Urban and peri-urban flood impact change: the case of the Metropolitan Area of Barcelona

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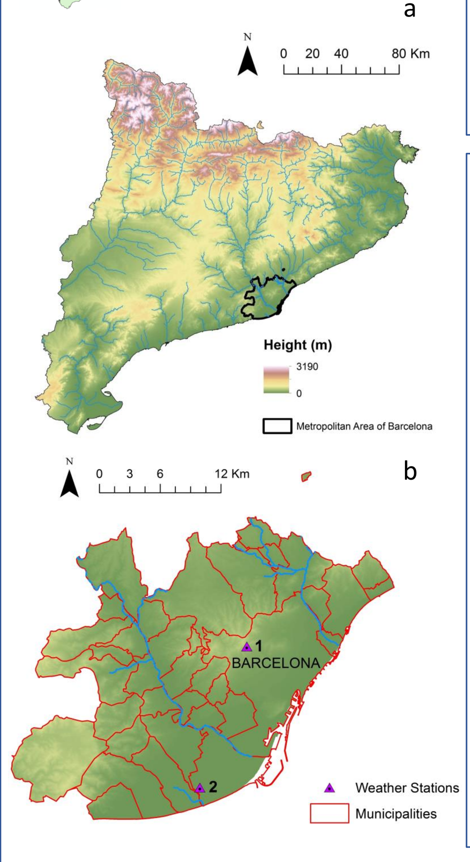
Nowadays there is a call for treating floods from a holistic perspective that integrates bottom-up (from impact and vulnerability) and top-down (from hazard) approaches (Hall et al., 2014). The study of flood risk in urban and peri-urban areas is complex and involves multiple factors. This is the case of the Metropolitan Area of Barcelona (AMB), which concentrates 43% of total population of Catalonia in less than 2% of the whole territory. The impervious soil has grown more than 200% from 1956 to 2009 (resulting in higher values of runoff), the population has increased more than 80% in the same period and, simultaneously, an improvement of the drainage system and flood prevention has been developed. Actually, floods in this region are usually due to drainage problems, flash floods in ungauged torrential catchments and, only in some occasions, river floods. But, in all the cases they are due to heavy precipitations. The main objective of the contribution is assessing the potential relationship between precipitation in the AMB and the impacts produced. In order to do it, different impact indicators have been proposed, such as the population affected or the duration of the flood event (Amaro et al., 2010, Barberia et al., 2014 and Merz et al., 2010) and have been implemented to selected cases which affected AMB for the period 1981-2015. The study also explores the evolution of land uses, population and precipitation from the middle of the 20th century until now, and how these changes have affected (or not) the flood risk in the AMB.

REGION OF STUDY AND DATA

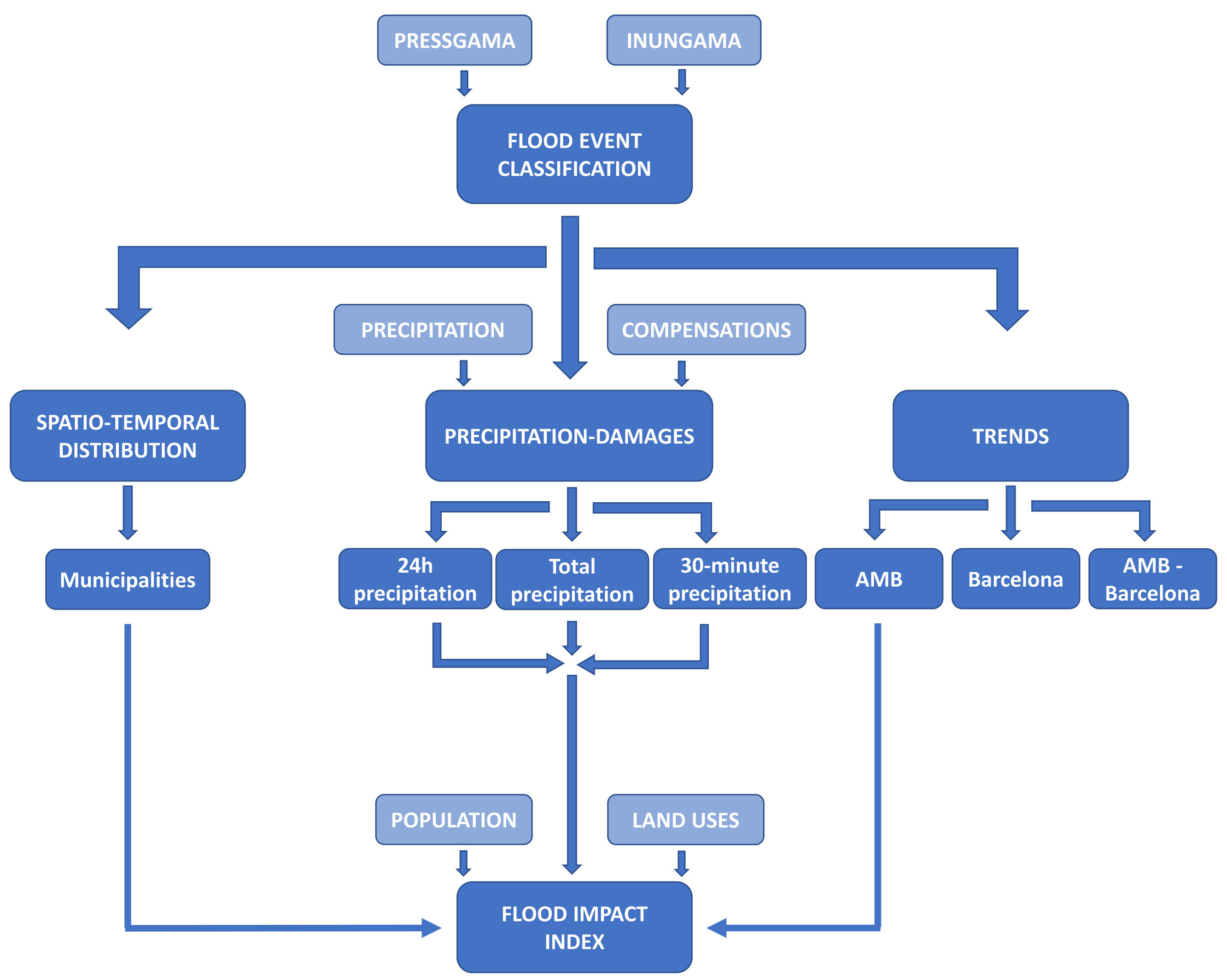


Catalonia: 31,895 km²; 7,508,106 inhab.; 947 municipalities.
Metropolitan Area of Barcelona (AMB): 636 km²; 3,239,337 inhab.; 36 municipalities.
Barcelona: 101 km²; 1,604,555 inhab.

INUNGAMA: flood events database in Catalonia (1900-2015), classified according to their severity (Llasat et al., 2016).
PRESSGAMA: press news database with 15,715 news about natural hazards and climate change (Llasat et al., 2009).
Rainfall data: series of Fabra Observatory (Barcelona) (1) and International Barcelona Airport (2); precipitation 24 h and accumulated for the whole event (State Meteorological Agency of Spain, AEMET); 30-minute precipitation (Meteorological Service of Catalonia, SMC).
Impervious/pervious maps: based on Land Cover and Land Uses maps (LCLU) (Centre for Ecological Research and Forestry Applications, CREAF) and Chow et al. (1988).
DAMAGE: compensations paid by the Spanish public reinsurer "Insurance Compensation Consortium" (CCS) and descriptions in the news.

Figure 1. a) Location of Catalonia and the Metropolitan Area of Barcelona; b) Map of the Metropolitan Area of Barcelona showing the municipalities included in and the weather stations. The Besòs River (at the Northern part) and the Llobregat River (at the Southern part) are also shown.

HYPOTHESIS: AMB is affected by flash floods and precipitation in situ → Heavy rainfall is the main driver



METHODOLOGY

IMPACT FLOOD CLASSIFICATION

INDICATOR	DEFINITION	CATASTROPHIC	EXTRAORDINARY	ORDINARY
Public buildings	City hall, hospital, school, church, emergence centres, police building…	Total destruction or collapsed	Partial destruction or structural damage	Flooded, habitable
Private houses	Houses with one or more floors, cellars….	Total destruction or collapsed	Partial destruction or structural damage	Flooded, habitable
Bridges	Bridges, footbridges	Destroyed, unusable	Structural damages, unusable bridges or damages in footbridges	Usable
Hydraulic infrastructures	Mills, irrigation channels	Destruction	Medium damage	Minor damages
Roads	Railway, highway, state road, country road, regional road, municipal road	Partially destroyed, one or more stretch of the road damaged	Flooded, break > 12 h	Flooded, break between 0 and 12 h or not break
Services	Gas, electricity, telephone, water	Destruction of infrastructures and/or breaks>24 h	Breaks between 6 and 24 h	Breaks < 6 h
Productive activities	Industry, agriculture and livestock, commerce, touristic infrastructures	Interruption of production and loss of productive system	Interruption of production and loss of products	Loss of products
Deaths	N of people death	More or equal to 10	Between 5 and 9	Between 1 and 4
Cars	Cars dragged or affected by water	More or equal to 20 dragged	Between 5 and 19 dragged	Damaged and/or between 1 and 4 dragged

Table 1. Indicators to determine the impact category of each flood event.

Figure 2. Photos of flood events in the AMB. (Source: *La Vanguardia* newspaper)

Flood events have been classified according to their impact (Llasat et al., 2016). This classification allows distinguishing between three categories: ordinary, extraordinary and catastrophic flood.

SPATIO-TEMPORAL DISTRIBUTION

1996-2015

Number of flood events in the AMB: 61
Flood events with catastrophic impact in the AMB: 5%
Flood events with extraordinary impact in the AMB: 16%
Total compensations paid for floods (CCS) in the AMB: 86.3 M€

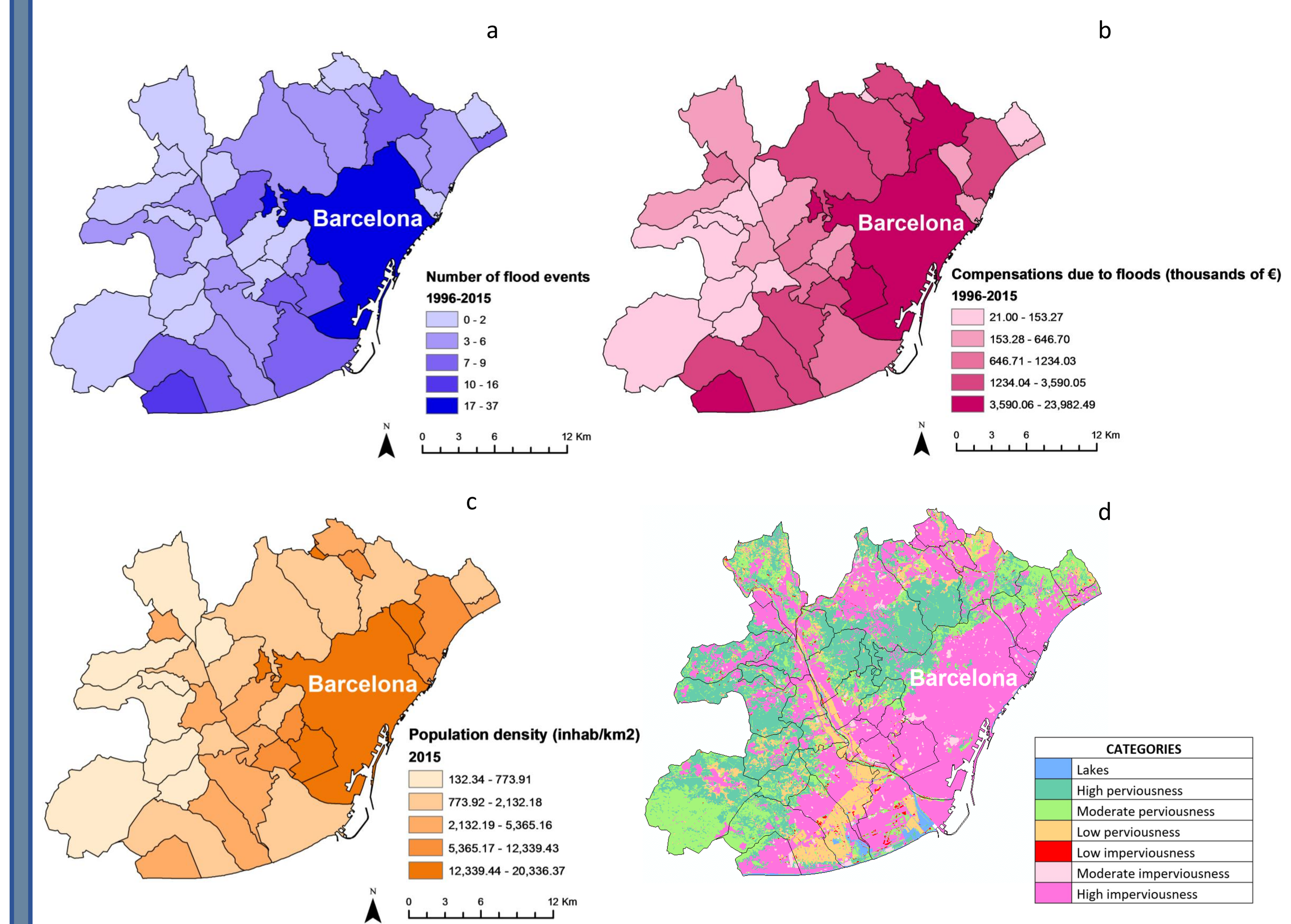


Figure 3. a) Municipality distribution of the total number of flood events; b) compensations paid by CCS for damages due to floods; c) population density; d) the impervious/pervious map based on Land Cover and Land Uses map 2009.

RELATIONSHIP BETWEEN PRECIPITATION AND DAMAGES

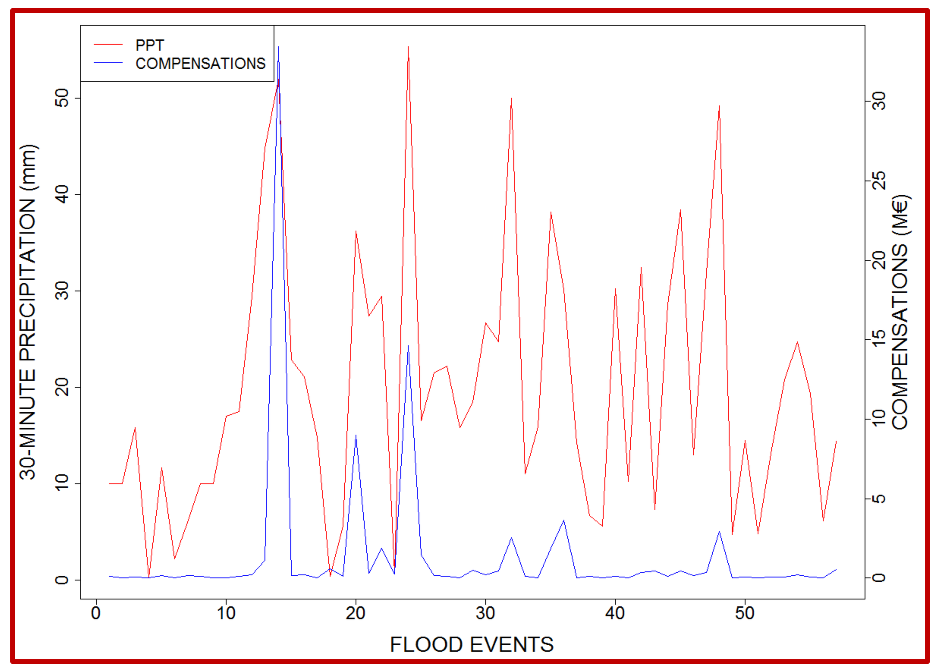


Figure 4. Correlation between compensations (CCS) and maximum 30-minute precipitation for flood events recorded in AMB (1996-2015).

	PRECIPITATION 24h	30-MINUTE PRECIPITATION	ACCUMULATED PRECIPITATION	DAMAGE
PRECIPITATION 24h		0.39***	0.97***	0.31**
30-MINUTE PRECIPITATION	0.39***		0.38***	**0.64*** **
ACCUMULATED PRECIPITATION	0.97***	0.38***		0.31**
DAMAGE	0.31**	**0.64*** **	0.31**	

** p-value<0.1; ** p-value<0.05; *** p-value<0.01*

Table 2. Correlation values between all the variables: maximum precipitation 24h, maximum 30-minute precipitation, maximum accumulated precipitation and damage (CCS) for each flood event. The red shaded squares show the best correlation with damage.

30-minute precipitation shows the best correlation with estimated damages from CCS. This is coherent with the hypothesis. The strong correlation between precipitation in 24h and accumulated precipitation points that the major part of the events lasts one day or less.

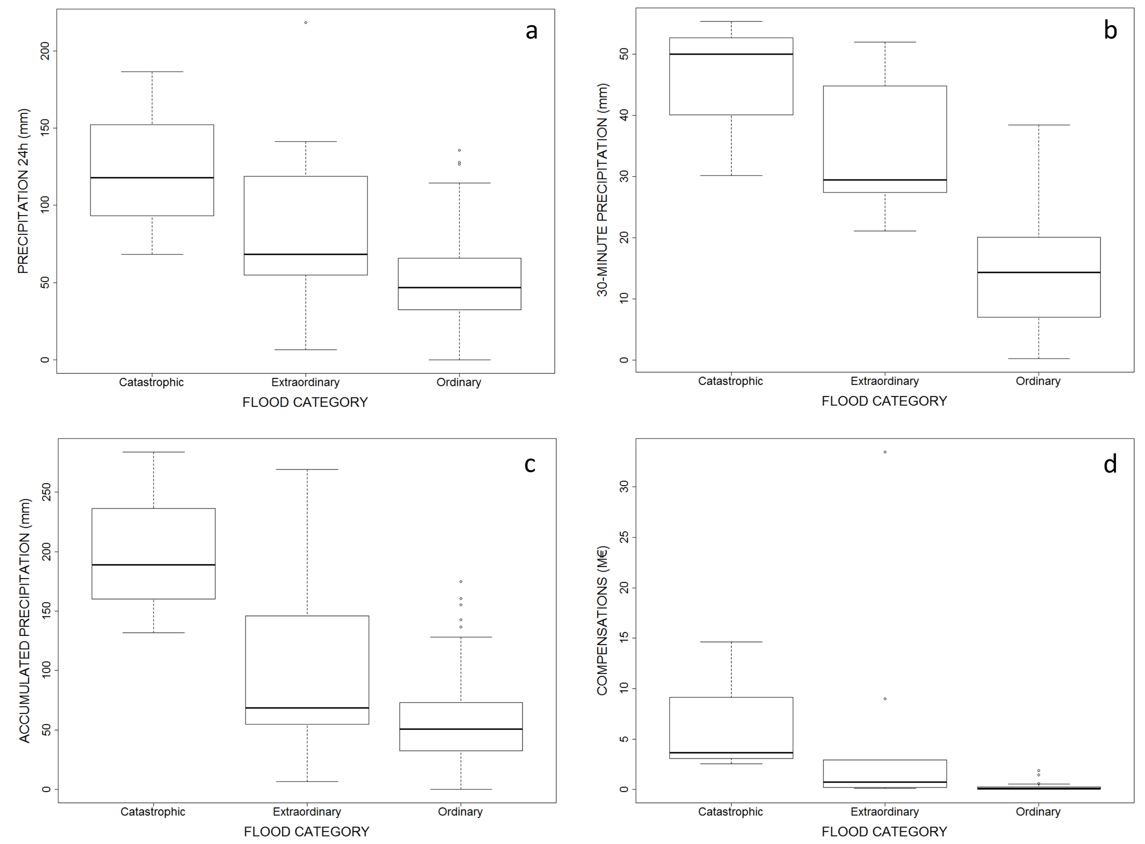


Figure 5. Boxplots showing the distribution for each category (1996-2015): a) Maximum precipitation 24h; b) Maximum 30-minute precipitation; c) Maximum accumulated precipitation; d) Compensations.

	CATASTROPHIC	EXTRAORDINARY	ORDINARY
PRECIPITATION 24h (mm)	118	68.45	46.70
30-MIN ACCUMULATED PRECIPITATION (mm)	50	29.40	14.30
ACCUMULATED PRECIPITATION (mm)	188.90	68.45	50.90
DAMAGE (M€)	3.63	0.71	0.10

Table 3. Median values for precipitation and damage variables according to flood category.

Catastrophic events presents higher values of precipitation and damage than extraordinary and ordinary ones, as it could be expected. The maximum 30-minute accumulated precipitation values for catastrophic and extraordinary categories are very high, being around 50 mm and 30 mm in 30 minutes, respectively. These results confirm that the most common type of floods in this region, flash floods, come from intense and short precipitation events (Llasat et al., 2016). Furthermore, the boxplots analysis shows that the classification of Table 1, made from qualitative criteria, can be associated with mean values and objective thresholds.

FLOOD IMPACT INDEX

Flood events: 13 selected events (extraordinary and catastrophic).
Area of Study: Metropolitan Area of Barcelona (AMB)
Period: 1996-2015.
Methodology: modified from Amaro et al. (2010) and Barberia et al. (2014).

VARIABLE	DEFINITION
LR	Maximum precipitation recorded in 24h
LI	Maximum 30-minute precipitation
LP100	Affected population (accumulated precipitation>100 mm)
LTR	Duration of the flood event

Standardised

$$FII = LR + LI + LP100 + LTR^{0.5}$$

FII — DAMAGES

0.6**

The Flood Impact Index (FII) presents a good and significant correlation with compensations paid by CCS.

TRENDS

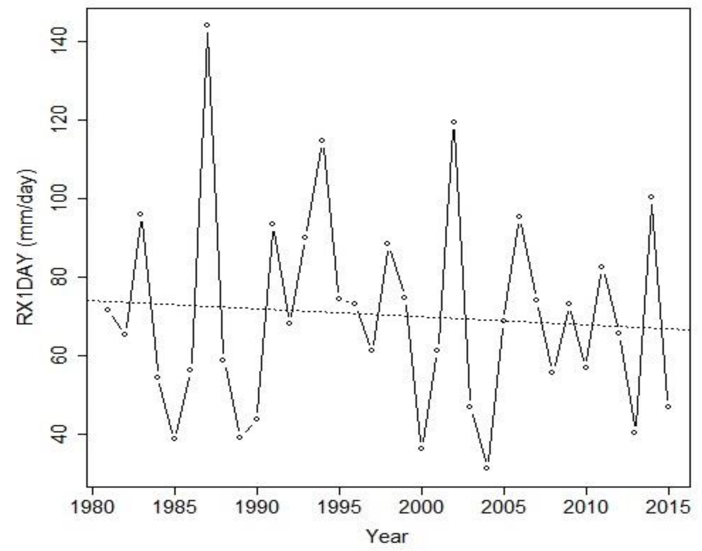


Figure 6. Evolution of the ETCCDI RX1DAY index (mm/day) for Fabra Observatory (1981-2015).

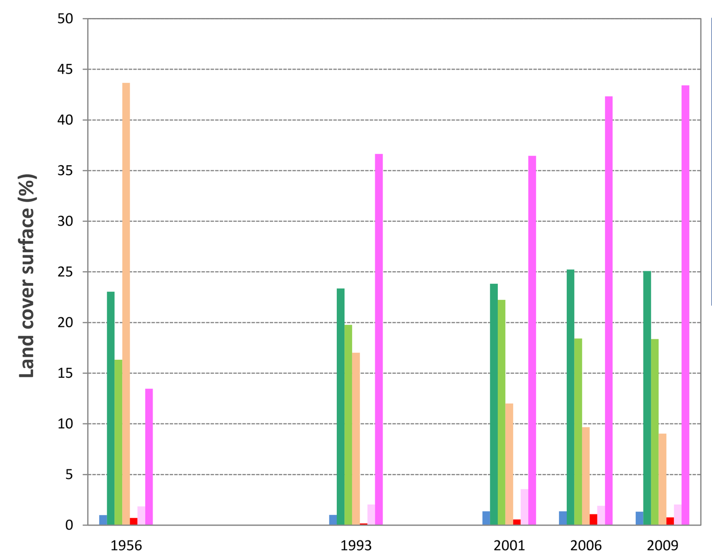
ETCCDI	Description
PRCPTOT	Total precipitation
SDII	Mean precipitation amount per rainfall day
RX1DAY	Maximum precipitation in one day
RX5DAY	Maximum precipitation accumulated in five days

AIRPORT	PRCPTOT	SDII	RX1DAY	RX5DAY
Trend (unit/year)	-5.44**	-0.08*	-0.60	-2.08*
FABRA	PRCPTOT	SDII	RX1DAY	RX5DAY
Trend (unit/year)	-2.74	-0.02	-0.20	-1.38

** p-value<0.1; ** p-value<0.05; *** p-value<0.01*

Table 4. Description of ETCCDI indices and trend analysis of ETCCDI (Airport and Fabra observatories).

All the series show a negative trend, being statistically significant only at the Airport station for the indices PRCPTOT, SDII and RX5DAY.



Although the impervious soil has grown more than 200% from 1956 to 2009, between 1993 and 2009 it has passed from 36.5% to 43.4%.

Figure 7. Evolution of the percentage of land cover surface classified according to their permeability.

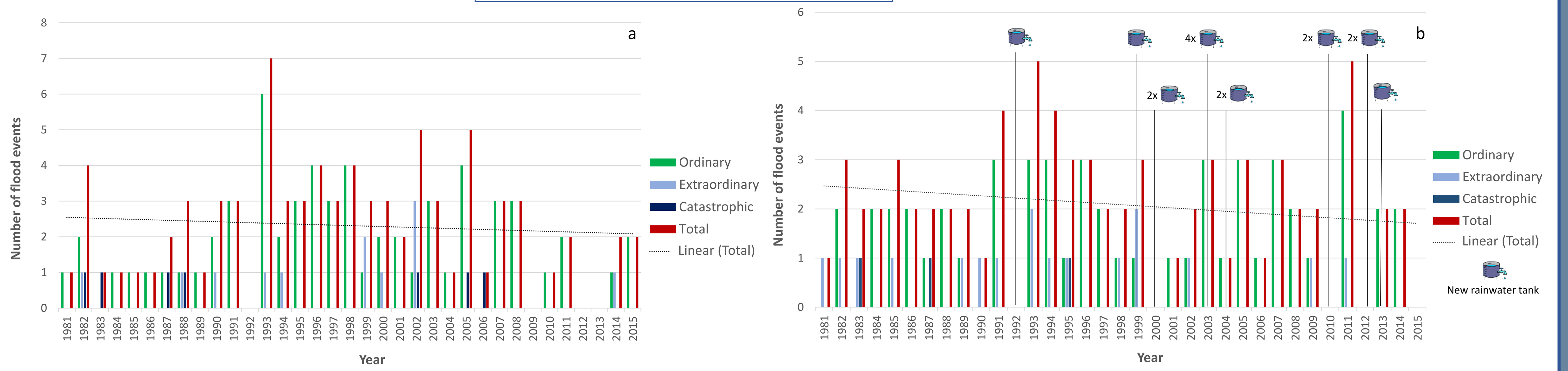


Figure 8. Number of flood events (1981-2015) according to their impact category in: a) the AMB without Barcelona; b) the city of Barcelona.

Although a positive and significant trend of 0.3 episodes / decade in the AMB has been found for the period 1900-2015, the trend in all the other periods and categories is negative (not significant). If we analyse it by separating the different categories, we observe that in the AMB there is an increase of the ordinary floods of 0.15 episodes / decade, mainly due to an increase of this type of events in Barcelona. In this city, however, there is a negative and significant trend of the extraordinary events, probably related to the protection measures implemented, such as the rainwater tanks built since the 1990s.

METROPOLITAN AREA OF BARCELONA	TOTAL	CATASTROPHIC	EXTRAORDINARY	ORDINARY
Trend (unit/decade)	-0.10	-0.10	-0.15	0.15
BARCELONA				
Trend (unit/decade)	-0.18	-0.08*	-0.20**	0.11
METROPOLITAN AREA OF BARCELONA WITHOUT BARCELONA				
Trend (unit/decade)	-0.13	-0.09	-0.03	-0.01

** p-value<0.1; ** p-value<0.05; *** p-value<0.01*

Table 5. Trend analysis for the number of flood events for AMB, Barcelona and AMB without Barcelona.

CONCLUSIONS

The Metropolitan Area of Barcelona is affected by an average of more than three flood events annually, some of them with catastrophic effects. Flood events evolution (including urban floods) for the period 1981-2015 does not show any significant trend. This fact could be explained by: the lack of positive trend in extreme precipitation indices in this area; the improvement in flood prevention measures, mainly in Barcelona city, where a negative significant trend on flood events has been found for extraordinary and catastrophic events; the little increase in the impermeable soil (urban uses, road infrastructures…); and the small growth of the population.
Although flood impact depends on multiple factors not considered in the present analysis (i.e. hydraulics), a good correlation has been found between 30-minute precipitation and compensations paid by CCS. Objective thresholds have been also identified for different impact categories. Catastrophic flood events exceed precipitation values of: 188.9 mm for the whole event, 118 mm/24h, 50 mm/30-minute and 3.63 M€ of compensations paid by CCS.

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