Arabian Journal of Geosciences (2021) 14: 44
https://doi.org/10.1007/s12517-020-06387-3

ORIGINAL PAPER

# Rain pattern analysis using the Standardized Precipitation Index for long-term drought characterization in Lebanon

Jamil Kobrossi[1] · Fadi Karam[2] · George Mitri[3]

Received: 13 May 2020 / Accepted: 23 December 2020 / Published online: 7 January 2021
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## Abstract

Drought may cause losses to natural ecosystems, agriculture, and other sectors. Reliable monitoring of drought is essential for planning future mitigation measures and reducing potential impacts on different environmental and socio-economic sectors. Indicators such as the Standardized Precipitation Index (SPI) have become essential tools for drought monitoring and analysis. In this context, monthly precipitation data for Lebanon during the period from 1926 through 2015 was analyzed using SPI at different time scales of 1, 3, 6, 9, and 12 months. When plotted over the whole study period (1926–2015), SPI-3 fall (October through December) showed neither an increase nor a decrease, while SPI-6 fall–winter (October through March) showed a sharp decrease. However, SPI-9 fall–winter–spring (October through June) showed slightly increasing trends. In addition, a slight decrease in SPI-12 values (fall–winter–spring–summer) was observed. Analyzing SPI-1, the months of December and January (i.e., months of highest precipitation) displayed decreasing trends across time, while the month of May displayed an increasing trend. These results indicated a decrease in fall and winter rain and an increase in late-in-the-season spring rain. In addition, SPI (3, 6, 9, and 12 months) experienced negative peak intensities in the range between − 1 and − 2, falling into a "very dry" classification. On the other hand, drought magnitude (DM) was negatively correlated with drought relative frequency (DRF). This indicated the association of lower DM with higher DRF.

**Keywords** SPI · Drought · Wet year · Dry year · Water resources

## Introduction

The climate crisis contributes to worsening drought conditions in different parts around the globe. Schneider et al. (2011) defined drought as "an extended period of deficient rainfall relative to the multi-year mean for a region." However, four types of drought can be identified, namely, meteorological, hydrological, agricultural, and socio-economic drought (Hisdal and Tallaksen 2000). These are mostly affected by extreme rainfall deficits and decrease in precipitation frequency. Yet, the influence of climatic factors in addition to diverse external conditions may alleviate or worsen hydrological drought (Van Loon and Lahaa 2015).

In most of the cases, drought may cause substantial socio-economic losses (Dracup et al. 1980; Bak and Kubiak-Wojcicka 2017). This makes understanding and monitoring drought tremendously important. Common tool utilized to monitor drought conditions involves the use of drought indices. Several drought indices can be used to forecast the possible evolution of an ongoing drought, in order to adopt appropriate mitigation measures and drought policies for water resources management (Cancelliere et al. 2007; Belayneh and Adamowski 2012). According to WMO-GWP (2016), Standardized Drought Indices (SDI) including the Standardized Precipitation Index (SPI) are the most commonly used indices in monitoring

Responsible Editor: Zhihua Zhang

✉ Jamil Kobrossi
jamil.kobrossi@balamand.edu.lb

Fadi Karam
fadkaram@gmail.com

George Mitri
george.mitri@balamand.edu.lb

1 Faculty of Business Management, University of Balamand- Kelhat, El Koura, Lebanon

2 Department of Environmental Engineering, Faculty of Agriculture, Lebanese University, Road to Mkales Roundabout, Dekwane, Metn, Lebanon

3 Institute of the Environment and Faculty of Arts and Sciences, University of Balamand - Kelhat, El Koura, Lebanon

meteorological and hydrological drought. The calculation of SPI (McKee et al. 1993) only requires precipitation data as an input data. This makes the ideal index for use when extensive climatic data is not available (Belayneh and Adamowski 2012). The fact that the SPI is based solely on precipitation makes its evaluation relatively easy (Cacciamani et al. 2007). Most importantly, standardization of a drought index ensures independence from geographical position as the index in question is calculated with respect to the average precipitation in the same place (Cacciamani et al. 2007).

In 2009, World Meteorological Organization (WMO) recommended SPI as the main meteorological drought index that countries should use to monitor drought conditions (Hayes et al. 2011). However, SPI requires long-term temporal precipitation and may be calculated at different time scales (McKee et al. 1993; WMO 2012; Saada and Abu-Romman 2017). The time scales used for SPI can be for a short time scale (1–3 months) or a long-term scale (6–12 and even 24 months). The 1–3-month SPI may be related closely with the short-term response of soil moisture conditions to precipitation (WMO 2012). In contrast, the 6–9-month SPI could be related to the streamflow while more than 12-month SPI could be related to groundwater flow (WMO 2012; Saada and Abu-Romman 2017).

Drought can be assessed in terms of intensity and magnitude. While drought intensity measures the departure of a climate index from its normal value (Saravi et al. 2009), drought magnitude (DM) corresponds to the cumulative water deficit over the drought period. The average of this cumulative water deficit over the drought period is considered as mean drought intensity (Thompson 1999). Dalezios et al. (2000) defined drought frequency as the average time lag between two events of the considered magnitude. Besides characterizing patterns of long-term precipitation, extensive rainfall data is essentially needed for monitoring a changing climate (Coffel and Horton 2015). Consequently, reliable rainfall data are required for widespread ranges of research in meteorology and hydrology among others. However, in developing countries, it is difficult to acquire long-term weather observations due to lack of reliable historical data of rain gauge stations. Accordingly, it is essential to explore rainfall characteristics and trend with the use of global datasets (Mahfouz et al. 2016). In this context, the Climate Change Knowledge portal uses globally available datasets including historical precipitation data (Harris et al. 2014). These datasets are originated from observation data generated from worldwide weather stations.

Exploring global datasets at the country level is expected to help in gaining deeper insights into climate risks and actions for adaptation. Salloum and Mitri (2014) indicated an increasing number of forest fires in Lebanon possibly linked, among others, to global climatic warming, due to reduction in fuel moisture and increase in fire occurrence and fire spread. Cook et al. (2014) highlighted that the recent 15-year drought in the Levant (1998–2012) was the driest on record.

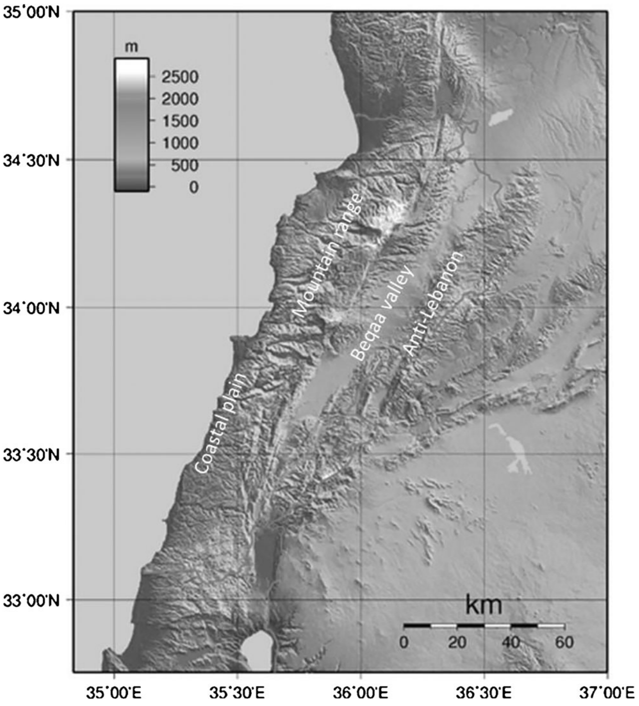


**Fig. 1** Map of Lebanon

In this context, the aim of this work was to explore historical rainfall data for long-term drought characterization in Lebanon. The specific objectives were to (i) investigate SPI over a long period of time (1926–2015) at different time scales, and (ii) analyze observed drought events in terms of their intensity, magnitude, and frequency.

## Methodology

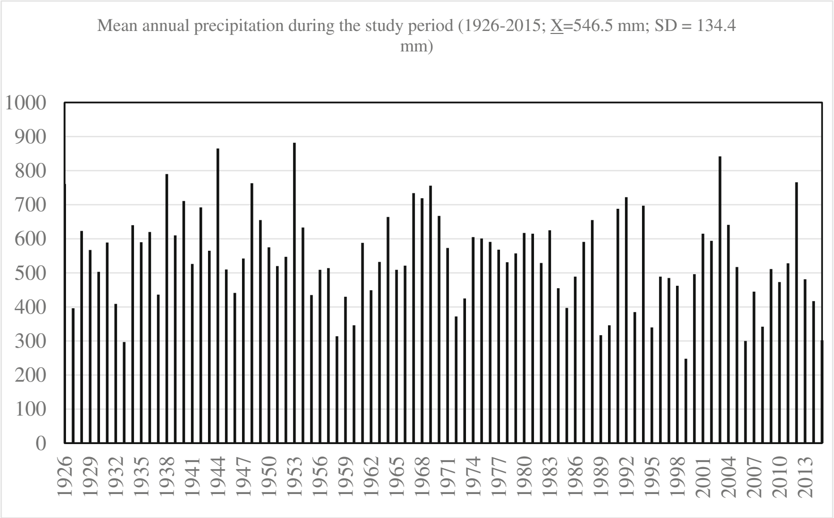
### Study area and dataset description

The study area of this work is the entire country of Lebanon. Located on the eastern basin of the Mediterranean Sea,

**Table 1** SPI and its corresponding moisture categories

| SPI | Index value | Class |
|---|---|---|
| Non-drought | $\mathrm{SPI} \geq 2.00$ | Extremely wet |
| | $1.50 \leq \mathrm{SPI} < 2.00$ | Very wet |
| | $1.00 \leq \mathrm{SPI} < 1.50$ | Moderately wet |
| | $-1.00 \leq \mathrm{SPI} < 1.00$ | Near normal |
| Drought | $-1.50 \leq \mathrm{SPI} < -1.00$ | Moderate drought |
| | $-2.00 \leq \mathrm{SPI} < -1.50$ | Severe drought |
| | $\mathrm{SPI} < -2.00$ | Extreme drought |

**Fig. 2** Mean annual precipitation in Lebanon (1926–2015)



Lebanon is divided into four distinct physiographic regions: the coastal plain, the Lebanon mountain range, the Beqaa valley, and the Anti-Lebanon Mountains (Mahfouz et al. 2016). In general, Lebanon's climate is characterized by dry summers, extending from June to October with around 90% of total annual precipitation falling between November and March (Salloum and Mitri 2014).

Historical monthly precipitation data were extracted from the Climate Change Knowledge portal which uses globally available datasets derived from the Climate Research Unit (CRU) of the University of East Anglia (Harris et al. 2014). More specifically, historical precipitation data originated from observation datasets generated from worldwide weather stations. These datasets are

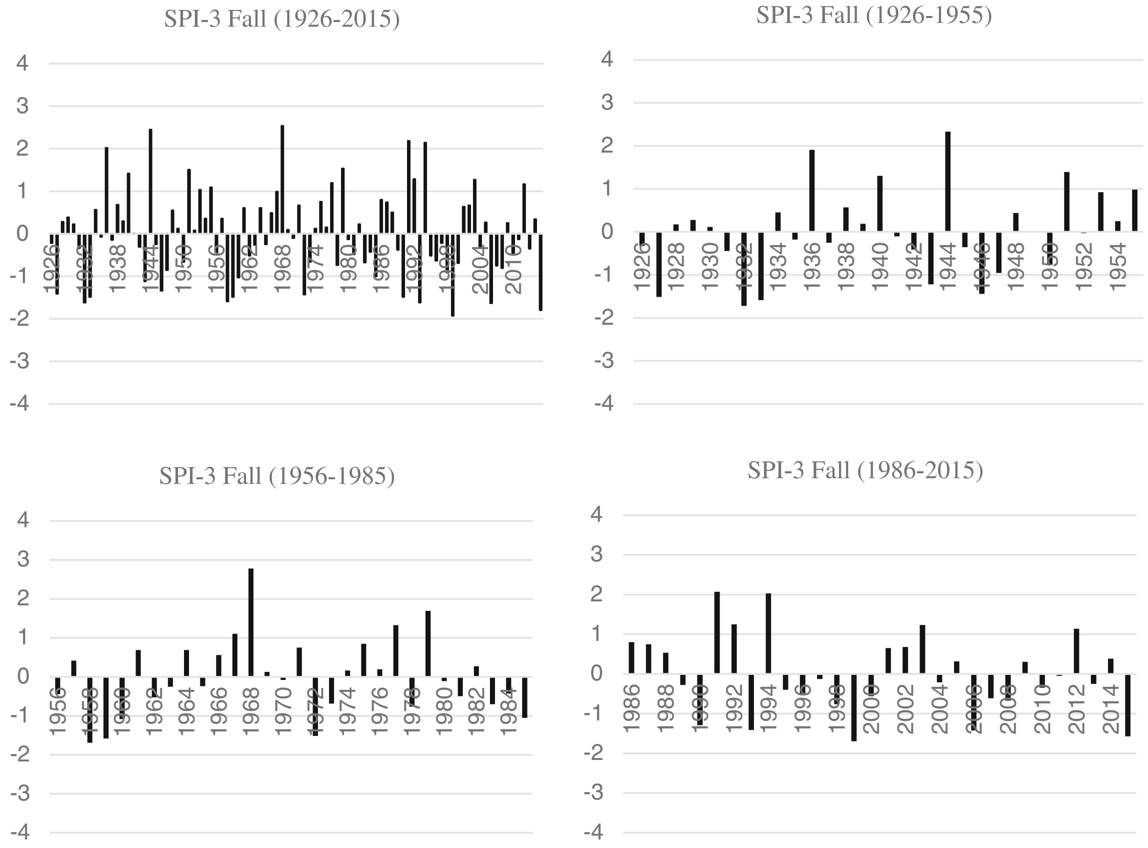


**Fig. 3** Time scale variation of SPI-3 (fall) during the whole study period and the three different 30-year time spans

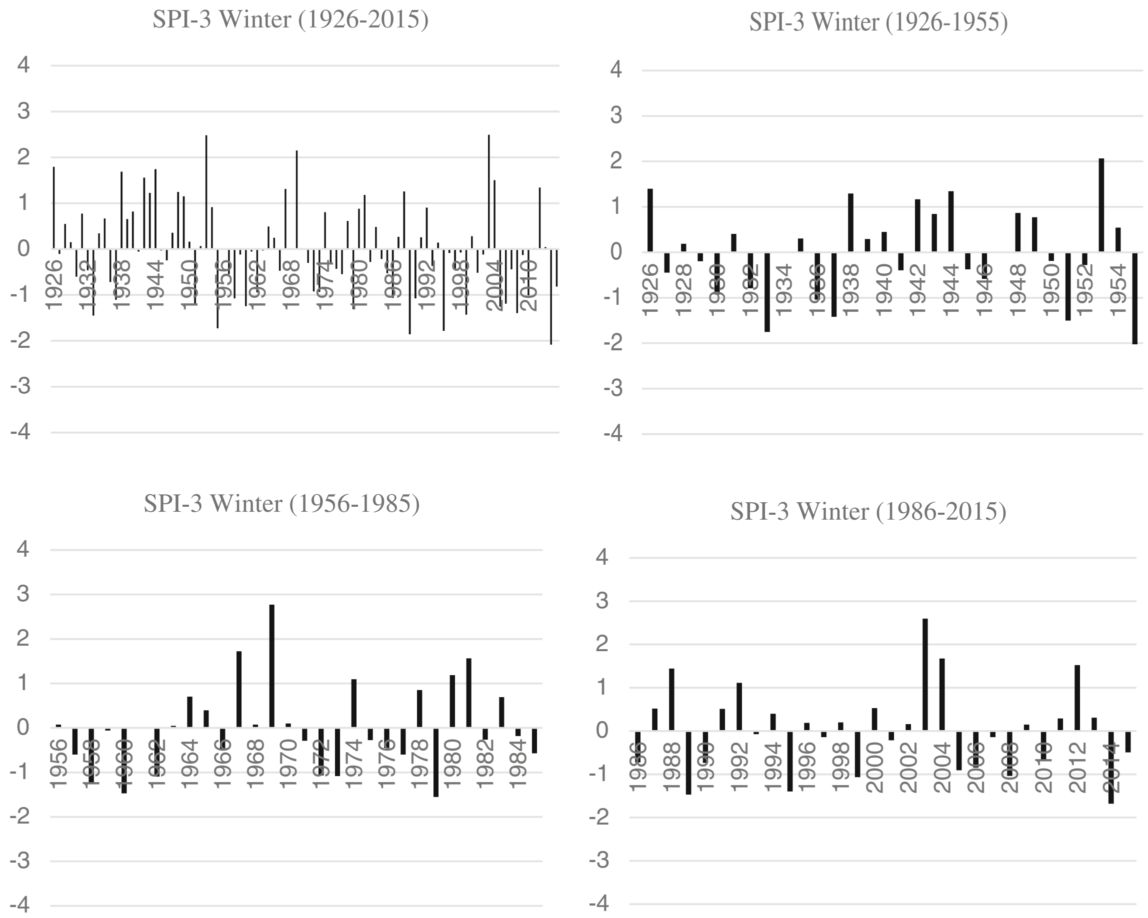


Fig. 4 Time scale variation of SPI-3 (winter) during the whole study period and the three different 30-year time spans

widely accepted as reference datasets in climate research. In this context, CRU provides quality-controlled rainfall data. In this work, country-aggregated monthly precipitation data (1926–2015) of Lebanon were employed (Fig. 1).

## SPI calculations

The SPI calculations involved four time scale levels, namely, 1 month (SPI-1), 3 months (SPI-3), 6 months (SPI-6), and 12 months (SPI-12). While SPI-1 provides monthly estimation of precipitation and SPI-3 provides a seasonal estimation of precipitation, SPI-6 and SPI-12 give medium-term and long-term trends in precipitation patterns, respectively (Salloum and Mitri 2014). More specifically, 1-month SPI reflects short-term conditions of soil moisture and its application can be linked closely to meteorological drought. A 3-month SPI reflects short- and medium-term moisture conditions and provides a seasonal estimation of precipitation. A 6-month SPI can be very effective in showing the precipitation over different seasons. A 9-month SPI provides an indication of inter-seasonal precipitation patterns over a medium time scale duration knowing that droughts usually take a season or more to develop. A 12-month SPI is usually tied to reservoir levels, streamflows, and groundwater levels at longer time scales.

The calculation of SPI involved the use of a 90-year historical monthly precipitation dataset divided into three time lots of 30 years each. Initially, precipitation data was normalized using a probability of distribution so that values of SPI are seen as standard deviations from the median. Accordingly, normal distribution was allowed for estimating both dry and wet periods. The SPI was calculated as follows (McKee et al. 1993, 1995):

$$SPI = \frac{\left(x - \overline{\mu}\right)}{\sigma} \tag{1}$$

where $x$ is the seasonal precipitation at the central point, $\overline{\mu}$ is the long-term seasonal mean, and $\sigma$ is its standard deviation.

Accordingly, a classification of seven categories of SPI (Table 1) was proposed (McKee et al. 1993, 1995).

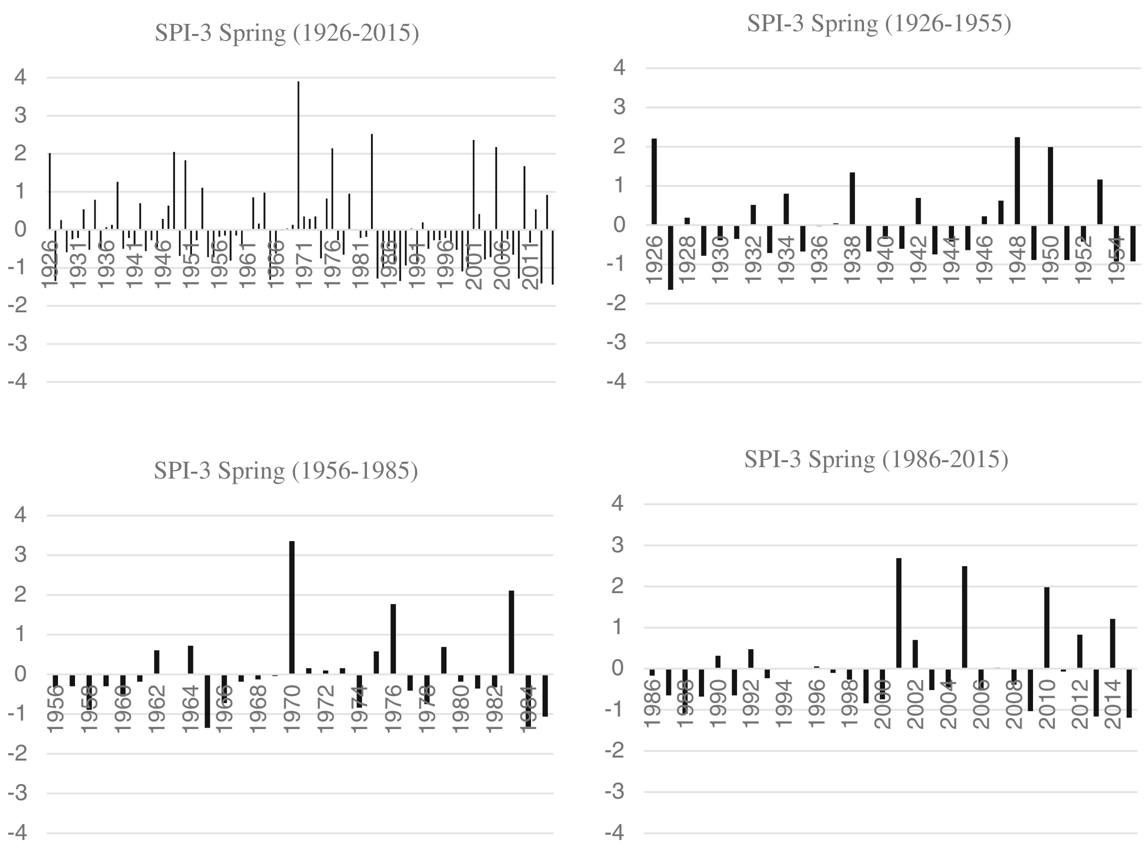


**Fig. 5** Time scale variation of SPI-3 (spring) during the whole study period and the three different 30-year time spans

Drought magnitude (DM) was calculated using the SPI values as follows (Thompson 1999):

$$DM = -\left(\sum_{j=1}^{x} \mathrm{SPI}_{ij}\right) \tag{2}$$

where $j$ starts with the first month of a drought and continues to increase until the end of the drought ($x$) for any of the $i$ time scales.

The DM has units of months and would be numerically equivalent to drought duration if each month of the drought has SPI = − 1.0.

Drought intensity (DI) was calculated as the average of drought magnitude over the drought period (Thompson 1999). Numerically, it is calculated as the ratio of drought magnitude and number of years in a given period with negative SPI values at different time scales (1, 3, 6, 9, and 12 months). At the same time, drought relative frequency (DRF) was calculated as (Mohseni-Saravi et al. 2009):

$$DRF = (n/N) \times 100 \tag{3}$$

where $n$ is number of months with drought events (i.e., negative SPI) and $N$ number of total months.

## Results and discussion

### General trend in annual precipitation

Time course evolution of mean annual precipitation for Lebanon (1926–2015) is illustrated in Fig. 2. This study used a 90-year (1926–2015) precipitation dataset to further describe the pattern of SPI at different time scales. A complete understanding of variations in the hydrologic cycle requires total precipitation data. Mean annual precipitation in Lebanon is 546.5 mm. It is worth noting that precipitation in Lebanon constitutes 99% of total internal renewal water sources. Moreover, about 95% of the precipitation falls between December and March. The months of December and January comprised the highest precipitation rates with averages varying from 111 mm in December to 131 mm in January. Moreover, about 90% of precipitation falls in autumn–winter months and 9.8% in spring months from April through June. Only 0.2% of precipitation falls during summer. Moreover, September was characterized as the driest month over the year. In Lebanon, September is the month of apple ripening at the high altitudes (i.e., ≥ 1200 m above the sea level). In agricultural production, water supplies by irrigation

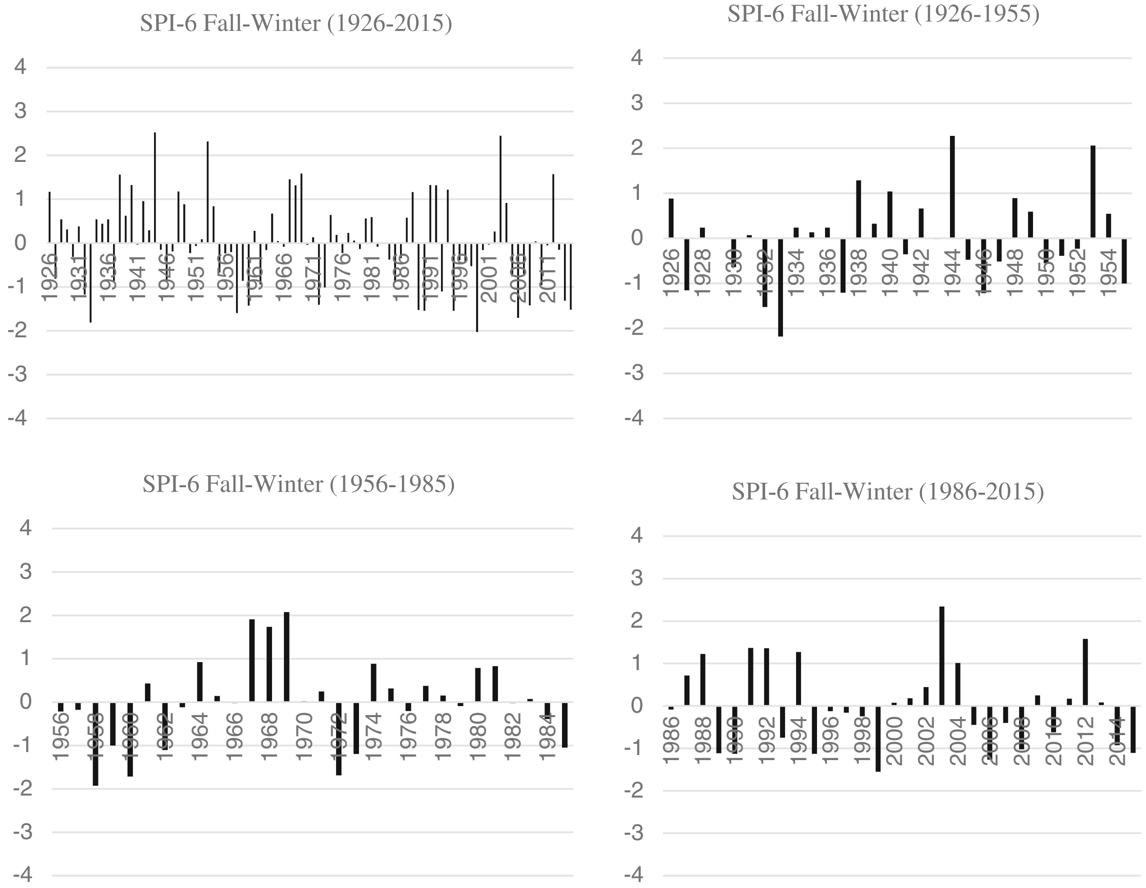


**Fig. 6** Time scale variation of SPI-6 (fall–winter) during the whole study period and the three different 30-year time spans

from June through September correspond to an amount of 600 mm to compensate a negative water balance calculated as the difference between potential evapotranspiration (ETp) and recorded precipitation over the whole year (Karam et al. 2019; Nasta et al. 2020).

Although the study period (1926–2015) is relatively long compared to the majority of gauge records, it is a period of strong and frequent drought events, and thus useful for developing relationships between annual precipitation and years. Drought spills during 1955–1960 and 1995–2000 and 2005–2010 are the most prominent. A regression made for mean annual precipitation across years gives negative slope (− 1.21) and high intercept (597.6), along with very weak correlation coefficient ($R^2 = 0.045$). In such bivariate correlation, the regression is more focused simply on the strength of a relationship between precipitation and years. In the present case, the regression between the two variables established a negative trending mathematical relationship, thus establishing a causal diminishing relationship of precipitation across years. This is commonly used as the simplest way to describe a rainy situation in a given location or region (Kiernan 2014).

## 3-month time scale variation

The time scale variation of SPI-3 for the fall season (October through December) during the whole study period (1926–2015) and in three different 30-year time spans (1926–1955; 1956–1985; and 1986–2015) is illustrated in Fig. 3. SPI-3 (i.e., fall) showed over the whole study period a very slight decrease, thus indicating no consistent changes in the rain pattern during the three fall months. However, SPI-3 showed a notable increase during the 1926–1955 and a slight increase in the 1956–1985 period, while trend evolution in the 1986–2015 showed a prominent decrease. A delay in rain occurrence in October–November, as it happened during the 2005–2010 drought period, forced wheat growers to use additional water resources to irrigate their fields, which contributed to lowering the level of aquifers and as a consequence increased water depletion rate.

The time scale variation of SPI-3 for the winter season (January through March) during the whole study period (1926–2015) and in the three different 30-year time spans is illustrated in Fig. 4. SPI-3 winter showed a sharp decrease over the whole study period, thus indicating a consistent decrease in the rain pattern in Lebanon during the three winter months. However,

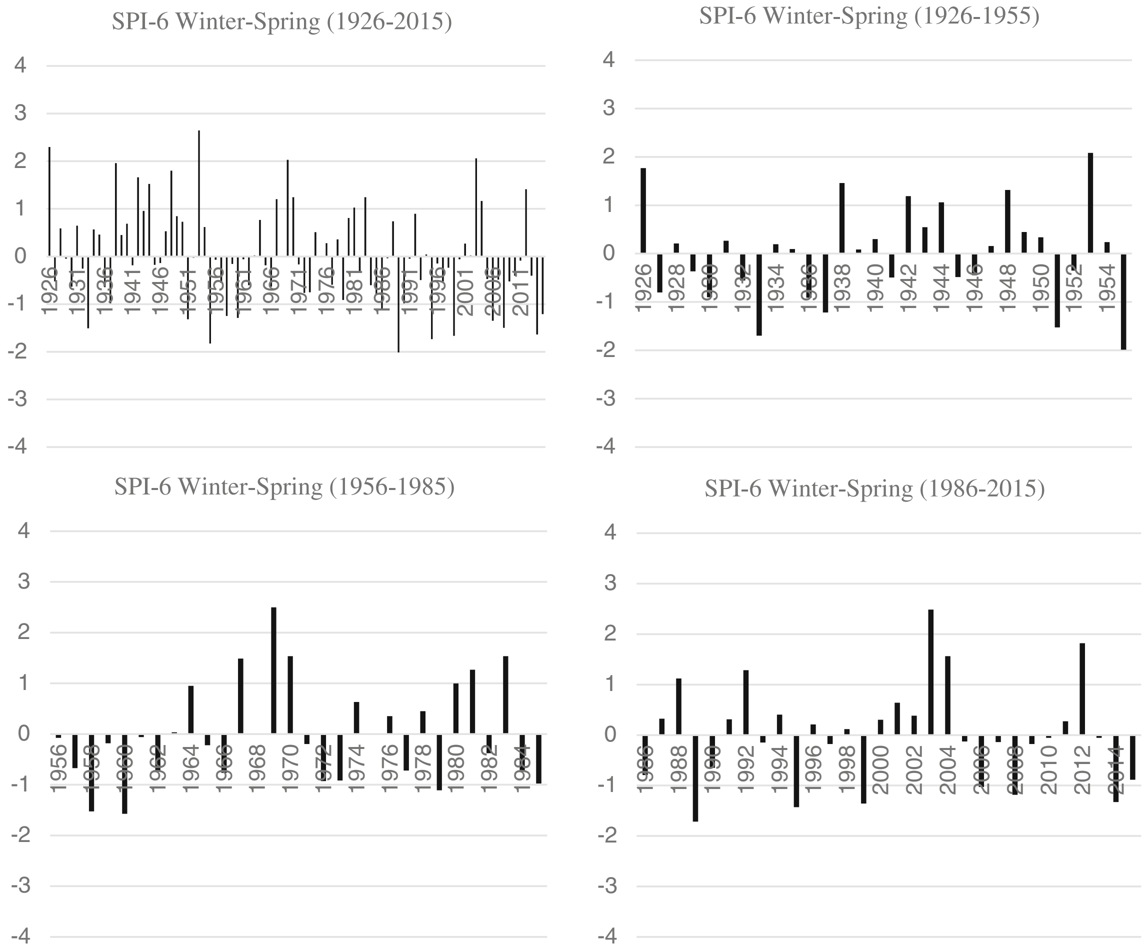


**Fig 7** Time scale variation of SPI-6 (winter–spring) during the whole study period and the three different 30-year time spans

SPI-3 winter showed a slight increase during 1926–1955, followed by increase that is more notable during 1956–1985, while a trending decrease was observed during 1986–2015.

Time scale variation of SPI-3 for the spring season (i.e., April through June) during the whole study period (1926–2015) and in the three different 30-year time spans is illustrated in Fig. 5. When plotted over the whole study period, SPI-3 spring showed a decreasing trend, thus indicating a change in the rain pattern in Lebanon during the three spring months. However, SPI-3 showed no change during 1926–1955 but increasing trends during 1956–1985 and 1986–2015. In normal wet years, rain recorded in April and May ease wheat growth and grain filling and limits the need for supplemental irrigation to compensate the lack in monthly rain.

In some dry years, the shift of rain towards spring months is often accompanied with hail fall on the mid and high altitudes, thus causing damages in stone fruits and pome fruits orchards, namely, cherry and apple. The occurrence of hail was often observed after a long dry period in March. This was the case in the dry years of 2005 and 2010 years.

On one side, SPI-3 showed an increase in the SPI values in spring, corresponding to projected wetter conditions in the future. On the other side, SPI-fall and SPI-winter showed a decrease in the obtained values, corresponding to an increase of the dryness during these two seasons of the year. The slope of the trend for the raw data was statistically more significant for the two SPI seasons of fall and winter, and less statistically significant in the case of SPI spring season.

## 6-month time scale variation

Time scale variation of SPI-6 for fall–winter (October–March) and winter–spring (January–June) during the study period (1926–2015) and in the three different 30-year time spans (1926–1955; 1956–1985; and 1986–2015) is illustrated in Figs. 6 and 7. For SPI-6 (fall–winter), a general negative trend was observed during the whole study period (1926–2015). Although positive trends were observed during the 1926–1955 and 1956–1985 periods, a slight decrease was exhibited during the period 1986–2015, thus indicating a decrease in the rain pattern during the six fall–winter months from October through March.

Long-term precipitation data over Lebanon during fall–winter period from October through March amounted to 491

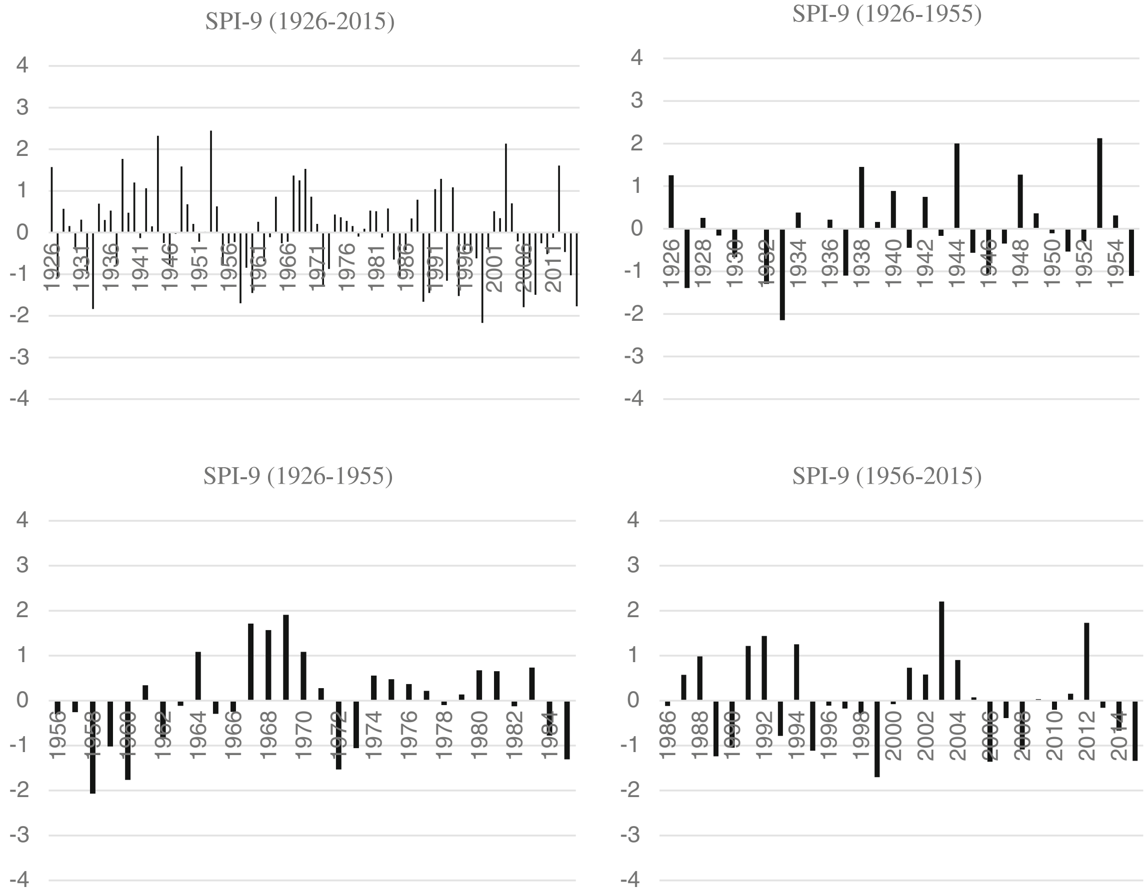


**Fig. 8** Time scale variation of SPI-9 (fall–winter–spring) during the whole study period and the three different 30-year time spans

mm, representing 90% of total rain. In the years 2006 and 2015 (i.e., considered as dry years), precipitation of the fall–winter months amounted to 269 mm and 293 mm respectively. These resulted in 49% and 53% of annual precipitation, respectively, compared to historical average of 90% of rain recorded in the fall–winter period. For these two years, the SPI-6 fall–winter was − 1.26 in 2006 and − 1.10 in 2015, both falling in the class "dry" in reference to the general SPI classification (McKee et al. 1993). In the wet years of 2009 and 2011, precipitation during the fall–winter period amounted to 496 mm and 484 mm, respectively. These corresponded to 91% and 88.5%, respectively, of total annual rain.

In the case of SPI-6 (winter–spring), a general negative trend was similarly observed during the whole study period (1926–2015). The main reason could be attributed to the decrease in the SPI-3 (winter), in spite of the observed increase in the SPI-3 (spring). However, the SPI-3 (spring) remains of a little effect compared to SPI-3 (winter), since rain recorded in winter season constitutes the bulk of total rain recorded over the whole year. Although no consistent change was observed in SPI-6 (winter–spring) during the 1926–1955 period, a positive trend was observed during 1956–1985 period. In general, SPI-6 (winter–spring) exhibited no change during the period 1986–2015, thus indicating no variations in the rain pattern in Lebanon during the six winter–spring months from January through June.

Overall, the results showed an increase in the SPI values during the spring months and a decrease for the other two seasons (i.e., fall and winter).

## 9-month and 12-month time scale variation

The results for the 9-month SPI values were extracted for precipitation totals over nine months from October through June, while the results for the annual scale (SPI-12), values were extracted for precipitation totals over the entire year (i.e., October through September). The results of 9-month level (SPI-9) (Fig. 8) and SPI-12 (Fig. 9) indicated no consistent differences knowing that no rain is usually recorded during the three summer months (July–August–September) in Lebanon.

For SPI-9, the calculations showed a decrease in the values during the whole study period (1926–2015). However, SPI-9 showed an increase for the two 30-year periods of 1926–1955 and 1956–1985, corresponding to increasing wet conditions during these two periods. The SPI values showed a decreasing trend for the 1986–2015 period, thus corresponding to drier conditions. The average rain from October through June amounted to 545 mm, (i.e., 99.6% of total annual rain). Any

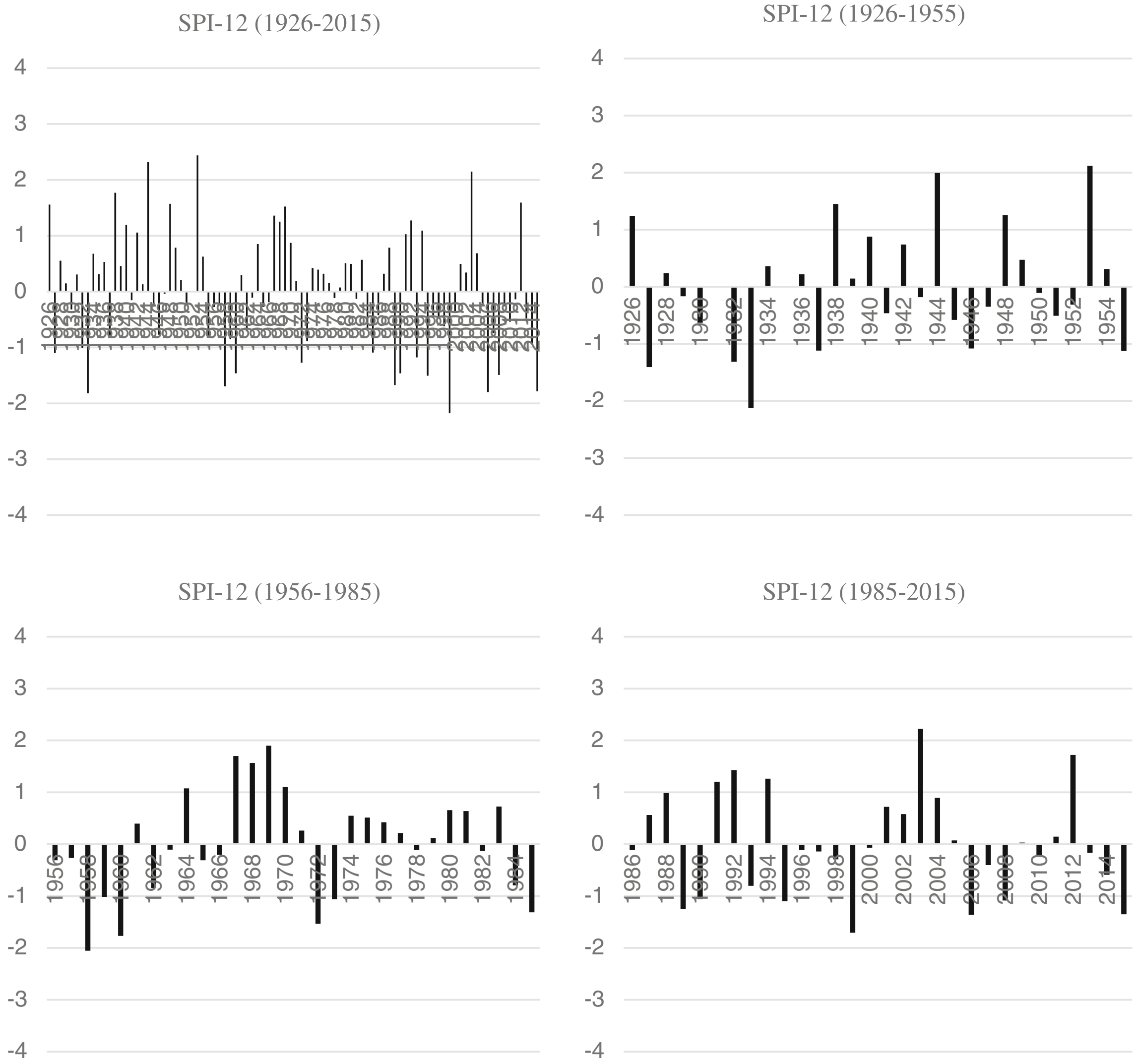


**Fig. 9** Time scale variation of SPI-12 (fall–winter–spring–summer) during the whole study period and the three different 30-year time spans

decrease (i.e., drier conditions) or increase (i.e., wetter conditions) in the SPI-9 affected directly the SPI-12 values. Accordingly, the estimated trends for the SPI-12 did not differ from those of SPI-9. The linear regression model projected a decrease in both SPI-9 and SPI-12 values during the whole study period, thus corresponding to increasing drier conditions. These results are in line with the findings of Stagge et al. (2015a and 2015b). Several severe drought periods (SPI $< -1.5$) were identified such as 1985–1986, 1988–1989, 1998–1999, and 2014-2015 droughts. These results seem to conform to other studies performed in other Mediterranean countries such as Cyprus and Greece (Bordi et al. 2001).

## 1-month time scales

The results of trend analysis for SPI-1 are presented in Fig. 10. The largest changes in fall and winter precipitation, as depicted in the results of SPI-3 (fall) and SPI-3 (winter), were expressed by decreases in the SP1-1 for the 6 months of the fall and winter seasons. While in 1926–1955 and 1956–1985 SPI-1 for January, February, and March were increasing, SPI-1 values showed slight decrease for the same months in 1986–2015, thus indicating drier conditions during the three winter months with comparison to average rain situation.

For the three spring months (April, May, and June), SPI-1 for April and May were found to increase during the time period of 1986–2015, thus corresponding to increasing wet conditions during these 2 months. The SPI-1 results for April and May allowed expecting more late-in-the-season rain to characterize Lebanon's future climate, and drier conditions earlier in March. However, these results lack statistically significant trends and need more solid correlations. However, the SPI-1 results look more consistent in the three fall months (i.e., October through December), following positive trends in 1926–1955 and 1956–1985 and negative trends in 1986–2015. However, in some cases, there was no consistency in the

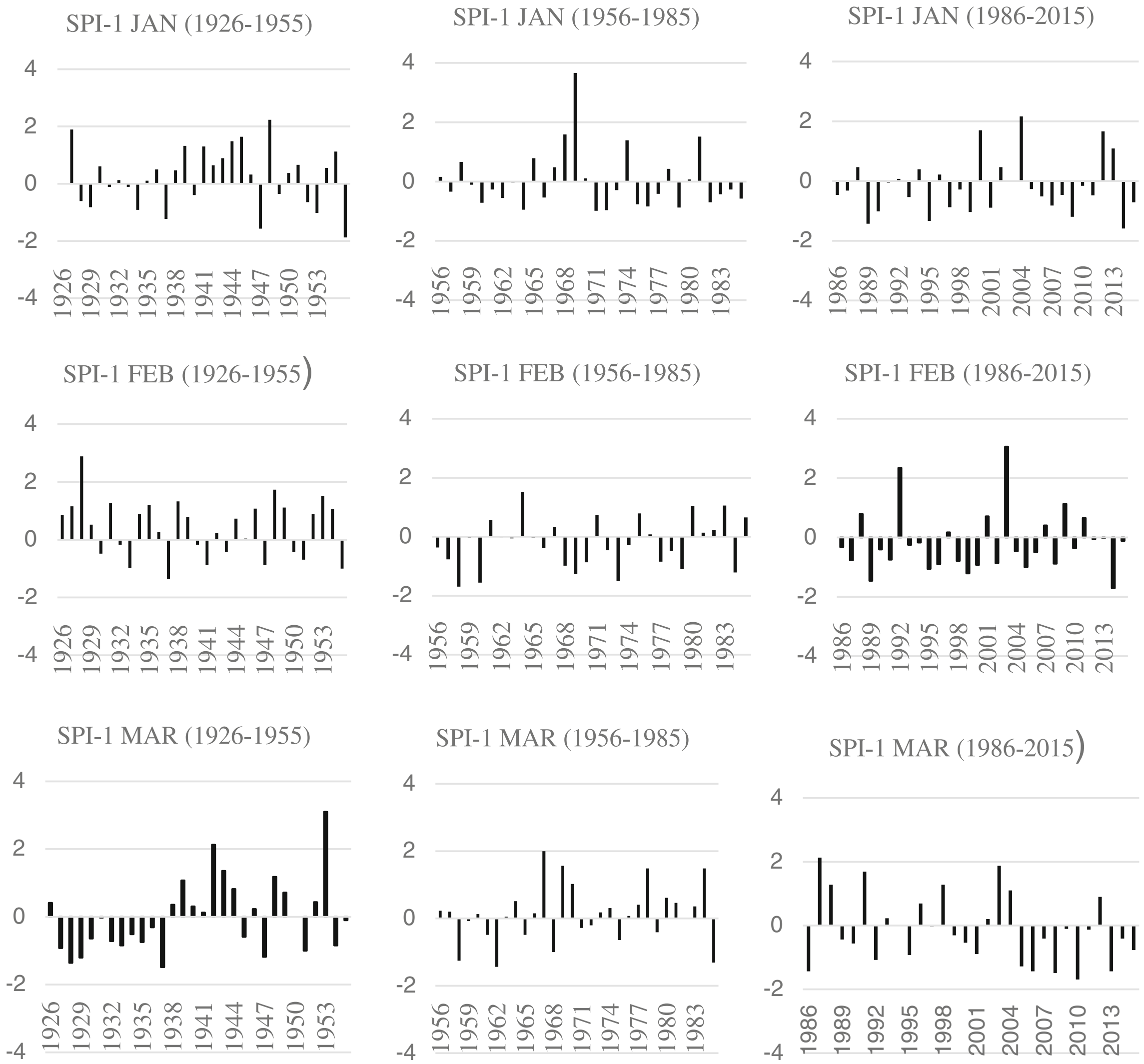

SPI-1 JAN (1926-1955)
SPI-1 JAN (1956-1985)
SPI-1 JAN (1986-2015)
SPI-1 FEB (1926-1955)
SPI-1 FEB (1956-1985)
SPI-1 FEB (1986-2015)
SPI-1 MAR (1926-1955)
SPI-1 MAR (1956-1985)
SPI-1 MAR (1986-2015)

**Fig. 10** Time scale variation of SPI-1 during the whole study period and the three different 30-year time spans

SPI-1 values with respect to the estimated trends, where no change (i.e., increase or decrease) was observed.

## Drought average intensity, magnitude, and relative frequency

Figure 11 summarizes drought main features (average intensity, magnitude, and relative frequency) during the whole study period (1926–2015) and in three different 30-year time spans (1926–1955; 1956–1985; 1986–2015) at different month scales (3, 6, 9, and 12). While average drought intensity (ADI) obtained for the different SPI scales during the observed periods fell in the range between − 0.5 and − 1.0, almost all SPI scales experienced negative peak intensities between − 1 and − 2, falling into a "very dry" classification as per Table 1. SPI scales with peak intensities less than − 2 were not commonly noticeable. In addition, most of the drought intensities occurred in the 1990s, especially during 1999, which was the driest year during the whole period. The SPI-12 and SPI-9 were both found to be equal − 2.17, while SPI-6 (fall–winter) and SPI-6 (winter–spring) were − 2.02 and − 1.66, respectively. For the same year, SPI-3 fall, winter, and spring were − 1.93, − 1.42, and − 1.09, respectively.

The year 1990 witnessed a remarkable drought. SPI-12 and SPI-9 equaled − 1.46 and − 1.45, respectively, while SPI-6 (fall–winter) and SPI-6 (winter–spring) equaled − 1.54 and − 0.98, respectively. For the same year, SPI-3 fall, winter, and spring equaled − 1.48, − 1.00, and 0.03, respectively. SPI-6 (winter–spring) and SPI-3 (spring) recorded less negative values, compared with other SPI scales, confirming once more that rain in dry years occurs later in spring after one or two successive fall and winter dry seasons.

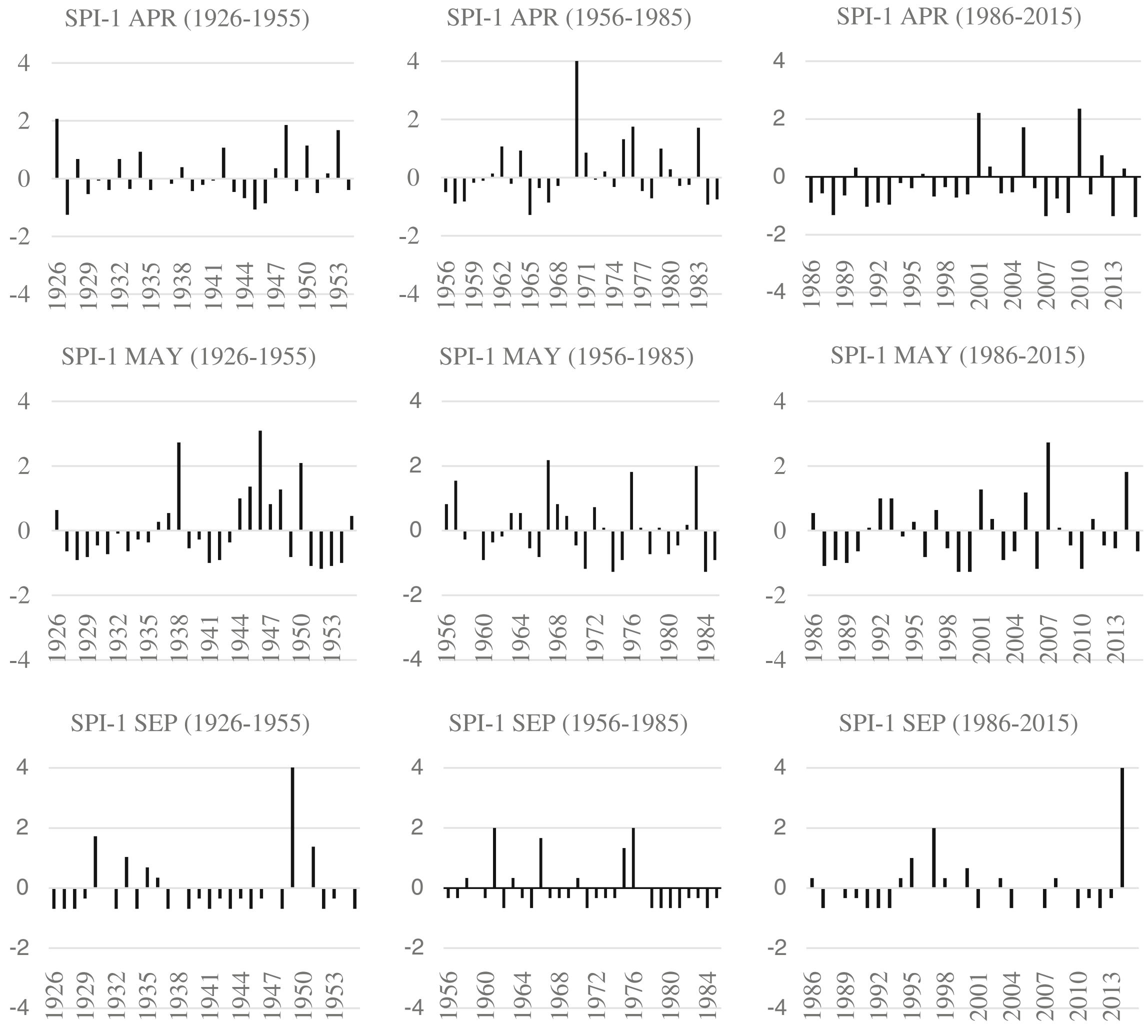

SPI-1 APR (1926-1955)
SPI-1 APR (1956-1985)
SPI-1 APR (1986-2015)
SPI-1 MAY (1926-1955)
SPI-1 MAY (1956-1985)
SPI-1 MAY (1986-2015)
SPI-1 SEP (1926-1955)
SPI-1 SEP (1956-1985)
SPI-1 SEP (1986-2015)

**Fig. 10** continued.

Year 2006 was also a dry year. The SPI-12 and SPI-9 equaled − 1.80 and − 1.79, respectively, while SPI-6 values equaled − 1.70 and − 1.35 during the fall–winter and winter–spring seasons, respectively. Moreover, SPI-3 values in 2006 equaled − 1.63, − 1.20, and − 0.78 during fall, winter, and spring seasons, respectively. This once more confirms that when a drought happens to occur in fall and winter seasons, an alleviation is observed in spring due to the occurring rain. Another dry year was observed in 2015. During this year, the SPI-12 and SPI-9 equaled − 1.78 and − 1.77, respectively, while SPI-6 (fall–winter) and SPI-6 (winter–spring) equaled − 1.52 and − 1.21, respectively. For the same year, SPI-3 fall, winter, and spring equaled − 1.79, − 0.81, and − 1.44, respectively. The greatest DI in 2015 (SPI = − 4.02) occurred in January.

In spite of the prevailing droughts in the 1990s, wet years were observed in 1992, 2003, and 2012, where SPI-12 equaled 1.27, 2.14, and 1.60, respectively. During these wet years, SPI-3 (spring) values were 0.20, − 0.78, and 0.54, respectively, indicating conditions near normal to slightly dry. In wet years, as in 1992, 2003, and 2012, slightly dry conditions were observed in spring time.

The ADI, calculated as the ratio of drought magnitude and the number of years with negative SPI-12 during a certain period of time (Mohseni-Saravi et al. 2009), was found for the different studied time scales between − 0.6 and − 0.8, falling into a “near normal” drought classification (Fig. 12).

DM varying between a maximum of − 30 and a minimum of − 36 was obtained for the different SPI time scales (3, 6, 9, 12) (Fig. 13). The 12-month and 9-month SPI drought magnitudes for the entire study period from 1926 to 2015 were very close to each other. Also, the 6-month SPI for the fall–winter and winter–spring periods were found to be very similar. However, the 3-month SPI drought magnitude showed a variation between fall, winter, and spring. SPI 3 is more sensitive to changes in precipitation over the long-term records

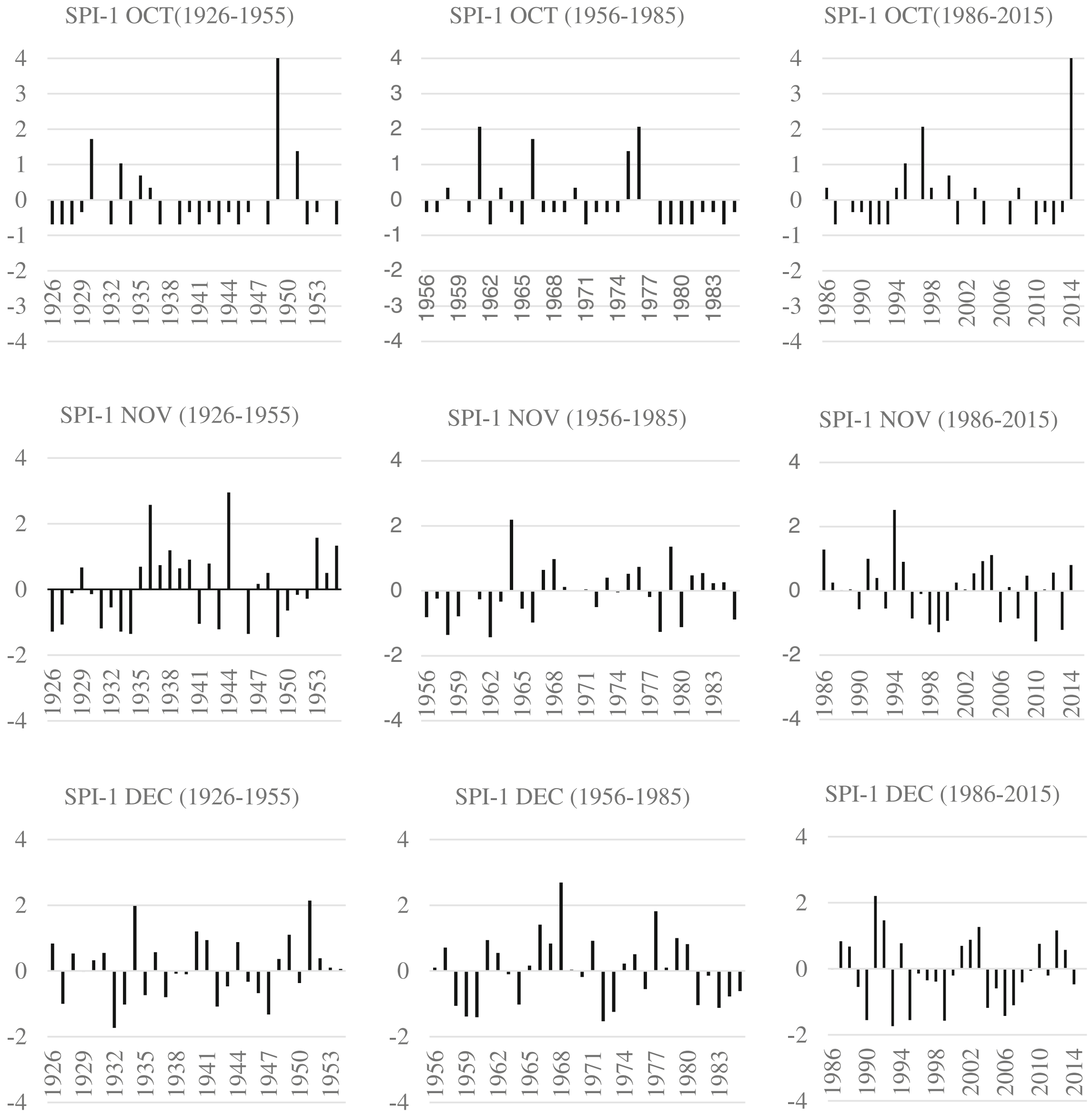


**Fig. 10** continued.

(Belayneh and Adamowski 2012). This explains the changes that were observed in drought magnitude for the whole study period. Knowing that SPI 12 is not as much sensitive to changes in precipitation as SPI-3 (Belayneh and Adamowski 2012), the results of drought magnitude were found to be much closer to each other. Moreover, the DRF has been found to vary for all time scales between 51% and 63% (Fig. 13).

DRF was found to positively correlate with ADI and DM, as seen in Figs. 14 and 15. In both cases, a high correlation coefficient ($R^2$) was found. The results showed that higher average drought intensities and drought magnitudes were associated with higher DRF. On one hand, this indicated higher probability of drought occurrence in years where DM is less negative. On the other hand, this may be an indication that the shift of rain towards spring months in dry years is likely to be observed as intensive rain over a short period of time, followed by an extended drought period with increased number of days with no rain.

## Conclusions

In this study, monthly precipitation data was analyzed using SPI at different time scales of 1, 3, 6, 9, and 12 months during the whole study period (1926–2015) and in three different 30-year time spans (1926–1955; 1956–1985; 1986–2015).

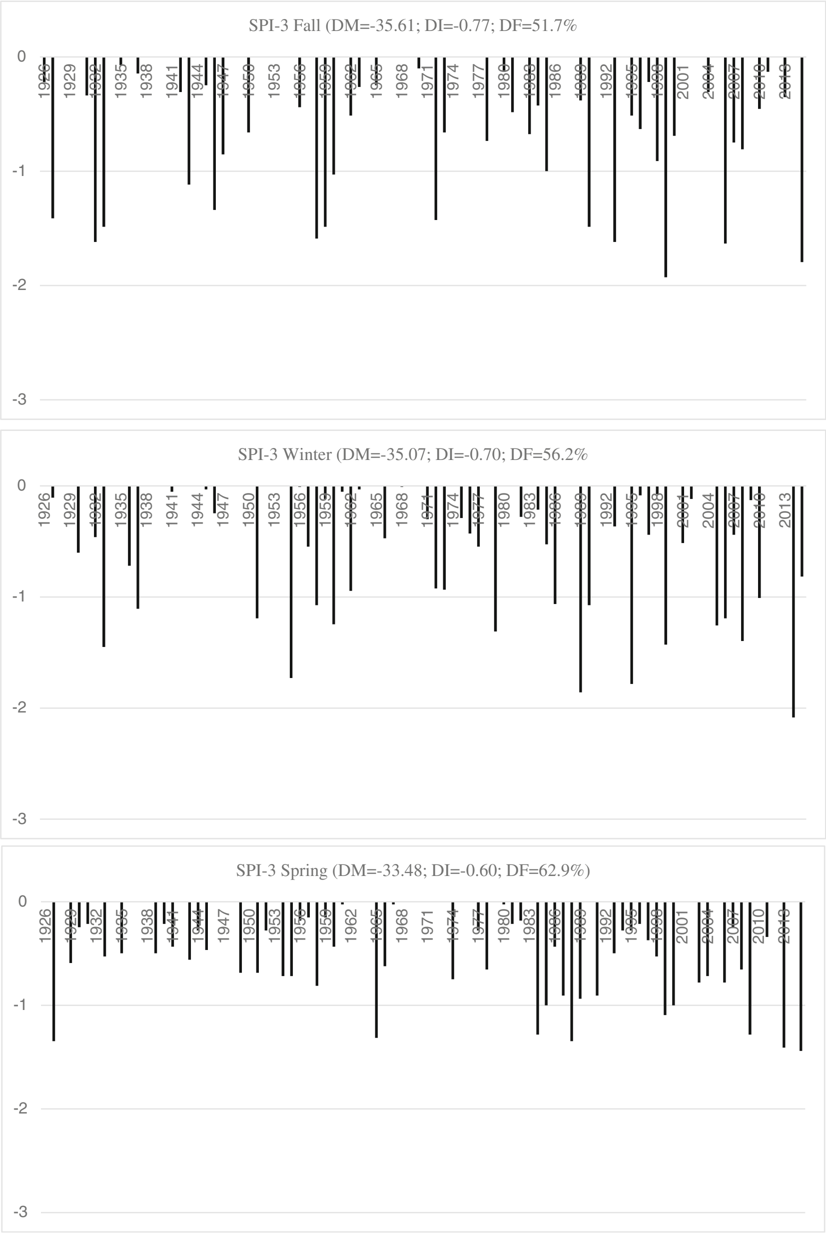


**Fig. 11** Drought characteristics (intensity, magnitude, and frequency) at different SPI scales (3, 6, 9, and 12 months) during the whole study period (1926–2015)

The SPI-12 data for the period of 1926–2015 revealed a dry period between 2005 and 2010 and a wet event between 2002 and 2004. Several severe drought periods (SPI < − 1.5) were identified such as the cases of 1985–1986, 1988–1989, and 1998–1999 droughts. The most recent 2015 drought was the worst drought on record and was identified as an extreme drought (SPI < − 2). These results seem to conform to other studies performed in other Mediterranean countries such as Cyprus and Greece. At seasonal levels (SPI-3 and SPI-6), the projections of SPI values indicated a possible increase in the degree of dryness (i.e., worse water availability) during the fall and winter months and a decrease in the spring period (better water availability). This reflected a shift in the rain pattern towards the spring period. As such, climate change may affect rain pattern and while many parts across the country may experience longer and milder *springs*. Nevertheless, the paradigm "wet season becomes drier" and "dry season becomes wetter" and the transition of wetness towards drier months or vice versa have to be fully explored under future climate conditions in Lebanon in particular and the Mediterranean region in general. The results for longer time scales showed a decrease of the SPI-9 and the SPI-12, corresponding to drier conditions. These results are in line with other regional findings.

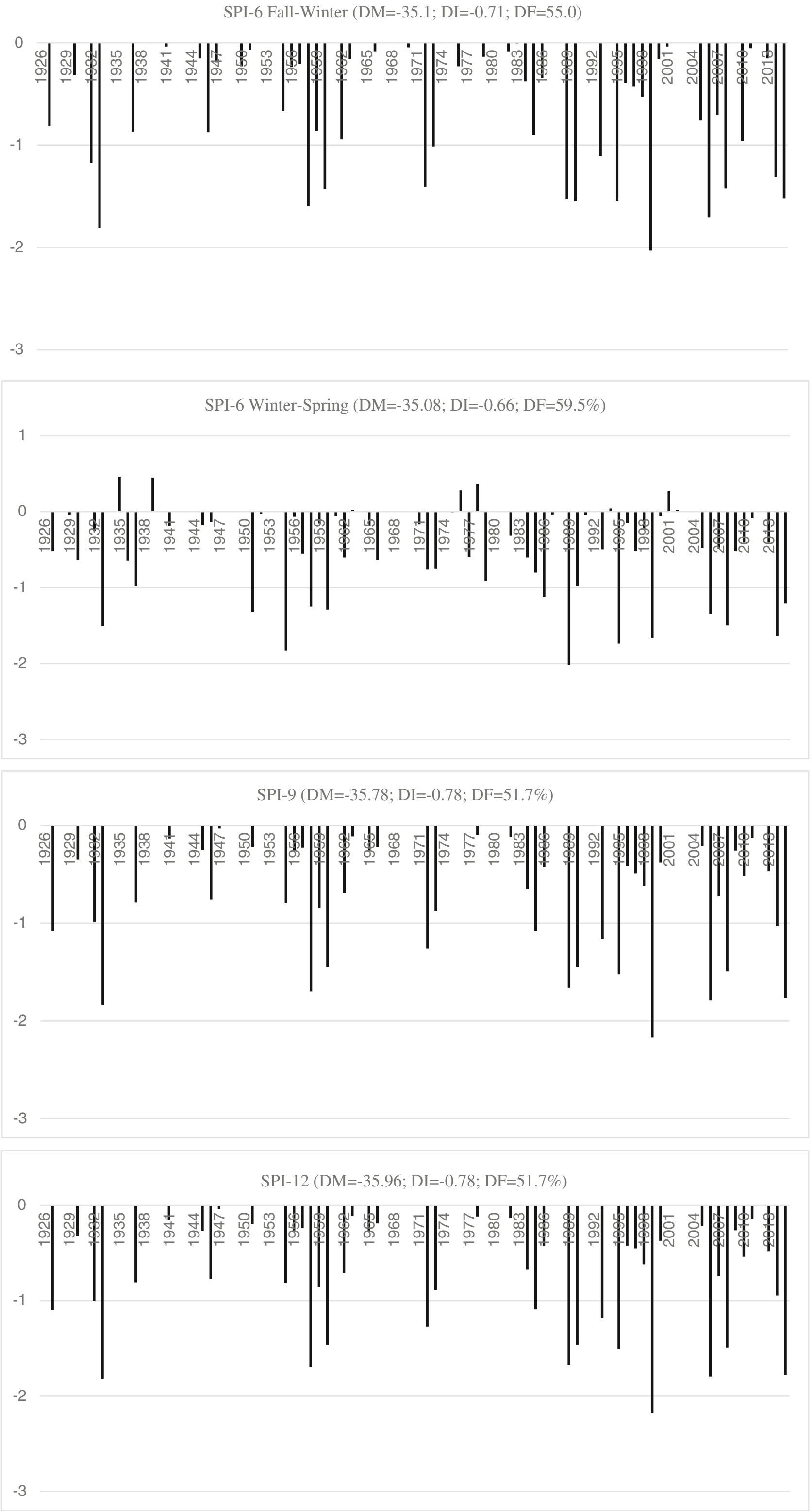


**Fig. 11** continued.

The SPI values for all time scales during the whole study period (1926–2015) and the three different 30-year time spans (1926–1955; 1956–1985; 1986–2015) clearly indicated the occurrences of moderate to severe drought events. The 3-month SPI showed that DM and ADI over the whole study period (1926–2015) were less prominent for spring (April–

**Fig. 12** ADI at different time scales during the whole study period (1926–2015) and in three time spans (1926–1955; 1956–1985; and 1986–2015)

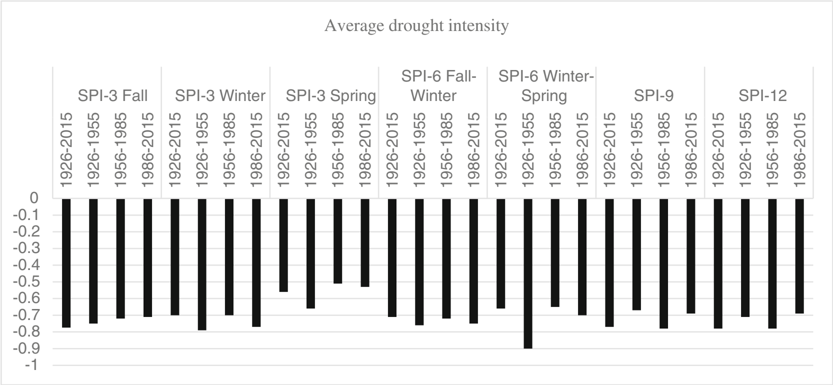


**Fig. 13** DM and DRF at different SPI scales (3, 6, 9, and 12 months) during the whole study period (1926–2015)

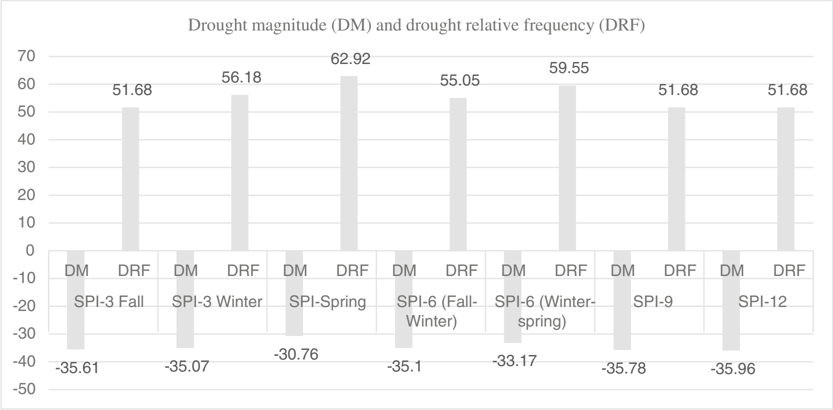


**Fig. 14** DRF versus ADI

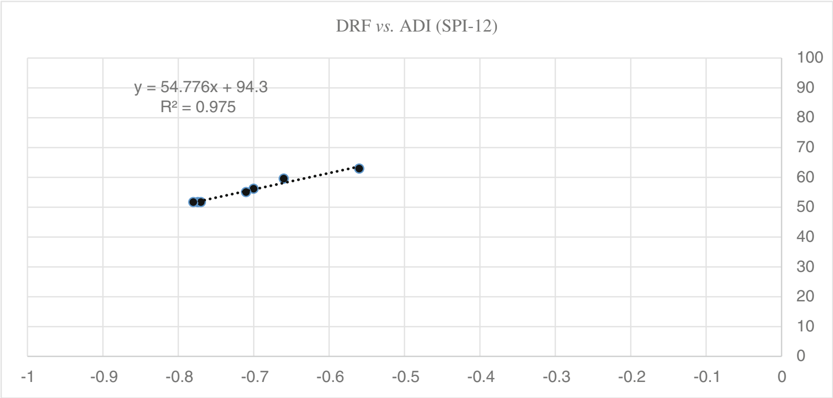
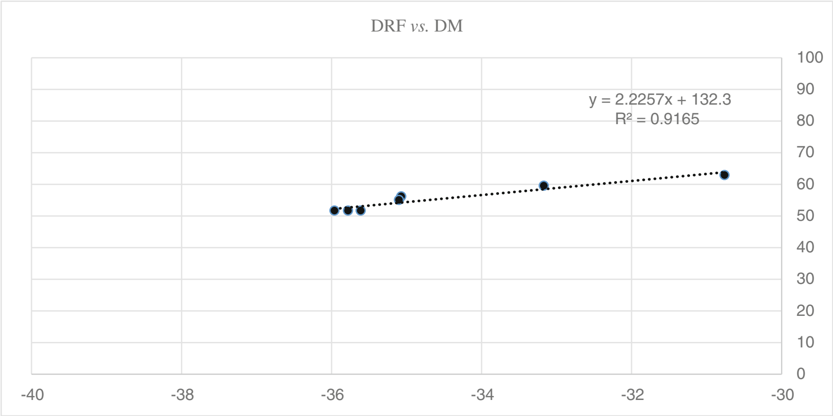


**Fig. 15** DRF versus DM



May–June), than for winter (January–February–March) and fall (October–November–December). Moreover, the DM and ADI of SPI-6 were found to be higher during the fall–winter period than the winter–spring period. These results confirmed that there was a shift in rain towards the spring months. The similitude of DM and ADI for the SPI-12 and SPI-9 is due to the fact that in Lebanon zero rain is recoded during the three summer months from July through September.

Climate change is expected to alter future rain patterns and occurrences of drought events. However, the amplitude of the change may broadly differ across seasons. A realistic assessment of future climate change is of great importance for Lebanon and the Mediterranean arid regions, which are vulnerable to climate variabilities, where extreme precipitation events are expected to intensify for all seasons.

Overall, the different scaled SPI assessment allowed an improve understanding of temporal distribution of drought in Lebanon. This facilitates exploring the paradigm "wet season becomes drier" and "dry season becomes wetter", and the transition of wetness towards drier months or vice versa under future climate conditions. Whereas climate change is expected to alter rain patterns, this work showed how the amplitude of the change broadly differed across seasons. This necessitates the need to device a monitoring program for investigating potential impacts of drought on all relevant sectors. Such a program would be of great importance for Lebanon and the Mediterranean arid regions.

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