

Abstract

In the last decade, a topic that has been placed at the forefront in Hydrology is the need not continue to assume the stationarity hypothesis in the study of the components of the hydrological cycle. This due the evidences of intensification of human activities, natural climate variability and climate change. In fact, in the scientific community there is a consensus that the assumption of stationarity in the Hydrological Cycle is compromised. Thus, in the light of the collapse of stationarity hypothesis which has been the cornerstone in the flood frequency analysis, various researchers have been expressed in the sense of the urgent need to propose ideas and alternative methods suitable to deal the task of hydrologic design in the context of climate and anthropogenic changes. Consequently, in response to the paradigm shift of not to continue assuming a stationary world this work aims to try to contribute to the study of flood frequency analysis under non-stationarity conditions. To do this, the effects of climate variability and human-induced changes through the reservoirs had been involved. Our interest focuses particularly on flood regimes in rivers of peninsular Spain.

The study begins with a literature review of two issues: the influence of macroscale phenomena in hydrological variables and the current state of flood frequency analysis. Subsequently, there is a description of the study area and an exploratory analysis of the information, which identifies the dominant types of flood regimes in the study gauging stations and introduces a proposed reservoir index to identify the impact of reservoirs in sites under the altered regime. The analysis showed the important role exerted by the winter precipitation in flood regimes in a significant percentage of gauging stations, allowing us to glimpse the potential of low-frequency circulation patterns (which are associated with these rainfall) as covariates in statistical modelling of floods.

In the second part of this thesis, it tests the hypothesis of stationarity in flood regimes at different time scales through various statistical tests. It was noted that the flood records exhibit significant deviations from the stationarity hypothesis. Furthermore, this analysis also identified the important role that patterns of low-frequency variability and reservoirs play in explaining the observed changes in statistical moments of the flood time series (mean and variance).

In the third part, we study the teleconnection between the flood regime and patterns of low-frequency variability from two approaches: correlation analysis and *wavelet* analysis. The results showed that the interannual variability of flood regimes in peninsular Spain is strongly influenced by the low-frequency circulation patterns of the AO, NAO and MO, while less influence is the identified with the WeMO which was observed mainly with gauging stations located in headwater basins of the confederation of the Ebro and the North. In the field of frequencies it was corroborated that climate variations significantly modulate the evolution of fluctuations in flood regimes, being interannual periods in which was observed that climatic and hydrological time series covary in the same frequency in time. This showed that the intensity of fluctuations in flood systems can be explained by changes in the fluctuation patterns. This showed that the intensity of fluctuations in flood systems can be explained by changes in the low-frequency circulation patterns. As to the spatial extent of the influence of low-frequency patterns, it was evident that the response sensitivity of rivers showed high variability in the space, which reflects the complex orographic and morphological characteristics of each basin. It was also observed that the disturbing effect of dams make it difficult to establish a relationship between climate and floods, as has been observed in sites that experience a high degree of regulation. In general the greater influence of low frequency

patterns on flood regimes was identified in the Central and North regions, decreasing it towards the Mediterranean region. With respect to the evaluation of the ENSO influence on flood regimes in peninsular Spain, our results do not enable conclusions about a strong influence, however, can be identified that the influence of ENSO events could be linked to the intensity of the events.

The modeling of the flood regime under nonstationarity conditions was addressed from the time series of averages daily peak flows and average daily mean flows above a threshold in 20 case studies. The implemented models were basically of two types: models incorporating temporal trends and models incorporating external covariates (in our case indices of the low-frequency circulations patterns and reservoir index). The results of the first approach, in which the parameters of the selected distributions were modelled as a function of time only, show the presence of clear non-stationarities in the flood regime in Peninsular Spain. Furthermore, it was observed in modelling of flood events above a threshold that the rate of occurrence of the events is a non-homogeneous Poisson process, showing that the occurrence rate is strongly dependent on the time. The approaches of non-stationary models with the addition of external forcings as explanatory covariates, revealed the feasibility of the climate indices and reservoir index in the proper characterization of non-stationarities in modelling the annual flood regimes, as well as the rate of occurrence of floods above a threshold. In addition, the results highlighted the improvement in the most appropriate description of the interannual variability of flood regime incorporating external covariates, with respect to the incorporation of temporal trends. A point to noted is the use of cubic splines, the addition of smoothing terms allowed us to identifying nonlinear dependence in modelling the parameters of parametric distributions on covariates, however, these types of models that provide a good fit and flexibility tend to over-parameterise when optimizing the degree of freedom and are highly sensitive to changes in the evolution of predictive variables.

The frequency analysis results with the models under nonstationary conditions showed that, for an annual maximum floods with 0.01 annual exceedance probability of exceedance (corresponding to the return period of 100 years under stationary conditions), the variations obtained are dramatic, with extended periods in which the flood quantile values are much higher than the estimates under stationary conditions. These results have far-reaching effects in hydrological practice and are evidence that the traditional stationary simplification we have accepted in past studies of flood frequency could lead us to assume greater risks in hydraulic design than intended. This raises the need to use alternative models that assume the dynamics of nature instead of continuing on with the classic flood frequency analysis. Finally, it is important to mentioning that in a non-stationary world, it is necessary to redefine the concepts of return period and risk reflective of the fact that probability density function changes over time.

Key words: flood frequency analysis / peninsular Spain / stationarity / low-frequency circulation patterns / reservoir index / GAMLSS