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

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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
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 9\textsuperscript{th} 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
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

\[ y = 0.1173x^{0.5706} \]
\[ R^2 = 0.999 \]

\[ y = 1.4178x^{0.1772} \]
\[ R^2 = 0.996 \]
Results: Catchment hydrological dynamics

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](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

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).
Precision technologies in the analysis of a catastrophic flash flood by Joan Estrany et al.

**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 southeast 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. Background 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 an unprecedented very flashy runoff response in a Mediterranean environment, triggering this natural disaster.

B. Streamflow monitoring data proved to be crucial in this flash-flood type event thorough an accurate calibration 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 a very high exposure of buildings and infrastructures to floods, the absence of early warning systems with efficient action protocols in case of flood emergency.

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