MULTITEMPORAL GEOMORPHOLOGICAL ANALYSIS TO PREDICT FLASH FLOOD IMPACTS: ITS CONTRIBUTION TO INFORM FLOOD RISK MANAGEMENT

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The 2016 implementation of the *EU Flood Directive* in Spain defines within the flood-prone zones *the Preferential Flow Zone (Zona de Flujo Preferente, ZFP)*. This zone includes

a) broadly, the area where the floods flow is concentrated;

b) for the 100 years return period flood, the intensive drainage waterway and the zone dangerous to persons.

However, the calculation of the 100 years flood poses multiple limitations:

• Different probability distributions produce different results for the same data series,

• For rainfall and discharge data, depending on the time interval considered in the calculation, the results are also different.

• Regarding rainfall, the meteorological radar data are still too new to extrapolate to 100 years.

• The destruction of meteorological and gauging stations during storms and floods is not rare; hence, a lack of data on major events in the data series can deeply affect the calculations.

• Similar rainfall can produce different discharges due to differences in the antecedent conditions or to land use changes.

All the above and the climate change, question the hypothesis of stationarity at the base of the floods return period concept and, thus, its calculation reliability.
Since the middle of the 20th century, significant socio-economic and land use changes occurred in the western Mediterranean region, resulting in changes in the morphology of rivers (e.g., reduced channel section, entrenchment).

The record of these morphological changes, including the effects of major floods, can provide insights to define the high-energy flow zone or ZFP.

This work contributes to determine the flash flood effects and, therefore, to define the ZPF, through multitemporal geomorphological analysis applied to a case study of the upper basin of the Francolí river in Catalonia, Spain.

This river was affected by several major floods in 1874, 1930, 1994 and 2019, where the first and the last events were the largest and of quite similar, centenial magnitude.
On October 22, 2019, a major flash flood affected the upper basin of the Francolí river (precipitation: 292.6 mm / 24 hours at Prades).

The river swept along a large quantity of vegetation, crops and infrastructures and caused a considerable economic damage (> 100 million euros) and loss of six human lives.

2019 flood morphological effects (channel migration, significant erosive and sedimentary morphologies, extension of the flooded areas through ephemeral evidence, avulsion phenomena, channel widening or bank erosion), can be detected and mapped through photo-interpretation.

Also, stereo and ortophotographs from previous dates and digital terrain models (DTMs) can be studied and analysed, and mapping oriented to flood interpretation can be carried out.
MAIN OBJECTIVES

To map:

• the 2019 flood Active Band (zone affected by this particular flood)
• the 1994 minimum area affected by the flood.
• the fluvial morphologies that can provide insights on the floods behaviour (documents of different dates: 2003 DTM, 1946 ortophoto)

To test whether:

• the main geomorphic effects of the 2019 flood could have been predicted using the multitemporal geomorphological analysis.

• the ZFP can be reasonably determined for major floods in this Mediterranean river through multitemporal geomorphological analysis.
Different reaches of the river are mapped, studied and compared to validate the analysis:

• reaches where 1994 and 2019 floods were similar and
• reaches where these floods were of very different magnitude;
• reaches where all the basic dataset is available (1946, 1956, 1995 post flood, pre and post 2019 orthophotos; 2003 detailed DTM; stereo photographs, post 2019 flood field data and GNSS-RTK data of river cross sections) and
• reaches with lack of some data (especially of the 1995 post flood image).

Historical information (water levels attained by the past floods and the calculated discharges -work in progress-) are also used to complement and validate the geomorphological analysis results.
MATERIALS AND METHODS

Historical floods:

- **2019**: severely affected all the upper Francolí river; minor affection at the Sec river
- **1994**: severely affected the Sec river and the Francolí river downstream L’Espluga; affected the Francolí river upstream L’Espluga
- **1930**
- **1874**: most severe flood in the area

Source ICGC. CC by 4.0 [on line]

Example reaches: a, b, c

Photo showing the water levels for the 2019 and 1994 floods (see next page)

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MATERIALS AND METHODS

Water levels at different sites corresponding to the 2019 and 1994 floods (see previous page)

P1. Molí de Guasch

P2. Pont Montblanc

P3. Molí de la Farga
MATERIALS AND METHODS


Source: ICGC. CC by 4.0 (on line)
MATERIALS AND METHODS
MATERIALS AND METHODS

Post 2019 flood
MATERIALS AND METHODS

Post 1994 flood

Source: ICGC. CC by 4.0 [on line]
AERIAL PHOTOS, ORTHOPHOTOS AND DTM USED IN THIS STUDY

- 1946
- 1956
- 1944 (Flood)
- 1994 (Flood)
- 2003 DTM
- 2019 (Flood)

1946

1956

1994 PRE FLOOD

1995 POST FLOOD

2003 DTM

2019 POST FLOOD
GEOMORPHOLOGICAL CHARACTERIZATION 1st STEEP: ANALYSIS CRITERIA EXAMPLES

2019 ORTHOPHOTO POST FLOOD

ANALYSIS CRITERIA

- Bank erosion
- Large wood accumulation
- Gravel bars
- Water marks
- Channel widening
- Affected crops
- Vegetal drifted ephemeral evidence
- Affected riparian trees

Source: ICGC. CC by 4.0 [on line]
Reference System: ETRS 89/UTM 31N
GEOMORPHOLOGICAL CHARACTERIZATION 1st STEEP: ANALYSIS CRITERIA EXAMPLES

- Bank erosion
- Large wood accumulation
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Source: ICGC, CC by 4.0 [on line]
Reference System: ETRS 89/UTM 31N
GEOMORPHOLOGICAL CHARACTERIZATION 1st STEEP: ANALYSIS CRITERIA EXAMPLES

- Vegetal drifted ephemeral evidence
- Gravel bars
- Large wood accumulation
- Affected crops
- Affected riparian trees
- Bank erosion
- Channel widening
- Water marks

Source: ICGC. CC by 4.0 [online]
GEOMORPHOLOGICAL CHARACTERIZATION 1st STEEP: ANALYSIS CRITERIA EXAMPLES

2019
ORTHOPHOTO POST FLOOD

ANALYSIS CRITERIA

- Bank erosion
- Large wood accumulation
- Gravel bars
- Water marks
- Channel widening
- Affected crops
- Vegetal drifted ephemeral evidence
- Affected riparian trees

Source: ICGC, CC by 4.0 [on line]

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GEOM. CHARACTERIZATION 2nd STEEP: INTERPRETATION OF THE FLOODED AREA

**Legend**

- **2019 FLOODED AREA:**
  - **ACTIVE BAND**
  - This area has been determined from the visualization of ephemeral evidence such as deposited drifted vegetation, tilted and flattened vegetation, watermarks, affected crops, bank erosion, etc.

- **2019 HIGH ENERGY FLOW AREA**
  - This area, that is part of the Active Band, has been determined from the functional channel, gravel deposits and bars and significant erosion.

Source: ICGC. CC by 4.0 [on line]
Reference System: ETRS 89/UTM 31N

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GEOM. CHARACTERIZATION 2nd STEEP: INTERPRETATION OF THE FLOODED AREA

2019 FLOODED AREA: ACTIVE BAND

2019 HIGH ENERGY FLOW AREA

Source: ICGC. CC by 4.0 [on line]
GEOM. CHARACTERIZATION 2nd STEEP: INTERPRETATION OF THE FLOODED AREA

Source: ICGC, CC by 4.0 [on line]
GEOM. CHARACTERIZATION 3st STEEP: PREVIOUS SITUATIONS

1995 ORTOPHOTO (POST 1994 FLOOD)

MINIMUM AREA FLOODED IN 1994
GEOM. CHARACTERIZATION 3st STEEP: PREVIOUS SITUATIONS

1946 ORTOPHOTO

1947 RIVERBED
GEOM. CHARACTERIZATION 3st STEEP: PREVIOUS SITUATIONS

MINIMUM AREA FLOODED IN 1994

1995 ORTOPHOTO (POST 1994 FLOOD)

Source: ICGC. CC by 4.0 [on line]

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GEOM. CHARACTERIZATION 3st STEEP: PREVIOUS SITUATIONS

1946 ORTOPHOTO

1947 RIVERBED

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GEOM. CHARACTERIZATION 3st STEEP: PREVIOUS SITUATIONS

Source: ICGC, CC by 4.0 [on line]

SCARPS 2003
GEOM. CHARACTERIZATION 3st STEEP: PREVIOUS SITUATIONS

Source ICGC, CC by 4.0 (on line)

1995 ORTOPHOTO (POST 1994 FLOOD)

MINIMUM AREA FLOODED IN 1994

Furdada et al. EGU21-15286
GEOM. CHARACTERIZATION 3st STEEP: PREVIOUS SITUATIONS

1995 ORTOPHOTO (POST 1994 FLOOD)

1994 ORTOPHOTO (PRE 1994 FLOOD)

MINIMUM AREA FLOODED IN 1994

RIVERBED 1994

Source: ICGC, CC by 4.0 [on line]
**RESULTS AND COMPARISON**

**2019 ORTHOPHOTO POST FLOOD**

**Legend**
- **2019 FLOODED AREA:** ACTIVE BAND
- **2019 HIGH ENERGY FLOW AREA**

- **SCARPS 2003**
  - Some scarps condition the High Energy Flow area.
  - Other scarps have been eroded.
  - Channel migration.
  - Areas with rough textures on the 2003 DTM correspond to areas where the flow reached high speed and energy during the 2019 flood.
  - Gravel bars.
  - Fine sediment accumulations.

Source: ICGC. CC by 4.0 [on line]
Reference System: ETRS 89/UTM 31N

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RESULTS AND COMPARISON

Some scarps limited the area with High Energy Flow (HEF) in 2019. Furthermore, HEF corresponds to the roughest texture likely modelled by the effects of previous floodings.

Source: ICGC. CC by 4.0 [on line]
Reference System: ETRS 89/UTM 31N
RESULTS AND COMPARISON

1995
ORTHOPHOTO
POST 1994 FLOOD

Legend
- 2019 FLOODED AREA: ACTIVE BAND
- 2019 HIGH ENERGY FLOW AREA
- SCARPS 2003

Some effects of the 1994 overflow can be observed.


Rough textures correspond to areas where the flow reached high speed and energy.

Fine sediment accumulation, low energy.

Gravel bars, high energy.

Source: IGOC. CC by 4.0 [on line]
Reference System: ETRS 89/UTM 31N

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RESULTS AND COMPARISON

1956-57
AMERICAN FLIGHT B SERIE

Legend

- 2019 FLOODED AREA: ACTIVE BAND
- 2019 HIGH ENERGY FLOW AREA

At this time, land use was more intensive. There was more crops near the channel.

Bend of the meander is a widening area in the following floods.

Source: ICGC. CC by 4.0 [on line]
Reference System: ETRS 89/UTM 31N

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RESULTS AND COMPARISON

1946 ORTOPHOTO

- **2019 FLOODED AREA:** ACTIVE BAND
- **2019 HIGH ENERGY FLOW AREA**
- **1947 RIVERBED**

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RESULTS AND COMPARISON

MINIMUM AREA FLOODED IN 1994

SCARPS 2003

MINIMUM AREA FLOODED IN 1994

1947 RIVERBED

Elements mapped: previous to the 2019 flood.

Is it possible to delineate the High Energy Flow area of 2019?
RESULTS AND COMPARISON
RESULTS AND COMPARISON

2019 FLOODED AREA:
ACTIVE BAND

2019 HIGH ENERGY
FLOW AREA

SCARPS 2003

2019 ORTOPHOTO
POST FLOOD
RESULTS AND COMPARISON

2019 FLOODED AREA:
ACTIVE BAND

2019 HIGH ENERGY
FLOW AREA

SCARPS 2003

2003

DTM 1X1
SCARPS ANALYSIS

b

ETRS98 UTM 31N. Source ICGE. CC by 4.0 [on line]
RESULTS AND COMPARISON

MINIMUM AREA FLOODED IN 1994

1995 ORTOPHOTO (POST 1994 FLOOD)

Source: ICGC, CC by 4.0 (on line)
RESULTS AND COMPARISON

1995 ORTOPHOTO (POST 1994 FLOOD)

2019 FLOODED AREA:
ACTIVE BAND

2019 HIGH ENERGY FLOW AREA

MINIMUM AREA FLOODED IN 1994

SCARPS 2003

2019 FLOODED AREA:
ACTIVE BAND

2019 HIGH ENERGY FLOW AREA

MINIMUM AREA FLOODED IN 1994

SCARPS 2003

1995 ORTOPHOTO (POST 1994 FLOOD)
RESULTS AND COMPARISON

2019 FLOODED AREA:
ACTIVE BAND

2019 HIGH ENERGY
FLOW AREA

1956
RESULTS AND COMPARISON

- 2019 FLOODED AREA: ACTIVE BAND
- 2019 HIGH ENERGY FLOW AREA
- 1947 RIVERBED

**1946 ORTOPHOTO**

- 1946 ORTOPHOTO

- 1947 RIVERBED

- 2019 FLOODED AREA: ACTIVE BAND

- 2019 HIGH ENERGY FLOW AREA

- 1947 RIVERBED

**1946 ORTOPHOTO**
RESULTS AND COMPARISON

Elements mapped: previous to the 2019 flood. Is it possible to delineate the High Energy Flow area of 2019?
RESULTS AND COMPARISON

SCARPS 2003
MINIMUM AREA
FLOODED IN 1994

1947 RIVERBED

2019 FLOODED AREA:
ACTIVE BAND

2019 HIGH ENERGY
FLOW AREA

Legend

2019_HighE_flow
RESULTS AND COMPARISON

2019 ORTOPHOTO POST FLOOD

- 2019 FLOODED AREA:
- ACTIVE BAND
- 2019 HIGH ENERGY FLOW AREA
- SCARPS 2003

Source ICGC, CC by 4.0 [on line]
RESULTS AND COMPARISON

2003 DTM 1X1 SCARPS ANALYSIS

2019 FLOODED AREA:
ACTIVE BAND

2019 HIGH ENERGY FLOW AREA

SCARPS 2003

Source ICGC. CC by 4.0 [on line]
RESULTS AND COMPARISON

1995 ORTOPHOTO (POST 1994 FLOOD)

1994 ORTOPHOTO (PRE 1994 FLOOD)

SCARPS 2003

- MINIMUM AREA FLOODED IN 1994
- RIVERBED 1994
RESULTS AND COMPARISON

1995 ORTOPHOTO (POST 1994 FLOOD)

1994 ORTOPHOTO (PRE 1994 FLOOD)

2019 FLOODED AREA: ACTIVE BAND
2019 HIGH ENERGY FLOW AREA
SCARPS 2003
MINIMUM AREA FLOODED IN 1994
RIVERBED 1994

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RESULTS AND COMPARISON

Elements mapped: previous to the 2019 flood.

Is it possible to delineate the High Energy Flow area of 2019?

SCARPS 2003
MINIMUM AREA
FLOODED IN 1994
1994 RIVERBED
1947 RIVERBED

Source ICGC. CC by 4.0 [on line]
RESULTS AND COMPARISON

SCARPS 2003

MINIMUM AREA FLOODED IN 1994

1994 RIVERBED

1947 RIVERBED

2019 FLOODED AREA:
ACTIVE BAND

2019 HIGH ENERGY FLOW AREA

SCARPS 2003

Legend

2019_HighE_flow

Source: ICGC. CC by 4.0 [on line]
RESULTS AND COMPARISON

• The HEF zone for the 2019 flood appears to be very similar to the following mapped areas:
  • 2003 DTM: the roughest texture area, probably shaped by the previous floods.
  • 1994 riverbed (when photo exists)
  • 1946 riverbed

• The 2003 scarps show quite well:
  • the main channel, which can migrate and/or avulse during the 2019 flood.
  • some clear boundaries of the roughest textured areas in the 2003 1x1m DTM

• The most severely affected 1994 minimum flooded area (roughest texture in 1995 ortophoto, when it exists) coincides quite well with the 2019 High Energy Flow area.
Multitemporal geomorphological analysis contributes to determine the river zones that can be affected by high energy flow (destructive) during floods.

The ZFP can be reasonably determined for major floods in this type of Mediterranean rivers.

Good skills on geomorphological mapping are essential to successfully carry out this kind of analysis.

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REFERENCES


