Monitoring and characterization of meteorological and hydrological drought in the high Ziz watershed

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Abstract. The understanding of the characteristics and the effects of drought is essential for an effective drought assessment and management in all regions of the globe. The south-east of Morocco is characterized by an arid and semi-arid climate, and the High Ziz watershed, which is part of this region of Morocco, is the area in that this study was conducted, consisting of the evaluation and characterization of the meteorological and the hydrological drought, respectively, through the application of the Standardized Precipitation Index (SPI), and the standardized Streamflow Index (SSI) indices on the time scales of 3, 6 and 12 months. The analysis of the indices shows that the study area has experienced several drought events with different characteristics depending on the time scale of calculation. In addition, this analysis has enabled the behavior of meteorological and hydrological drought.

1 Introduction

The drought affects more populations than any other natural disaster, making it the most complex and yet least understood hazard [1,2]. This natural hazard has multiple aspects and includes different measures, as for the hydrological and the meteorological elements that contribute to its occurrence. The drought is generally classified into different categories taking into account the phase of water scarcity in the hydrological cycle [3–5]. Firstly, there is meteorological drought, which refers to the lack of precipitation over a specific period of time; this is the initial phase of drought. A prolonged meteorological drought leads to a deficit in soil moisture, which is known as an agricultural drought. With an additional lack of precipitation, the surface water and groundwater decrease; this phase is defined as the hydrological drought [6]. The transition from meteorological to hydrological drought is frequently considered as the propagation of drought [7].

Drought is a very common phenomenon, which can provoke a complex array of repercussions touching on many aspects such as the economy, the society and the

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environment, and which can extend far beyond the area affected by the drought [8,9], given that around half of the planet's land surfaces are susceptible to this phenomenon. Indeed, intensive and widespread droughts have been seen in the last years on all continents, affecting vast areas [8], which has brought increased attention to drought studies [10]. Many of them have revealed the increased frequency of droughts has led to major consequences on the environment, the water resource and the food security [11].

As drought is considered a regional phenomenon, the effects of climate change on this phenomenon may vary from region to another around the globe. Accordingly, it can be assumed that drought incidence and evolution present diverse models in different climatic conditions. Furthermore, despite the vulnerability of overall arid areas to drought [12,13], the ability of each area to cope with drought differs. In fact, for the drought of the same level of severity, the arid areas are considerably more susceptible to drought than the wet areas [13].

The monitoring of drought contributes decisively to the assessment of drought severity, and to the determination of the spatial and temporal variation of drought events. This monitoring relies on several indices based on various parameters, including the precipitation, the temperature, the soil moisture, the potential evapotranspiration and the runoff [8,14]. Each of these indices is intended for a specific drought category [13]. The time series of indices indicating the drought events over a given period can be characterized by attributes [3], which notably are the duration (the time elapsed between the onset and the end of a drought event), the severity (the total water shortage during a drought event) and the intensity (the average water shortage during a drought event), [15–17].

In this context, the present study was carried out for the evaluation and the characterization of the meteorological and the hydrological drought at the level of the three stations in the high Ziz watershed (South-East of Morocco). Two indices were therefore used: the Standardized Precipitation Index (SPI) [18] for the meteorological drought and the Standardized Streamflow Index (SSI) [19] for the hydrological drought. These two indices were calculated on multiple time scales, in particular 3, 6 and 12 months. On these three time scales, the characterization of the meteorological and the hydrological stress was also studied, in order to enrich the information on the phenomenon of drought in Morocco.

2 Material and methods

2.1 Study area

This study was conducted in southeast Morocco, precisely in the upper Ziz watershed (Fig. 1), which is bounded to the north by the massifs of the Eastern High Atlas, directed toward the west by the Rheris watershed, and to the south by the hills (over 800 m in altitude), besides to the east by the Guir watershed [20]. The higher Ziz watershed is mainly comprised of alternating calcareous marls, dolomites, limestones, and silico-clastic detritus [21].

The study area has a climate marked by significant continental influences [22]. It is characterized by a complicated topography, dominated by precipitous slopes, as well as by a large variation in altitude [23]. This variation in altitude is associated with the variation in rainfall, which increases with the altitude [12].

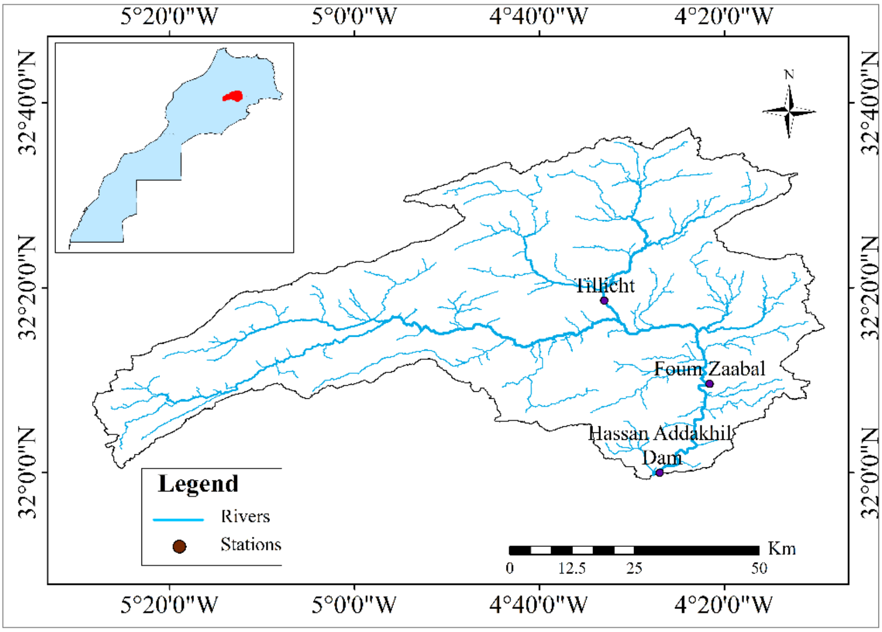


Fig. 1. Geographical situation of the high Ziz watershed.

2.2 Data

The data used in this study were obtained from the Hydraulic Basin Agency of Guir Ziz and Rheris and comprise series of monthly precipitation and flow records at different time intervals:

- Hassan Addakhil dam: precipitation data from 1974 to 2017;
- Tillcht station: precipitation data from 1976 to 2017;
- Foum Zaabal station: precipitation and debit data from 1971 to 2014.

On the basis of these collected data, the Standardized Precipitation Index (SPI) is calculated at the three above-mentioned stations and the Standardized Streamflow Index (SSI) is calculated at the Foum Zaabal station.

2.3 SPI and SSI calculations

The calculation of the SPI designed to delineate temporal evolutions of meteorological drought, requires a series of monthly precipitation data over a long period. Furthermore, the hydrological drought is captured by the SSI, whose calculation is reliant on flow data.

The process of calculating SPI and SSI consists of fitting a cumulative probability density function with the precipitation (for SPI) and flow (for SSI) recorded monthly, which are then converted to a standard normal distribution via an equal probability transformation, in order to obtain the actual SPI and SSI values [18,19]. The series of SSI and SPI were obtained by applying the exponential, gamma, Weibull and lognormal probability density functions, respectively. The details of the SPI and SSI calculations are explained in earlier research [18,19]. The SPI and the SSI values above 0.5 indicate wet conditions, and values between -0.5 and 0.5 indicate normal conditions, while values -0.5 to

-0.99, 1 to -1.49, -1.5 to -1.99 and below -2.0 denote mild, moderate, severe and extreme dry conditions respectively.

Depending on the requirements of the study, the SPI and SSI can be calculated across various timescales, ranging from one to several months, reflecting different characteristics of hydrological and meteorological drought.

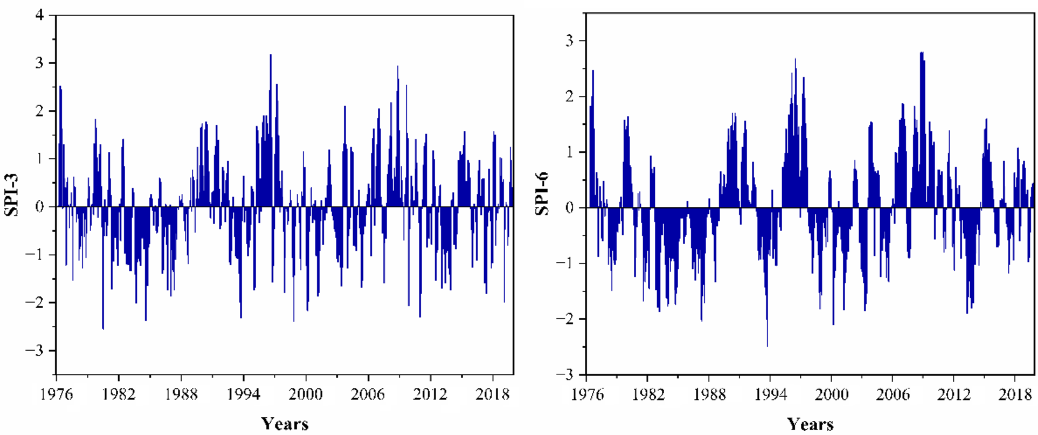
2.4 Characterization of drought

The identification of the various characteristics of drought, notably its duration, severity and intensity, is an essential part of the study of drought, enabling the assessment of drought impact. These drought characteristics have been conducted using race theory [24], which is applied notably in the drought index time series. The length of time between two successive drought events is known as the drought duration. The severity of drought is obtained by the summation of the index values of a drought event (below the critical threshold). The intensity of a drought event is calculated as the product of its severity and duration [25].

3 Results

3.1 Analysis and characterization of meteorological drought at the Tillicht station

The multi-scale SPI series of the Tillicht station over the period 1976-2019 is shown in figure 2. According to SPI results (the SPI on a time scale of 12 months), the Tillicht station experienced mild to moderate drought conditions during the years; 1978-1979 and 98-2001, moderate to severe drought conditions in the 80s (1981-1988), the years 1993-1994, and the year 2003, as well as moderate to extreme dry conditions during the period 2013-2014. Moreover, the multi-scale analysis of the SPI shows that the number of drought events is higher on short calculation timescales, these events last longer on long timescales, whereas their frequency decreases. Indeed, the longest durations on the time scales 3, 6 and 12 months were 18, 38 and 99 months respectively, with magnitudes of 1.26, 1.09 and 1.01 (Fig. 3). These long drought durations correspond to the 1980s (for example, 99 months on the 12-month scale corresponds to the period 1981-1989).



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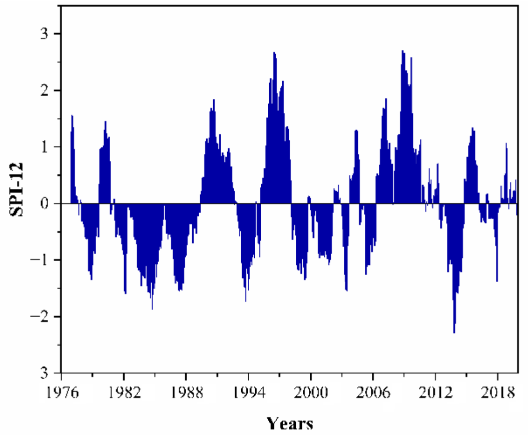


Fig. 2. Time series of SPI (time scales of 3, 6 and 12 months) at the Tillicht station, over the period 1976-2019.

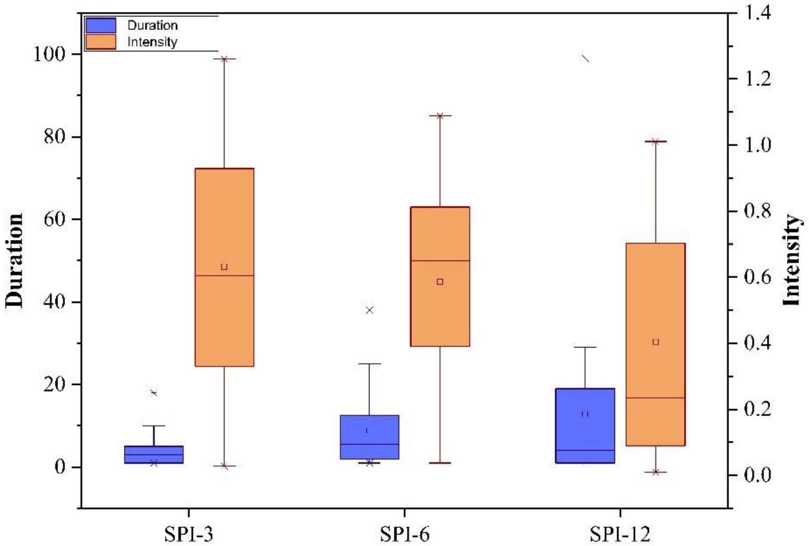


Fig. 3. Box plot of duration and intensity of meteorological drought at the Tillicht station.

3.2 Analysis and characterization of meteorological drought at the Hassan Addakhil dam

The SPI time series at the Hassan Addakhil dam for the period 1974-2017 reveals mild and severe meteorological drought conditions for the years 1983-1984, along with mild to extremely dry events during the period 1997-2005 and 2013-2014 (Fig. 4).

As with the results from other stations, short-term calculation time scales (3 month) revealed more drought events than long-term time scales. From a timescale of 3 months to 12 months, the average magnitude of drought decreased, reaching values of 0.64 for the SPI-3, 0.54 for the SPI-6 and 0.40 for the SPI-12 (Fig. 5). However, the average duration of drought showed the inverse evolution, increasing from a time scale of 3 months to a time scale of 12 months, with an average duration of 3.87, 5.48 and 10.19 months for SPI-3, SPI-6 and SPI-12 respectively (Fig. 5).

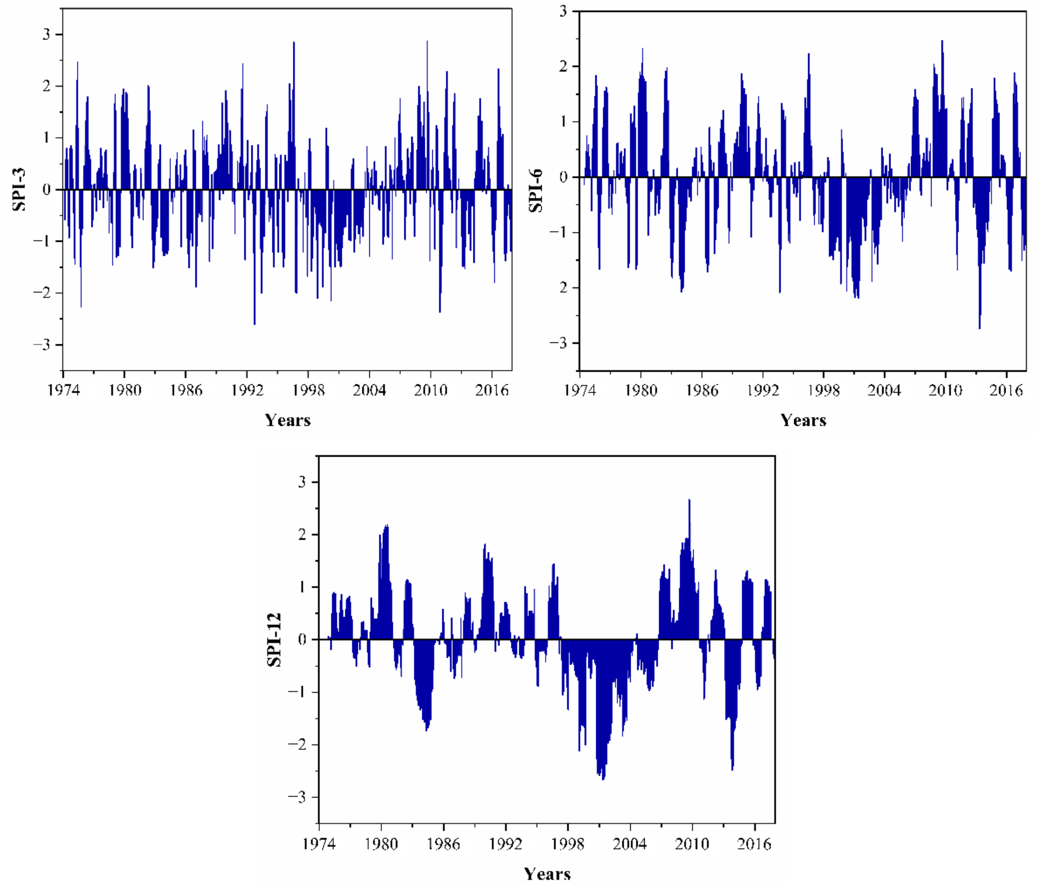


Fig. 4. Time series of the SPI (time scale of 3, 6 and 12 months) at the Hassan Addakhil dam, over the period 1974-2017

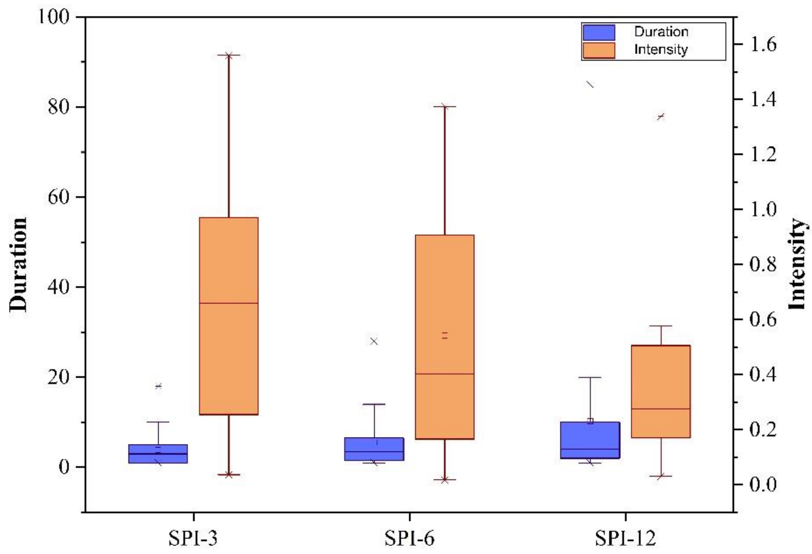
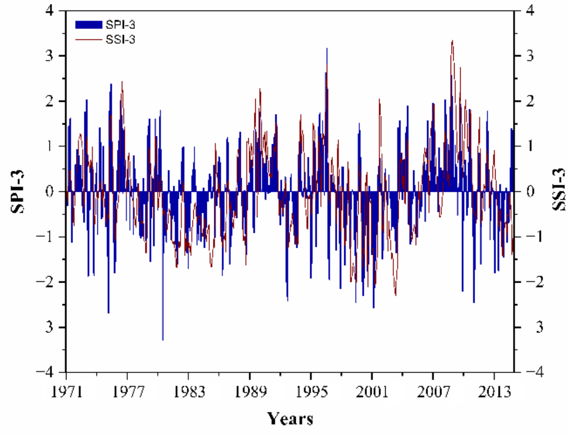


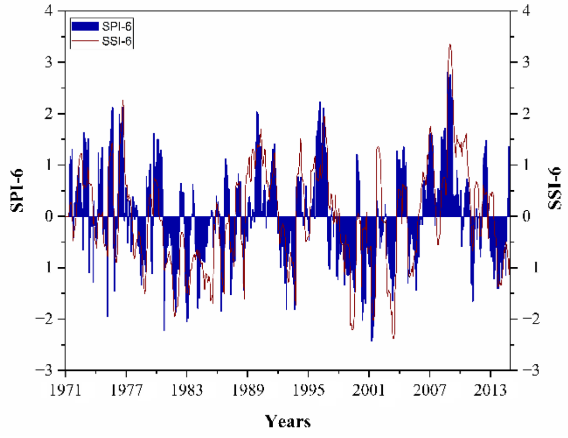
Fig. 5. Box plot of duration and intensity of meteorological drought at the Hassan Addakhil dam.

3.3 Analysis and characterization of meteorological and hydrological drought at the Foum Zaabal station

The figure 6 shows the variation in SPI and SSI determined on a multi-time scale at the Foum Zaabal station between 1971 and 2014. The analysis of the time series reveals that the concentration of meteorological and hydrological drought events detected by SPI and SSI mainly occurred in the late 1970 (e.g., 1977-1979), the 1980s (1981-1987), the early and the late 1990s (e.g., 1992-1993, 1997-2003), as well as the years 2013-2014 (The SPI and the SSI on a time scale of 12 months).

The results of the analysis also reveal that the frequency of the meteorological and the hydrological drought on the short time scale (3 months) was higher than on the long timescale of 12 months. As well, the number of the meteorological drought events is higher than that of the hydrological drought, especially on the 3-month time scale. As indicated by the SPI, the average durations of meteorological drought were 3.5, 7.18 and 10.32 months, and their average magnitudes were 0.68, 0.57 and 0.43, respectively for SPI-3, SPI-6 and SPI-12 (Fig. 7). In turn, the SSI revealed average durations of 7, 11.17 and 21.33 months, as well as average magnitudes of 0.57, 0.59 and 0.55 respectively for SSI-3, SSI6 and SSI-12. Comparing the three calculation time scales, the average duration of the meteorological and the hydrological drought reached its maximum at the 12-month timescale, and at this scale, the average magnitude of the SPI and the SSI reached their lowest point (Fig. 7). It should also be noted that the average duration of the hydrological drought was longer than that of the meteorological drought across all the time scales calculated. In other words, a hydrological drought event of long duration can be composed of several metrological drought events of short duration.





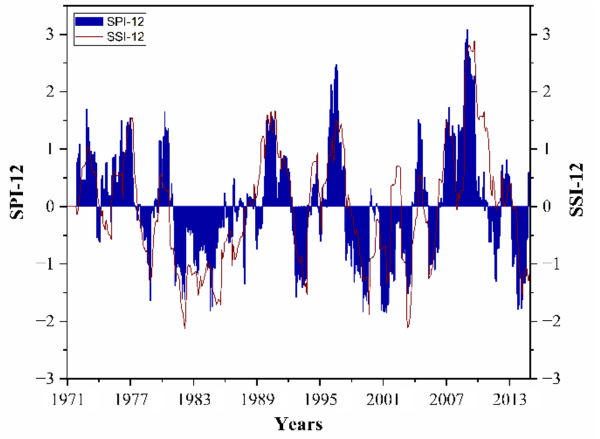


Fig. 6. Time series of the SPI and the SSI (time scale of 3, 6 and 12 months) at the Foum Zaabal station, over the period 1971-2014.

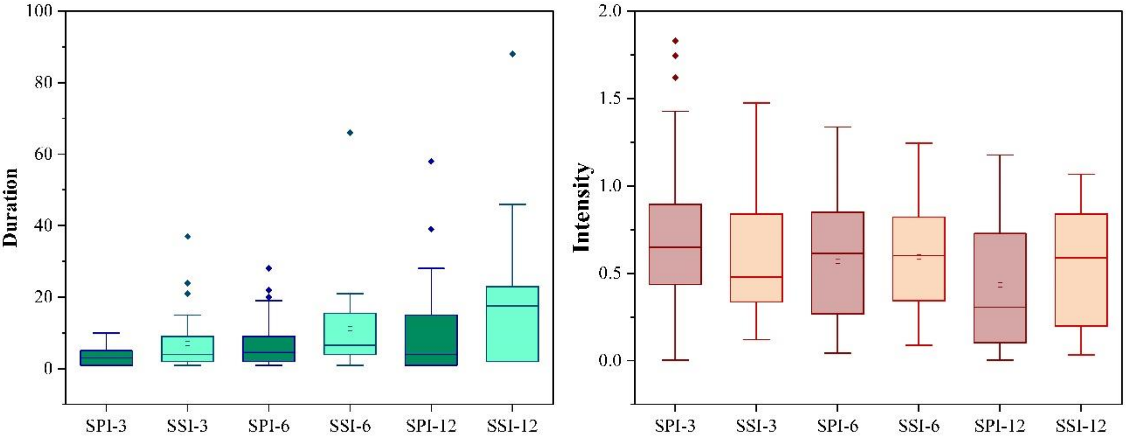


Fig. 7. Box plot of duration and intensity of meteorological and hydrological drought at the Foum Zaabal station.

3.4 Correlation of the hydrological and meteorological indices

The Pearson correlation [26] between the SPI and the SSI is calculated on the three timescales (3, 6 and 9 months). As a result, the correlation coefficient between the meteorological (SPI) and the hydrological (SSI) drought is 0.635, 0.72 and 0.78 at 3, 6 and 12 months respectively. It is evident to note that as the calculation time scale increases, the calculated correlation coefficient between the SPI and the SSI also increases. The relationship between the SPI and the SSI on the time scales of 3, 6 and 12 months was expressed in three equations shown in Figure 8.

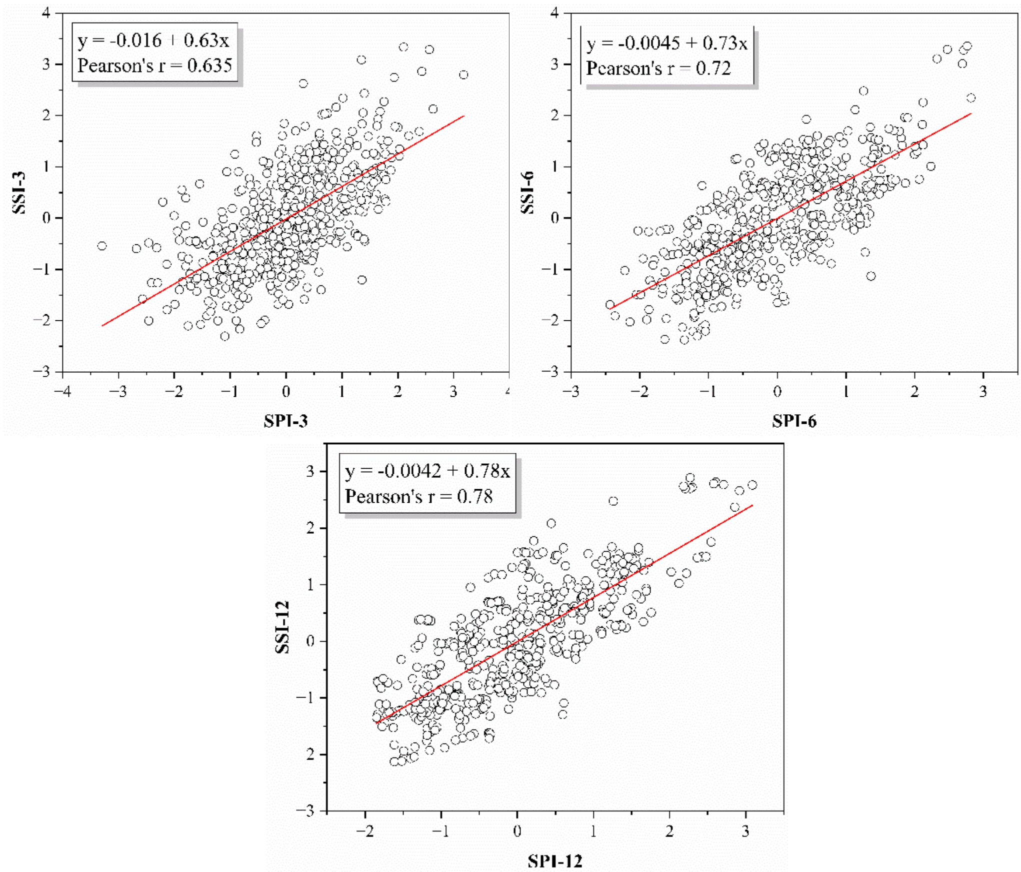


Fig. 8. Pearson correlation and linear relation between SPI and SSI.

4 Conclusion

This study enabled to analyse and characterize on different time scales the meteorological (SPI) and the hydrological (SSI) drought in the high Ziz watershed, which allows to understand the behavior of each drought studied. The analysis of the SPI time series (for the Tillicht, Foum Zaabal stations and Hassan Addakhil dam) and of the SSI (for the Foum Zaabal station) revealed several drought events with different intensities. It is noteworthy that the 1980s and the years 1998-2001 and 2013-2014 were overshadowed by the drought events in the three stations. the frequency of drought events was more significant on the short time scale of 3 months and decreased towards the time scale of 12 months, however the average duration of drought events presented an inverse trend, and evidently an ascending average intensity with the time scale. It is also worth emphasizing that at all scales of calculation, the number of meteorological drought events is higher than that of hydrological drought, and that the average duration of hydrological drought has been longer than that of meteorological drought. This means that a long hydrological drought event can be composed of several short meteorological drought events. Furthermore, the Pearson correlation coefficient calculated between the SPI and the SSI increases with time scale, notably 0.635, 0.72 and 0.78 at timescales of 3, 6 and 12 months respectively.

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