Driving factors of non-linearity rainfall-runoff relationships at different time scales in small Mediterranean-climate catchments

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Introduction

The complexity of Mediterranean fluvial systems is caused by the multiple temporal and spatial heterogeneities in the relationships between the natural and human-induced abiotic and biotic variables (Borg Galea et al. 2017). The Mediterranean climate, between 32º and 40º N and S of the Equator, is characterized by a wet and mild winter, a warm and dry summer and a high inter- and intra-annual variability in rainfall patterns.

Under these climatic conditions, catchments are mostly characterized by a high diversity in hydrological regimes (Oueslati et al. 2015) promoting significant temporal and spatial differences in the hydrological response. The seasonality of the Mediterranean climate plays a key role in the runoff generation processes, increasing the non-linearity of the rainfall-runoff relationship at the event scale (Lana-Renault, 2007).

To reduce the spatio-temporal scale variability, small experimental and representative catchments are useful to observe the hydrological response under different or specific land use, lithology and human effect characteristics .

Aim

The aim of this work is to investigate the rainfall-runoff relationship at different temporal scales in representative **small Mediterranean-climate catchments** (i.e., <10 km^2), evaluating the role of lithology and land use. At the annual scale, the runoff response was assessed at **43 catchments** under a pervious or impervious lithology. At the event scale, the rainfall-runoff response of **203 events** was investigated to examine the effects of seasonality, lithology and land use.

In addition, the inter- and intra-annual variability of the rainfall-runoff and the temporal downscaling (i.e., annual to event scale) was studied in the Es Fangar Creek catchment (3.35 km^2; Mallorca, Spain) during five hydrological years.

Methods - study areas

Catchment area from 0.05 to 9.61 km^2. Median and standard deviation of 1.03 and 2.6 km^2 respectively.

Mean annual rainfall from 367 to 1794 mm yr^{-1} with a median value of 833 mm yr^{-1} ± 334 mm yr^{-1}.

Mean annual temperature from 6.6 to 17.2º C with a median value of 13.9ºC ±3º C.

The **predominant lithology** was pervious in 12 catchments, and was impervious in the other 31.

Within the 43 catchments, the studies of 12 of them also contained information related to **the main land uses**, which was used in this paper for assessing their hydrological response at the event scale. The main land uses were agriculture (3 catchments), agroforestry (3), forestry (1) and shrub (5).

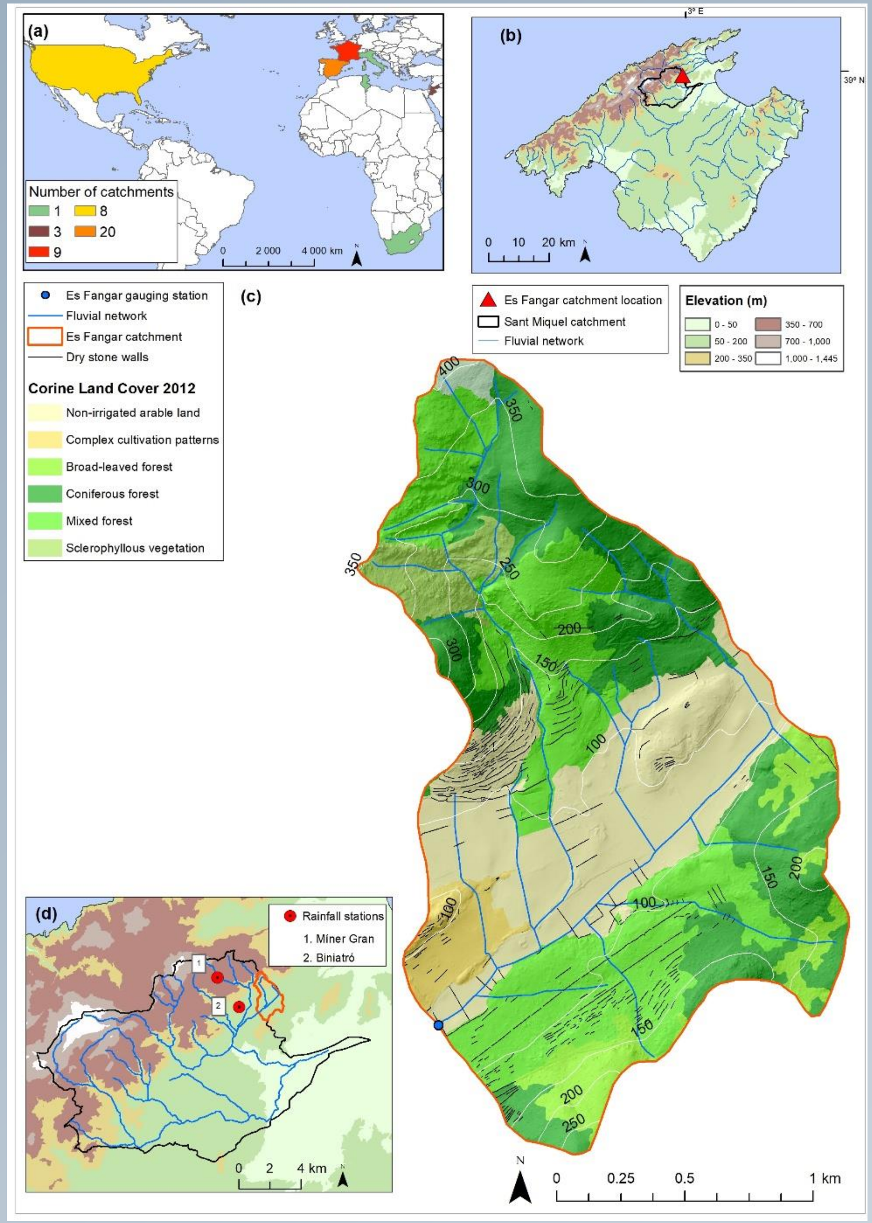


Figure 1. (**a**) Map of the small Mediterranean-climate catchments selected to assess the rainfall-runoff relationship at the annual and event scale. (**b**) Map of Mallorca Island, showing the location of the Sant Miquel River and Es Fangar Creek catchments. (**c**) Map of the Es Fangar Creek catchment, showing the different land-uses, the stream network and the gauging station. (**d**) Map of the Sant Miquel River catchment with the location of rainfall stations used in this study.

Methods – hydrological response small Mediterranean-climate catchments

Bivariate statistical regressions were used to establish the correlations at the annual and event scales between rainfall and runoff in order to assess the hydrological response.

At annual scale, data from the 43 representative catchments were collected to observe the influence of lithology on this response; i.e., the catchments were classified as pervious or impervious by using the information regarding the catchments’ characteristics (e.g., soil type, soil texture or lithology materials)

At the event scale, 203 events from 12 representative catchments were classified according to (a) seasonal occurrence (autumn, winter, spring or summer), (b) pervious or impervious lithology and (c) main land use (agricultural, agroforestry, forest or shrub)

Methods – Es Fangar catchment

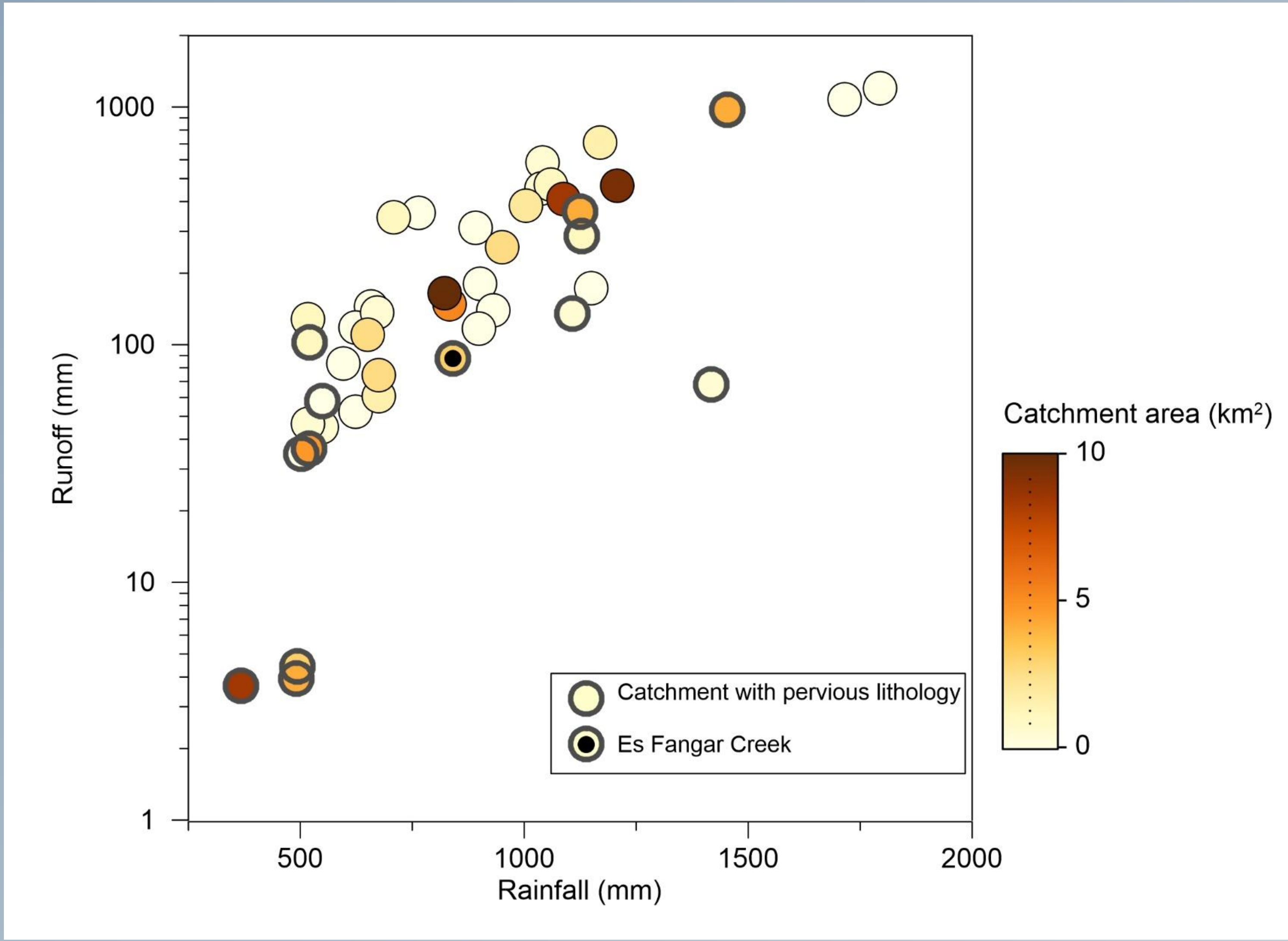
Rainfall and discharge data analysis of five hydrological years (2013 – 2017) at annual, seasonal and event scale (49 events)

At evet scale, 8 variables were derived from hyetograph and hydrograph and there were classified into pre-event conditions and event characteristics

a) Pre-event conditions		b) Event conditions	
Q_0	Baseflow at the start of the flood ($m^3\ s^{-1}$)	P_{tot}	Rainfall depth (mm)
AP1d	Antecedent precipitation 1 day before (mm)	$IP_{mean}30$	Average rainfall intensity ($mm\ h^{-1}$)
		$IP_{max}30$	Maximum 30' rainfall intensity ($mm\ h^{-1}$)
		Q_{max}	Maximum peak discharge ($m^3\ s^{-1}$)
		R	Runoff (mm)
		R_c	Runoff coefficient

For non-linearity analysis, 7 events were selected with a rainfall depth range from 41.8 to 49.8 mm but with different antecedent conditions or rainfall dynamics

Results: small Mediterranean-climate catchments at annual scale

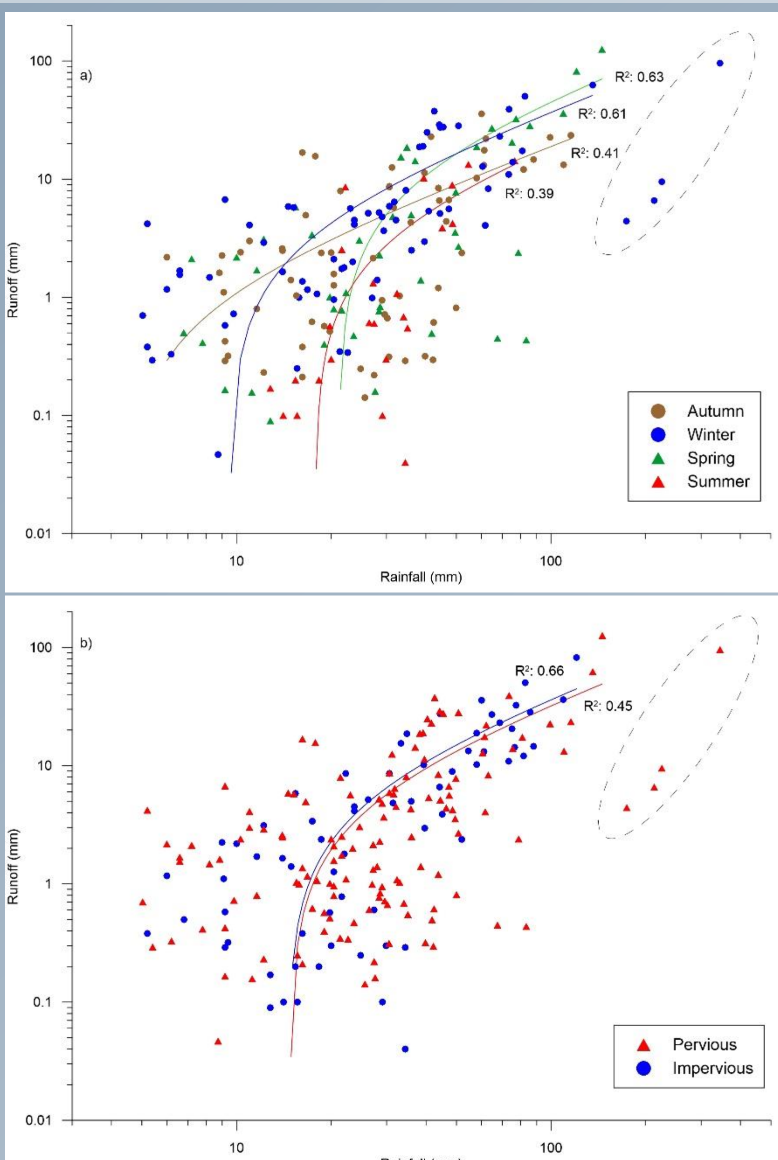


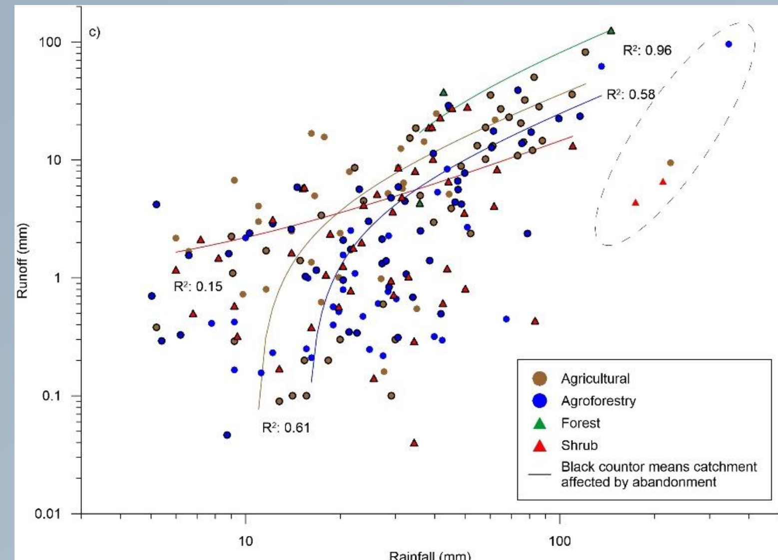
The relationship between annual rainfall and runoff showed a significant positive linear correlation ($R^2 = 0.68$; $p < 0.01$).

However, some scattering was also apparent in the relationship because when catchments with pervious lithology were not included, the regression increased ($R^2 = 0.82$; $p < 0.01$)

Figure 2. Rainfall – runoff for 43 small Mediterranean-climate catchments at annual scale. Catchments with pervious lithology are marked with a grey halo. Es Fangar Creek value is illustrated with a black dot.

Results: small Mediterranean-climate catchments at event scale





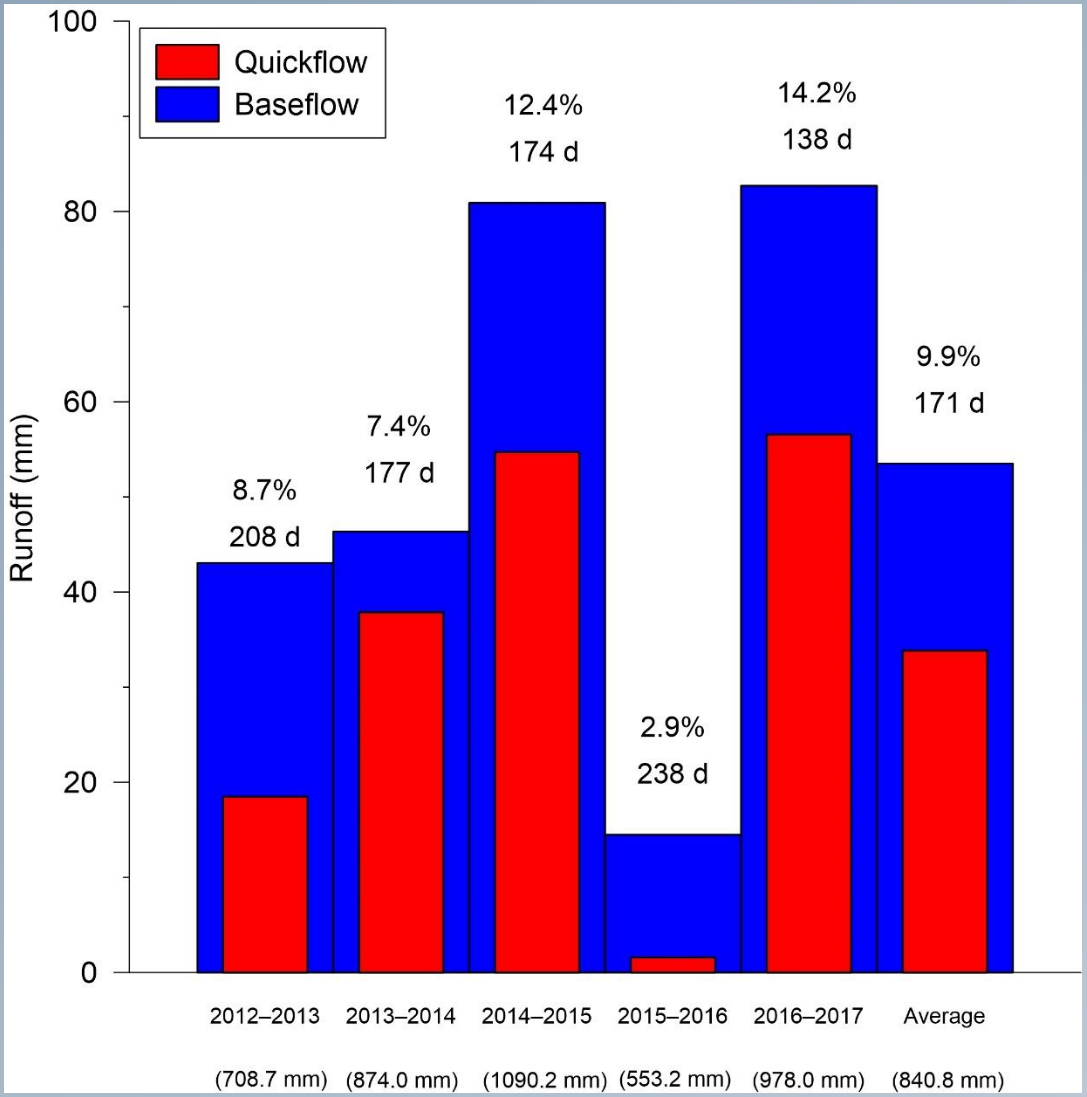
The highest seasonal median of event runoff occurred in winter (4.2 mm). However, those events occurred during the transition periods depicted a similar median runoff (autumn = 2.3 mm; spring = 2.2 mm) being the lowest value for summer events (0.6 mm) (Fig. 3a).

Small differences between the median of runoff events in catchments with pervious lithology (2.2 mm) and catchments without pervious lithology (3.1 mm) were observed. Nevertheless, significant differences in rainfall-runoff relationships were detected as events in catchments with pervious lithology showed the highest correlation and the lowest scattering (Fig. 3b).

The median event R in forest (37.6 mm) was higher than agricultural (5.0 mm), shrub (2.0 mm) and agroforest (1.5 mm) catchments (Fig. 3c).

Figure 3. Rainfall – runoff relationship at event scale classified by (a) season, (b) lithology and (c) land uses at 12 small Mediterranean-climate catchments. Out layers are marked with an ellipsoid.

Results: Es Fangar catchment at annual scale



Linear positive relationships were observed between annual rainfall, runoff, runoff coefficient, baseflow and quickflow ($R^2 \geq 0.84$).

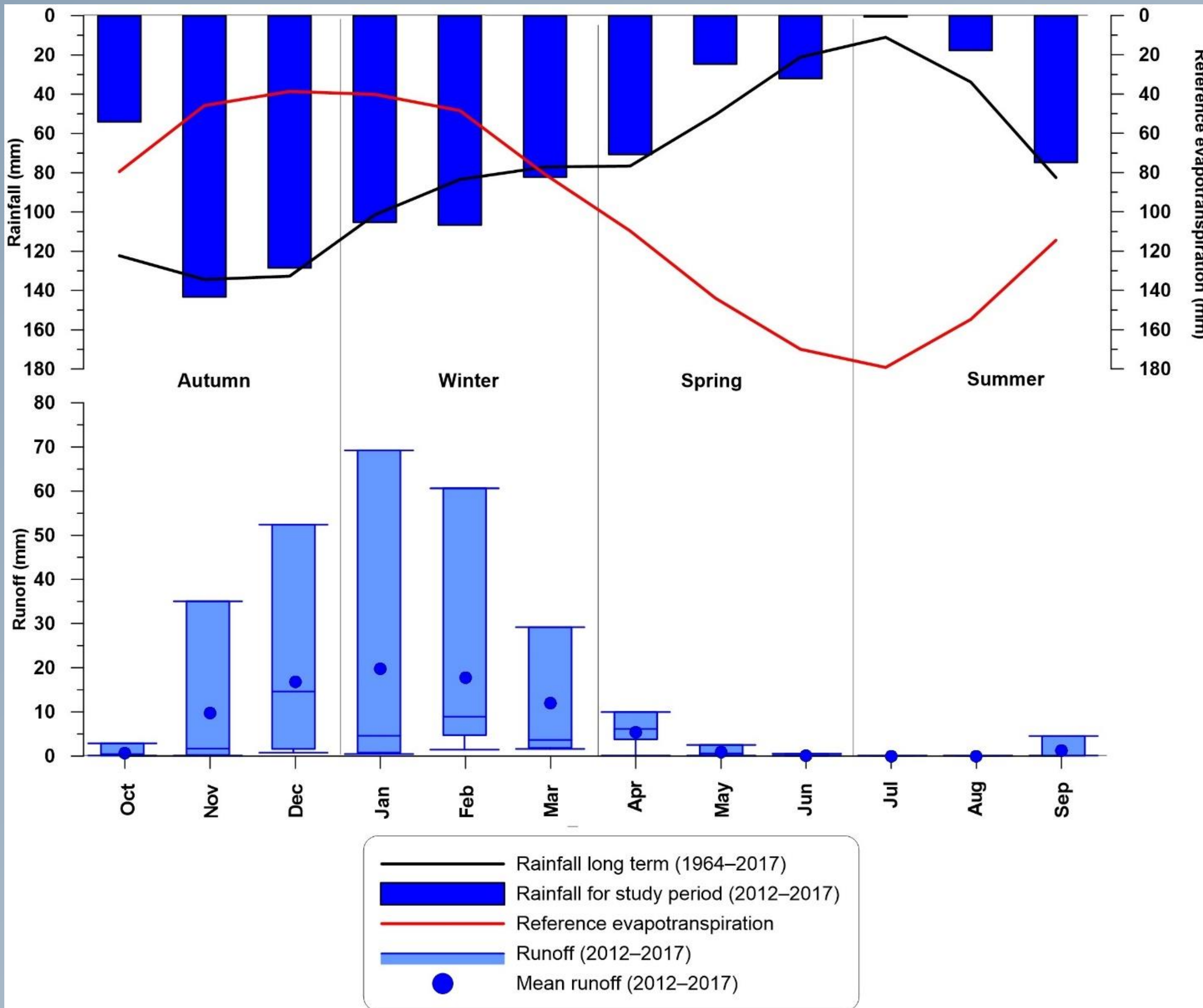
An inverse relation between annual runoff and the number of days with flow was established.

Hydrological years with the largest runoff (2013–2014, 2014–2015 and 2016–2017) showed fewer days with flow and a lower baseflow contribution (<60%).

In these years, 50% to 62% of the annual runoff was reached in 5 or fewer days. In addition, days with more R were always during autumn and winter.

Figure 4. Baseflow and quickflow contributions (mm) in the total flow for each hydrological year (October to September) at Es Fangar Creek. The annual Rc is depicted in % as well as the total number of days (d) with recorded flow at the gauging station. The total annual rainfall is also illustrated between brackets.

Results: Es Fangar catchment at seasonal scale



The seasonal dynamics of rainfall and evapotranspiration controlled the runoff response. Characteristic wet (winter) and dry (summer) periods alternated throughout the year, separated by transition periods (last autumn and early spring).

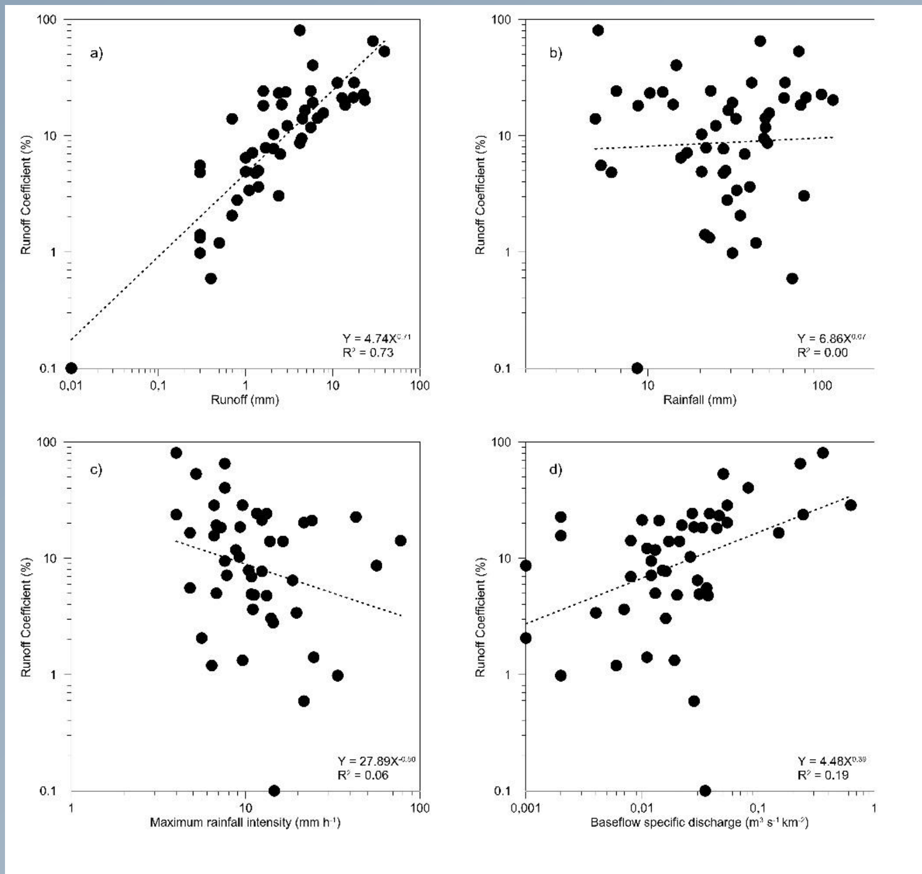
Autumn was the rainiest season, with low evapotranspiration and flow observed at the outlet for 52.7% of the time.

During winter, flow occurred during 90.6% of the time, although the mean rainfall amount (294 mm) was lower than in autumn (326 mm).

This more frequent presence of flow was caused by the low evapotranspiration demand, thus keeping the hydrological pathways active, as already established in autumn.

Figure 5. Monthly time series of rainfall, R, reference evapotranspiration during the study period (2012-2017) at Es Fangar Creek. Box plots show minimum, median and maximum monthly R. Blue dots show mean monthly R. Long term (1964-2017) monthly rainfall distribution is also depicted.

Results: Es Fangar catchment at event scale



In Figure 7, runoff coefficient ranged from 1% to 65%, depending on the catchment moisture conditions, rainfall intensities and seasonality characteristics. The highest hydrological response occurred under marked wet soil moisture conditions in the winter period, even with low rainfall intensities

Figure 6. Relationship between (a) R and Rc coefficient, (b) rainfall and Rc, (c) IPmax30 intensity and Rc and (d) base-flow specific discharge and Rc at Es Fangar Creek. Dotted lines show significant (p< 0.01) fits with a power function.

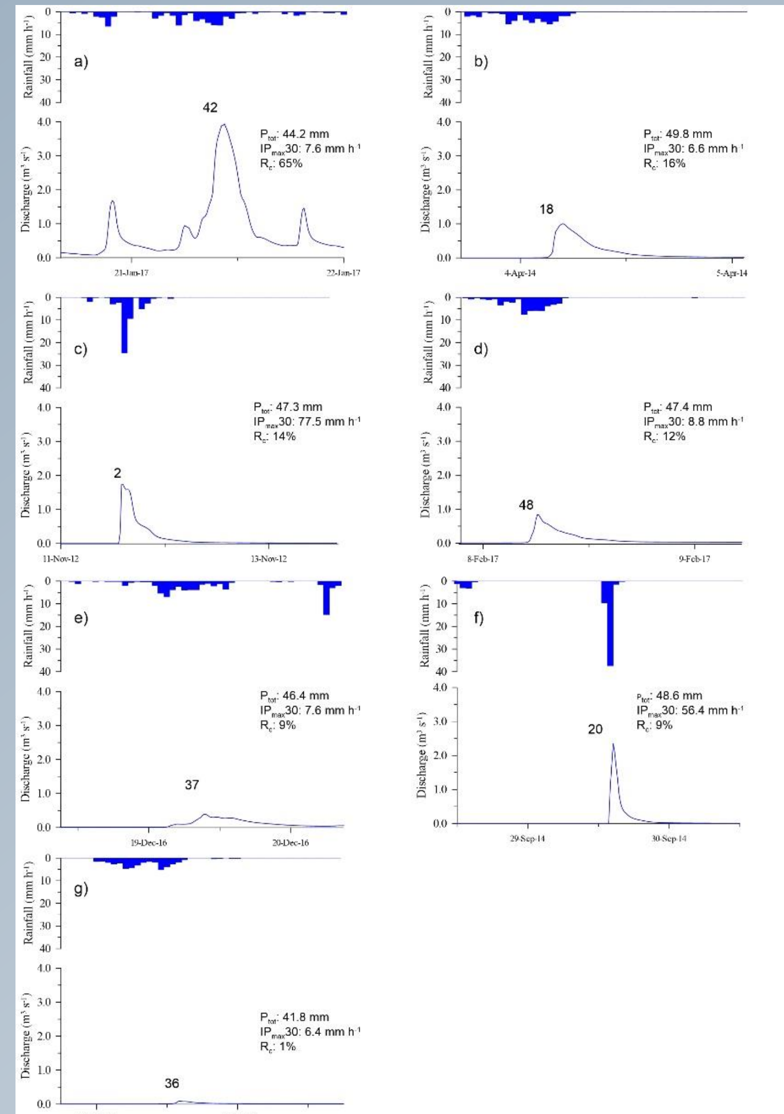


Figure 7. Selected events for non-linearity analysis at Es Fangar Creek. Events with a total precipitation between ca. 40-50 mm. The numbers located at the peak of each hydrograph indicate the ID of the events recorded in Es Fangar Creek during the study period 2012-2017

Conclusions

The assessment of rainfall-runoff relationships at the annual scale in small Mediterranean-climate catchments showed a significant linearity in the hydrological response due to the importance of the annual rainfall amount

Lithology effects on runoff generation explained an increase in the scattering in the rainfall-runoff relationship because pervious and impervious materials triggered larger and lower runoff contribution, respectively

Es Fangar Creek dataset illustrated a huge intra-annual variability of the rainfall-runoff relationship during the five hydrological years, as seasonal rainfall and evapotranspiration dynamics controlled the runoff response

Events under agricultural land use or which occurred in the winter season independently of the land use and lithology catchments were the situations which were able to generate a higher linearity in the rainfall-runoff relationships

The assessment of rainfall-runoff relationships under contrasted lithology, land use and seasonality is a useful approach to improve the hydrological modelling of global change scenarios in small catchments where the linearity and non-linearity of the hydrological response—at multiple temporal scales—can inherently co-exist in Mediterranean-climate catchments

For more information

Fortesa J., Latron J., García-Comendador J., Tomàs-Burguera M., Calsamiglia A., Estrany, J. 2020. *Multiple Temporal Scales Assessment in the Hydrological Response of Small Mediterranean-Climate Catchments.* Water, 12(1), 299.

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