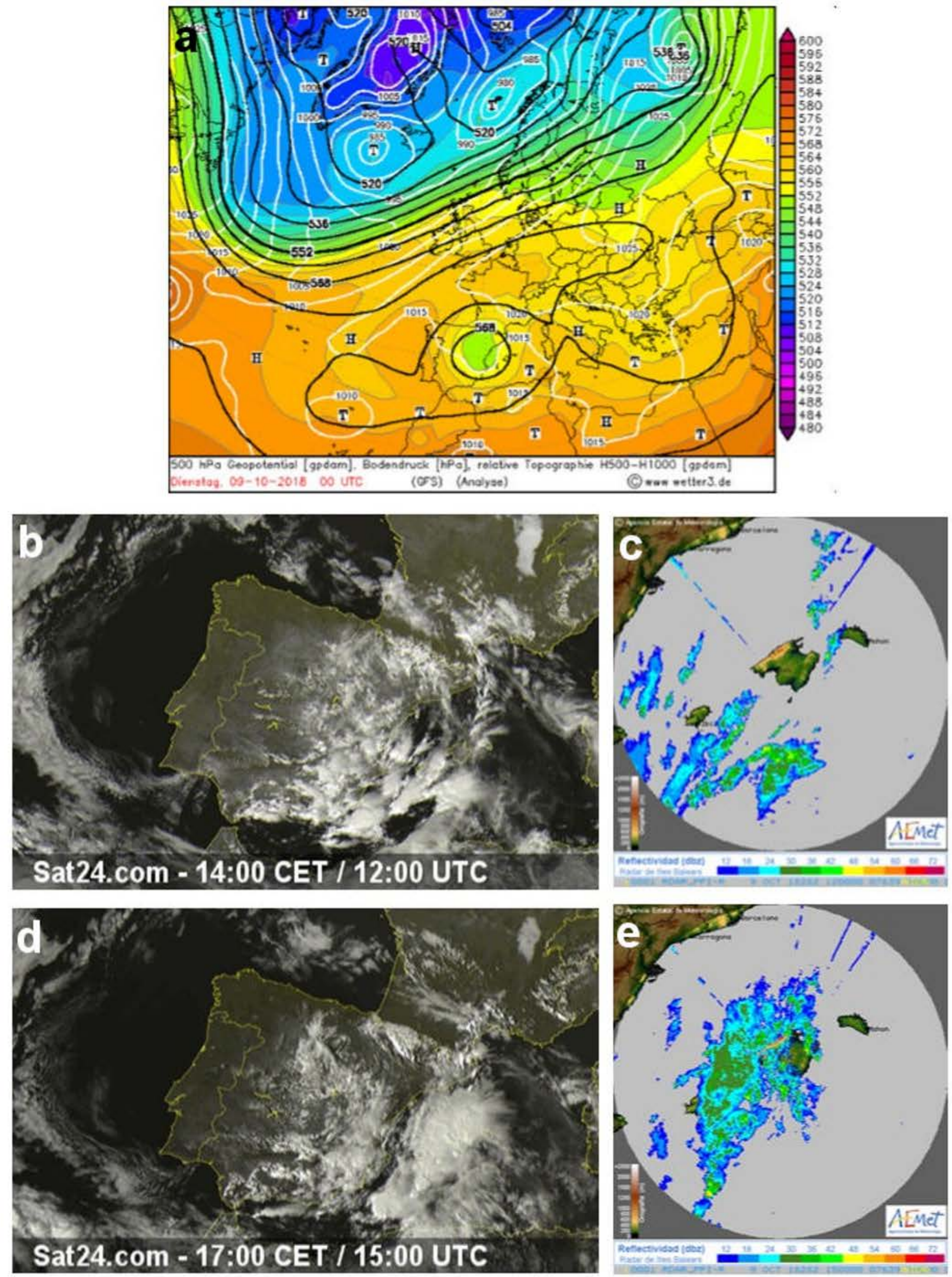
- Urban
- Non-irrigated arable land
- Fruit trees and berry plantations
- Annual crops - permanent crops
- Complex cultivation patterns
- Land principally occupied by agriculture
- Broad-leaved forest
- Coniferous forest
- Mixed forest
- Sclerophyllous vegetation
- Transitional woodland-shrub
- Terraced area

Study area Sant Llorenç des Cardassar village: flooded areas by Copernicus EMS



Synoptic situation

(a) Surface pressure and 500-hPa height analyses at 1200 UTC 9th October 2018 Source: http://wetter3.de; i.e. , at the beginning of the precipitation event. Satellite image at (b) 12.00UTC and (d) 15.00UTC Source: http://www.sat24.com. EUMETSAT and radar images at the same hours (c and e) Source: http://www.aemet.es.



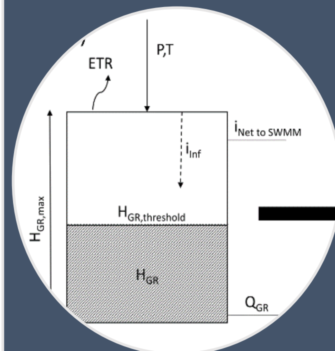
Integrated methods

Rainfall data

Remote-sensing and field-based data

Discharge data

Continuous monitoring of water stage

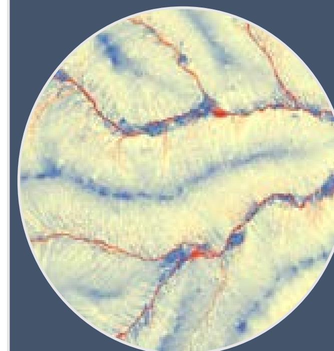


Hydrological modelling

GSM-SOCONT model

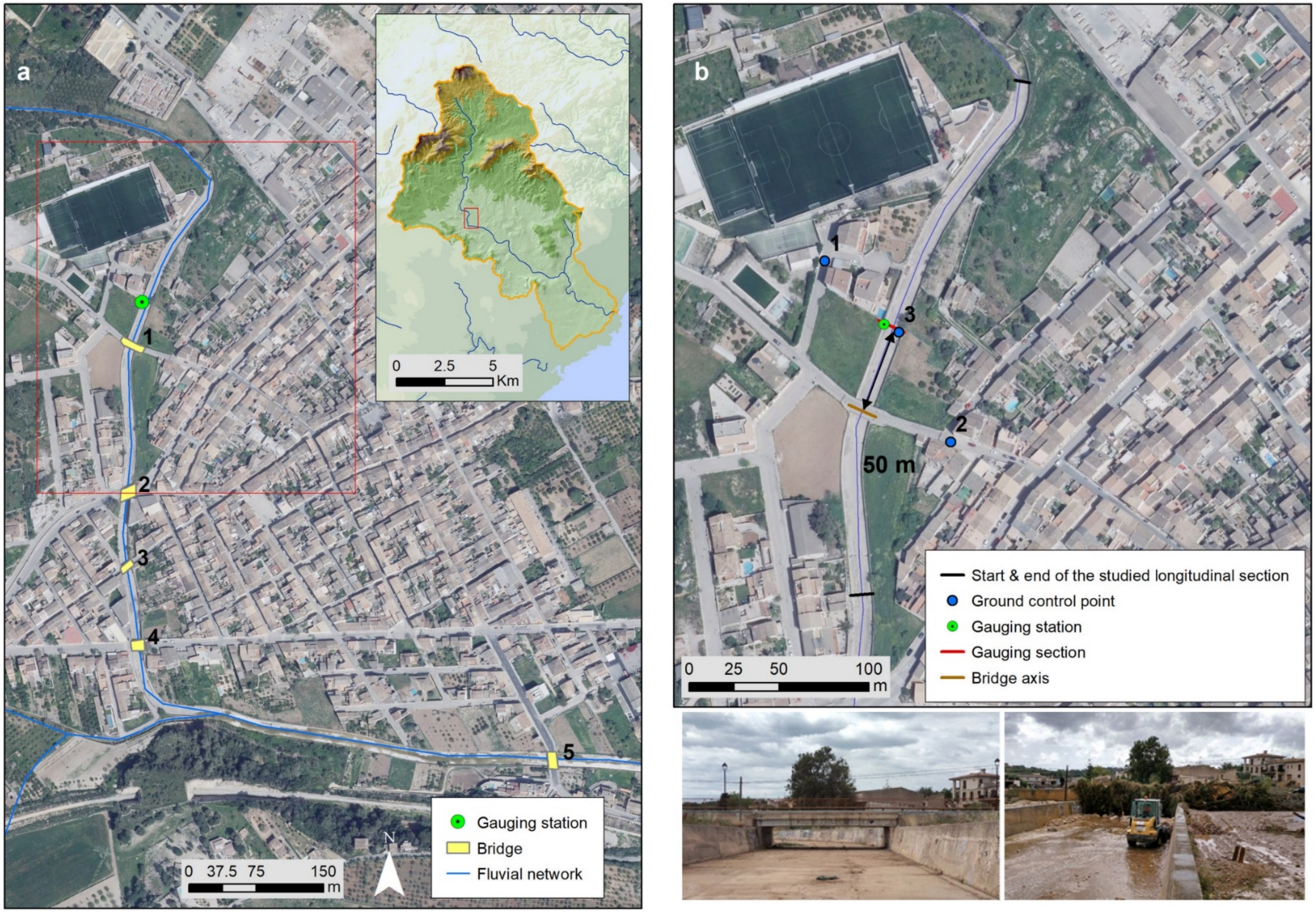
Damage assessment

Ground-based information, rapid mapping & GIS tools



Sediment Connectivity & geomorphic change detection

Discharge data

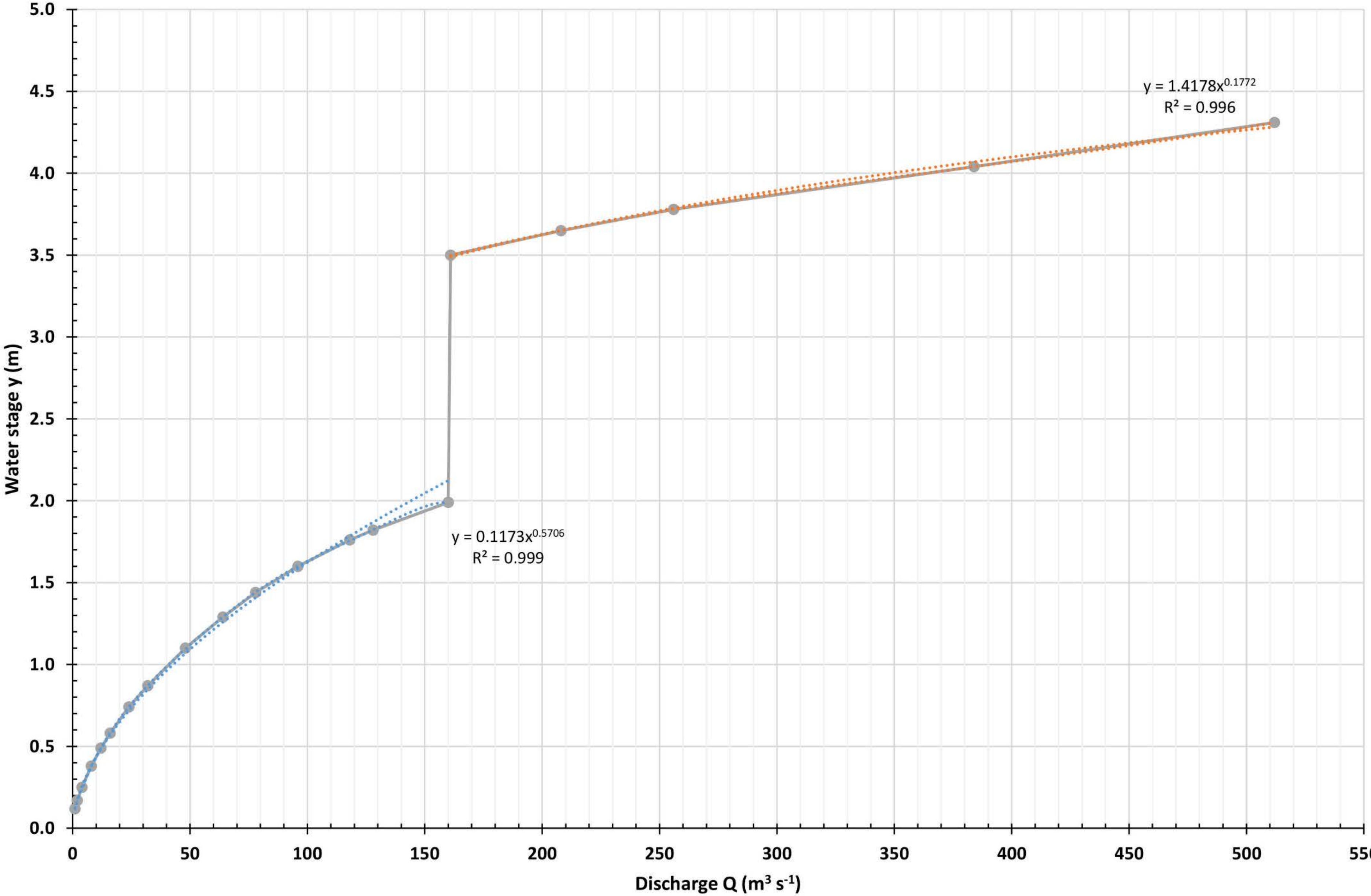


(a) Aerial view of the Begura de Saumà River of concrete channelization that crosses Sant Llorenç des Cardassar village and the location of bridges. (b) Detailed aerial view of the very beginning of this concrete channelization where the hydrometric station is located. The photographs show a view of the Bridge 1 from the hydrometric station when (the right picture) was installed the digital equipment, 10th June 2015 and (the left one) few hours after the flash flood, the 10th October 2018. Background: aerial photography and DEM data (PNOA, 2015).

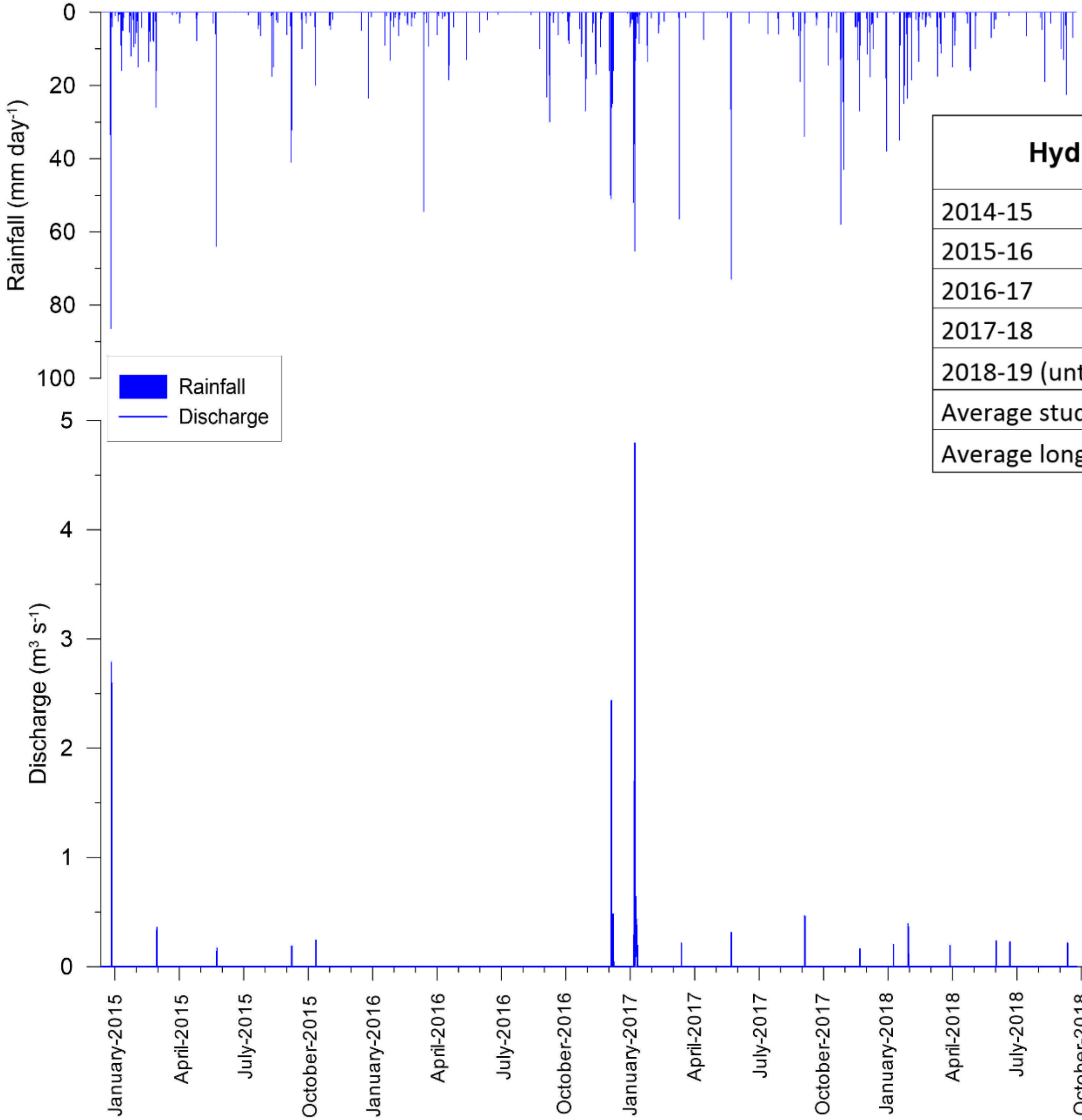
Methods Discharge data

Hydrometric station of the Begura de Saumà River. (Left) Installation of the digital equipment, 10th June 2015. (Right) Data downloading the day after the flash-flood -10th October 2018-.

Methods Calibrated Stage-discharge rating curve



Results Catchment hydrological dynamics

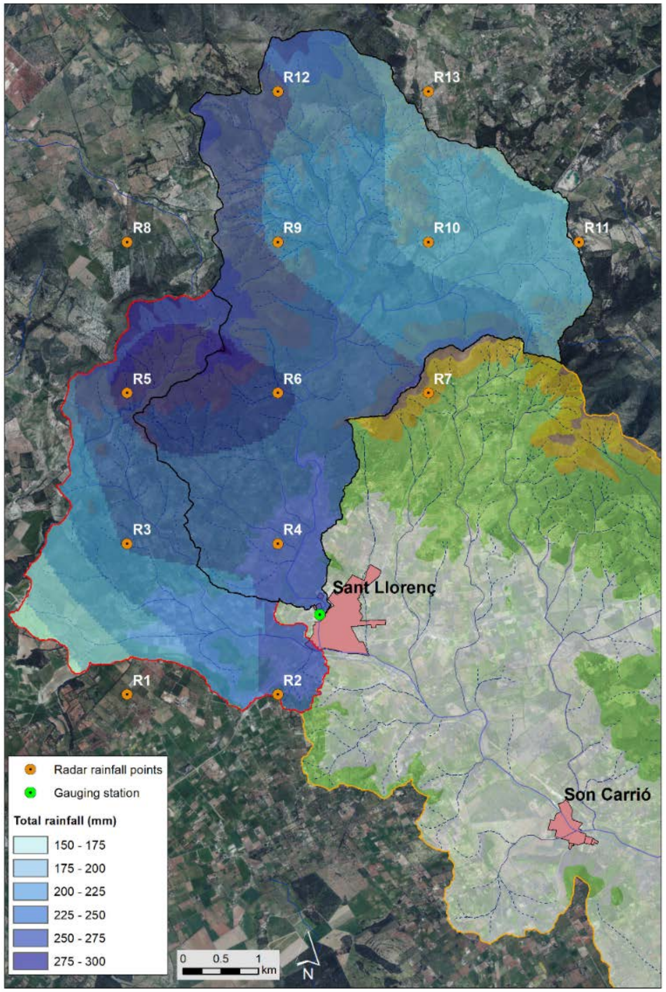


Hydrological year	Rainfall (mm)	Runoff (mm)	Qmax ($m^3\ s^{-1}$)	Qavg ($m^3\ s^{-1}$)
2014-15	823	2.0	2.8	0.002
2015-16	363	0.1	0.2	0.000
2016-17	825	12.9	4.8	0.009
2017-18	763	0.8	0.4	0.001
2018-19 (until April)	500	91.8	442.0	0.118
Average study period (2014-2018)	655 ± 211	21.5	---	0.026 ± 0.1
Average long term (1968-2018)	652 ± 176	---	---	---

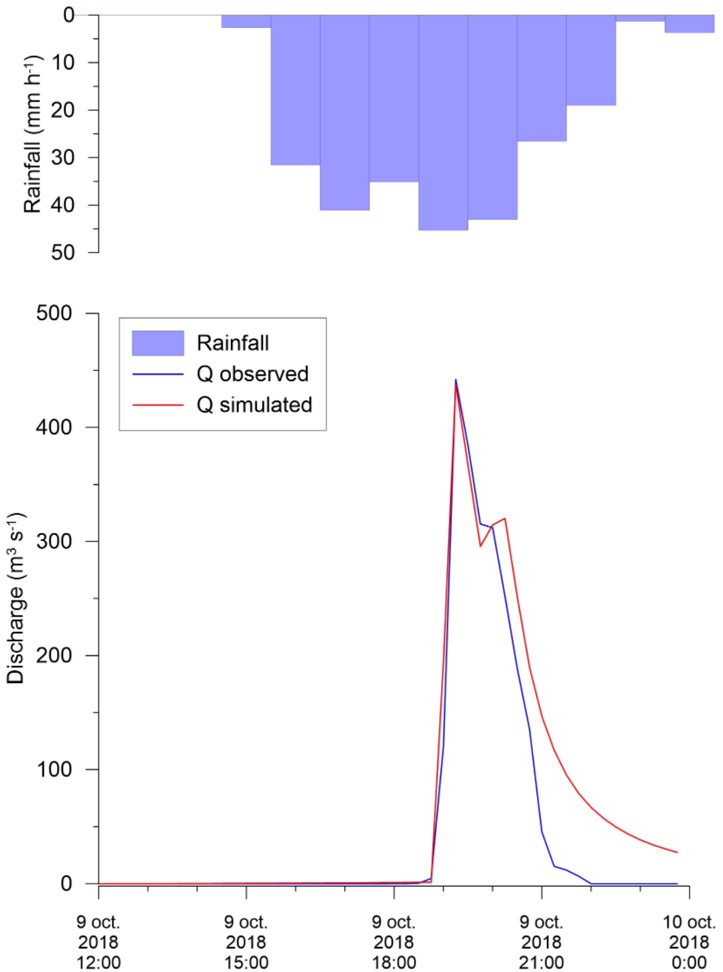
Discharge at 15-min interval measured in the MEDhyCON hydrometric station located at the beginning of concrete channelization of the Begura de Saumà River in Sant Llorenç des Cardassar. Likewise, daily rainfall measured at the AEMET- B630 Ses Pastores during the monitored period (10th January 2015-30th September 2018), previous to the catastrophic flash flood of 9th October 2018.

Table: Rainfall, runoff and peak discharge for hydrological years during study period. Rainfall data is from AEMET-B630 Ses Pastores, located 10.5 km from the Begura de Saumà catchment outlet and representative of rainfall dynamics of the Llevant Ranges headwater parts.

Results Hydrological response of the flash flood

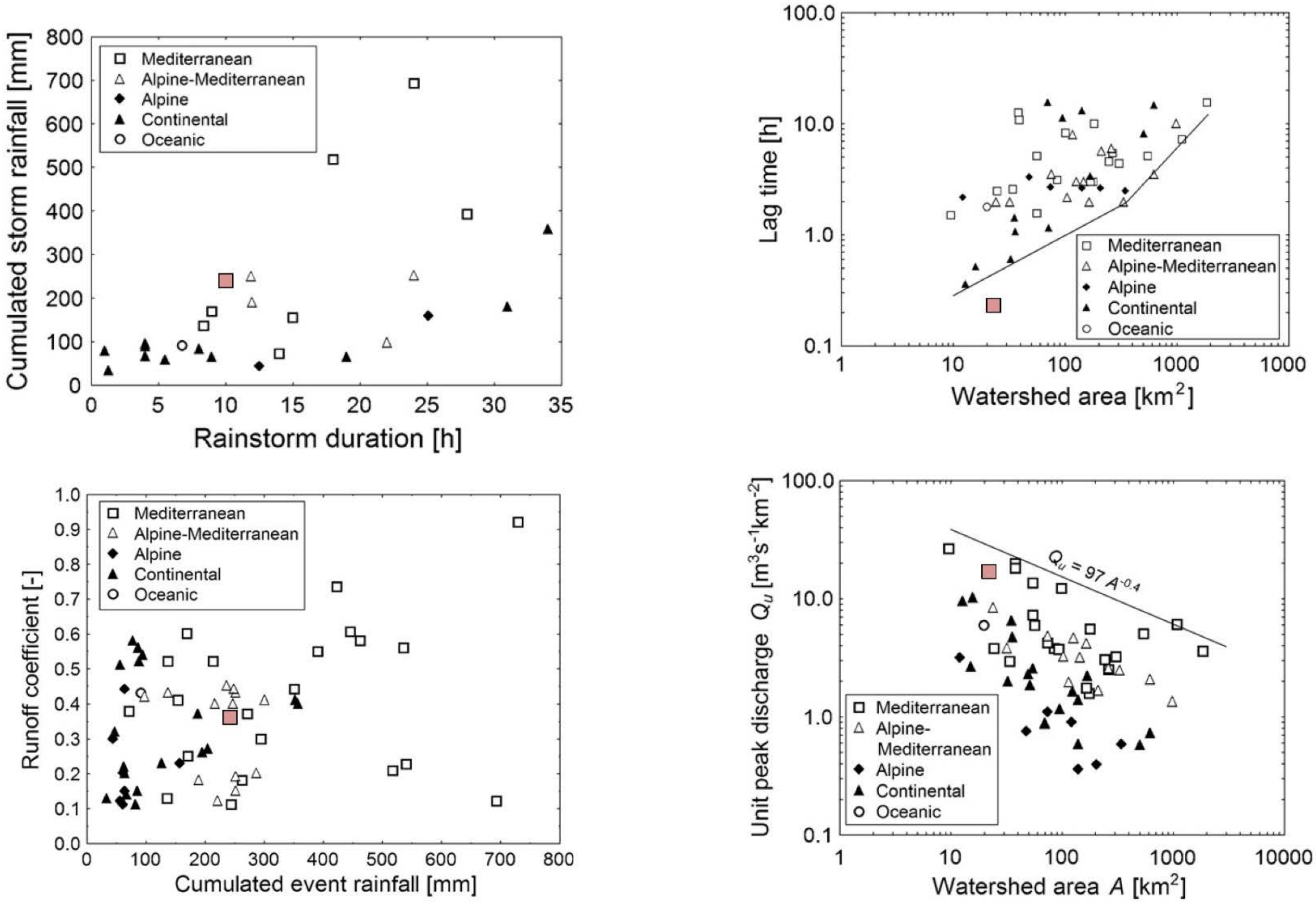


Map of isohyets of the rain storm occurred 9th October 2018 in the two headwater catchments of the Ca n'Amer River; i.e., Blanquera and Begura de Saumà rivers. Source: 10-minute radar images obtained from the web https://opendata.aemet.es/. Background: aerial photography and DEM data (PNOA, 2015)



Observed discharge measured at the MEDhyCON hydrometric station as well as the result of the rainfall-runoff simulation using a modified version of the GR3 model.

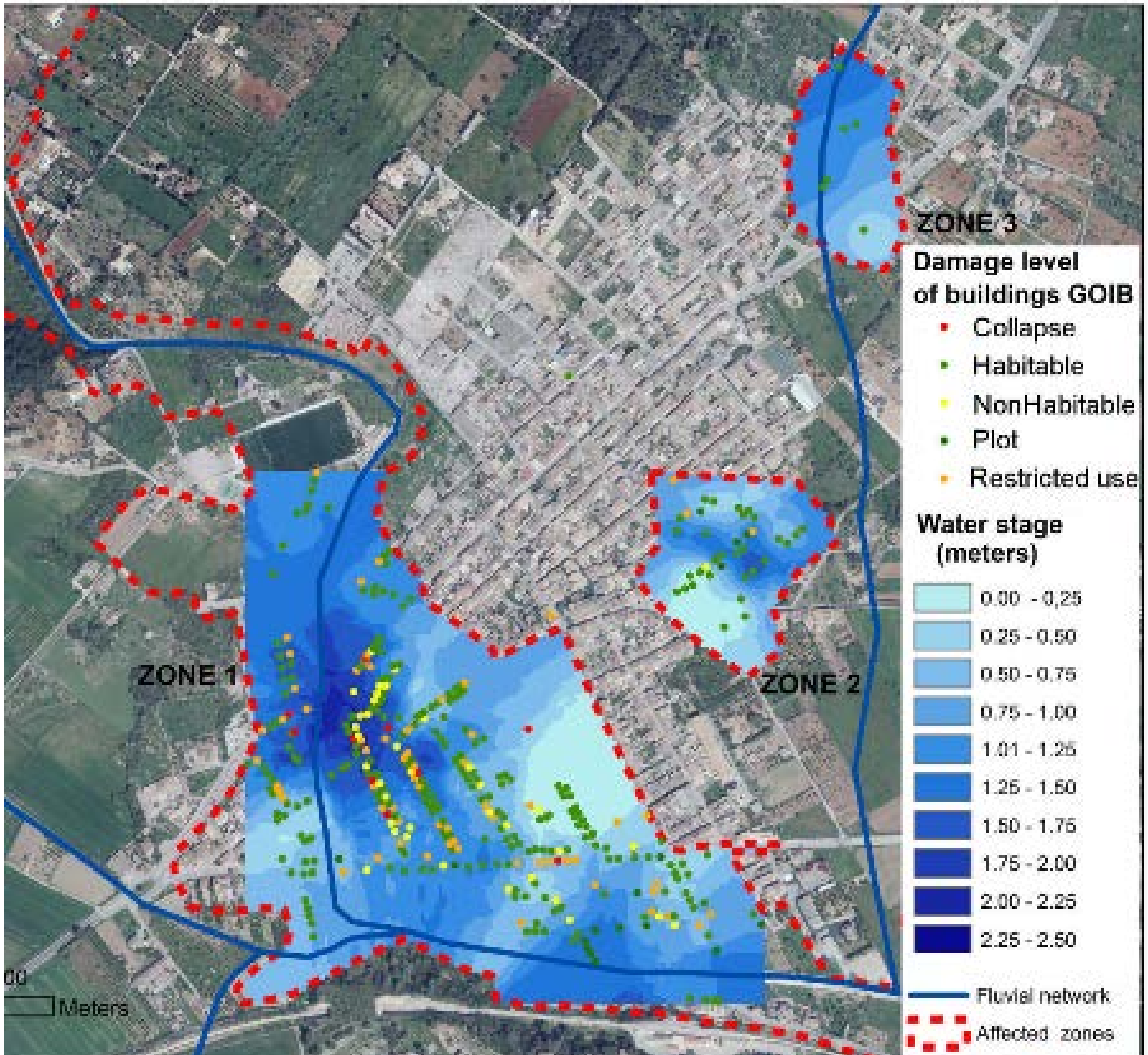
Results Hydrological response and flash flood modelling in small Mediterranean karstic catchments



Pink square: Sant Llorenç des Cardassar flash-flood

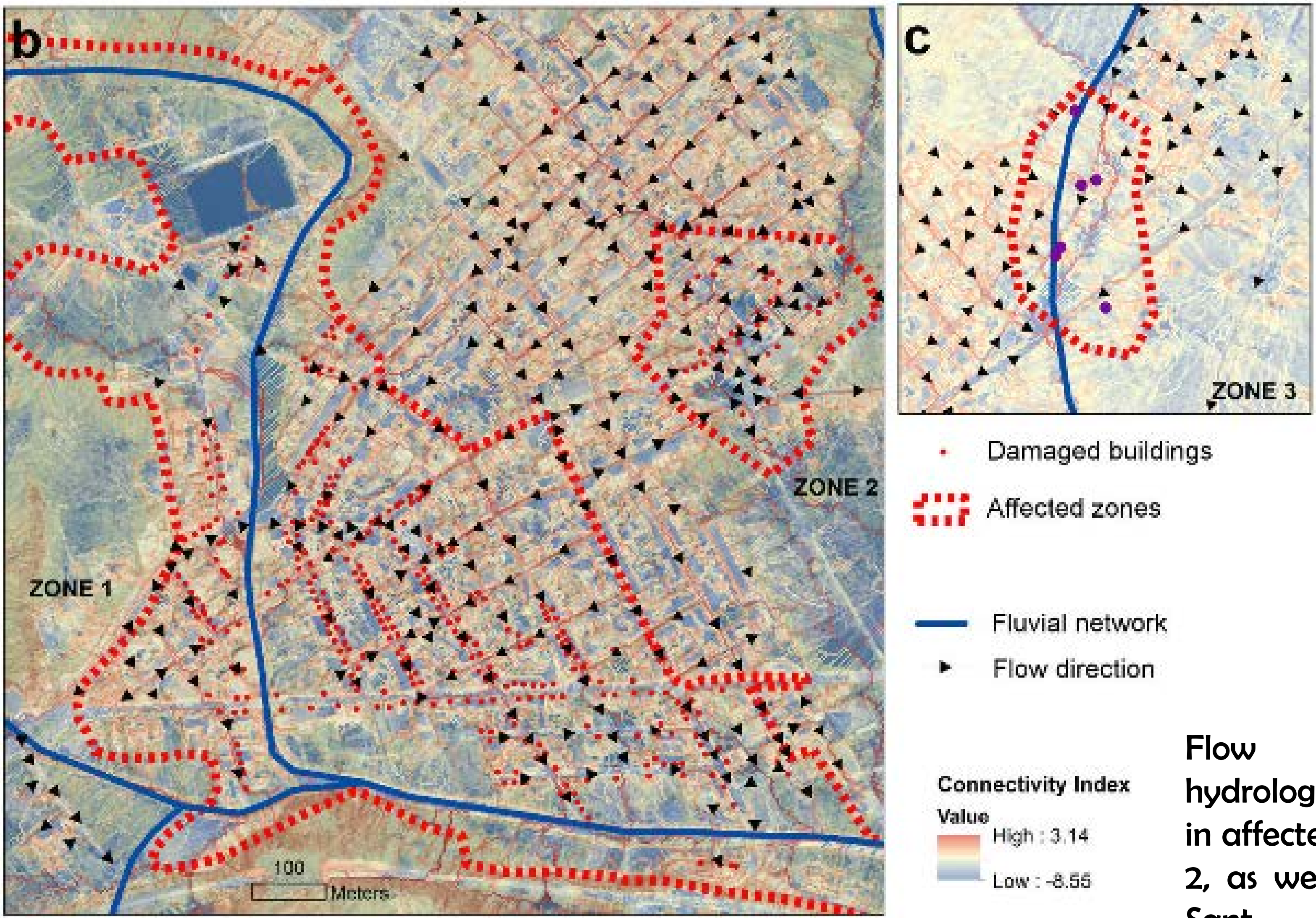
Figure adopted from Marchi L, Borga M, Preciso E and Gaume E. 2010. Characterisation of selected extreme flash flood in Europe and implications for flood risk management. Journal of Hydrology, 394 (1-2), 118-133

Results Damage assessment & Copernicus EMS



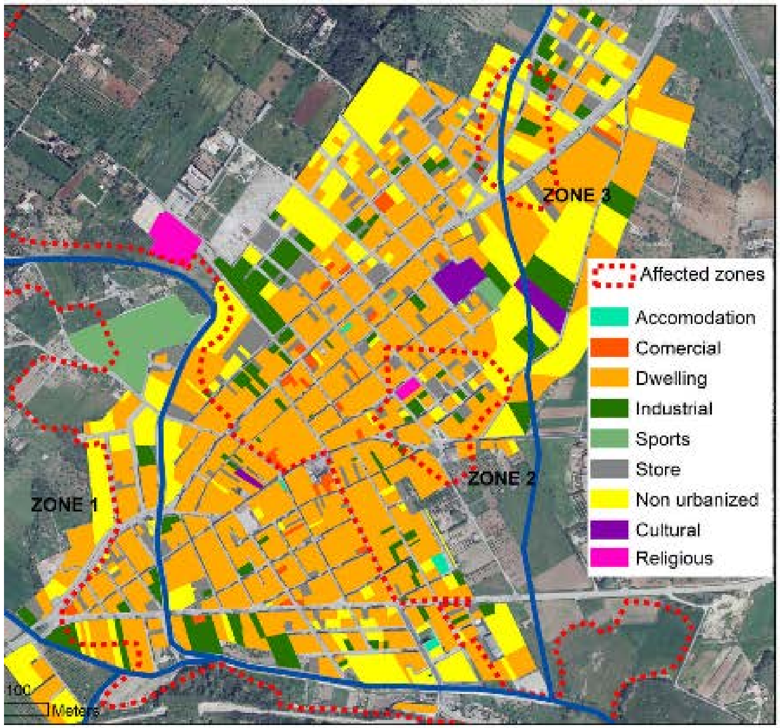
Map of the damage level classification of buildings and water stage reached in the different affected zones at Sant Llorenç des Cardassar according to Balearic Islands Autonomous Government in comparison with the flood delimitation carried out by Copernicus EMS.

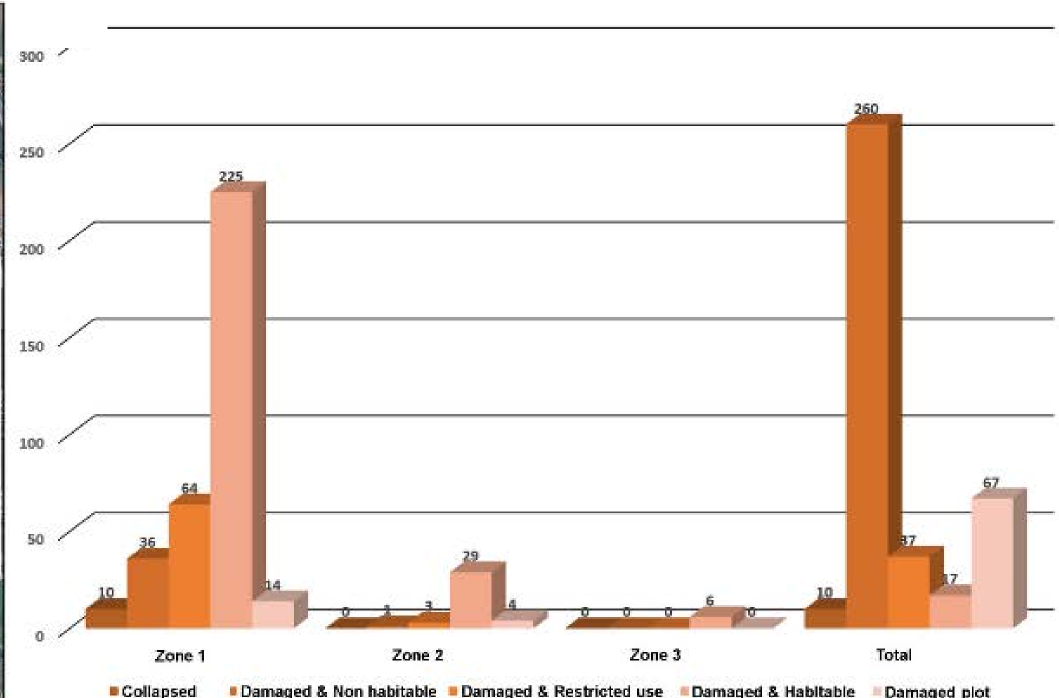
Results Damage assessment & precision technologies



Flow direction and hydrological connectivity in affected zones (b) 1 and 2, as well as (c) 3 in the Sant Llorenç des Cardassar urban network.

Results Damage assessment and Cadastre

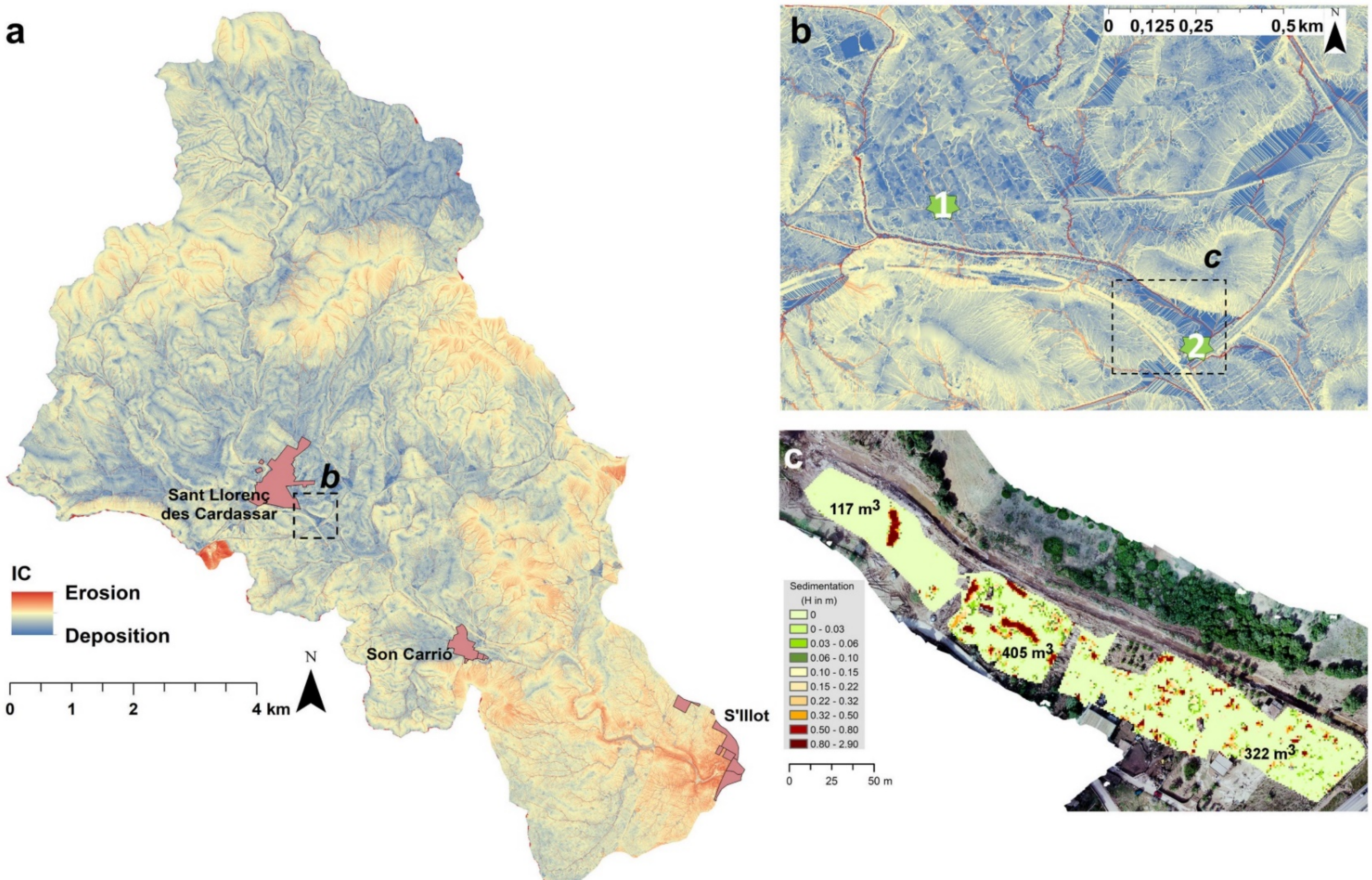




Damage level classification of buildings in the different affected zones at Sant Llorenç des Cardassar. Background: aerial photography (PNOA, 2015).

Damage level classification of buildings in the different affected zones at Sant Llorenç des Cardassar. Background: aerial photography (PNOA, 2015).

Results Sediment Connectivity and geomorphic change detection as emergency tools



Spatial patterns of hydrological and sediment connectivity (deposition zones in blue colours) (a) in the Ca n'Amer River basin, (b) in the south-east part of Sant Llorenç des Cardassar with numbers indicate (1) the point where the missing person was last seen and (2) where this person was found with the application of this connectivity index from a digital terrain model (MDT) of 2 m resolution (Instituto Geográfico Nacional, 2014). (c) Overbank sedimentation estimated after the flash-flood from a DEM performed with SfM from a UAV flight (15th October 2018) in relation to the ground points of the 2014 LiDAR data. Back ground aerial orthophotography of ca. 2 cm resolution obtained also from the drone images. Numbers indicate the total volume of deposited sediments in the three measured areas.

Conclusions

The hydrogeomorphological analysis and damage assessment has provided the following conclusions:

A. The use of rainfall data combined with Q data from stream gauge observations elucidated how spatio-temporal distribution of rainfall amounts and intensities, karstic features and land use/cover resulted in <u>an unprecedented very flashy runoff response in a Mediterranean environment</u>, triggering this natural disaster.

B. <u>Streamflow monitoring data proved to be crucial in this flash-flood type event thorough an accurate calibration</u> with two-dimensional hydraulic model also integrating the influence of bridges obstruction in flow routing.

C. Despite the flood risk planning evidenced the high level of risk exposure, the disaster was generated by <u>a very high exposure of buildings and infrastructures to floods</u>, the <u>absence of early warning systems</u> with efficient action protocols in case of flood emergency.

D. The incorporation of <u>hydrogeomorphological precision tools during Emergency post-catastrophe operational</u> enabled a rapid identification of deposition zones in the different compartments of a catchment helping in the search and rescue of missing persons

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This work was supported by the research project CGL2017-88200-R "Functional hydrological and sediment connectivity at Mediterranean catchments: global change scenarios –MEDhyCON2" funded by the Spanish Ministry of Science and Innovation, the Spanish Agency of Research (AEI) and the European Regional Development Funds (ERDF)".