Article

Identification of flood-rich and flood-poor periods by using the longest streamflow records in Spain

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Abstract: Currently, there is general concern about the non-stationary behaviour of flood series. Consequently, several studies have been conducted to identify large-scale patterns of change in such flood series. In Spain, a general decreasing trend was found in the period 1959-2009. However, a multi-temporal trend analysis with varying starting and ending years showed that trend signs depended on the period considered. Flood oscillations could influence the results, especially when flood-rich and flood-poor periods are located at the beginning or end of the series. In Spain, a flood-rich period in 1950-1970 seemed to lead to the generalised decreasing trend, as it was located at the beginning of the flood series. Nevertheless, the multi-temporal test can only find potential flood-rich and flood-poor periods qualitatively. A methodology has been developed to identify statistically significant flood-rich and flood-poor periods. The expected variability of floods under the stationarity assumption is compared with the variability of floods in observed flood series. The methodology is applied to the longest streamflow series available in Spain. Seven gauging stations located in near-natural catchments with continuous observations in the period 1942-2014 are selected. Both annual maximum and peak-over-threshold series are considered. Flood-rich and flood-poor periods in terms of flood magnitudes and the annual count of exceedances over a given threshold are identified. A flood-rich period in the beginning of the series and a flood-poor period at its end are identified in most of the selected sites. Accordingly, a flood-rich period placed at the beginning of the series followed by a flood-poor period influence the generalised decreasing trend in flood series previously found in Spain.

Keywords: Non-stationarity; Trends in flood series; Flood-rich and flood-poor periods; Peak over threshold; Spain;

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1. Introduction

There is current general concern about the non-stationary behaviour of flood series, due to both climate change and anthropogenic effects, such as changes in land uses and urbanisation, deforestation and river training [1]. Specially, non-stationarity is more evident in long series recorded at gauging stations. Consequently, several studies have recently attempted to identify patterns of change and trends in flood series at both small and large scales [2-5]. In Spain, [3] found a generalised decreasing trend in flood magnitude that was more evident in the period 1959-2009. A multi-temporal test with varying starting and ending years showed that trend signs depended on the period considered. Series with beginning years in the period 1950-1970 usually led to significant decreasing trends.

This study aims to conduct a sounded statistical analysis to identify potential oscillations in flood series in Spain that cannot be identified by the traditional Mann-Kendall (MK) test. Temporal oscillations may drive consecutive flood-poor and -rich periods. Accordingly, the longest available flood series in near-natural catchments in Spain have been selected. A methodology has been developed based on the comparison between the expected variability of floods under the stationarity assumption with the variability of floods in observed flood series. Statistical significant flood-poor and -rich periods have been identified.

At most of the sites, a flood-rich period has been identified from the beginning of the series to 1980 and a flood-poor period at the end of the series, usually finishing in 2014.

2. Methodology

The methodology proposed in this study to identify flood-poor and -rich periods in flood series analyses the temporal oscillations in annual maximum series (AMS) of floods. AMS are usually characterised by an extremal distribution function. In Spain, a regional study concluded that the distribution function that best characterises AMS in the selected gauging stations is the generalised extreme value (GEV) distribution with the L-moments method [6]:

$$F(x) = exp\left\{-\left[1-k\left(\frac{x-u}{\alpha}\right)\right]^{\frac{1}{k}}\right\} \tag{1}$$

where x is the flood magnitude, u is the location parameter, α is the scale parameter and k is the shape parameter.

Assuming a stationary behaviour in the arrival of floods in the AMS, flood occurrences should be driven by a random process. Therefore, successive flood magnitudes in AMS should be independent. Flood-poor and -rich periods will be identified when such a stationary hypothesis is not met for a significance level α, through the following steps in each gauging station:

1. A GEV distribution function is fitted to flood magnitudes in AMS.
2. N random series of n years are generated from the GEV distribution function fitted in Step 1.
3. The mean value for each N series of n years generated in Step 2 is calculated.
4. Upper and lower thresholds are obtained from the series of N mean values obtained in Step 3, for the confidence intervals ($\alpha/2$) and ($1 - \alpha/2$).

If the mean value of flood magnitudes in n consecutive years in the observed AMS is larger than the upper threshold obtained in Step 4, meaning that the stationary hypothesis is rejected and that the result cannot be explained by climate variability. Consequently, a significant flood-rich period of n years is identified. If the mean value of flood magnitudes in n consecutive years in the observed AMS is smaller than the lower threshold obtained in Step 4, a significant flood-poor period of n years is identified.

In this study, N equals 100,000, n equals 10, 20 and 30 years and α equals 10%, in order to identify flood-poor and -rich periods of n years for a significance level of 10%, with 5% in each tail. However, only the results for 20 years are shown.

In addition, a similar methodology has been developed to identify flood-rich and -poor periods in peak-over-threshold (POT) series, in terms of the flood magnitude of exceedances over a given threshold and the annual number of such exceedances. POT3 series with an average of three exceedances per year are considered. The methodology and results for POT series are not included in this proceeding because of extension limitations.

3. Case study

[3] selected a set of 60 gauging stations in near-natural catchments with long flood series in Spain. From such sites, the seven gauging stations with observations in the longest period 1942-2014 are selected for this study. No continuous longest series are available in Spain, with the reason being that despite observations beginning in 1912 there is a gap in the period 1936-1942 due to no data being recorded either during the Spanish Civil War or for a three-year period after it ended.

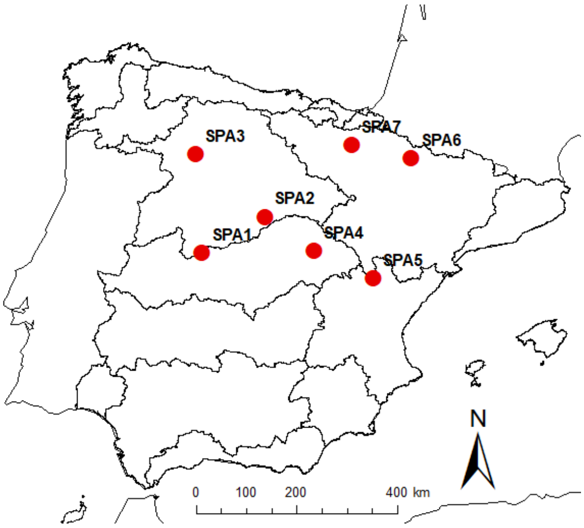


Figure 1. Location of the seven gauging stations with observations in the period 1942-2014.

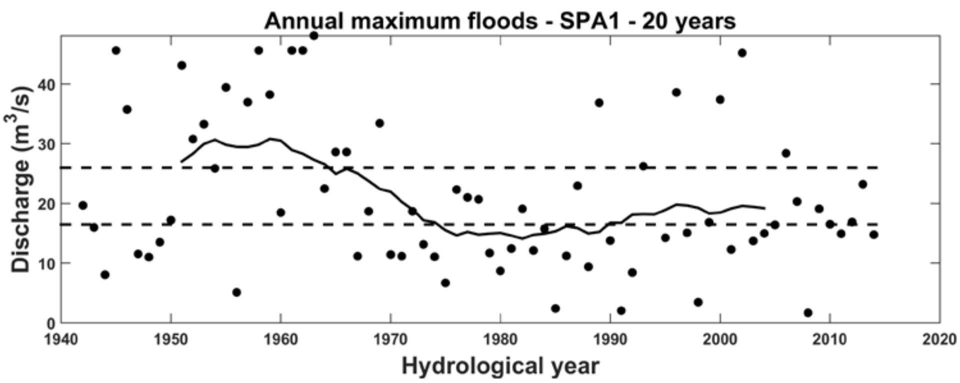
4. Results

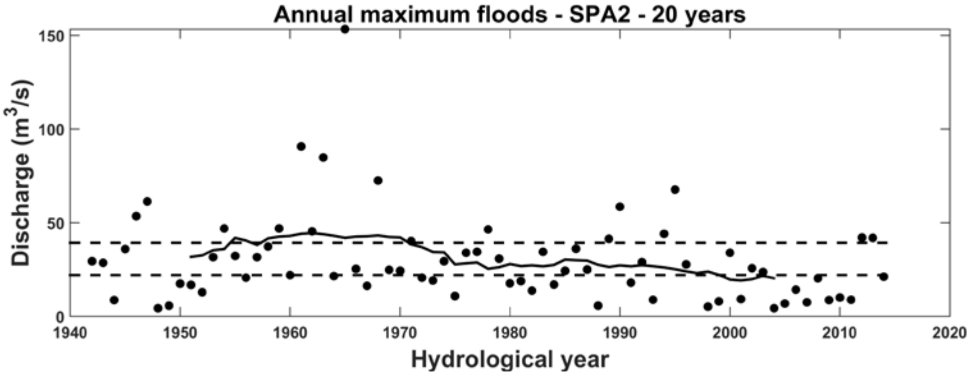
The methodology has been applied to the AMS of floods recorded at the seven gauging stations with observations in the period 1942-2014. A set of 100,000 synthetic series of annual maximum floods with 10, 20 and 30 years were generated. Upper and lower thresholds were obtained for a significance level of 10 % (5% in each tail of the distribution). Significant flood-rich periods were identified when the moving average in *n* years exceeds the upper threshold. Significant flood-poor periods were identified when the moving average in *n* years was below the lower threshold. The results for the moving average in 20 years are shown in Figure 2 and Table 1.

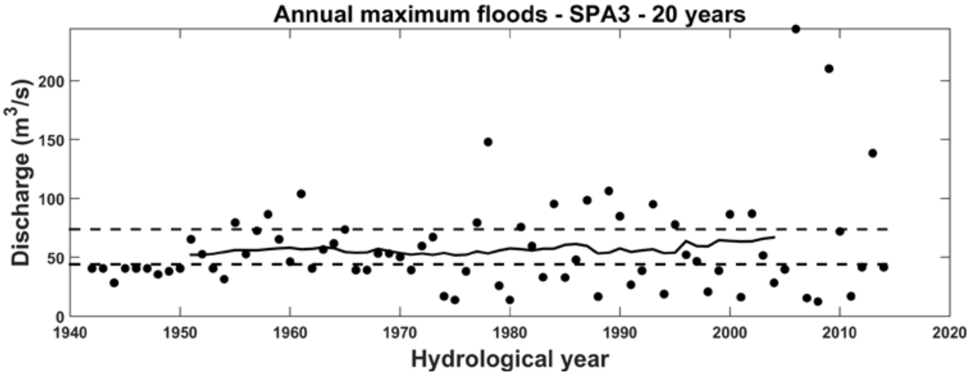
In six of the seven gauging stations, a significant flood-rich period was identified at the beginning of the series, in a period ending around 1980. Such a period ended a little earlier, in 1974, in the case of SPA1. In the case of SPA3, the flood-rich period was delayed, beginning in 1959 and ending in 1986.

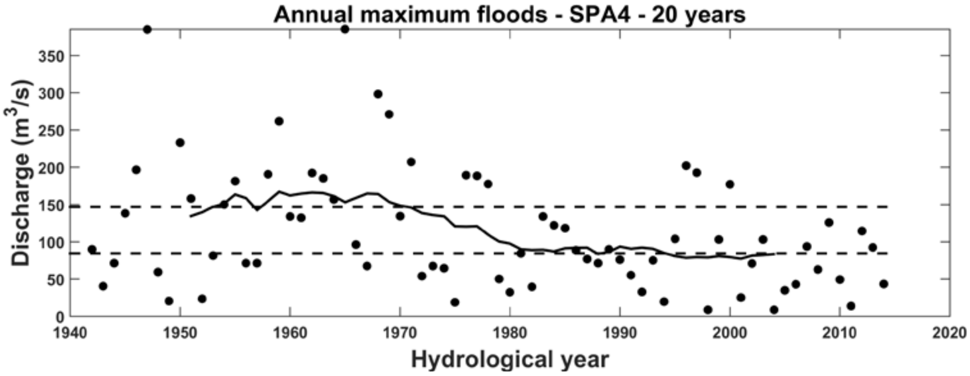
In five of the seven gauging stations, a significant flood-poor period was identified at the end of the series. However, the beginning and ending years vary from one site to another. In four of them, the flood-poor period ended around 2014 and began between 1974 and 1991. In the case of SPA1, the flood-poor period occurred a little earlier in 1966-1999. A flood-poor period was identified at the beginning of the series in SPA6.

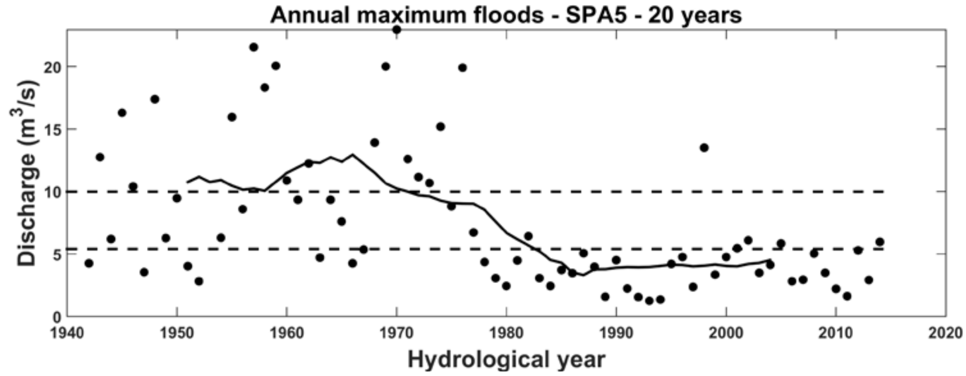
Neither flood-rich nor flood-poor periods were identified in the gauging stations SPA3.

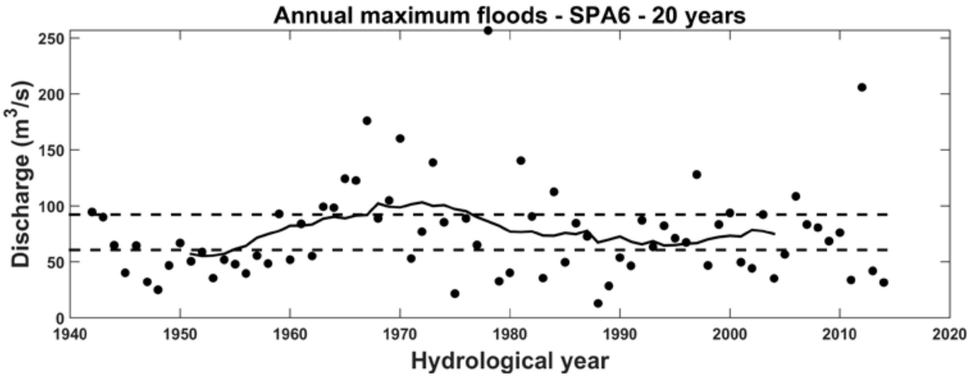



Annual maximum floods - SPA2 - 20 years
Discharge (m3/s)
Hydrological year


Annual maximum floods - SPA3 - 20 years
Discharge (m3/s)
Hydrological year


Annual maximum floods - SPA4 - 20 years
Discharge (m3/s)
Hydrological year


Annual maximum floods - SPA5 - 20 years
Discharge (m3/s)
Hydrological year


Annual maximum floods - SPA6 - 20 years
Discharge (m3/s)
Hydrological year

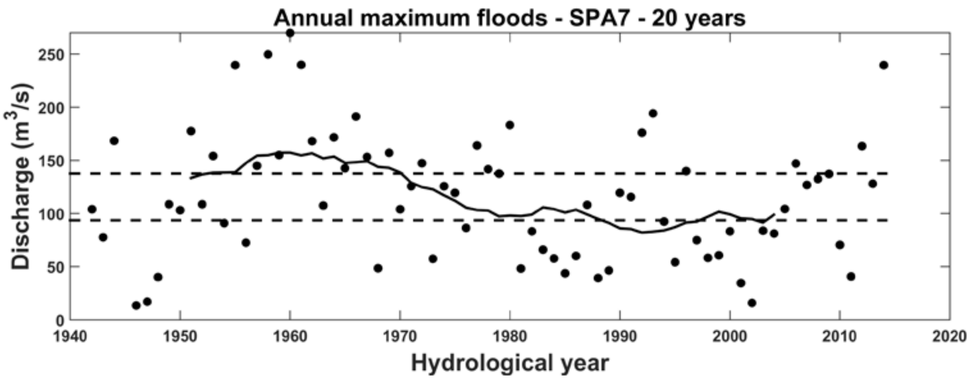


Figure 2. Flood-poor and -rich periods identified in the AMS of floods. The circles represent the magnitude of annual maximum floods in the recorded series at each gauging station. The solid line represents the 20-year moving average. The dashed lines represent the upper and lower thresholds for the confidence intervals ($\alpha/2$) and ($1 - \alpha/2$).

Summarising, in six of the seven gauging stations, a significant flood-rich period is identified from the beginning of the series to around 1980. In addition, at five of the seven sites, a significant flood-poor period is identified at the end of the series with a varying beginning year, but most likely finishing at the ending year of the series.

Table 1. Significant flood-rich and -poor periods identified in the observed flood series.

Gauging station	Flood-rich periods	Flood-poor periods
SPA1	1942-1974	1966-1999
SPA2	1946-1980	1991-2014
SPA3	-	-
SPA4	1945-1980	1986-2014
SPA5	1942-1981	1974-2014
SPA6	1959-1986	1942-1964
SPA7	1944-1980	1980-2007

5. Conclusions

A methodology to identify statistical significant flood-poor and -rich periods has been presented. The methodology is based on the comparison between the expected variability of flood magnitudes under an assumption of stationarity and the actual variability of flood magnitudes in observed flood series.

Seven gauging stations with the longest recorded flood series in the period 1942-2014 in Spain have been selected. In six of the seven gauging sites, periods that do not meet the hypothesis of stationarity have been found. A period with unexpected large and consecutive floods, or a flood-rich period, from the beginning of the series to around 1980 has been identified at six of the seven sites. A period with unusual small consecutive floods under the hypothesis of stationarity, or flood-poor period, has been identified at the end of the series in four of the seven gauging stations.

This finding could explain the generalised significant decreasing trend identified by the MK test at most of gauging stations located in Spain in [3]. A flood-rich period at the beginning of the flood series followed by a flood-poor period at the end of the series influence such trends. Consequently, the decreasing trend may not point to decreasing flood magnitudes in the future, though it seems to have been caused by a natural temporal oscillation in flood magnitudes with consecutive flood-rich and -poor periods.

Abbreviations

The following abbreviations are used in this manuscript:

AMS: Annual maximum series
GEV: Generalised extreme value
MK: Mann-Kendall
POT: Peak over threshold

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