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Alterations in precipitation and drought indices over the last thirty years in Peloponnese, Greece

A. Tsirimpi[1] and E. Dimitriou[1,2]
[1] *School of Science and Technology, Hellenic Open University, Aristotelous 18, 26335 Patra*
[2] *Hellenic Centre for Marine Research, Institute of Marine Biological Resources and Inland Waters, 46.7 km of Athens – Sounio Ave., 19013, Anavissos, Attiki, Greece*
e-mail: tsirimpi.aikaterini@gmail.com, elias@hcmr.gr

Abstract: Drought is a complicated and difficult to predict phenomenon that causes significant socioeconomic and environmental impacts, worldwide. Many research efforts attempted to study and quantify drought characteristics by using different drought indices such as the Standardized Precipitation Index (SPI), which is a widely applicable and robust index based solely on precipitation data. Greece, as a Mediterranean country, suffers from long lasting droughts and semi-arid conditions especially in its Southern part, that lead to frequent and intensive socioeconomic problems. The main objective of this study is to examine the drought events during the last thirty years at the Peloponnese Peninsula in order to identify their dominant trends and spatiotemporal characteristics. The SPI index has been estimated for various time scales and statistical elaborations indicated the existence of a wet period during 1975 - 1984 followed by an intensive dry period of (1985 - 1994). The northeastern part of Peloponnese illustrated the highest decrease in the SPI values, throughout the entire study period, indicating a strong spatial pattern of drought. Thus, mitigation measures should be designed and implemented, some of which are proposed in this effort, focusing in that part of Peloponnese, to minimize the future impacts from potential extended drought periods.

Key words: drought indices, Standardized Precipitation Index, forecasting methods, contingency plan, risk management system

1. INTRODUCTION

Climate change and global warming enhance drought phenomenon through the interaction of physical and anthropogenic parameters (Dasaklis et al. 2012). Droughts significantly affect the water balance in a given area causing water shortage and socioeconomic problems that can sometimes lead to public health issues. Both surface runoff and groundwater levels are strongly impacted from extended droughts, which may lead to low availability of water for domestic supply, irrigation, and industrial uses.

There is a variety of drought indices that have implemented globally, in order to study and understand the characteristics and impacts of this phenomenon. Among the most widely used ones, are the Standardized Precipitation Index (SPI, McKee et al. 1993), the Palmer Drought Severity Index (PDSI, Palmer 1965) and the Deciles of Precipitation index (Gibbs and Maher, 1967). SPI is the most commonly used index, since it is easy to apply, through the use of precipitation values only, and it is consistent across different spatial and temporal scales. The Palmer Drought Severity Index (PDSI, Palmer 1965) is based on the water balance equation by taking into account the parameters of precipitation, temperature and soil moisture while the Net Bhalme and Mooley Drought Index (BMDI, Bhalme and Mooley 1980) is mostly used to study short-term, regional meteorological droughts. Many other indices have been developed but not used extensively such as the Rainfall Anomaly Index (RAI, Van Roy 1965) and the Reconnaissance Drought Index (RDI, Tsakiris and Vangelis, 2005) which also follow water balance approaches to estimate the drought events.

Comparing the SPI and the RDI index, Zarch et al. (2014) showed that there is no significant tendency in the drought indices with the existence of both increasing and decreasing drought trends in various aridity zones for the period 1960 – 2009. However, investigating the two indices separately RDI showed more decreasing trends in the humid zones, while the SPI index showed that drought phenomena affected areas prior 1998. At a global scale, another study of Damberg and Aghakouchak (2013) indicated no significant trend of drought in the period 1980 – 2012. It has been revealed that the areas in the Southern Hemisphere present significant positive tendency of the SPI index, in contrast to the areas of Northern Hemisphere where normal distribution of drought values dominate.

Spinoni et al. (2015) implemented three drought indicators at a European scale, the Standardized Precipitation Index, the Standardized Precipitation Evapotranspiration Index (Begueria et al. 2014) and the Reconnaissance Drought Index for the period 1950 – 2012. The results showed that drought phenomena occurred in Northern Europe and Russia during the years of 1950 and 1960, as well as in Central Europe and the British Islands in 1970 and in the Mediterranean area and Baltic States during the years of 1990 and 2000.

As for the drought conditions in the Mediterranean areas, Sousa et al. (2011) used the PDSI and Self Calibrated PDSI and illustrated that the 20th century was characterized by dry conditions in most western and central Mediterranean areas, except for northwestern Iberia and most of Turkey. Moreover, Merino et al. (2015), estimated negative values of SPI (droughts) for the period 1901 - 2010 mainly affecting the western Iberia.

In this study, the SPI index has been estimated for the period 1970-2012 for the Greek peninsula and particularly for Peloponnese area. The complex topography in Greece and particularly in Peloponnese has a significant effect on the climatic conditions due to strong orographic barriers that either enhance or minimize the precipitation patterns. Thus, the scope of this study is to analyze the SPI values in Peloponnese during the last thirty years and identify the dominant spatiotemporal trends on multiple time scales.

2. STUDY AREA

Peloponnese is a peninsula that is situated in the southern mainland of Greece. It is connected with the rest of the Greek mainland through the Isthmus of Corinth and the Rio – Antirio Bridge. The territory covers an area of about 21.649 km^2 and its population has reached the number of 1.046.897 inhabitants (HSA, 2011).

The climate of the study area is a typically Mediterranean with mild, wet winters and dry, hot summers while the highlands are characterized by continental climate during the winter months. In the central part of the Peloponnese, the temperature ranges from 16 to 30^{o}C in summer and 2 to 10^{o}C in winter, while in the eastern part ranges from 21 to 33^{o}C during the summer months and from 6 to 15^{o}C in winter. The average annual temperature is 18^{o}C in the coastal zone while in the higher altitudes reaches 14^{o}C (NTUA, 2008).

The average annual rainfall is approximately 774mm in the eastern and central Peloponnese while it reaches 800mm in the western part. The highest precipitation levels are recorded during the winter and spring months and the average number of rainy days ranges from 80 to 120 per year (NTUA, 2008).

3. METHODOLOGY

In order to study the alterations of the precipitation levels and drought intensity, monthly precipitation data have been used for the last 35 years, the SPI index has been estimated and statistically analyzed, while the geographic distribution of these fluctuations have been also analyzed with the contribution of an ArcGIS software.

3.1 Precipitation Data

The precipitation data, which have been used, cover the entire study area of Peloponnese (Figure 1), for the hydrological years 1970 – 2012. The data have been acquired by the Hellenic National Meteorological Service (HNMS) and consist of monthly precipitation values for 15 selected weather stations (Figure 1). These stations cover satisfactorily the geographic and topographic gradients of the the study area which is an important aspect due to the intensive topographic relief of Peloponnese (Table 1, Figure 2).

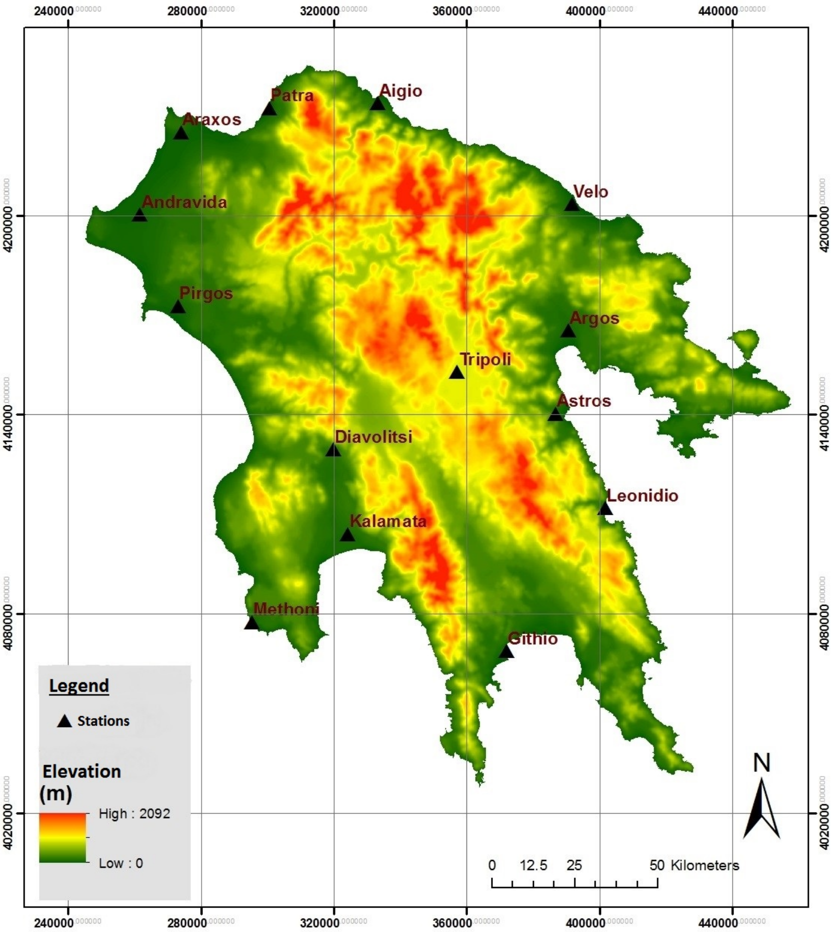

Figure 1. The geographic location of the 15 weather stations.

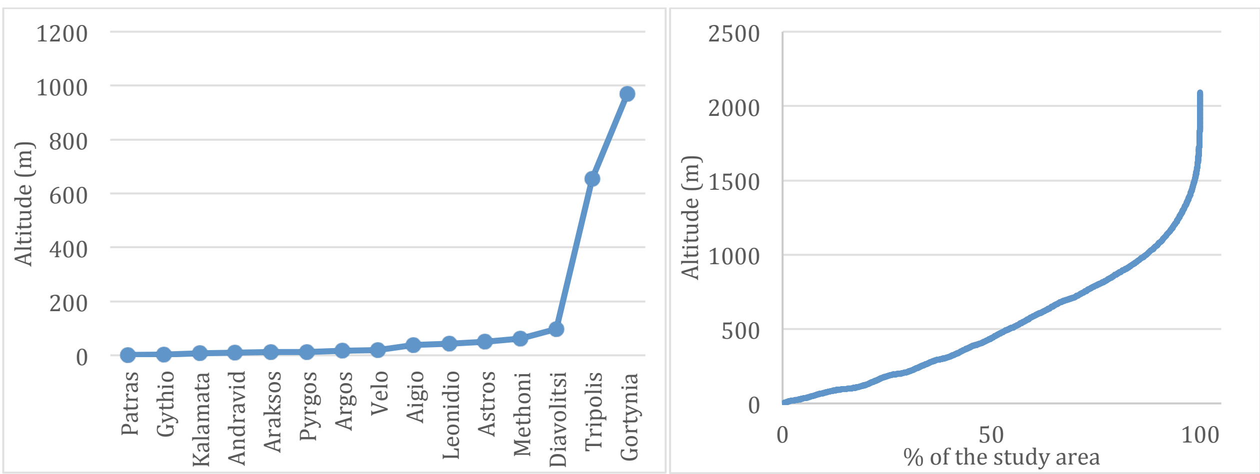

Figure 2. Precipitation stations altitude and hypsographic curve of the study area

Table 1. List of precipitation stations used for the SPI estimations

No	Stations	Altitude (m)	X	Y	Start date	End date
1	Aigio	37.2	333000.6	4234009	1974	2003
2	Andravida	9.8	261415.6	4200436	1970	2004
3	Araxos	11.5	273965.8	4225212	1970	2004
4	Argos	16	390418	4165508	1981	2011
5	Astros	49.6	386502.1	4140466	1974	2012
6	Diavolitsi	97.5	319604.7	4129634	1974	2004
7	Gortynia	970	372634.8	220349.6	1975	2004
8	Gythio	2.7	371888.1	4068845	1979	2004
9	Kalamata	6.3	324055.8	4104082	1970	2012
10	Leonidio	43	401454.6	4111960	1987	2012
11	Methoni	61.6	295120.2	4077635	1970	2012
12	Patras	1.5	300351.6	4232482	1970	2002
13	Pyrgos	11.8	272878	4172841	1975	2012
14	Tripolis	655	356925	4153011	1970	2012
15	Velo	20	391485.4	4203561	1987	2012

The precipitation data have gone through Quality Control Analysis by the Hellenic National Meteorological Service but they were also examined in this study to identify potential inconsistencies and gaps. The least squares approach has been used to check the neighboring stations data while the annual precipitation levels for all the stations have been plotted against time, to identify extremely low values that could be associated with gaps in the data. During this process, 3 meteorological stations were abandoned from the analysis due to data gaps and the data from the remaining 15 stations have been used for the particular study. Limited gaps of data (less than 3% of the total) were allowed in some stations in order to achieve a minimum number of stations necessary for the study. Moreover, these limited gaps of data could not be filled in due to the relatively low correlation between the neighbouring stations originating mainly from the long distance and complex topographic relief between them.

3.2 Simulation Time and Analysis of the SPI Drought Index

The SPI index were estimated for each station for 1-, 3-, 6- and 12– month time scales, for the period 1970 – 2012, in order to analyze droughts on both seasonal and annual bases. Then the SPI3 index estimations were used for the seasonal study (winter: December, January and February) and summer: June, July and August precipitation) while the SPI12 index has been used for the interannual study. The selection to study only winter and summer seasons out of the usual 4 seasons were taken due to the local hydrometeorological conditions in Greece that illustrate significant extremities in these particular seasons which are also associated with high impact droughts and floods. For the aforementioned estimations, a software tool that is freely available from the National Drought Mitigation Center of US has been used (http://drought.unl.edu/monitoringtools/ downloadablespiprogram.aspx) that have been developed and operationally maintained by the Colorado Climate Center (http://ccc.atmos.colostate.edu/standardizedprecipitation.php).

The SPI estimations were initially plotted against time to identify the extreme values and the strong temporal trends throughout the entire study period and then further elaborated by using SPSS software package to depict dry/wet periods and frequency patterns. A drought episode is recorded when the SPI index takes values less than -0.5, and gets extreme when the SPI value is less than -1.28 (table 2, Agnew, 2000). The particular classification system proposed by Agnew (2000) has been widely used during the recent years in Mediterranean countries such as Portugal (Santos, et at.

2010) and Spain (Vicente-Serrano et al. 2004), capturing very well the drought conditions since it is based on precipitation percentiles analysis used to capture low-flow conditions.

Table 2. SPI index classes for characterization of dry/wet periods

Classes	Characterization
higher than 1.28	Extreme wet
0.84 to 1.28	Very wet
0.5 to 0.84	Moderate wet
0 to 0.5	No wet
0 to -0.5	No drought
-0.5 to -0.84	Moderate drought
-0.84 to -1.28	Severe drought
less than -1.28	Extreme drought

3.3 Statistical analysis

The statistical analysis of the SPI values for all weather stations were performed by utilizing the statistical package SPSS. Initially, the Pettit (1979) Homogeneity test has been used to identify points of change in the SPI time series of the entire study period. The output of this effort indicated a fluctuating point of change for the various stations from the year 1983 to 1991. Therefore, given this significant variability in the stations main trends, the data were split in 3 time periods (1975 – 1984, 1985 – 1994 and 1995 – 2004), in order to be able to compare the different stations' SPI time series. The particular periods were also selected (apart from the aforementioned point of change issue) because they were covered satisfactorily by all the available stations (without significant gaps). A descriptive statistical analysis of the data followed for all the stations, as well as a more sophisticated analysis including the development and description of patterns derived from boxplots and frequency distribution diagrams. The diagrams indicating the annual SPI values included all the available data for each station in order to maximize the study period while the frequency diagrams and box-plots illustrate the SPI values of the commonly available period for all stations (1975 – 2004) so as to compare differences among the various stations. The distinctive features and patterns of the estimated statistical figures were compared along the various stations and time periods in order to identify significant drought periods and precipitation long-term trends.

3.4 Geographic distribution of the SPI

The scope of this step is to illustrate the geographic distribution of the SPI index in the study area and identify areas of Peloponnese with strong drought impacts in the last 30 years. The mean values of SPI12 for the years of 1975, 1984, 1985, 1994, 1995 and 2004, as well as the mean SPI12 values for each decade, from all the available stations have been imported to the ArcGIS software. Several built-in interpolation algorithms have been used (Krigging, Spline and IDW) to interpolate the point SPI12 values between the different stations and cover the entire area of Peloponnese, creating maps in scale of 1:250.000. These algorithms are widely used to integrate spatial information and facilitate mapping of environmental and climatic parameters (Tait et al., 2006).

The interpolation technique chosen is Spline since it provided smooth and physical interpretable, geographic gradients of the SPI values. Spline has been successfully used, in many similar cases, globally to interpolate climate data from surface observations (Borga and Vizzaccaro 1997, Daly et al., 2002, Saveliev et al., 1998). The Spline algorithm in ArcGIS Desktop software uses the 'thin plate smoothing spline modelling approach', in which a modelled data surface is fitted to the data, allowing some error at specific data point, in order to produce a relatively smooth surface. Each station is omitted from the estimation of the fitted surface at each repetition of the algorithm and a mean error value is calculated. This process is repeated until the estimated mean error value is minimized and there is an optimum smoothing of the modelled surface map (generalized cross validation process). Thus, the annual SPI maps of the aforementioned years and the averages SPI maps for each decade have been estimated, followed by the percentage change between the different decades. The spatial patterns in the SPI values over different years, decades and the associated temporal changes have been analyzed and described based on the maps' comparisons.

4. RESULTS AND DISCUSSION

4.1 Temporal Variability of the SPI3 and SPI12 Values

The annual and seasonal SPI values have been estimated for each station, in order to recognize the extended or extreme drought episodes on an annual basis as well as for the winter and summer months. Indicative SPI values are presented in the following figures.

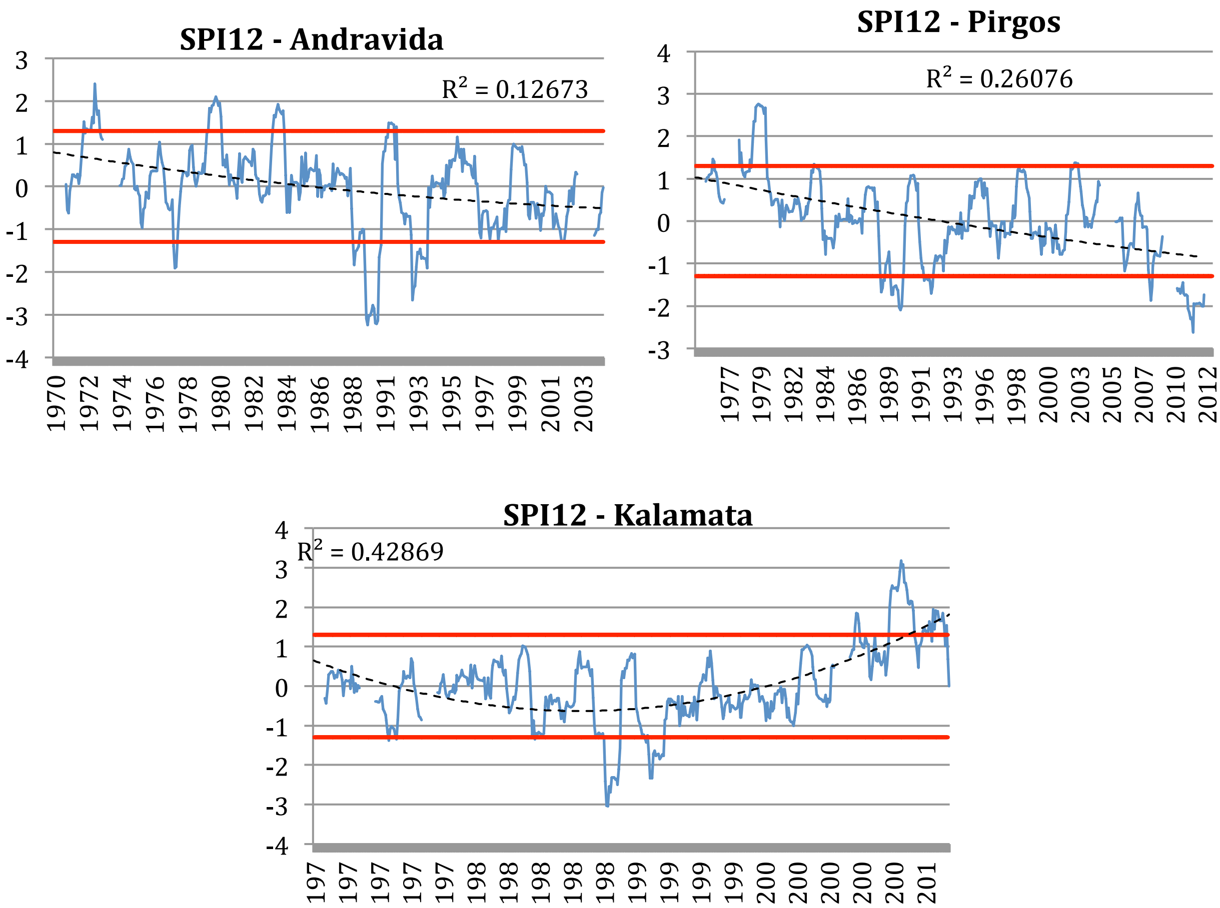

Figure 3. Variation of the SPI12 index for the: a) Andravida Station, b) Pirgos station and c) Kalamata station.

In the case of the Andravida station, the years of 1972, 1980 and 1984 were particularly wet, whereas the subperiod of 1989 – 1994 was the driest with extreme drought in 1990 and 1992. There is a significantly downward trend over the period 1970 – 2004, which is due to the appearance of wet years at the beginning (3 very wet years in the 1st decade) and extreme dry years during the last 15 years (Figure 3a). The mean value of SPI12 is 0.001, and the maximum value (2.4) appeared in the very wet year of 1972, while the minimum (-3.2) in 1990.

During the last decade the values of SPI12 show lower fluctuations compared to the past(Figure 3a), which are within the limits of the normal values (between -1.3 and 1.3). The number of the very dry years (SPI12<-1.3) are 6 for the whole study period (average frequency: 1.9 very dry years/decade), while the number of the wet years is 5 (average frequency: 1.6 very wet years/decade).

At Pirgos station (Figure 3b), the SPI12 values were mostly positive at the subperiod 1978 – 1980 while only three very dry years recorded, in 1990, 2011 and 2012 (figure 7). There is a strong decreasing trend compared to that of Andravida, while during the subperiod of 1993 – 2002 there is a normal distribution of the SPI values indicating the absence of extreme wet and dry years.

During the study period in Pirgos station, there is a major dry episode occurred in 2012 with a minimum SPI value of -2.62, while the extreme wet year was in 1980 with a maximum SPI value of 2.76. The number of the very dry years is 7 (average frequency: 2 very dry years/decade), while the number of the very wet years is 6 (average frequency: 1.7 very wet years/decade).

The station of Kalamata (Figure 3b) presents average to low values of SPI12 until the end of the 80s and heavy rainfall towards the end of the study period. The associated trend has a relatively high coefficient of determination (R^2 = 0.4287, Figure 3b) while the most dry years were 1989, 1990 and 1992 and a very wet period was recorded from 2006 to 2012.

The maximum SPI12 value (3.18) was presented in the very wet year of 2009 and the minimum price (-3.04) was recorded in the extremely dry year of 1990. The decades of 1979 - 1989 and 1995 - 2005 don't exceed the limits of the normal values of precipitation (Figure 3b). The number of the very dry years is equal to 6 over the study period and its average frequency is calculated 1.5 per decade. Simultaneously, the number of wet years is equal to 5 with an average frequency of 1.3 per decade.

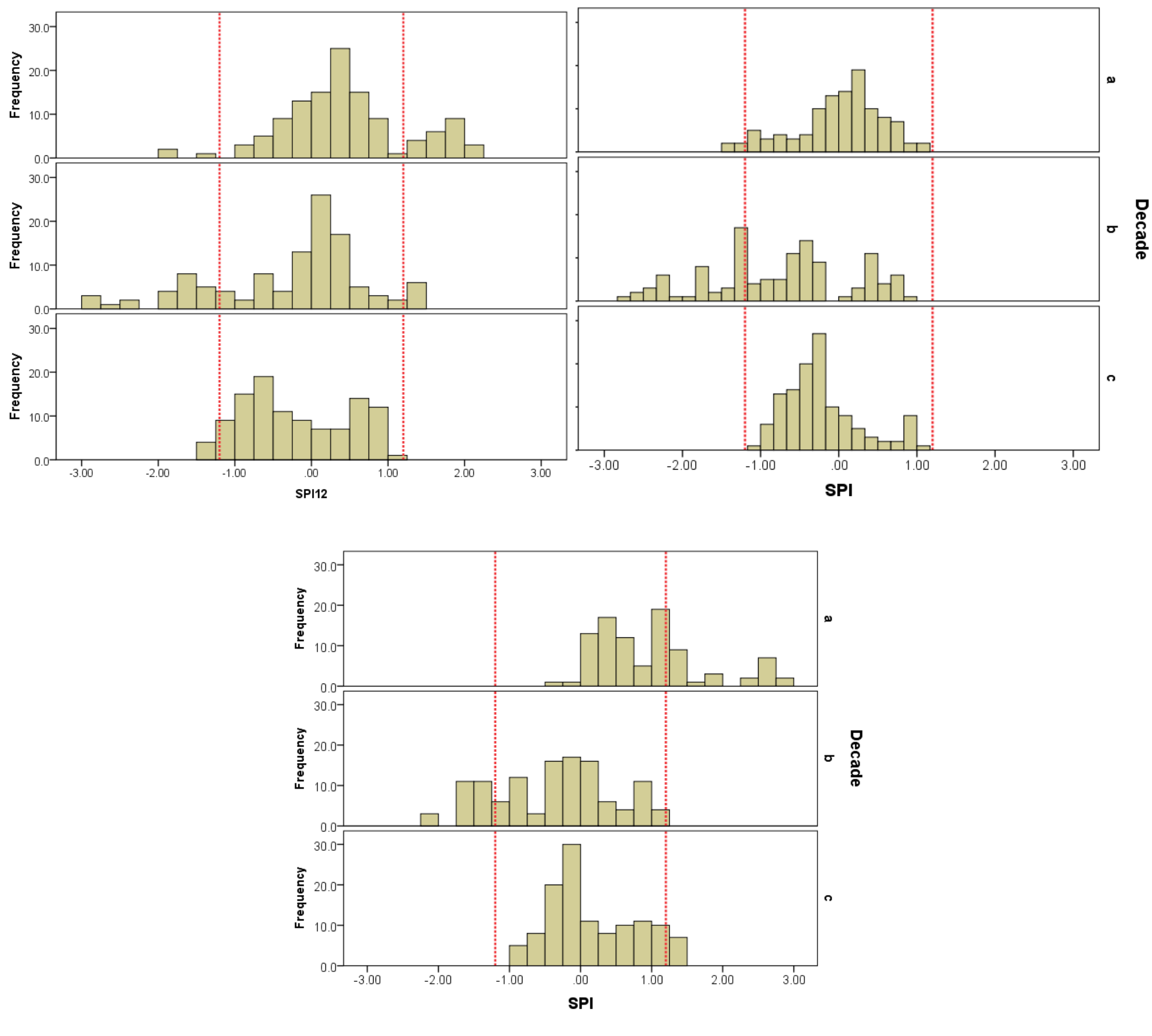

Figure 4. SPI12 frequency diagram for the 3 subperiods studied in: i) Andravida station, ii) Kalamata Station and iii) Pirgos station (a: 1975 - 1984, b: 1985 – 1994, c: 1995 - 2004).

The frequency distribution of the SPI12 in the Andravida station (Figure 4i) area indicates that the first subperiod (1975 - 1984) was a relatively wet period with very few droughts while the second subperiod (1985 – 1994) was a period with many months of average precipitation and quite a lot of extreme droughts. The third subperiod the SPI12 values fluctuate mostly within the normal thresholds indicating a lack of very wet and few very dry months.

The frequency distribution of SPI12 for Kalamata station (Figure 4ii) illustrates a pretty similar pattern with the previously mentioned stations, having a characteristic and more pronounced dry second decade which may be due to the geographic location of the station (Southern part of Peloponnese).

The frequency distribution of SPI12 in Pirgos station indicated a relatively wet first decade, a drier second decade and an average, normal third decade (Figure 4iii). This pattern is very similar to Andravida station and accredits the aforementioned temporal fluctuations of the SPI values in the particular stations.

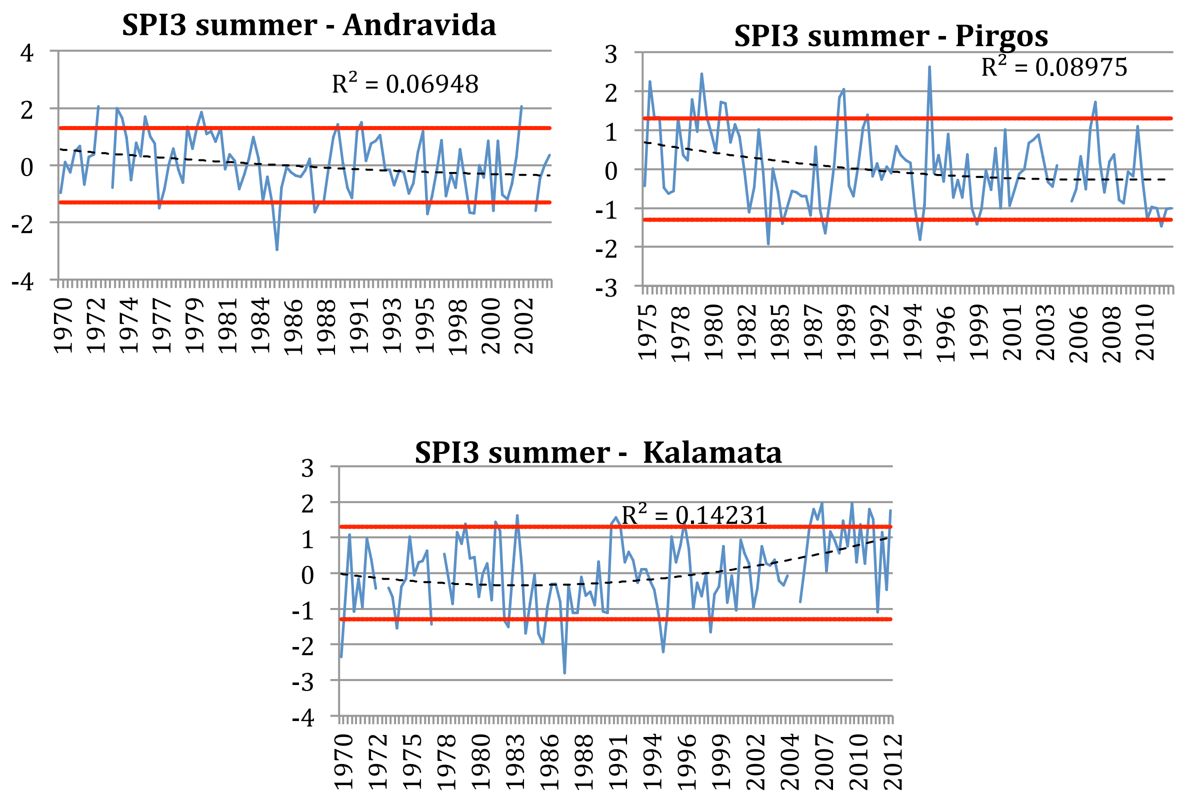

Figure 5. Variation of the SPI3 of summer months for the: a) Andravida Station, b) Pirgos Station and c) Kalamata Station.

During the summer months of June, July and August the SPI3 values in Andravida station, displays a slight descending trend in the station of Andravida, (Figure 5a). This decreace is attributed to the growing intensity of the drought in the beginning and the reduction of the intense precipitation amounts to normal range from 1985 onwards. The most dry summer presented in 1985, while relatively wet summers were recorded in 1972, 1974, 1980 and 2002.

The wettest month was noted in August of 1972 (Figure 5a) with the maximum value of 2.05 and the driest month was in July of 1985 with the minimum value of -2.96. The number of the very dry summers is 7 for the entire study period (average frequency: 2.2 very dry summers/decade), while there is an increased number of wet summers that reach 9 over the entire study period (average frequency: 2.8 very humid summers/decade).

In the summer months of the period 1975 – 2012, Pirgos station displayed a considerable decreasing trend till 1990, while the remaining years showed a more stable, horizontal trend (Figure

5b). The most dry summers were recorded in 1985 and 1995 and the most wet ones in the period from 1976 to 1995.

The highest SPI value (2.62) was recorded in August - 1995 (Figure 5b) and the lowest value (-1.92) was encountered in July 1984. The SPI3 index received values less than -1.3 for 6 very dry summers with an average frequency of 1.7 per decade, and it takes values greater than 1.3 for 9 very humid summers with an average frequency of 2.6 per decade.

During the summer trimister, the data of the Kalamata station showed an almost stable, horizontal trend until 1989 and then, an intense upward trend until 2012, (Figure 5c). The extremely drought events were traced in the years of 1970, 1987 and 1995, while the wetter summers were appeared in 2007 and 2009.

The maximum SPI value (1.96) was recorded in July of 2007 (Figure 5c) and the minimum value (-2.8) in July of 1987. The number of severe drought phenomena is 10 during the summer months with an average frequency of 2.6 summer droughts per decade and 11 very wet summers with an average frequency of 2.8 events per decade.

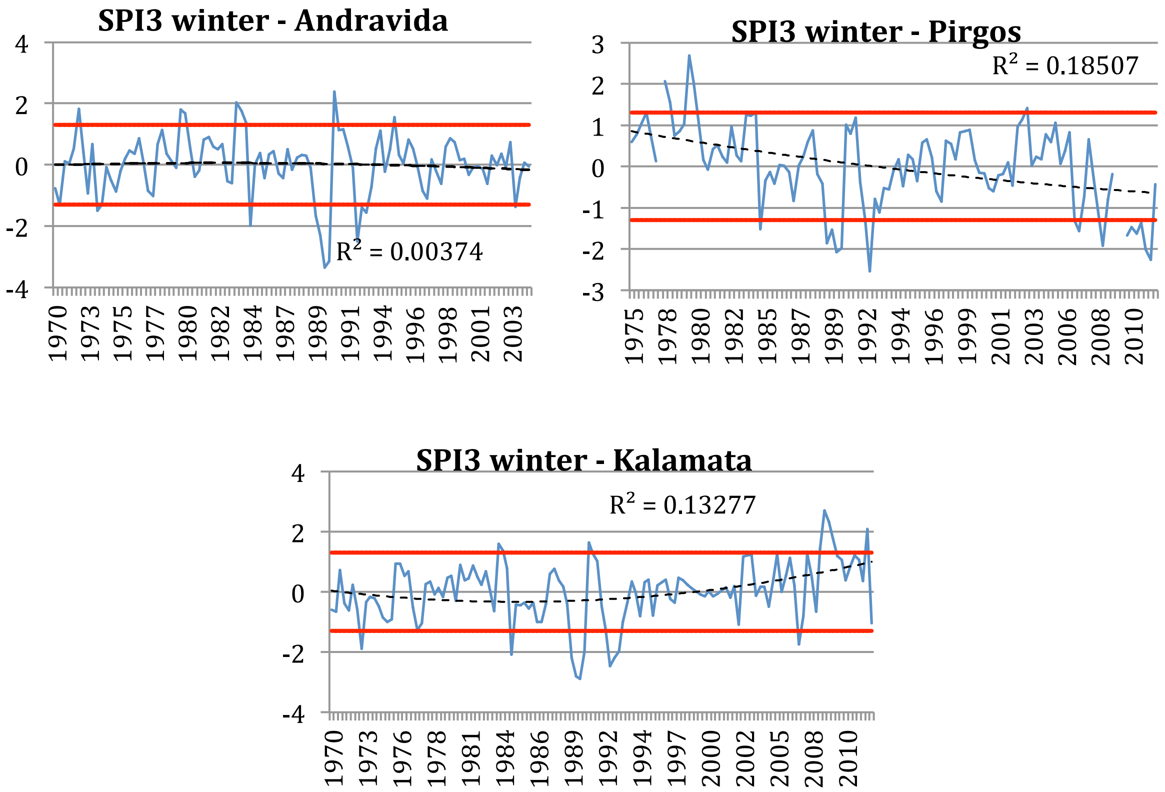

Figure 6. Variation of the SPI3 of winter months for the: a) Andravida Station, b) Pirgos Station and c) Kalamata Station.

At the Andravida station the dry and wet winters are uniformly distributed per decade indicating absence of a clear trend, (Figure 6a). The driest winter seasons were in the years of 1989, 1990 and 1992, while the most rainy winters are recorded in the years 1972, 1983 and 1990.

The maximum value was encountered in December of 1990 (2.39) while the minimum value (-3.34) was noted in January of 1990 (Figure 6a). The number of the very dry winters is 8 (average frequency: 2.5 very dry winters/decade), and the number of the very wet winters is 7 (average frequency: 2.2 very wet winters/decade).

The winter months of Pirgos station present a characteristic downward trend of SPI3 (Figure 6b). The significant reduction of SPI3 values along time were expressed with the presence of extreme drought events from the middle till the end of the study period. The driest winters were in the years: 1990, 1992, 2011 and 2012, while the most rainy winters were encountered from 1978 to 1980.

The wettest episode for the winter years appeared in December - 1979 with the maximum value of 2.68, while the extreme drought episode in February of 1992 with the minimum value of -2.54 (Figure 6b). The number of the very dry winters is 9 (average frequency: 2.3 very dry winters/decade), and the number of the very wet winters is 10 (average frequency: 2.6 very wet winters/decade).

As for the winter months of Kalamata station, the SPI index presents a similar fluctuations pattern to the summer months of the same station, (Figure 6c).The driest winters occurred in the years 1984, 1989, 1990 and 1992, while the wettest ones in 2009 and 2012.

The maximum SPI value (2.70) is presented on January - 2009 and the lowest value (-2.89) in January - 1990. For the subperiods 1974 - 1983 and 1994 - 2006 the SPI3 index did not exceed the limits of moderate wet/dry year (Figure 6c).The number of very dry winters is estimated at 7 with an average frequency of 2 per decade and the number of wet winters is 6 with an average frequency of 1.3 per decade.

4.3 Statistical Analysis

The statistical analysis indicated that, the highest mean SPI value was recorded in the station of Pirgos – west coast of Peloponnese (0.19), followed by Astros (0.12) and Argos (0.01) – east coast, while the lower SPI means were encountered in Kalamata station – south coast (-0.34), Tripoli highland (-0.13) and Velo – northeast coast (-0.11, Table 3, Figure 7). The majority of the stations (53%) have negative average values of SPI12 (Table 3) while the median is negative for all the stations apart from 2 (Argos and Leonidio) indicating the dominance of dry years. The standard deviation ranges from 0.775 to 1.064 accrediting the intense SPI fluctuations at an inter- as well as intra-annual basis. The maximum SPI value has been noticed in Aigio station (3.17, extremely wet conditions), in contrast to the Patra station, in which the lowest one was recorded (-3.53, 2).

The highest SPI variation is observed in Araxos (Northwest coast) while the lowest fluctuations were captured in Githio (Southeast coast, Figure 7). The lowest median is observed in Patra and Kalamata which is close to the -1.3 threshold for extreme drought while the highest median values were observed for Argos and Leonidio which illustrated positive values in more than 75% of the study period (Figure 7). The variability of N values in Table 3 is related to the number of months that some or all data were missing. In the descriptive statistical analysis those months illustrating even partial gaps were excluded to avoid distortion on the analysis output.

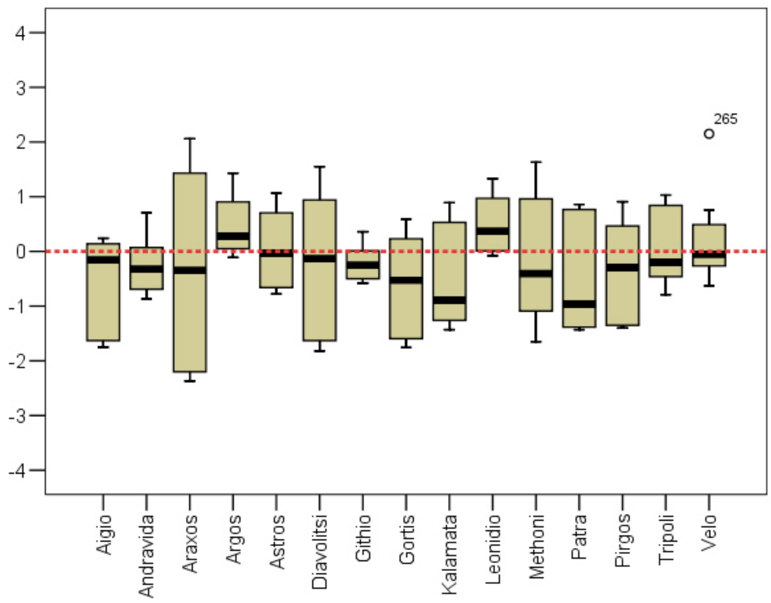

Figure 7. Boxplot of SPI12 values over the period 1975 – 2004.

Table 3. Descriptive statistics of SPI12 for the stations of the Peloponnese over the period 1975 – 2004.

Stations	N	Min	Max	Mean	Std. Dev
Aigio	270	-2.16	3.17	0.00	1.002
Andravida	348	-3.24	2.10	-0.08	0.994
Araxos	360	-3.27	2.46	-0.02	1.033
Argos	265	-3.02	2.48	0.01	0.996
Astros	163	-2.29	2.11	0.12	0.953
Diavolitsi	265	-2.18	2.55	0.00	1.002
Githio	222	-2.93	2.74	0.00	1.004
Gortis	232	-2.34	2.47	0.00	1.002
Kalamata	348	-3.04	1.04	-0.34	0.775
Leonidio	155	-2.55	1.35	-0.02	0.783
Methoni	315	-2.44	2.47	-0.03	1.008
Patra	230	-3.53	1.75	-0.06	1.064
Pirgos	332	-2.09	2.76	0.19	0.912
Tripoli	360	-2.83	1.80	-0.13	1.011
Velo	194	-2.21	2.15	-0.11	0.849

Regarding the subperiods SPI fluctuations, the highest mean value was presented at the Pirgos station (0.97) in the first decade of the study period (1975 – 2004), followed by Patra (0.55) and Aigio (0.50, Table 4). The minimum average SPI for the particular decade has been observed at the station of Gythion (-0.09) which was the only station with a negative average SPI value in the specific period. The standard deviation of all stations ranged from 0.44 to 1.14, which combined with the aforementioned positive average SPI values indicate the dominance of wet years during the period 1975 - 1984. The wettest year was presented in Aigio with the maximum SPI value of 3.17 is, while the driest year was recorded in Methoni – Southwest coast (-2.08).

The difference of the SPI boxplot diagram for the period of 1975 - 1984 in comparison to the entire study period (1975 - 2004) is significant since in the particular subperiod only one station (Gythion) has a negative median value, while all the rest have highly positive SPI values in the majority of the time period (Figure 8a). The stations with the highest median values are Pirgos, Astros and Patra, while the largest SPI fluctuations have been noticed in Aigio and Astros.

Table 4. Descriptive statistics of SPI12 for the stations of the Peloponnese over the studied subperiods.

Stations	1975 - 1984				1985 - 1994				1995 - 2004			
	Min	Max	Mean	Std. Dev.	Min	Max	Mean	Std. Dev.	Min	Max	Mean	Std. Dev.
Aigio	-1.67	3.17	0.50	1.26	-2.16	0.58	-0.59	0.65	-1.13	1.82	0.14	0.71
Andravida	-1.91	2.10	0.42	0.81	-3.24	1.49	-0.46	1.17	-1.31	1.16	-0.21	0.7
Araxos	-2.07	1.43	0.22	0.75	-3.27	0.90	-0.84	0.94	-1.29	2.46	0.56	0.83
Argos	-0.90	1.58	0.44	0.69	-3.02	1.02	-0.39	0.99	-1.60	2.48	0.30	0.94
Astros	-1.73	2.11	0.37	1.14	-2.29	0.82	-0.46	0.6	-0.66	1.58	0.54	0.65
Diavolitsi	-1.86	1.36	0.36	0.77	-2.18	1.02	-0.08	0.89	-2.07	2.55	-0.26	1.16
Githio	-1.13	0.52	-0.09	0.44	-2.93	1.73	-0.06	1.10	-2.31	2.74	0.16	1.09
Gortis	-1.32	1.93	0.32	0.82	-2.34	0.53	-0.71	0.76	-2.13	2.47	-0.03	1.12
Kalamata	-1.37	1.02	0.00	0.55	-3.04	0.87	-0.78	0.96	-1.00	1.04	-0.21	0.49
Leonidio	-	-	-	-	-2.55	0.70	-0.46	0.78	-1.03	1.35	0.26	0.65
Methoni	-2.08	1.73	0.12	0.83	-2.44	2.47	-0.17	1.30	-1.21	1.63	-0.01	0.68
Patra	-1.17	1.75	0.55	0.71	-2.88	1.00	-0.60	0.88	-3.53	0.86	-0.56	1.44
Pirgos	-0.43	2.76	0.97	0.78	-2.09	1.09	-0.39	0.82	-0.87	1.38	0.18	0.61
Tripoli	-1.94	1.80	0.26	0.88	-2.68	1.44	-0.28	0.10	-2.83	1.54	-0.37	1.04
Velo	-	-	-	-	-2.13	1.15	-0.49	0.87	-2.21	2.15	0.13	0.74

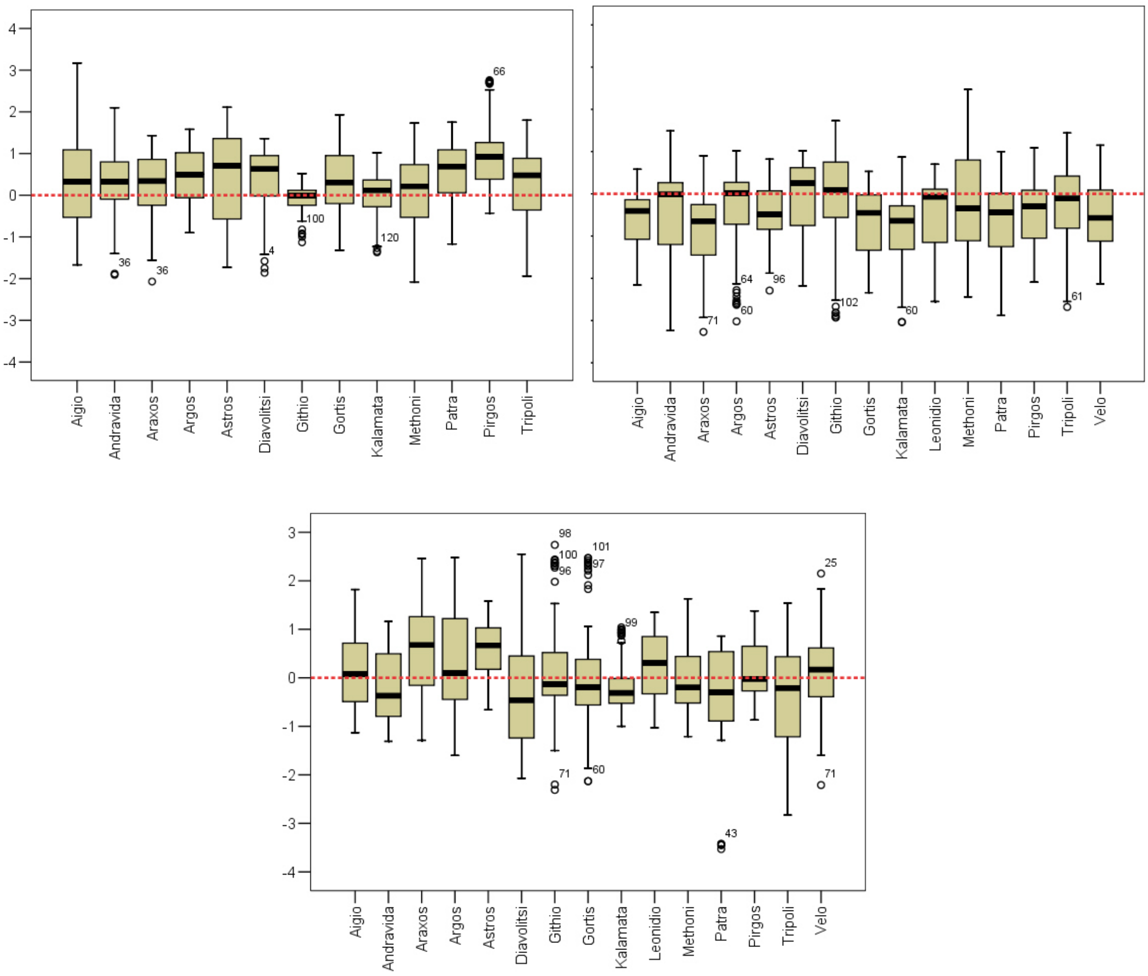

Figure 8. Boxplot of SPI12 values over the subperiods: a) 1975 –1984, b) 1985 –1994 and c) 1995 – 2004.

During the second decade (1985 - 1994), the Gythio station had the highest mean SPI12 value (-0.06) despite the fact that it is negative, while Diavolitsi (-0.08) and Methoni (-0.17) followed (Table 4, Figure 8b). All the stations presented negative average SPI values and the lowest ones were observed in Araxos (-0.84), Kalamata (0.78) and Gortyna (-0.71), which indicates a clear dominance of dry years at this subperiod. The highest SPI value occurred at the station of Methoni, in contrast to the previous decade, in which the maximum negative SPI value (severe drought) was observed in the particular station.

All the stations apart from two (Diavolitsi and Githio) have negative median values and the lowest ones are recorded in Araxos, Kalamata and Velo (Figure 8b). The largest SPI fluctuations have been recorded in Andravida and Methoni while Araxos, Gortis, Kalamata and Patra had negative SPI values in more than 75% of the time period and extreme drought in more than 25% of the particular decade. Therefore, the period 1985 - 1994 was a very dry period for almost all the stations and this pattern has affected the SPI values of the last 40 years, as observed in the relevant statistical figures (Table 3 and Figure 7).

During the 3rd decade (1995 – 2004, Figure 8c), the highest mean SPI value was observed in the station of Araxos (0.56), followed by Astros (0.54) and Argos (0.30). The stations that illustrated the lowest average means are Patra(-0.56), Tripoli (-0.37), and Diavolitsi (-0.26). Nevertheless, all stations have a normal distribution in the mean SPI values, ranging from -0.37 to 0.30. Patra station is characterized by a slightly dry period (-0.56), while the Araxos station and Astros are characterized by the opposite (0.56 and 0.54, respectively). The maximum value of SPI12 is recorded in Gythio (2.74), while the lowest value in Patra -3.53 (Table 3, Figure 8c).

The SPI median values fluctuate slightly around zero in all stations with the exception of Diavolitsi, which has a significantly negative median and Araxos, which illustrates a highly positive value (Figure 8c). The highest SPI fluctuations are observed in Argos, Diavolitsi and Tripoli while the lowest ones in Kalamata and Astros. However, the majority of the stations indicate positive SPI12 values, in most of the decade which indicates a time period with normal fluctuations in the precipitation regime.

4.4 Spatial Simulation of the SPI12 Index

During the 1st decade, (1975 – 1984), the mean values of SPI12 have a broad distribution around zero and a strong geographic gradient (Figure 9a). The wider region of Astros (East coast) illustrates very negative SPI values while SPI gets positive in the northeast and southeast parts of Peloponnese. The central and western parts of the study area indicate SPI values within the expected, normal thresholds (-1 to 1, Figure 9). The mean value of the SPI12 index for the 1st decade ranges from -2.2 to 6.45 and these fluctuations are the highest among all the subperiods studied (Figure 9a, b and c).

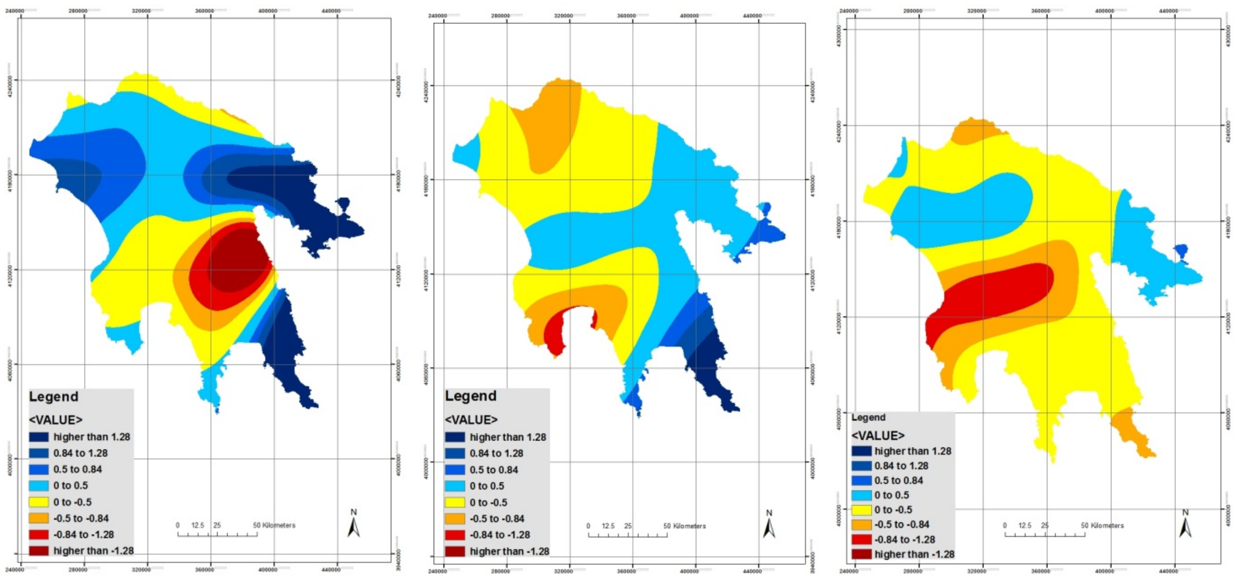

Figure 9. Spatial variation of the SPI12 index for all stations over the periods: a) 1975 – 1984, b) 1985-1994, c) 1995-2004.

In the 2nd decade, (1985 – 1994), the SPI distribution is relatively homogenous at a spatial basis with mostly negative values for the the biggest part of Peloponnese (Figure 9b). In the wider area of Methoni, Kalamata, and Patra (western part) negative values are dominated with the presence of mild dry conditions. In the central and eastern part of the Peloponnese the SPI12 index gets slightly positive values that get higher towards the eastern edges of the peninsula. The mean value of SPI12 for that period ranges from -0.95 to 2.81 with the highest extent of the area to be covered by low negative values, resulting in a decade with dry conditions.

In the 3rd decade (1995 – 2004), the spatial distribution of the mean values of SPI12 is characterized by normal rainfall amounts in the most regions of the study area. Although, from the west to the central Peloponnese slight negative values are observed indicating severe dry years, especially for the areas of Diavolitsi and Tripoli (Figure 9c).

The interpolation errors for the 3 examined maps (figure 9) were relatively low, with RMSE values ranging from 0.11 in the 1st decade map to 0.38 in the 2nd decade map. Nevertheless, since the high altitude areas were not meteorologically represented in this study due to the lack of stations above 1000m, these areas were not discussed and assessed in terms of SPI changes over the 3 different decades.

The long term evolution of SPI values in the entire Peloponnese indicates a drying trend over most of this area which will probably affect the regional socioeconomic conditions. Peloponnese is one of the most important regions of Greece since it combines extensive fruit cultivations, highly touristic and historically significant areas (eg Ancient Olympia) and fragile ecosystems of global importance (eg Strofilia forest and wetland, *Careta Careta* sites, etc). Therefore, the aforementioned drying trends could lead to the significant redution of water resources availability as well as degradation of the water quality status which will affect all the above stated socioeconomic and enveronmental factors. Thus, there is a necessity to develop and implement drought mitigation strategies and measures at a timely basis by considering the vulnerability and importanct of the economic, cultural and environmental heritage of the area.

5. CONCLUSIONS

Based on the aforementioned analysis, the annual and seasonal values of precipitation vary considerably. Except for the eastern part of the Peloponnese, the rest of the study area indicated relatively high rainfall values that reach more than 900mm in an annual basis.

Moreover, in east Peloponnese the intensity of precipitation is more pronounced by the alteration of seasons. The lowest winter rainfall was recorded in the Argos weather station with an average rainfall height of less than 400mm, while the lowest summer rainfall was observed in the station of Leonidio with an average value of less than 100mm, for the period 1970 - 2012. The rest of the stations exceed the amount of 900mm during winter and 100mm during summer periods.

As far as the temporal evolution of the annual and seasonal SPI is concerned, the period 1970 – 1999 was mainly characterized by normal precipitation levels on average with some extreme droughts in 1977 and the subperiod 1988 – 1993 for most stations. The most wet years of 1972, 1979 and 1980 prevailed in the stations of the western and central Peloponnese. From 2000 to 2012 there was a strong variation in the SPI12 values, receiving significantly positive values in 2003 and during the period 2009 – 2012.

Similar efforts about the SPI index fluctuations have been realized in several areas of Greece, such as Eastern Crete using the SPI and RDI indices for the period 1960 - 1990 (Tsakiris et al. 2007), in the river Nestos and Mornos for the period 1962 - 2001 (Tsakiris and Pangalou, 2006), in Thessaly for the period 1960 - 1993 (Loukas and Vasiliades, 2004) and in the entire coutrny (Kazakis et al., 2008).

A future estimation of drought phenomena has been also estimated in the region of Thessaly by Loukas et al. (2008). Comparing the SPI values of historical precipitation time series of the period 1960 - 1990 with the two future periods of 2020 - 2050 and 2070 - 2100, the investigation showed that the dry months were increased by 40-50% for the period of 2020-2050, while under two scenarios it was observed a significant increase of 100% or even more than 160% in the number of months with drought events in certain areas for the period 2070 to 2100. Finally, this assessment revealed the highest frequency of the drought phenomenon and the increase of its severity at the end of the period (2070 to 2100).

Analyzing the historical records of severe drought episodes and the potential hazards of such events in populated areas are essential practices for the application of early warning and mitigation measures. According to Ameziane et al. (2013), some of the most appropriate practices that can contribute to minimize the impacts from drought events include: a) the water pricing policies that can readjust the water demand, b) the application of innovative irrigation techniques to minimize overconsumption, c) recycling and reuse of water in the domestic and industrial sectors and d) water reuse of treated wastewater in the agricultural sector.

In Peloponnese region all of the above can be efficiently implemented while one of the most important measures that will enhance the efficiency of any applicable practice, is to increase public awareness and promote environmental education activities regarding the rational use of water resources.

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