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Investigating the Temporal Variability of the Standardized Precipitation Index in Lebanon

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Abstract: The impact of global climate change on Lebanon's society, environment, and economy is expected to be tremendous. Indices have been developed to help in the identification and monitoring of drought and characterization of its severity. In this context, this work aimed at assessing the temporal variability of the Standardized Precipitation Index in Lebanon for improved understanding of drought occurrence. This is expected to help in mitigation and response actions to future drought circumstances across the country. The methodology of work involved the calculation of the Standardized Precipitation Index over different time series from four regions across the country using both the Variability Analysis of Surface Climate Observations (VASClimO) gridded rainfall dataset for the period 1951–2000 and the European rainfall dataset E-OBS for the period 1950–2014. In general, higher precipitation values were recorded by the VASClimO dataset than those coming from the E-OBS dataset. Intra-annual precipitation changes showed increasing precipitation starting in September-October and decreasing precipitation starting in February. The VASClimO dataset showed a 50% increase in the frequency of severe drought conditions, while the E-OBS dataset indicated a 60% increase in the frequency of moderate drought conditions. In addition, it was observed that the winter of 2014, characterized by extreme drought conditions, was the driest in the past 56 years. Although specific years were commonly characterized by severe to extreme drought conditions with the use of both datasets, considerable differences between the two datasets were observed with respect to the identification of the degree of wet and dry conditions for some other years. Overall, trend lines for the Standardized Precipitation Index values, as derived from VASClimO and E-OBS datasets, commonly point to a relatively slight increase in drought conditions mainly in the winter-spring season; however, the situation on the ground could vary greatly given that many other environmental factors (e.g., changes in land cover) may also play an important role in affecting drought conditions.

Keywords: drought; climate variability; VASClimO; E-OBS; Standardized Precipitation Index

1. Introduction

Climate change is expected to increase the risk of drought in some areas of the world and the risk of extreme precipitation and flooding in others [1]. As increases in droughts over low and mid-latitudes are projected [2], a decrease in summer precipitation in southern Europe and across the Mediterranean region, accompanied by rising temperatures, would inevitably lead to reduced summer soil moisture and more frequent and intense droughts [3]. In this regard, [4] found that precipitation changes under climate change had a greater impact on the water and soil resources than did changes in either the CO_2 level or temperature increases. In addition, [5] found that climate variability influenced the catchment hydrology more significantly than the land use change, suggesting that the influence of climate variability should be considered and assessed separately when quantifying the hydrological effect of vegetation restoration in a catchment area.

Many aspects of projected climate change will likely affect forest growth and productivity in response to elevated atmospheric CO_2 and increases in temperature [6,7]. Drought is one of the main results of a changing climate, and one of the main natural causes of agricultural, economic, and environmental damage [8–10]. During the past decades, however, there has been a high concern that the frequency, severity and duration of drought are going to increase [11]. The frequency of a drought event is usually expressed by its return period or occurrence interval, which may be defined as the average time lag between two events of the considered magnitude or larger magnitude [12]. The magnitude of a considered drought event corresponds to the cumulative water deficit over the drought period [13], while the average of this cumulative water deficit over the drought period is mean intensity. Drought duration is closely linked to its onset and withdrawal date and is sometimes expressed in terms of the number of consecutive days of no rain [14].

In Lebanon, it is expected that drought periods over the whole country will become 9 days longer by 2040 and 18 days longer by 2090 [15]. Even though there is no universally adopted definition of drought, the chief characteristic of a drought is a decrease in water availability in a particular period over a particular area [16].

The analysis of drought may incorporate different indices and methodologies that consider meteorological and hydrological variables such as rainfall, soil moisture, evapotranspiration, ground and surface water levels [17,18]. The Standardized Precipitation Index [19] (SPI) has been used as a tool to identify and assess drought events in many countries [20–22]. SPI is a simple index since precipitation is the only parameter [23]. The main advantage of this drought analysis technique is its simplicity and temporal flexibility, because it only uses the precipitation data over time.

SPI can be used to monitor short-term water supplies such as soil moisture, which is important for agricultural production, and long-term water resources such as groundwater supplies [24]. In addition, SPI is a tool that can be used on an operational basis as a regional or national drought watch system. On a relatively short timescale, soil moisture conditions respond to precipitation anomalies [25]. Accordingly, 1- to 6-month SPI values can be investigated for monitoring agricultural drought, while 6-month up to 24-month SPI values can be investigated for analyzing hydrological drought.

As an alternative index to SPI, [26] evaluated the use of a modified version of the Rainfall Anomaly Index (mRAI) and found that mRAI was highly correlated with SPI on monthly and seasonal timescales. In addition, it was observed that precipitation-based indices like the tested SPI and mRAI bear some limitations and tend to underestimate the real drought. In general, it was assumed that the mRAI provides sufficiently robust results for the evaluation of future precipitation anomaly trends for climate change adaptation purposes. Yet, [20] observed that the use of SPI can also contribute to an improved understanding of drought duration, magnitude, and spatial distribution in semi-arid areas. Taking into account that SPI does not require information about land surface conditions and is solely a function of the precipitation amount [25], it would be more convenient to use the index for assessing drought conditions in a country like Lebanon, especially with the severe lack of information needed to develop other drought indices.

Overall, drought indices and their association with disasters such as forest fires needs be further investigated [27]. According to a previously conducted study [28], increasing forest fires in Lebanon could be linked among others, to global climatic warming, which reduces fuel moisture and increases fire occurrence and fire spread. Most recently, [29] concluded that the recent 15-year drought in the Levant (1998–2012) was the driest on record. The same study indicated an 89% likelihood that this drought was drier than any comparable period of the last 900 years.

In this context, it would be essential to further investigate drought conditions in the Eastern part of the Mediterranean and attempt to relate these to natural disasters. Accordingly, the aim of this study was to assess the temporal variability of SPI in Lebanon for improved understanding of drought occurrence. However, continuous and reliable historical data of rain gauge stations from Lebanon are not always available. Consequently, it is essential to explore rainfall characteristics and trends in Lebanon using gridded precipitation datasets such as the global dataset VASClimO [30] and the European dataset E-OBS [31].

2. Study Area and Dataset Description

The study area is the country of Lebanon located in the Eastern Mediterranean. The Lebanese territory is divided into four distinct physiographic regions: the coastal plain, the Lebanon mountain range, the Beqaa valley and the Anti-Lebanon mountains. The Lebanon mountain range, where most of Lebanon's forests are present, is carved by narrow and deep gorges, rises steeply parallel to the Mediterranean coast, and peaks at 3088 m. Lebanon's climate is characterized by dry summers extending from June to November with average daytime temperatures above 30 °C, and little rain with around 90% of the total annual precipitation falling between November and March [28]. Like many other countries in the Mediterranean, Lebanon has experienced increasing risk of hazards such as floods and wildfires during the past three decades. This situation could be mainly attributed to changes in landcover/landuse [32] and worsened by a changing climate [28].

Climatic data, namely monthly precipitation were collected. In this study, monthly precipitation datasets were acquired from the Global Precipitation Climatology Centre database (GPCC) for the years 1951 through 2000 mainly due to the lack of periodical reliable data from actual stations across Lebanon over the required period of time. More specifically, the employed dataset was developed within the research project VASClimO (Variability Analysis of Surface Climate Observations) in the form of gridded monthly precipitation with a spatial resolution of 0.5° × 0.5° [30]. This dataset subdivided the total surface of Lebanon into distinct GPCC datasets with four center points located within the country. These central points, namely Bazourieh in Tyre (around 197 m above sea level), Mrah El Abed in Hermel (around 1428 m asl), Bmahray in Aley (around 1215 m asl), and Kfarhay in Batroun (around 375 m asl), are shown within the grid (Figure 1).

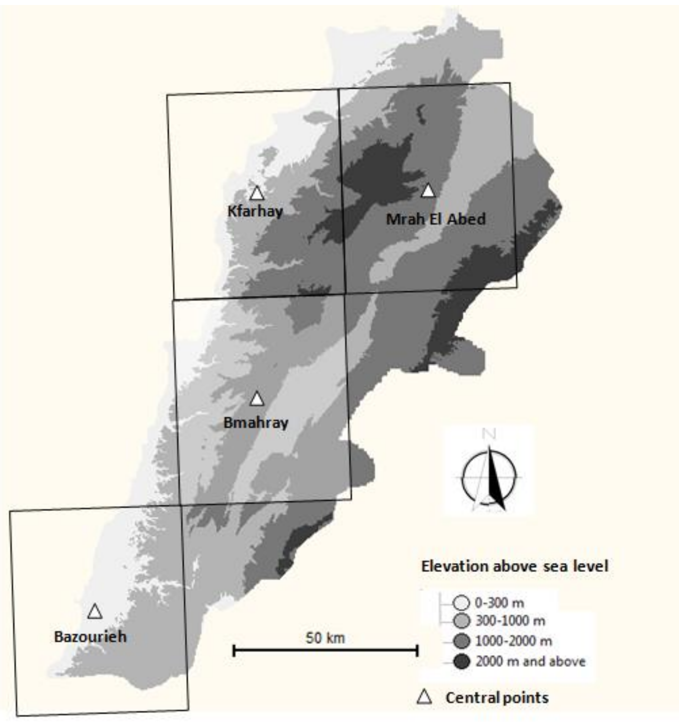

Figure 1. Center points of the VASClimO and E-OBS grid boxes within Lebanon.

In addition, the E-OBS rainfall gridded data set (v12.0 released in October 2015) with a spatial resolution of 0. 5° × 0. 5° and covering the years 1950 throughout 2014 was obtained for this study. The grid cells of this dataset and their center points coincide with those from the VASClimO dataset. Accordingly, data from the same central points were considered in this study. It is worth noting that the reliability of both datasets varies from region to region based on the distribution of involved stations.

The grids of both datasets showing central points of GPCC and E-OBS are displayed in Figure 1.

3. Methodology of Work

Calculation of SPI for a specific time period at any location requires a long-term monthly precipitation database (⩾30 years). First, a probability distribution function is determined from the long-term record by fitting a gamma distribution function to the data. Second, the cumulative fitted probability distribution is transformed into a normal distribution, with a mean of zero and standard deviation of one. Hence, SPI represents a *z*-score, or the number of standard deviations above or below that an event is from the mean [33]. The magnitude of departure from zero represents a probability of occurrence so that decisions can be made based on this SPI value. Positive SPI values indicate greater than median precipitation, while negative values indicate less than median precipitation [17].

Originally, [19,34] used an incomplete gamma distribution to calculate SPI. Further efforts have been made to standardize SPI computing procedure so that common temporal and spatial comparisons can be made by SPI users [23]. Computation of SPI involves fitting a gamma probability density function to a given time series of precipitation [19,34], whose probability density function, $g(x)$, is defined as:

$$g\,(x) = \frac{1}{\beta^{\alpha}\,\Gamma\,(\alpha)} x^{(\alpha-1)}\, e^{\left(\frac{-x}{\beta}\right)} \quad (\text{for } x\ > 0) \tag{1}$$

where $\alpha > 0$ is a shape parameter, $\beta > 0$ is a scale parameter, $x > 0$ is the amount of precipitation, $\Gamma(\alpha)$ is the gamma function, which is defined as:

$$\Gamma\,(\alpha) = \int_0^{\infty} y^{(\alpha-1)} e^{-y}\, dy \tag{2}$$

The parameters α and β are estimated by fitting the probability distribution function to the data:

$$\alpha\ = \frac{1}{4A}\left(1+\sqrt{1+\frac{4A}{3}}\right),\ with\ A = \ln\,(\overline{x}) - \frac{\Sigma \ln\,(x)}{n} \tag{3}$$

$$\beta\ = \frac{\overline{x}}{\alpha} \tag{4}$$

where n is the number of rainfall observations (years).

The calculated α and β parameters for the four center points are given in Table 1.

Table 1. Calculated α and β parameters for the four center points.

	Bazourieh	Mrah el Abed	Kfarhay	Bmahray
α	0.0149	0.0140	0.0132	0.0140
β	44,499.13	45,171.54	58,949.97	43,300.73

Once parameters α and β are known, the rainfall distribution function at the central point is represented by a mathematical cumulative probability function as given by [35]:

$$G\,(x) = \int_0^{x} g\,(x)\ dx = \frac{1}{\beta^{\alpha}\ \Gamma(\alpha)} \int_0^{x} x^{(\alpha-1)}\, e^{\left(\frac{-x}{\beta}\right)}\, dx \tag{5}$$

In order to account for zero value probability, since the gamma distribution is undefined for $x = 0$, the cumulative probability function for gamma distribution is modified as [36]:

$$H(x) = q + (1 - q)\ G(x) \tag{6}$$

where q is the probability of zero precipitation.

Finally, the cumulative probability distribution is transformed into the standard normal distribution to compute SPI by fitting the log-normal distribution with the sample mean and variance of the logarithmic transformed data μ_y and σ_y, SPI becomes:

$$\text{SPI} = z = \frac{ln(x) - \mu_y}{\sigma_y} \tag{7}$$

Because gamma distribution tends towards the normal as the shape parameter (α) tends to infinity, it would be possible to use the normal probability distribution instead of gamma, mainly because it is easier to calculate and more accurate. As a result, SPI anomalies are calculated as a z-score:

$$\text{SPI} = z = \frac{(x - \overline{\mu})}{\sigma} \tag{8}$$

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

Since SPI is equal to the z-value of the normal distribution, seven-category classifications for SPI (Table 2) were proposed [19].

Table 2. SPI and its corresponding moisture categories.

SPI	Index Value	Class
Non Drought	SPI ⩾ 2.00	Extremely Wet
	1.50 ⩽ SPI < 2.00	Very Wet
	1.00 ⩽ SPI < 1.50	Moderately Wet
	−1.00 ⩽ SPI < 1.00	Near Normal
Drought	−1.50 ⩽ SPI < −1.00	Moderate Drought
	−2.00 ⩽ SPI < −1.50	Severe Drought
	SPI < −2.00	Extreme Drought

In this study, SPI was initially generated for four different regions across Lebanon using VASClimO dataset. The calculations involved three different timescale levels, namely 3 months (SPI-3), 6 months (SPI-6) and 12 months (SPI-12). While SPI-3 provides a seasonal estimation of precipitation, SPI-6 and SPI-12 gives medium-term and long term trends in precipitation patterns, respectively.

Accordingly, SPI values for every single grid cell were calculated separately. In the overall analysis of drought characteristics, the individual grid cell precipitation and SPI values were averaged (arithmetic average).

Similarly, SPI monthly, seasonal, and yearly values for the period 1950–2014 were calculated using rainfall data collected from the previously described four center points of E-OBS gridded dataset.

4. Results and Discussion

Results from processing VASClimO datasets were used for studying general precipitation characteristics and analyzing trends in drought conditions for the period 1951–2000. It was possible to take full advantage of the E-OBS dataset for analyzing precipitation characteristics and drought conditions for the longest period with data availability covering the years 1950 throughout 2014.

4.1. Precipitation Characteristics

In reference to VASClimO data, annual precipitation totals in Lebanon for individual grid cells ranged from 315 mm in the semi-arid area of Hermel in North-Beqaa (the inland region) to 1222 mm in North-Lebanon. Yearly average precipitation (September through June) varied from 610 mm in central inland Lebanon (Bmahray) to 780 mm in North Lebanon (Kfarhay). In addition, variability in monthly precipitation patterns was observed among the different sites. Average monthly precipitations values were highest in January recording 174 mm in North Lebanon (Kfarhay), 158 mm in South Lebanon (Bazourieh), 139 mm in central Lebanon (Bmahray) and 138 mm in the semi-arid region of inland North Beqaa (Mrah el Abed). Overall, the peak month for precipitation was January.

As for the E-OBS data, values of annual precipitation totals varied from approximately 100 mm in Bmahray to 955 in Bazourieh. Yearly average precipitation varied from 519 mm in Bazourieh to 573 mm in Kfarhay. Average monthly precipitations were highest in December, recording approximately 80 mm in Kfarhay and 82 mm in Bmahray. The year 2014 recorded the lowest precipitation amount in Bmahray in the past 50 years.

On average, 60% of total precipitation in the two datasets occurred between December and February. Intra-annual precipitation changes in both datasets showed increasing precipitation starting September-October and decreasing precipitation starting February.

Overall, the magnitude of the values for individual grid varied considerably depending on the chosen gridded dataset. In general, the annual precipitation totals for the period 1951–2000 were higher in the VASClimO dataset than those in the E-OBS dataset except for the years 1957, 1991, 1997, and 2000 (Figure 2). However, the variations in precipitation totals at the local level are considerably higher as the values of the grid cells only represent spatially strongly smoothed records. Analyses based on station data described annual precipitation totals of more than 1000 mm in the North, more than 1200 mm in Mount-Lebanon, around 930 mm in the South, and 705 mm in the Beqaa (inland) [15]. This makes the employed VASClimO dataset a more representative dataset of local precipitation conditions.

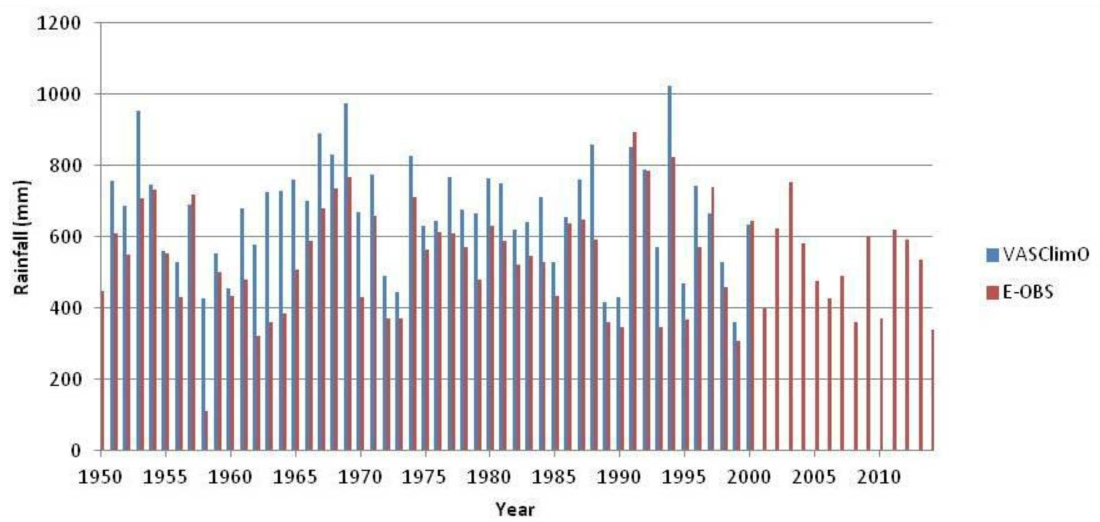

Figure 2. Distribution of yearly averaged precipitation totals as recorded by the two datasets.

4.2. SPI Trends

SPI values were calculated using both datasets on different timescales, namely at 12, 6 and 3 months bases. The use of VASClimO data shows a decreasing trend of SPI-12 for all selected regions, thus indicating a higher tendency of increased drought occurrence throughout the country (Figure 3). A more careful observation of the results showed that severe ($-2.00 \leqslant$ SPI < -1.50) to extreme (SPI < −2.00) drought conditions occurred over the four studied locations at an average of 10- to 15-year-time intervals.

Furthermore, it was observed that moderate drought conditions (−1.50 ⩽ SPI < −1.00) occurred at an average of 5-year time intervals.

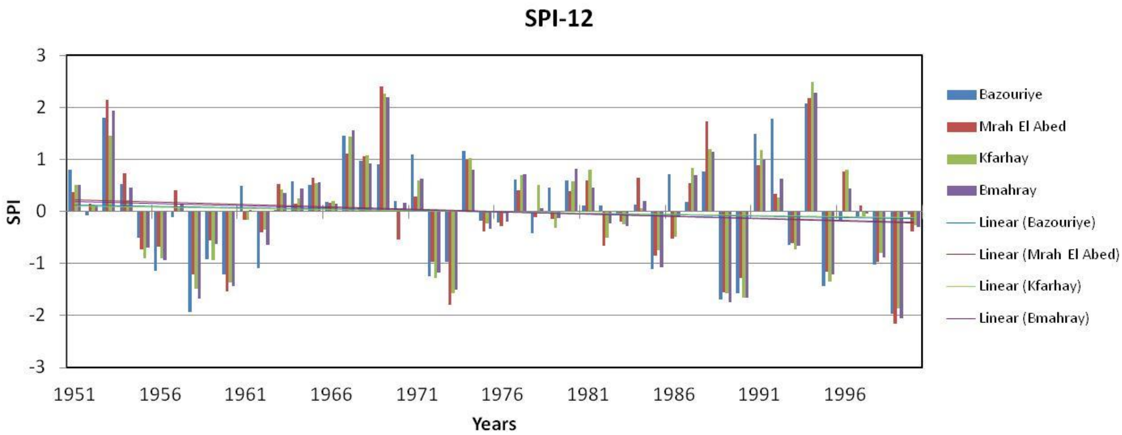

Figure 3. Yearly SPI (SPI-12) over the period 1951–2000 using VASClimO dataset.

When comparing drought conditions between two sub-periods, namely 1951–1975 and 1976–2000, it was found that the latter was characterized by a threefold decrease in the frequency of moderate drought conditions and a twofold increase in the frequency of severe drought conditions. In addition, the second period was characterized by both, an extremely wet condition in the year 1994 and an extremely dry condition in the year 1999.

Similarly, the use of E-OBS dataset showed a decreasing trend of SPI-12 for all selected regions, also indicating a higher tendency of increased drought occurrence across the country (Figure 4). A more careful observation of the results showed an extreme drought condition (−2.00 > SPI) in the year 1958. Severe (−2.00 ⩽ SPI < −1.50) to extreme (SPI < −2.00) drought conditions occurred over the four studied locations at an average of 16-year-time intervals. Further, it was observed that moderate drought conditions (−1.50 ⩽ SPI < −1.00) occurred at an average of 5- to 6-year time intervals. The year 2014 was classified as the driest period in the past 15 years.

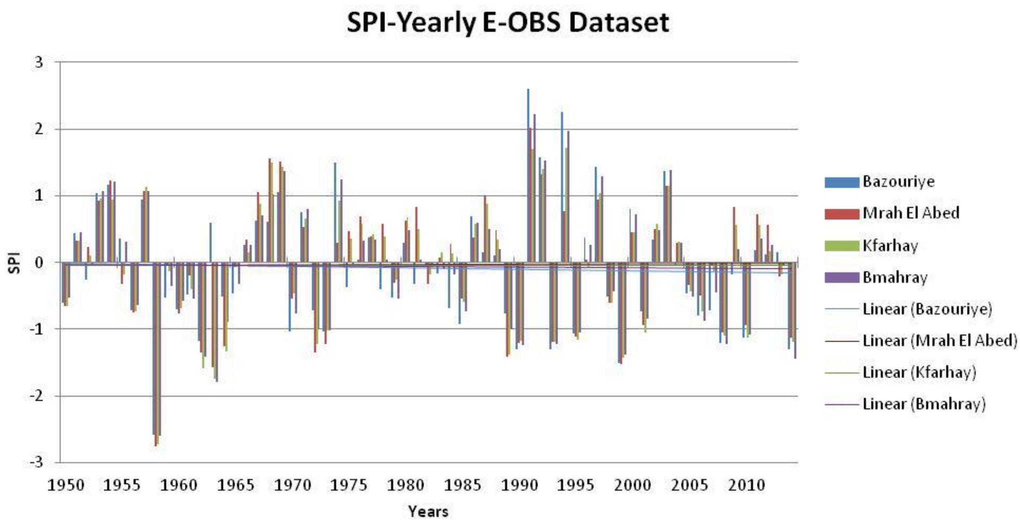

Figure 4. Yearly SPI (SPI-12) over the period 1950–2014 using E-OBS dataset.

When comparing drought conditions between the same two sub-periods, namely 1951–1975 and 1976–2000 using the E-OBS dataset, no significant changes in the frequency of moderate and severe drought conditions were observed. However, when considering the two sub-periods, namely 1950–1982 and 1983–2014, it was found that the latter was characterized by a 60% increase in the frequency of moderate drought conditions, mainly in the years 2001 throughout 2014.

Averaged SPI-6 values were also calculated from the four center points using both datasets. In general, SPI-6 is commonly used, along with SPI-3 for monitoring agricultural drought conditions [25]. The fall-winter interval, also named the winter half-year period, includes the 6-month period extending from October till March, while the winter-spring interval includes the 6-month period extending from December till May. In this study, SPI-6 showed a decreasing trend for the four locations when using the VASClimO dataset (Figure 5). In addition, SPI-3 was calculated for the different locations showing also decreasing trends in SPI values for fall, winter, and spring seasons (Figure 5). The year 2000 was the driest during the period 1951–2000. In general, an increasing drought frequency was observed to be more prominent during the winter season.

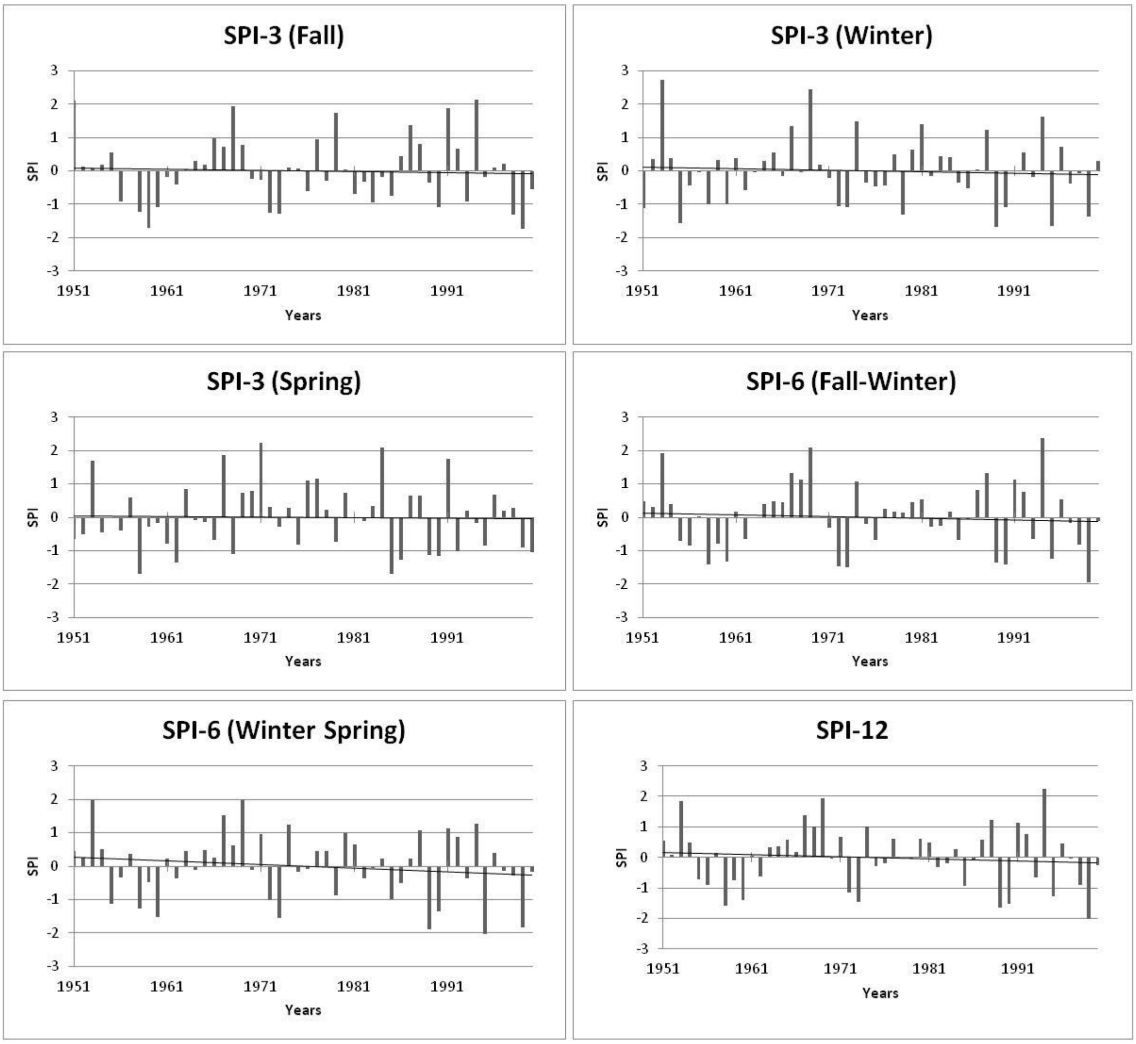

Figure 5. Trend lines of SPI averaged values using VASClimO dataset.

When using the E-OBS dataset, SPI-6 (winter-spring) showed also a decreasing trend (Figure 6). In addition, SPI-3 was calculated for the different locations, also showing decreasing trends in SPI values mainly for the winter and spring seasons (Figure 6). More specifically, the winter of 2014, characterized by extreme drought conditions, was the driest in the past 56 years. The winter-spring period of 2014, characterized by severe drought conditions, was the driest in the past 50 years. In general, an increasing drought frequency was observed to be more prominent during the winter-spring period and during the spring season.

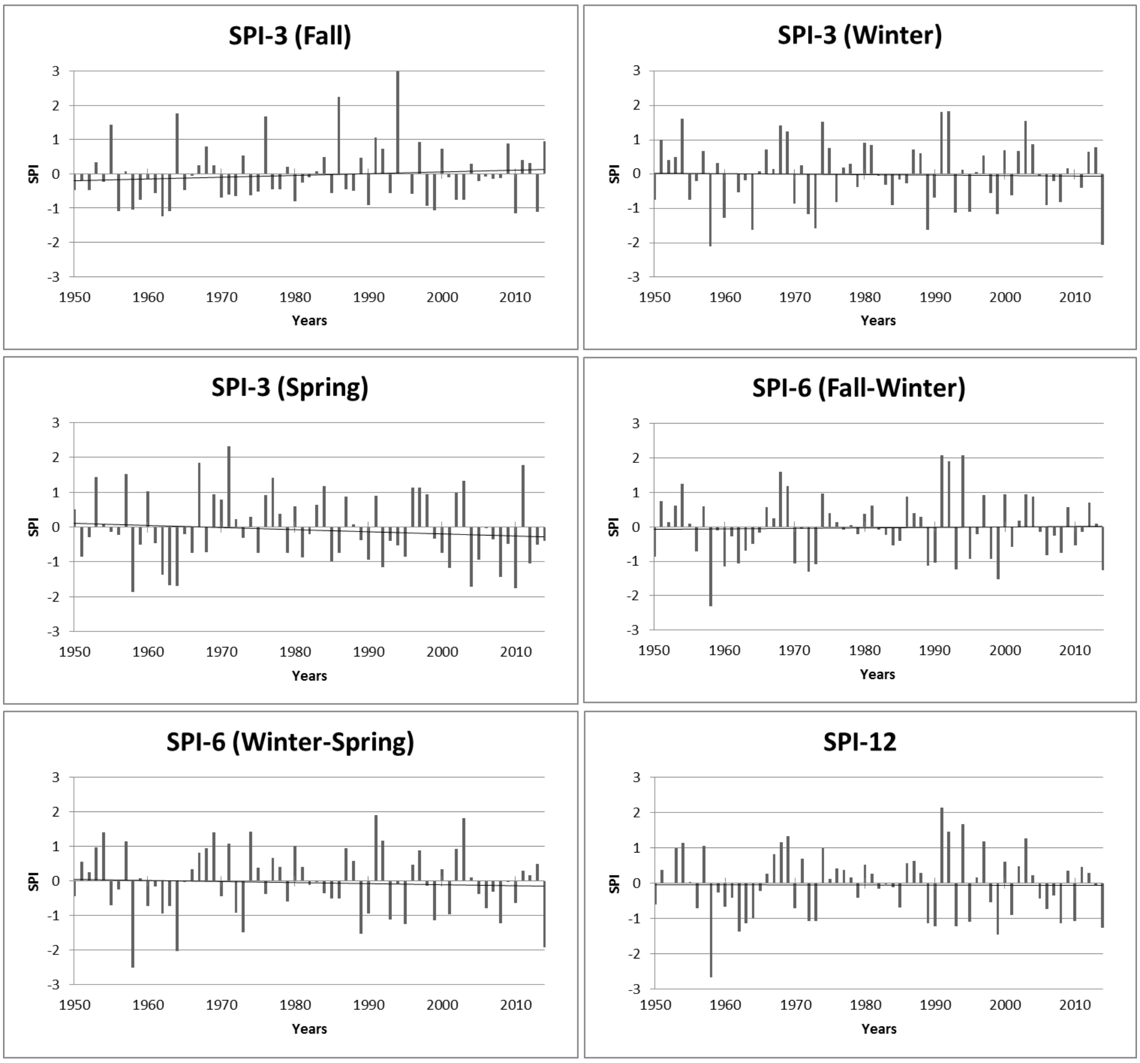

Figure 6. Trend lines of SPI averaged values using E-OBS dataset.

A comparison between the yearly SPI values, as derived from the two datasets, was also conducted to obtain an overview of possible agreements and/or disagreements in drought and wet conditions (Figure 7). In general, there were periods where there was considerable disagreement between the two datasets in identifying wet or dry conditions. This applies, e.g., to the year 1963 where VASClimO indicated near normal to slightly wet conditions, whereas E-OBS indicated moderate drought conditions. Further, there were periods where there were disagreement cases in the classification of wet or dry conditions. This applies, e.g., to 1958 where VASClimO indicated severe dry conditions, whereas E-OBS indicated extreme dry conditions. In addition, it applies, e.g., to 1994 where VASClimO indicated extremely wet conditions, whereas E-OBS indicated very wet conditions. These differences disappear in some regions, while being particularly pronounced in others especially with the presence of significant differences among the regions. For instance, the E-OBS dataset indicated an SPI-12 value of 0.7 in Mrah El Abed (North Beqaa) in 1994, whereas Bazourieh (South Lebanon) recorded a value of 2.25. In another case involving the E-OBS dataset for the year 1963, Bazourieh recorded an SPI-12 value of 0.58, whereas the remaining regions recorded an SPI-12 close to −1.7. This suggests potential inaccuracies in the gridded datasets, which could be attributed to differences in the groups of stations composing the basis of the grids, and therefore, their identified precipitation trends [37]. Simultaneously, there were periods where there was considerable agreement between the two datasets in the classes of wet or dry conditions. This applies, e.g., to 1995 where both datasets indicated moderate drought conditions.

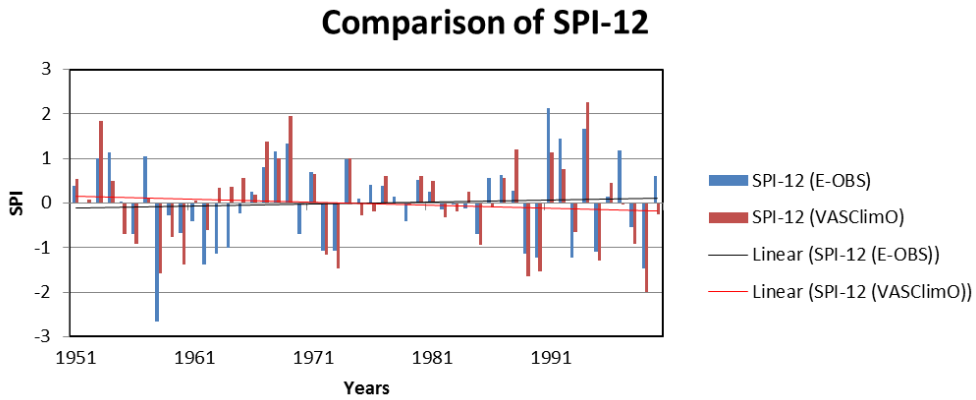

Figure 7. Comparison of yearly SPI from both VASClimO and E-OBS datasets.

Overall, comparing the annual SPI trends of the two gridded products showed slightly opposite trend directions. This was mainly due to (1) an exceptionally low rainfall total in 1958 in E-OBS not reflected in VASClimO; and (2) rainfall totals in the years 1991 and 1997 in E-OBS that were exceptionally higher than rainfall totals in VASClimO. In turn, this resulted from a combination of factors, namely the underlying station data and the precipitation estimation methodology. Therefore, it is not possible to assign superiority/inferiority qualifications to the two datasets. Yet, it would be necessary to evaluate the E-OBS dataset, among others, in the future, against long-term station data in the country. Accordingly, it would be highly desirable to increase the number of measurement stations and make available all existing meteorological datasets in the country.

Overall, an increasing drought frequency potentially contributes to higher agricultural, economic, and environmental damages. Results from another study [28] showed that the length of the fire season was negatively correlated with mean annual precipitation ($r = -0.836$ at $P < 0.01$). It was also shown by other studies conducted in the Mediterranean ecosystem [38,39] that fire probability and number of fire events increased in seasons that were warmer and drier than average. In addition, other studies [24,40,41] showed that large-scale forest fires were associated with high long drought periods, among others.

With the lack of continuous and reliable historical data of rain gauge stations from Lebanon, the use of gridded datasets for deriving SPI has potential use in Lebanon for monitoring drought conditions and possibly their impact on different sectors such as forestry and agriculture. Yet, the resolution of the employed grid cells is too coarse to represent the precipitation characteristics that might arise from topographic variability. The use of other gridded datasets such as E-OBS, which is a European daily high-resolution gridded dataset of surface temperature and precipitation [31], might have also other limitations. However, the VASClimO and E-OBS datasets have their individual pros and cons. In reference to [30], VASClimO is specifically designed for trend analysis purposes, while both datasets have the same limitations in comparison to station data, interpolation error, and underestimation of extremes [37].

As shown by [37] in a study targeting a neighboring region, both datasets correlate well with few exceptions for specific years. Furthermore, trend lines of SPI showed slight increases in drought conditions for specific regions.

Overall, VASClimO in the four regions agree with [37] in identifying the year 1999 as one of the driest years in the record. That year was indicated as one of the warmest years possibly due to the strongest El-Nino event in the 20th century [37]. As per the E-OBS dataset, the year 1999 was the second driest after the year 1958.

Finally, it would be of value to identify the role of temperature increase in drought conditions. This could not be assessed with the sole use of SPI. However, with availability of additional data, other indices such as the standardized precipitation evapotranspiration index (SPEI) can be used to account for possible effects of temperature variability and temperature extremes [10].

5. Conclusions

Monitoring drought conditions with the use of reliable drought indices can help decision makers adopt appropriate processes and measures for mitigation and adaptation to changing environmental conditions. In this work, SPI was calculated from monthly precipitation values of four center points from the gridded VASClimO and E-OBS datasets. Higher precipitation values were recorded by the VASClimO dataset than those coming from the E-OBS dataset. However, reliability of the employed gridded datasets in Lebanon need to be further assessed with regard to the station data that are incorporated in the products.

The VASClimO dataset showed that yearly average precipitation (September through June) varied from 610 mm in central inland Lebanon (Bmahray) to 780 mm in North Lebanon (Kfarhay), while average monthly precipitations were highest in January, recording 174 mm in North Lebanon (Kfarhay), 158 mm in South Lebanon (Bazourieh), 139 mm in central Lebanon (Bmahray) and 138 mm in the semi-arid region of inland North Beqaa (Mrah el Abed). Simultaneously, E-OBS data showed that yearly average precipitation varied from 519 mm in South-Lebanon to 573 in North Lebanon, while average monthly precipitations were highest in December, recording approximately 80 mm in North Lebanon, and 82 mm in central inland of the country.

SPI values as derived from the VASClimO dataset showed a decrease in the frequency of moderate drought conditions when comparing drought conditions between two sub-periods, namely 1951–1975 and 1976–2000. Simultaneously, it was found that the second period was characterized by a twofold increase in the frequency of severe drought conditions. Further, the second period was characterized by both, an extremely wet condition in the year 1994 and an extremely dry condition in the year 1999. When comparing drought conditions between the same two sub-periods while using the E-OBS dataset, no significant changes in the frequency of moderate and severe drought conditions were observed. However, when considering wider sub-periods, namely 1950–1982 and 1983–2014, it was found that the latter was characterized by a 60% increase in the frequency of moderate drought conditions, mainly in the years 2000 throughout 2014.

On the one hand, the use of the VASClimO dataset showed a decreasing trend in SPI-6. In addition, SPI-3 showed decreasing trends in SPI values for fall, winter, and spring seasons. Yet, an increasing drought frequency was observed to be more prominent during the winter-spring season. On the other hand, the use of the E-OBS dataset also showed a decreasing trend in SPI-6 (winter-spring) for all considered regions. In addition, SPI-3 showed also decreasing trends in SPI values, mainly for winter, and spring seasons, while an increasing drought frequency was observed to be more prominent during the winter-spring period and during the spring season.

This study noted considerable differences between the two gridded datasets with respect to the identification of wet and dry conditions for specific years. This could be attributed to differences in the groups of stations composing the basis of the grids, and therefore, their identified rainfall trends. However, the results of this study are partially in line with the findings of other similar studies in the region.

In general, the results pave the way towards scientific evaluation of dryness and wetness temporal and spatial variability. However, it is essential to note that drought conditions could always vary in reality with the involvement of many other factors such as changes in land cover/land use, among others. Accordingly, further studies are required to assess the impact of such factors on drought conditions. In addition, future work would involve spatial mapping of SPI to allow for a more advanced investigation of temporal and spatial variability of drought frequencies and their association with possible hazards such as forest fires and floods. Further, the use mRAI and its correlation with the occurrence of natural disasters can be further investigated in the future.

Nevertheless, this study showed a severe lack of historical and spatially explicit meteorological and climatic data. In this context, Lebanon should benefit from an extensive network of weather stations across the country for conducting a proper monitoring of future drought conditions. This is supposed to ensure an improved and continuous monitoring of drought conditions in the country, therefore undertaking proper mitigation measures and triggering appropriate policy response.

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