FLOOD ANALYSIS WITH THE STANDARDIZED PRECIPITATION INDEX (SPI)

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Abstract

The occurrence of flood spells is difficult to monitor and detect. However, there are some indices that permit to monitor hydrological and climatological conditions in river basins. The SPI (Standardized Precipitation Index) is one of those indices. Though the SPI was originally developed for drought detection and monitoring, it can also be applied to perceive wetter than normal conditions. This study pretends to characterize the relationship between the SPI and annual peak flow occurrences in the Tejo (Portugal) river basin and provide a tool for prediction of high flood risk. Results indicate that SPI satisfactorily explained the development of circumstances leading up to major peak flow events.

1. INTRODUCTION AND OBJECTIVES

Floods and droughts are climatic events that occur at variable time frequencies in many areas of the world (Seiler *et al.*, 2002). Several regions in Portugal are flood-prone areas and, depending on the degree of a wetter than normal event, a flood spell can have an effect on regional and national economic development, with severe social and environmental impacts. There are concerns that current climate changes may intensify floods and droughts. In this context flood risk indicators are an indispensable tool for watershed management, monitoring, risk assessment, and civil protection. The Standardized Precipitation Index (SPI), developed by McKee *et al.* (1993) may be a tool for identification of these events.

The SPI is defined as the number of standard deviations that the cumulative precipitation at a given time scale (usually 1, 3 or 6 months and 1 or 2 years) deviates from the long-term mean. In order to determine SPI, 1, 3, 12 and 24 months of precipitation data are accumulated and fit to a gamma distribution, which is a necessary condition for the SPI calculation (McKee *et al.*, 1993; Ntale and Gan, 2003). The SPI is the value of z from the standard normal distribution calculated based on the same cumulative probability of the gamma distribution. Therefore, the SPI values are the standardization of total gamma-transformed accumulated precipitation values.

A positive value of SPI indicates that precipitation is above average and a negative value, below average. Consequently, values of SPI ranging from −1 to +1 express a normal precipitation regime and values out of this range represent relevant deviations from the normal rainfall amount. Values of SPI ranging from +1 to +1.5 and +1.5 to +2.0 are associated with moderately wet and very wet episodes, respectively, and SPI values exceeding +2 are representative of extremely wet episodes. Moderately dry, very dry and extremely dry spells are characterized by the same SPI ranges with a negative sign (McKee *et al.*, 1993).

Being the SPI normally distributed, a mild/normal precipitation regime is expected 68% of the time (both wet and dry conditions), moderately wet conditions 9.2% of the time, severely wet conditions 4.4% of the time, and extremely wet conditions 2.3 % of the time (McKee *et al.*, 1993, Wu *et al.*, 2007).

The standardized precipitation index (SPI) was developed as a drought index but it has been suggested to be used as an indicator of the progress of soil saturation conditions conducting to floods (Seiler *et al.*, 2002). Morid *et al.* (2006), following McKee *et al.* (1993), state that an important characteristic of the SPI is the possibility of analysis of both dry and wet periods.

SPI may be computed over an extensive variety of time scales, allowing users to choose the most appropriate time scale for their particular analysis (Wu *et al.*, 2005). The use of different timescales allows assessing the effects of precipitation on different water resources components like groundwater, reservoir storage, soil moisture, streamflow (Morid *et al.*, 2006). In practice, a monthly precipitation time series is softened using a moving window of width equal to the number of months desired, e.g. an annual SPI in July is computed using the cumulative rainfall from August of the previous year to July of the year under analysis. Edwards and McKee (1997), in Ntale and Gan (2003), selected a 3 month SPI for a short-term drought index, a 12 month SPI for an intermediate-term drought index, and a 48 month SPI for a long-term drought index. Guerreiro *et al.* (2006) verified that three months time scale is the most appropriate for evaluation of impacts on runoff.

This study focuses on wet periods occurring in the Tejo river basin, Portugal, during the last century. Its main objective is the application of SPI as a flood-risk indicator, and the analysis of the best time scale for flood risk prediction.

2. MATERIAL AND METHODS

The region studied is in the Tejo river basin, in Portugal, on the Southern part of the Tejo river, where agriculture plays a major role in the communities.

Monthly precipitation data sets are available from the national water institute INAG (http://snirh.inag.pt). The analysis was performed using monthly precipitation data from Pavia and Chouto raingauges (Figure

1) with precipitation records between 1911 and 1992. Associated streamgauges used in this study were Pavia and Ponte de Coruche (Figure 1) with maximum annual flow data ranging from 1960-1992 and 1913-1979, respectively. Raingauges and streamgauges were chosen based on length of records and proximity among them.

Figure 1 Raingauge and streamgauge location

The Standardized Precipitation Index (SPI) was calculated monthly for 3, 12 and 24 months time scales. The SPI was determined using monthly precipitation data which was adjusted to a Gamma probability distribution, a necessary condition for SPI calculation (McKee *et al.*, 1993). Gamma distribution is well explained in the literature (Wu *et al.*, 2005), and is described by the following equation:

$$G(x) = \frac{1}{\beta\,\Gamma(\alpha)} \int_0^x x^{\alpha-1} e^{-x/\beta} dx$$

where

G(x) - cumulative probability
β - scale parameter
α - shape parameter
x - random variable (monthly precipitation)
Γ(α) -gamma function

Parameters α and β are estimated by

$$\alpha = \frac{1}{4A}\left(1 + \sqrt{1 + \frac{4A}{3}}\right)$$

and

$$\beta = \frac{\bar{x}}{\alpha}$$

where

$$A = \ln(x) - \frac{\sum(\ln(x))}{n},$$

being n the number of observations.

A Kolmogorov-Smirnov with 5% significance goodness of fit test was performed in order to pursue the SPI calculation (Lajinha and Guerreiro, 2006). The cumulative probability calculated from the Gamma distribution was transposed to the equivalent cumulative probability of the standard normal distribution (zero mean and unit standard deviation), with the resulting z value being the SPI (McKee *et al.*, 1993).

The SPI values correspond to a standardization of gamma-transformed total precipitation values, therefore a SPI equal to zero implies that there was no deviation from the mean rainfall value at the chosen time scale for the analyzed period. Positive values of SPI indicate that precipitation is above the mean value and negative values of SPI indicate that precipitation is below the mean value (Table 1). Thus, humid periods are characterized by positive values of SPI.

Table 1 Classification of the SPI values

SPI	Classification	SPI	Classification
0 to -0.99	Near normal	0 to 0.99	Near normal
-1 to -1.49	Moderately dry	1 to 1.49	Moderately wet
-1.5 to -1.99	Severely dry	1.5 to 1.99	Severely wet
≤ -2	Extremely dry	≥ 2	Extremely wet

As stated by Seiler *et al.* (2002), "a wet period according to the SPI, may be defined, for a time scale i, as the period during which the SPI is continuously positive and reaches a value of +1 or higher". The wet periods were evaluated based on this statement.

Streamflow gauges Pavia and Ponte de Coruche, with a total of 32 years and 50 years of annual peak flow data, respectively, were used in this study. For the frequency analysis of annual peak flow data, a Weibull plotting position was used. Peak flow data above the 85% percentile (SPI>1.0) were selected for this analysis.

From the SPI values and selected peak flow events, wet dynamics was analyzed graphically, at the various time scales (3, 12, and 24 months).

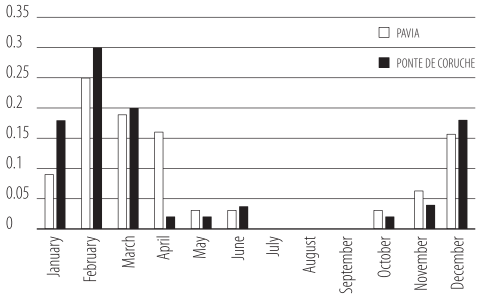
3. RESULTS AND DISCUSSION

Pavia and Chouto rain stations and Pavia and Ponte de Coruche streamflow stations were selected based on the length of records and relative proximity. A minimum of thirty years of precipitation data is necessary to evaluate the SPI, being both stations' records above this value.

Analysis of the outcome of the Kolmogorov-Smirnov goodness of fit test, implied that monthly precipitation data fit a Gamma distribution at both meteorological stations, therefore Pavia and Chouto SPI values were calculated.

Annual peak flow events were analyzed for both Ponte de Coruche and Pavia streamflow gauges. The hydrologic year begins on October, and peak flows tend to occur mainly from December to March. From the 50 peak flow records at Ponte de Coruche station, 15 occurred in February, 10 in March, and 9 at both January and December. From the 32 peak flow records at Pavia station, 8 occurred in February, 6 in March and 5 at both April and December (Figure 2). As expected, there were no recorded peak flows in the summer months of July, August and September, due to low precipitation (Figure 2).

Figure 2. Relative frequency of annual peak flows



Monthly relative frequency of annual peak flows at both stations are very similar, except for the month of April, in which Pavia shows a higher frequency of peak flows than Ponte de Coruche.

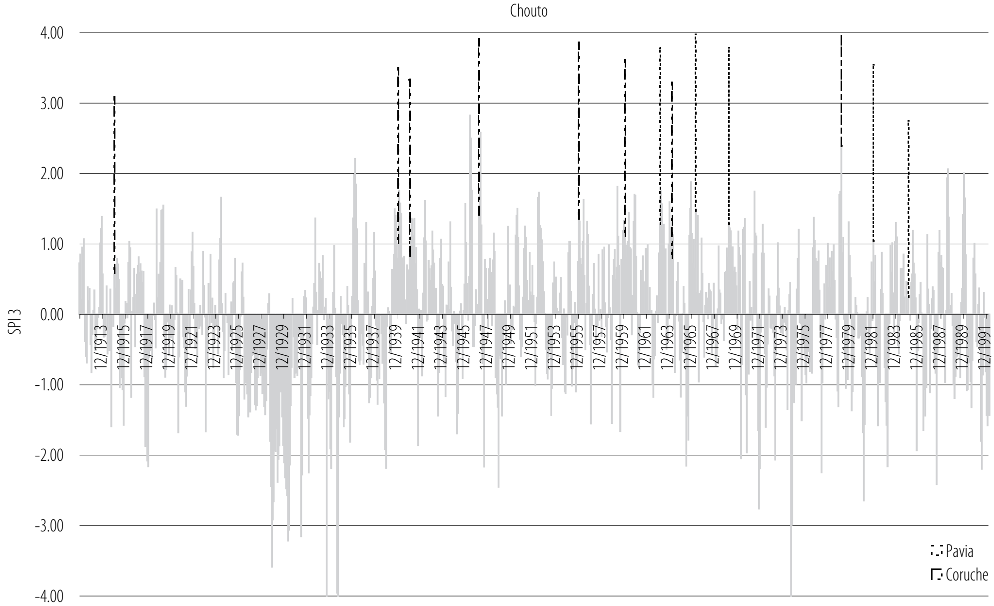
Annual peak flow events from both streamflow stations with a frequency of occurrence below 15% were identified in time and their occurrence and magnitude are presented in Table 2.

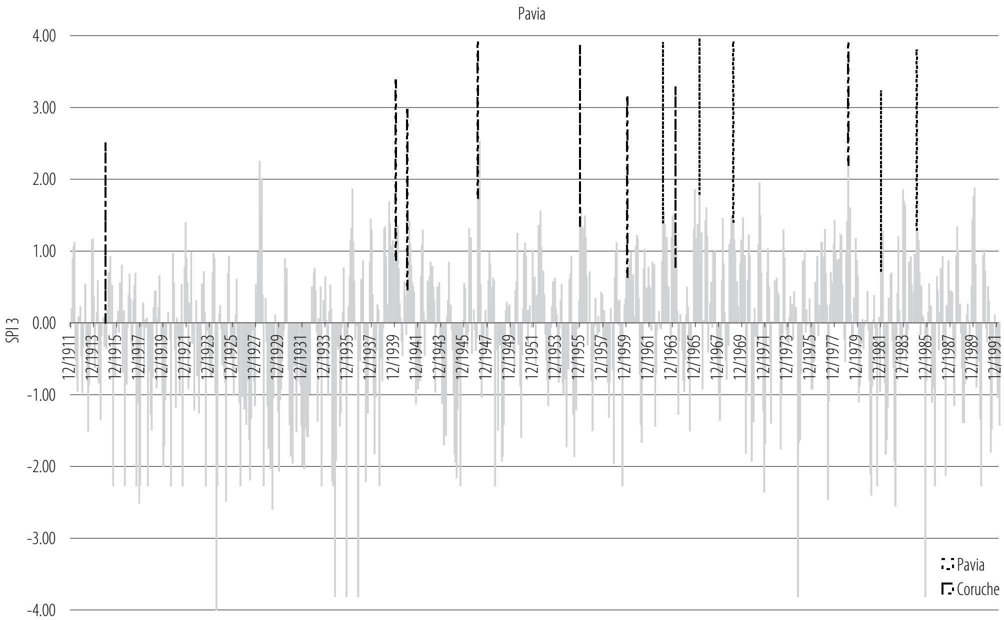
Table 2 Annual peak flows with frequency of occurrence below 15%

Ponte de Coruche stream flow gauge		Pavia stream flow gauge	
Date	Magnitude (m^3/s)	Date	Magnitude (m^3/s)
Jan-1960	1400	Feb-1979	657
Jan-1940	1384	Dec-1981	640
Jan-1941	1354	Mar-1969	620
Dec-1956	1280	Jan-1985	596
Dec-1915	1251	Feb-1963	580
Feb-1979	1178	Apr-1966	540
Feb-1947	1078		
Mar-1964	904		

The SPI values for a time scale of 3 months (SPI 3), 12 months (SPI 12), and 24 months (SPI 24), are presented in Figure 3, along with the major annual peak flows. Major wet and dry periods may be identified from SPI 24 analysis. A long wet period after an extreme dry period that occurred in the 20's and 30's is evident upon analysis of Chouto and Pavia SPI 24, even though Pavia shows longer periods of dry years after this dry period than Chouto.

Figure 3 SPI and annual peak flow events





On the other hand, SPI 12, which represents the yearly deviation of precipitation from the mean, identifies more dry periods within the major wetter period, revealing wetter and drier years within the time span studied. As expected, this is even more evident when analyzing SPI 3, because SPI 3 is more revealing of the randomness of precipitation, identifying possible causes of major annual peak flow events. For larger time scales, there is a slower response of the SPI to short-term precipitation variation and as may be seen from Figure 3, the cycles of positive or negative SPI values are more evident, as supported by McKee *et al.* (1993) and Seiler *et al.* (2002).

It is evident from SPI 24, both at Pavia and Chouto stations that major annual peak flows occurred during a well defined wet period, suggesting that humid soil conditions are the major cause of annual peak flows in the area. SPI 12 also shows this tendency, but also shows that annual peak flows tend to occur after a slightly dry period. This tendency is more evident upon analysis of SPI 3, which suggests that annual peak flows tend to happen when high values of precipitation (large SPI) occur within a short period, following a short dry period.

There are eight well recognizable wet cycles evaluated using SPI 24: 1939 to 1944, 1947 to 1949, 1952 to 1953, 1956 to 1957, 1959 to 1971, 1977 to 1980, 1984 to 1986, 1995 to 1999 at both Chouto and Pavia, which are corroborated by SPI 12. The 1914 and 1981 peak flow events were not expected based on the analysis of SPI 24, SPI 12 or SPI 3. These events might have occurred due to a high intensity precipitation event, which unfortunately is data not available for consultation. The longer time scales (12 and 24 months) with high values of the SPI, imply abundance of water resources over the region, which can be associated to increased runoff during major annual peak flow events.

4. CONCLUSIONS

Overall, it was observed, that a long dry period occurred until the 40's and after that period, there seems to be a tendency for wetter than normal periods.

In a global manner it was observed that major annual peak flow events occurred after the 50's. This fact is more evident when annual peak flows are compared with SPI computed over 12 and 24 months periods. The major peak flow events occur within the wet periods, mostly following a slightly dry period.

For flood mitigation purposes, an analysis of all three time scales should be used, and whenever within a wet period declared at SPI 24, analysis of SPI 12 and SPI 3 should be made, for most peak flow events occur after that slight decreased in SPI values within a wet period.

SPI satisfactorily explained the development of circumstances leading up to major peak flow events.

REFERENCES

GUERREIRO, M. J., Lajinha, T. e Abreu, I. (2006). *Análise de Correlação entre Escoamento e Níveis Piezométricos e o Índice de Precipitação Padronizado SPI (Standardized Precipitation Index).* ***In: 5º Congresso Ibérico de Gestão e Planeamento de Água.*** Faro, Universidade do Algarve.

LAJINHA, M.T. e Guerreiro, M.J. (2006). *Análise de Correlação entre o Escoamento e o Índice de Precipitação Padronizado SPI (Standardized Precipitation Index) na Bacia Hidrográfica do Rio Lima.* ***In: Revista da Faculdade de Ciência e Tecnologia da Universidade Fernando Pessoa****,* Nº. 3, pp. 28-39.

MCKEE, T.B., Doesken, N.J. e Klei, J. (1993). *The Relationship of Drought Frequency and Duration to Time Scales*. ***In: Eighth Conference on Applied Climatology***, 17-22 January 1993, Anaheim, California.

MORID, S., Smakhtin, V. e Moghaddasic, M. (2006). *Comparison of Seven Meteorological Indices for Drought Monitoring in Iran.* ***In: International Journal of Climatology***, Volume 26, pp. 971–985.

NTALE, H.K. e Gan, T.Y. (2003). *Drought Indices and their Application to East Africa.* ***In: International Journal of Climatology,*** Volume 23, pp. 1335-1357.

Seiler, R.A., Hayes, M. e Bressan, L. (2002). *Using the Standardized Precipitation Index for Flood Risk Monitoring.* ***In: International Journal of Climatology***, Volume 22, pp. 1365-1376.

WU, H. Hayes, M.J., Wilhite, D.A. e Svoboda, M.D. (2005). *The Effect of the Length of Record on the Standardized Precipitation Index Calculation.* ***In: International Journal of Climatology***, Volume 25, pp. 505-520.

WU, H., Svoboda, M.D., Hayes, M.J., Wilhite, D.A. e Wen F. (2007). *Appropriate Application of the Standardized Precipitation Index in Arid Locations and Dry Seasons.* ***In: International Journal of Climatology***, Volume 27, pp. 65–79.