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Article

Application of the Standardized Precipitation Index (SPI) in Greece

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Abstract: The main premise of the current effort is that the use of a drought index, such as Standardized Precipitation Index (SPI), may lead to a more appropriate understanding of drought duration, magnitude and spatial extent in semi-arid areas like Greece. The importance of the Index may be marked in its simplicity and its ability to identify the beginning and end of a drought event. Thus, it may point towards drought contingency planning and through it to drought alert mechanisms. In this context, Greece, as it very often faces the hazardous impacts of droughts, presents an almost ideal case for the SPI application. The present approach examines the SPI drought index application for all of Greece and it is evaluated accordingly by historical precipitation data. Different time series of data from 46 precipitation stations, covering the period 1947–2004, and for time scales of 1, 3, 6, 12 and 24 months, were used. The computation of the index was achieved by the appropriate usage of a pertinent software tool. Then, spatial representation of the SPI values was carried out with geo-statistical methods using the SURFER 9 software package. The results underline the potential that the SPI usage exhibits in a drought alert and forecasting effort as part of a drought contingency planning posture.

Keywords: drought index; Standardized Precipitation Index; geo-statistical methods; kriging; drought contingency planning

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1. Drought and Indicators

The existing tendency among professionals, politicians, managers or even common citizens is to view and consider drought as a natural hazard; a traditional disaster causing emergency mobilization. Drought is also indiscriminate in terms of geography, climate and political boundaries. Drought may be considered as a normal, recurrent feature of the climate, although often inaccurately believed to be an extraordinary event. Drought is a temporary aberration within the natural variability and may be regarded as an insidious hazard of nature. However, a precise, unambiguous definition of drought remains elusive [1,2]. Droughts generally result from a combination of natural factors that can be enhanced by anthropogenic influences. The primary cause of any drought is a deficiency in precipitation, and, in particular, the timing, distribution, and intensity of this deficiency in relation to the existing water storage, demand, and use. This deficiency may result in water shortages necessary for the functioning of natural eco-systems, and/or pertaining to human activities. Hence, due to the "*creeping nature*" of the drought phenomenon, the natural event and the consequences are often interfaced in the definitions. On the other end of the spectrum, due to constraints in time, economic resources and professional expertise, drought definitions have sometimes focused only on one of the various drought components creating a long established misleading practice.

Central to this quest, a general definition of drought may evolve for the scope of this effort. Drought might be defined as "*the state of adverse and wide spread hydrological, environmental, social and economic impacts due to less than generally anticipated water quantities*" [3]. Such water deficiencies may originate from precipitation decreases, physical and/or operational inefficiencies in water supply and distribution systems, as well as from incompetent water management. It is believed that a broad drought definition may lead towards a more complete analysis and evaluation of the phenomenon. However, since there is no single definition for drought, its onset and ending point are difficult to determine. On one hand, as a drought is not beginning with an extreme meteorological event, like a flood, its onset may be difficult to be recognized by stakeholders. On the other hand, the onset of drought is gradual and drought usually hits different regions of a country, with varying levels of intensity and at different time periods. In this context, a drought indicator is an objective measure of the system status that may help in identifying the onset, increasing or decreasing severity, and termination of a drought. Nevertheless, no single indicator or index alone may precisely describe the onset and severity of the event. In this regard, effective early-warning systems for drought should be based on multiple indicators to fully describe a drought event magnitude and severity. Numerous climate and water supply indices are in use to present the severity of drought conditions. Although none of the major indices is inherently superior to the rest in all circumstances, some indices are better suited than others for certain uses. In the literature different indices have been discussed and applied. Among those are: Percent of Normal [4], Deciles [5], Palmer Drought Severity Index (PDSI) [6], Surface Water Supply Index (SWSI) [7], Standardized Precipitation Index (SPI) [8], Palfai Aridity Index (PAI) [9] and others [3,10,11]. The nature of the indicator, local conditions, data availability and validity usually determine the indicator to be applied. Such criteria are discussed in the next sections.

2. Drought and SPI application

In the last decades, particularly with the onset of the 21st century, it has become apparent that traditional crisis management approaches (reactive posture) have been replaced by risk assessment (proactive strategies), by addressing questions of anticipatory action, and multi-stakeholder involvement [1,10,12,13]. Rapid socio-economic changes, socio-political upheavals and the transitions necessitated by the turbulent decades of the 1980s, 1990s and 2010s underscore the increasing emphasis on the variety of environmental challenges; the search for sustainable development; the promotion of integrated planning and management; and, the attempt to combine structural and non-structural solutions to persistent drought problems. In this regard, Integrated Water Resources Management (IWRM) is used as the general context for comprehensive drought management approaches and the articulation of marks and threshold conditions that can measure progress, performance, and product. Thus, drought indicator development efforts are converging towards not only methodological improvements and conceptual advances; but, they support also policy goals for improvement of drought management, comparability, identification of critical areas, threshold definitions, monitoring progress, and better planning and mobilization of resources and adaptation efforts.

The overall complementary goals of indicators may be: technical credibility, policy relevance, and technical relevance. The SPI seems to include such options. It was proposed as an indicator that may be served as a versatile tool in drought alert, monitoring and analysis [8]. In 1999, Hayes, M.J. *et al.* [14], monitored the severe drought of 1996 in the Southern Great Plains and the southwestern United States using the SPI. They deduced that the SPI identified the onset and severity of the drought one month in advance of the Palmer drought Severity Index (PDSI) index. Guttman, N.B [15] observed monthly precipitation time series for 1,035 sites spread all over the US and described the effect on the SPI values computed with different probability models. He compared the 2-parameter gamma (GAM), the 3-parameter Pearson Type III (PE3), the 3-parameter generalized extreme value (GEV), the 4-parameter Kappa (KAP) and the 5-parameter Wakeby (WAK) in order to find which density distribution function fitted better the monthly precipitation data. The parameters of the above distributions where calculated with using the L-moments method. He also used the 2-parameter gamma distribution based on the maximum likelihood parameters estimation. The last one was also proposed by [8] for the estimation of the SPI. Guttman, N.B [15] concluded that the Pearson type III, with parameters estimated using the method of L-moments seemed as the more appropriate choice to describe dry and wet events. Wu, H. *et al.* [16] indicated that the differences among the SPI values computed using different lengths of records were not considerable, if the precipitation pattern is stable. In another effort they claim that the SPI users should be careful when adapting short time scale SPI values in arid locations and they should concentrate on the duration of the drought rather than on its severity (2007). Lana, X., *et al.* [17] used the SPI to analyze spatial and temporal behaviors of rainfall shortage and excess for Catalonia, Spain. Lloyd-Hughes, B. *et al.* [18] found that the 2-parameters gamma distribution seems to be the most appropriate approach to describe monthly precipitation over Europe and to calculate the SPI index. They have also compared for both the SPI and the PDSI and conclude that SPI provided a more appropriate spatial standardization than the PDSI. In southeastern Europe, Tsakiris, G. *et al.* [19] applied the SPI in Crete Island.

Livada, I. *et al.* [20] used monthly precipitation data from 23 stations to assess drought for Greece. In another effort, Sönmez, F.K. *et al.* [21] examined the drought vulnerability of Turkey using the SPI. Loukas, A. *et al.* [22], as well as Vasiliades, L. *et al.* [23] have used SPI as a forecasting tool for climate change impacts on droughts. Finally, Chortaria, C. *et al.* [11] developed the SPI using 41 stations all over Greece for a time period from 1989 to 1994 and concluded that it described very closely the 1989–1990 severe drought.

3. Applied Methodology

3.1. Case Study Area and Data Processing

Greece is located at the southeastern tip of Europe. The country is comprised of the Greek peninsula as well as of the adjacent approximately of 3,000 islands archipelago. The terrain is predominantly mountainous with 27 peaks higher than 2,033 m. Plains are only about 28% of the total country's area. The climate is typical northern Mediterranean with most of the precipitation falling during the winter with hot and very dry summers. The average annual rainfall ranges from 350 mm/yr to 2,150 mm/yr (increasing from southeast to northwest), with an approximate average of 760 mm/yr and [2]. However, due to the country's unique topography, Greece has a remarkable range of micro-climates and local variations. To the west of the Pindus mountain range (running from north to south and being the "spine" of the country), the climate is generally wet and has some maritime features. To the east of the Pindus range is generally dry and windy in the summer, particularly in the Aegean Sea islands a favorite tourist destination and an area of valuable agricultural activities with highly specialized products. This variety in topography intensifies the need of a large number of meteorological stations throughout the Greek territory. The meteorological network in Greece covers all the country's area of over 132.000 km^2. The data are measured in various types of stations, ranging from fully automatic ones to manned stations.

The total water resources of Greece are estimated at about 65×10^9 m^3/yr from which approximately 85% are surface water and 15% groundwater. The average water consumption is about 5×10^9 m^3/yr. From the total annual water use, it is estimated that agriculture accounts for about 80–84%, domestic users for about 13–15%, and power as well as industry account for about 2.5–4% on average [1,2]. Overall, Greece is heavily dependent on the annual precipitation patterns, since water supply of the major cities as well as the large irrigation schemes rely on reservoir storage operated mostly on an annual basis. In the islands and coastal zones dependencies on the swallow aquifers are also exhibiting a strong annual replenishment cycle.

In this regard, the precipitation extreme seasonal variability with very dry summers; the absence of large plain areas combined with extremely scarce soil moisture data and corresponding measurements practically unachievable in the mountainous areas, which comprise more than 70 per cent of Greece, as well as the insular character of the country are leading towards a direct dependency on available precipitation with limited water storage capacities. Such constraints are creating an almost ideal environment for the SPI application in an effort to identify drought conditions in Greece. Thus, in the current approach, drought in Greece for the years 1985 to 2004 was depicted using the SPI with time series from the period 1947 to 2004. The drought was spatially pictured with geo-statistical methods applying the Surfer 9 software package. Monthly precipitation data were collected from 46 meteorological stations in collaboration with the National Meteorological Service of Greece (HNMS), the Ministry of Public Works and the Public Power Corporation S.A., covering different time periods from 1947 to 2004. The stations also cover various locales with 16 stations on the islands and 30 on the mainland as presented on Table 1 (Greek Geodetic Reference System XY) and their geographical location on Figure 1. Figure 2 shows representatively the time series of precipitation for the Hellenicon meteorological station in the Metropolitan Athens area.

Table 1. Meteorological stations and time periods.

Station	Altitude (m)	Time Series	X	Y
Alexandroupolis	3	1947–2004	662,821.24	4,523,618.93
Herakleion	39	1947–2004	607,395.45	3,910,363.07
Pyrgos	12	1948–2004	273,464.99	4,171,636.48
Hellenicon	15	1948–2004	476,989.70	4,193,354.66
Araxos	12	1949–2004	279,911.59	4,225,147.38
Kerkyra	4	1949–2004	147,783.91	4,391,112.67
Larissa	74	1949–2004	366,008.76	4,389,788.05
Ioannina	484	1950–2004	227,392.02	4,398,141.29
Melos	165	1950–2004	538,541.95	4,065,090.13
Trikala	110	1952–2004	308,723.25	4,380,419.84
Kozane	626	1955–2004	311,408.64	4,461,260.03
Lesvos	5	1955–2004	725,179.25	4,325,645.06
Naxos	10	1955–2004	622879.70	4,106,184.40
Rodos	12	1955–2004	866,517.69	4,035,914.60
Agchialos	15	1956–2004	396,082.70	4,342,228.76
Lamia	17	1956–2004	360,383.21	4,300,968.99
Serres	34.5	1957–2004	463,452.85	4,547,812.89
Tympaki	7	1959–2004	570,227.09	3,880,381.63
Chania	152	1959–2004	512,901.68	3,932,269.85
Monastirakion	390.2	1960–2004	327,850.86	4,328,853.22
Tanagra	140	1960–2004	461,951.48	4,243,016.32
A.Fragista	725.3	1960–2004	292,569.43	4,314,776.76
Ardanovo	357	1960–2004	278,052.56	4,336,273.11
Thessalonike	5	1960–2004	412,412.02	4,485,367.97
Plastera	801.2	1961–2004	307,017.61	4,353,851.56
Thera	34	1961–2004	632,478.91	4,029,392.55
Tauropos	793.8	1963–2004	335,686.29	4,356,201.41
Kastrakion	74.8	1964–2004	273,283.51	4,293,922.69
Kremasta	801.2	1964–2004	289,229.69	4,304,259.11
Pertouli	801.8	1964–2004	286,307.18	4,376,127.18
Ierapetra	10	1964–2004	658,162.62	3,875,193.64
Kythira	321	1964–2004	411,309.62	4,014,666.13
Andravida	10	1967–2004	261,465.38	4,199,167.76
Methone	34	1967–2004	295,151.20	4,077,583.50
Tripolis	652	1967–2004	358,423.25	4,154,541.74

Table 1. *Cont.*

Station	Altitude (m)	Time Series	X	Y
Lymnos	5	1968–2004	605,166.73	4,419,248.05
Skyros	28	1970–2004	541,787.38	4,312,174.03
kalamata	11	1971–2004	324,360.97	4,102,811.24
Aktion	4	1973–2004	219,283.86	4,312,709.01
Chios	4	1974–2004	687,028.85	4,245,693.86
Arta	10.5	1976–2004	240,224.50	4,338,878.73
Samos	7	1978–2004	756,986.43	4,175,249.62
Argos	11	1981–2004	388,373.27	4,164,292.45
Kastoria	604	1981–2004	269,220.67	4,480,918.49
Kos	129	1982–2004	775,821.87	4,076,770.28
Chrysoupolis	5	1985–2004	552,539.07	4,530,084.08

Figure 1. Location of precipitation stations.

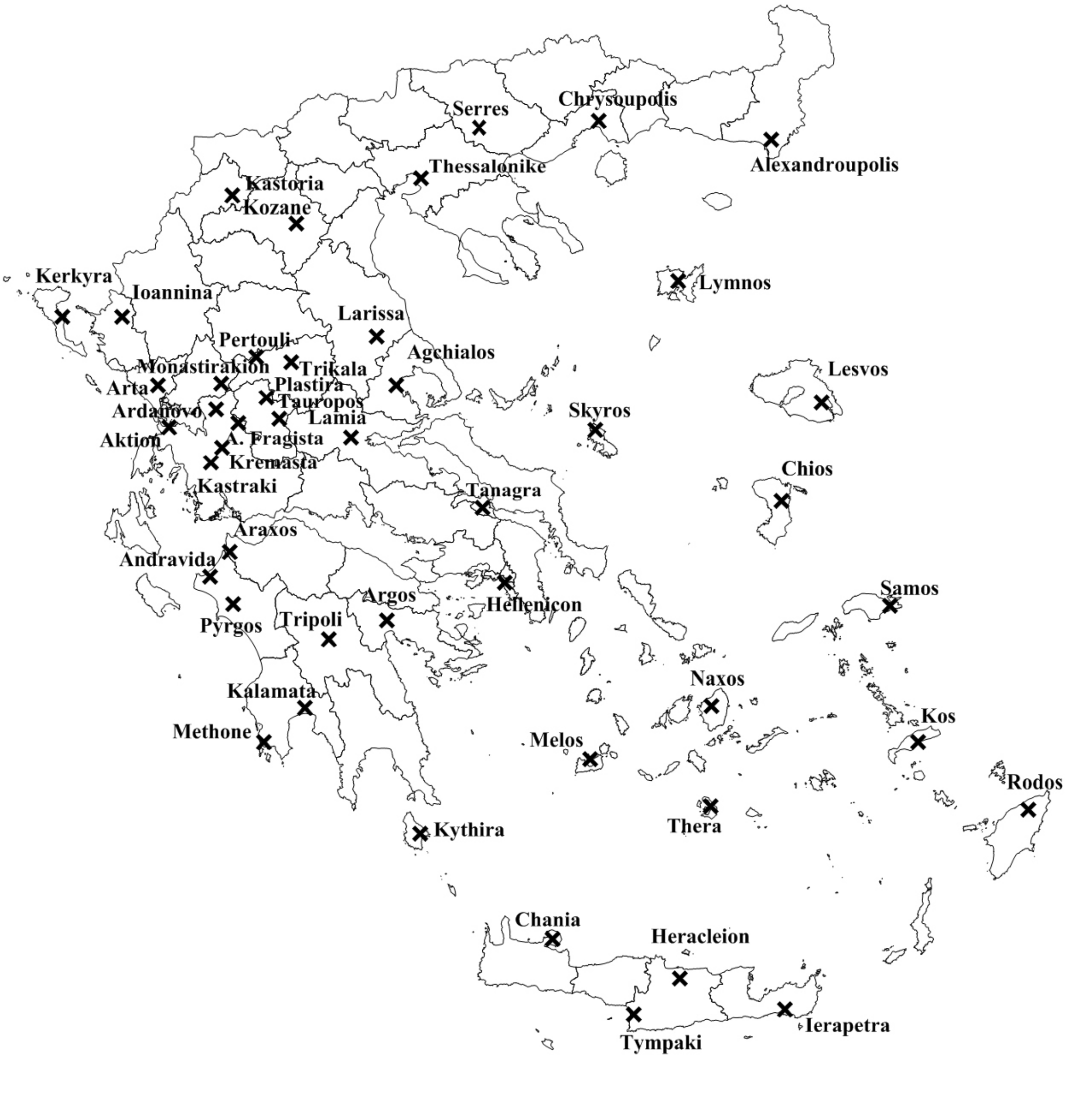
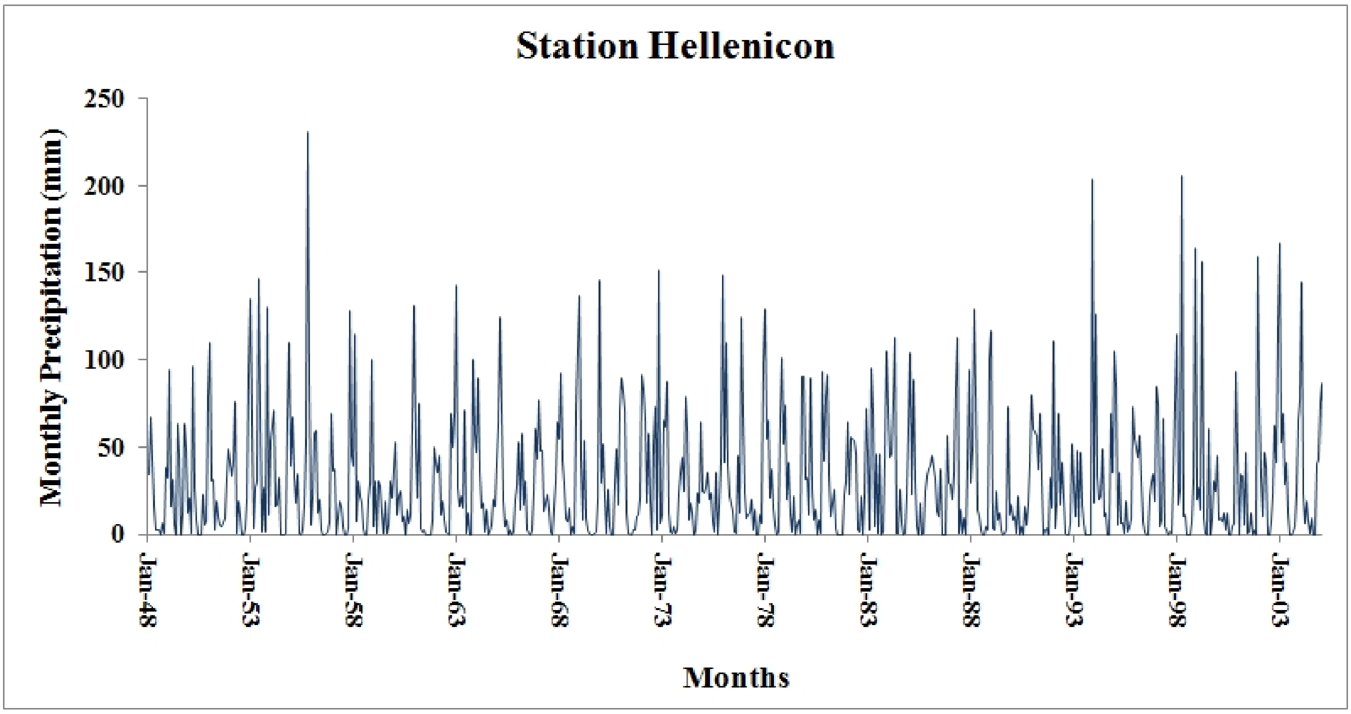
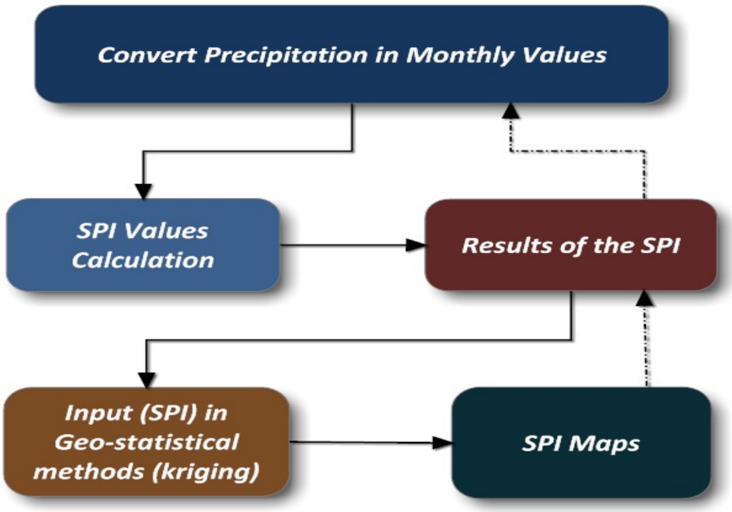


Figure 2. Time series of precipitation for the Hellenicon meteorological station (1948–2004).



All the precipitation data were converted to monthly values. All the chosen precipitation stations (see Table 1) exhibit good data quality, according to the main criterion for such a selection namely the existence of minimal data gaps in the time series. No attempt to fill in any existing data gaps was made, since it was considered that raw data may be more appropriate to represent natural drought conditions (extreme minimum values) rather than enforcing "corrective" homogeneity. Then precipitation over time graphs were made for all 46 stations in order to visualize the data time series and to serve as also an ad hoc quality control of the precipitation values. Figure 2 presents such an example of the Hellenicon station. The monthly precipitation data were used as input for the SPI calculation algorithm programmed in a Fortran 95 tool developed by the DMCSEE Project [24] The calibration period was from 1985 to 2004 and the SPI values were calculated. Because of the difficulties in the spatial attribution of the calculated SPI values, the geo-statistical method of kriging was chosen for the spatial distribution and intensity of the drought. Thus, the calculated SPI values were fed into the SURFER 9 software package, producing the visualization of SPI in maps. Such a methodological procedure is delineated in Figure 3.

Figure 3. Methodology of SPI estimation and spatial representation.



3.2. SPI Algorithm Application

The SPI algorithm development and application was achieved by the following rationale. Based on [15] for the calculation of the SPI, the first step is to find the probability density function which best describes the distribution of the precipitation data over the different time scales. This pattern is applied separately for each month. The appropriate distribution function was selected by using the L-moments ratios diagrams [25]. Thus, the gamma probability density function with two parameters was applied. and the pertinent parameters were estimated using the maximum likelihood approach [8,26,27]. Variable time scales of 1, 3, 6, 12, 24 months can be selected for the estimation of the index, which represents arbitrary time scales for precipitation deficits in relation to SPI application premises. Each of the data sets is fitted to the gamma probability density function with shape parameter α and scale parameter β to define the relationship of probability to precipitation. With the equal-probability transformation the gamma cumulative distribution function converges to the standardized normal cumulative distribution function with a mean of zero and standard deviation of unity. This standardization gives the advantage of having consistent values in space and time for the frequency of extreme dry and wet events. More explicitly a continuous random variable X follows a gamma distribution if the p.d.f. of X is:

$$g(x,\alpha,\beta) = \frac{1}{\beta^{\alpha} * \Gamma(\alpha)} x^{\alpha-1} * e^{-x/\beta} \tag{1}$$

For $x \geq 0$, otherwise $g(x) = 0$,
where the parameters α and β satisfy $\alpha > 0$, $\beta > 0$.

For $\alpha > 0$ the gamma function $\Gamma(\alpha)$ is defined by

$$\Gamma(\alpha) = \int_0^{\infty} x^{\alpha-1} e^{-x} dx \tag{2}$$

Adjusting the gamma distribution to the data set needs the α and β parameters to be estimated through the maximum likelihood estimation using the approximation of [28]:

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

$$\hat{\beta} = \frac{\bar{x}}{\hat{\alpha}} \tag{4}$$

where for n observations

$$A = \ln\left(\bar{x}\right) - \frac{\sum \ln(x)}{n} \tag{5}$$

Integrating the probability density function with respect to x and attach α and β parameters yields the cumulative probability distribution function G(x):

$$G\left(x\right) = \int_0^x g\left(x\right) dx = \frac{1}{\hat{\beta}^{\hat{a}}\,\Gamma\left(\hat{\alpha}\right)} \int_0^x x^{\hat{a}}\, e^{-x/\hat{\beta}} \tag{6}$$

substituting t for $-\frac{x}{\hat{\beta}}$yields the incomplete gamma function:

$$G\left(x\right) = \frac{1}{\Gamma\left(\hat{\alpha}\right)} \int_0^x t^{\hat{a}-1}\, e^{-t} dt \tag{7}$$

The gamma distribution is undefined for x = 0 and q = P(x = 0) > 0, where P(x = 0) is the probability of zero (null) precipitation. Thus, the cumulative probability distribution function becomes:

$$H\left(x\right) = q + \left(1 - q\right) * G\left(x\right) \tag{8}$$

The cumulative probability distribution function is converged into the standard normal cumulative distribution function so that both of them have the same probability. To avoid the solution derived directly from the pertinent distributions graphs, the SPI calculating tool was applied [24,29,30].

The spatial representation of the SPI values was done with the usage of the Surfer 9 software package. Generally there are two groups of techniques for estimating grid points on a surface from scattered observations. The first called "global fit", and calculates a single function describing a surface that covers the entire map area, and evaluated to obtain estimates at the grid nodes. The second technique "local fit", estimates the surface at successive nodes in the grid using only a selection of the near closed data points. This last approach was chosen to be applied. In this regard, the kriging method and specifically the ordinary kriging method was used. The basic function of kriging is:

$$V\left(x\right) = \sum_{i=1}^{n} w_i * V\left(x_i\right) + \left[1 - \sum_{i=1}^{n} w_i\right] * m \tag{9}$$

Where w_i(x)-kriging weights, assigned to the sample data V(x_i). Values m(x) and m(x_i) are expected values (means) of V(x), V(x_i). The number of data n used for the estimation and their weights may vary depending on the estimation point x. If kriging is compared with other methods used for the creation of interpolation surfaces (*i.e.* inverse distance weighting, deterministic splines, Thiessen polygons), it looks more flexible as an approach. Depending on the scale of fluctuation, weights of higher or lower influence may be used, whereas *i.e.* in the Thiessen method the same weights are continuously used regardless of whether the equation has smaller or larger scale fluctuations.

Based on the above, the SPI index was estimated for all of Greece. The Gamma probability density function was fitted to a given frequency distribution of precipitation over a time period. The α and β parameters of the Gamma probability density function were computed for time periods of 1, 3, 6, 12, and 24 months, and for each month of the year. Furthermore, SPI values of 6 months and above time scale step seem more appropriate for SPI estimation than the one (1) month step. In this way, discontinuities of the Gamma function for the one (1) month step may be avoided [11,22]. Additionally, since annually the Greek climatic conditions usually exhibit a minimal rain period from May to October, the SPI values of 6 months and above time scale step seem more useful than the 3 month one, which would show a drought period almost in every summer due to the precipitation pattern (*i.e.*, Figure 2 with recursive zero precipitation values for the summer months). Furthermore, the surface waters in Greece are the major available water resources, thus the SPI-12 becomes central since the irrigation and the urban water supply depends greatly on annual reservoirs storage. According to the results of the index all the tables and the maps visualizing the SPI for all the time scales and meteorological stations, SPI1, SPI3, SPI6, SPI12 and SPI24 were created (more than 400). Indicative SPI values calculation results are presented on Figures 4 and 5. Such outputs also serve as a second quality control of the input data by checking the relevance of the results. A recalculation loop was available in order to repeat the procedure in case of missing or misplaced input. Finally, the computed SPI values were used as input for the geo-statistical software, producing the digital maps of spatial SPI representation.

Figure 4. SPI values for Hellenicon meteorological station with a 6 month time scale.

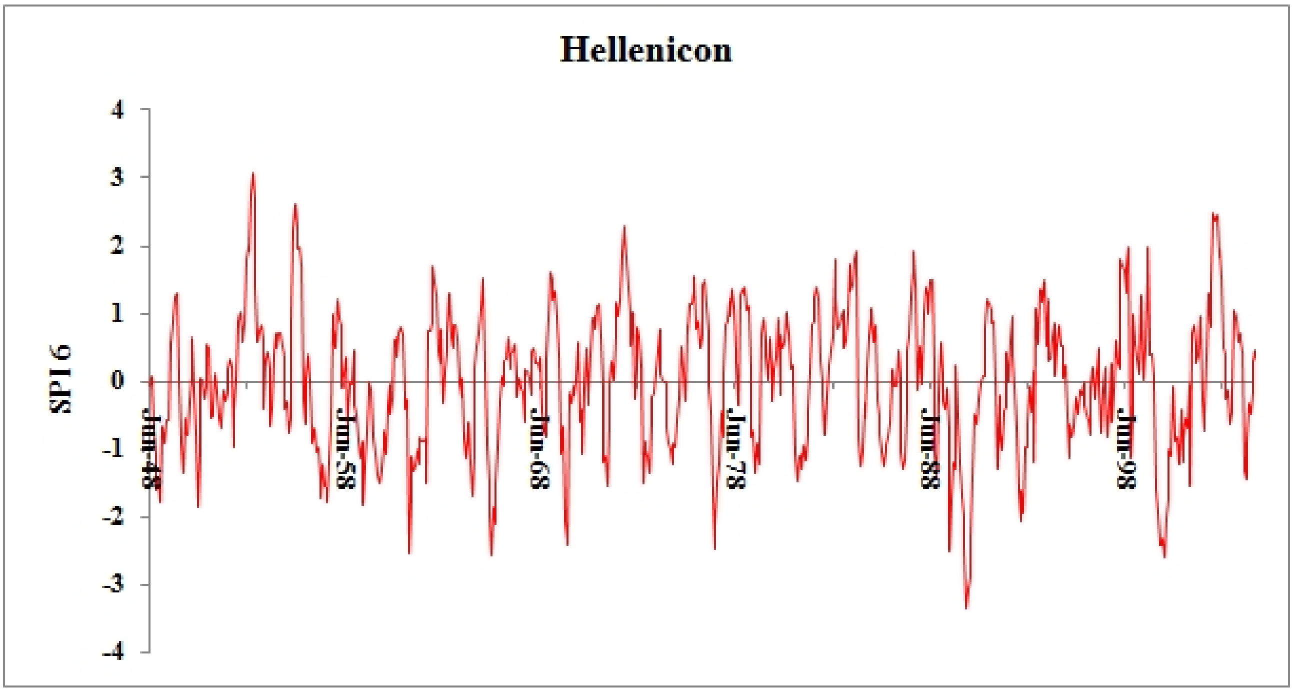
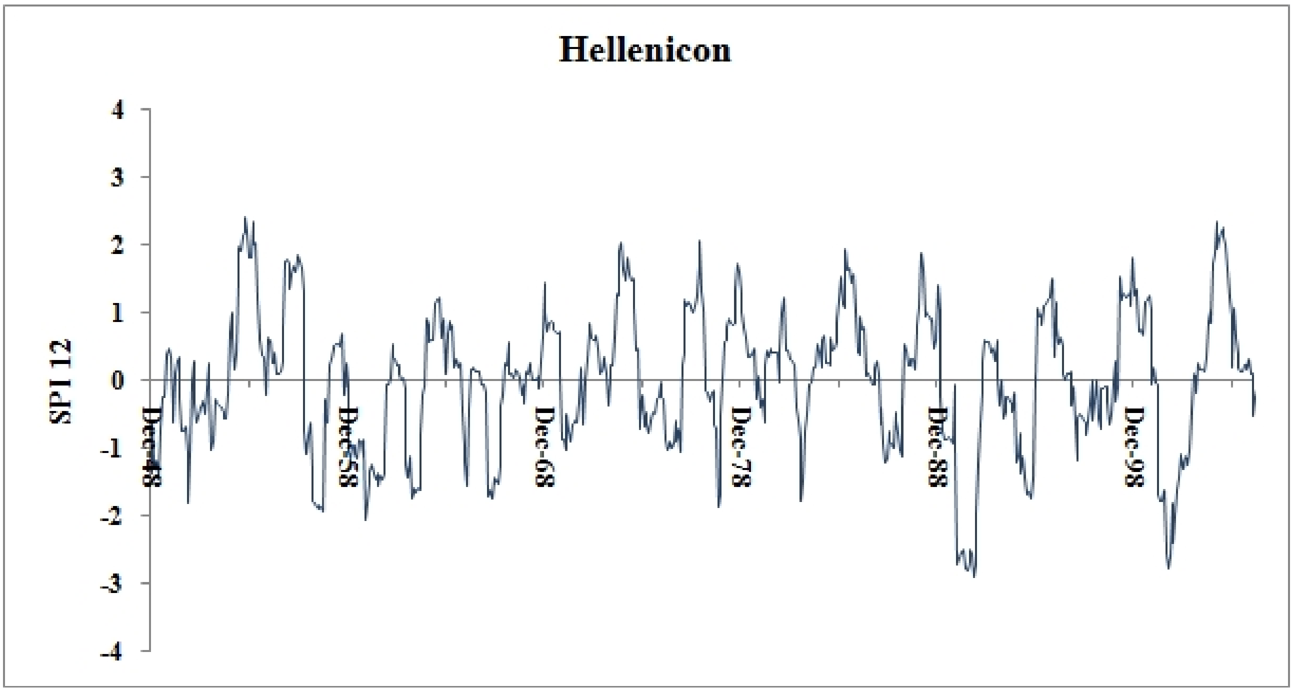


Figure 5. SPI values for Hellenicon meteorological station with a 12 month time scale.



4. Results and Discussion

The results identified that the severe drought years were 1989–1990, 1993 and 2000. The drought of 1989–1990 (Figures 6 and 7) began in January 1989, with its peak in June 1990 (Figures 8 and 9) and dissipated in December 1990. Such results are fortified by the recorded conditions in the Metropolitan Athens water supply, where the impacts of the drought were intense. In 1990, the inflow in the supplying reservoirs had reached record lows, the Athens area in October had water reserves for only 56 days and drought dissipated as reported only with the November rains. The drought of 1993 started in December 1992 and it was well established in January 1993 (Figures 10 and 11). In the Aegean islands the problem became worse during the summer months due to increased water demand (tourism), and, the phenomenon ended in December 1993 [1]. The drought of 2000–2001 commenced in January 2000 and its peak was recorded in December 2000 (Figures 12 and 13). By March of 2001 the values returned to “normal” for the area. Finally, the year 2004 was chosen because it has recorded a rainfall increase in comparison with the four (4) previous years showing a tendency in approaching “normal” values almost over the whole of Greece [31]. However, from February to August (Figures 14 and 15), the index showed that there was a significant drought problem in Macedonia and Peloponnese (specifically in the Tripolis area).

Figure 6. SPI 6 month time scale June/1989.

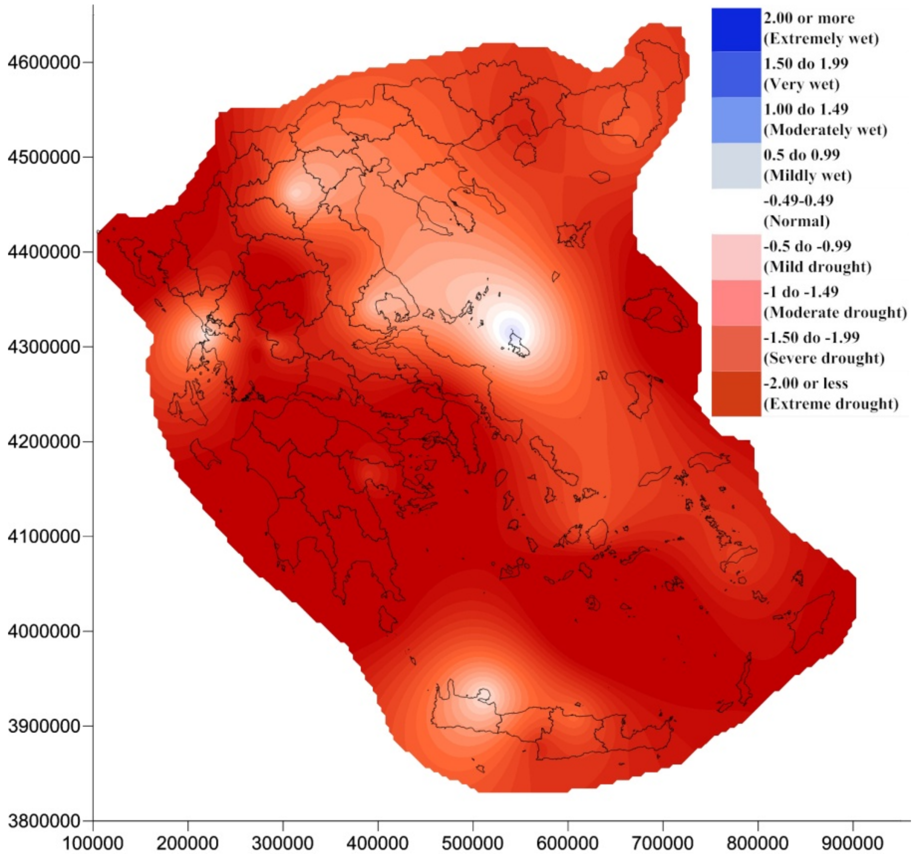


Figure 7. SPI 12 month time scale June/1989.

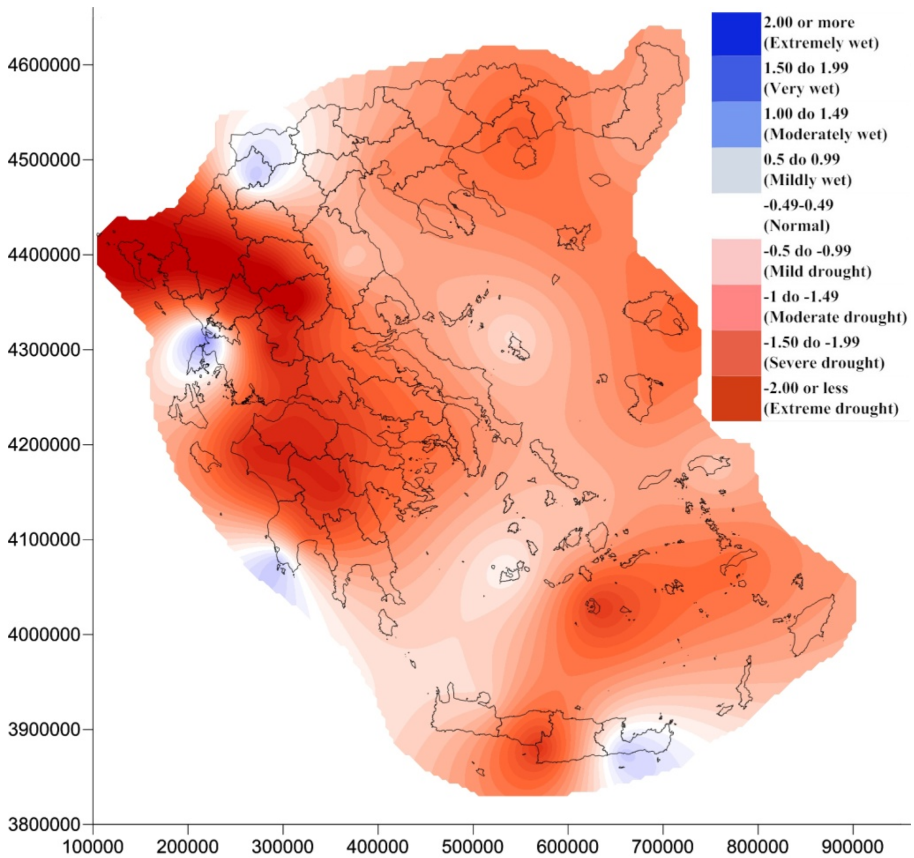


Figure 8. SPI 6 month time scale June/1990.

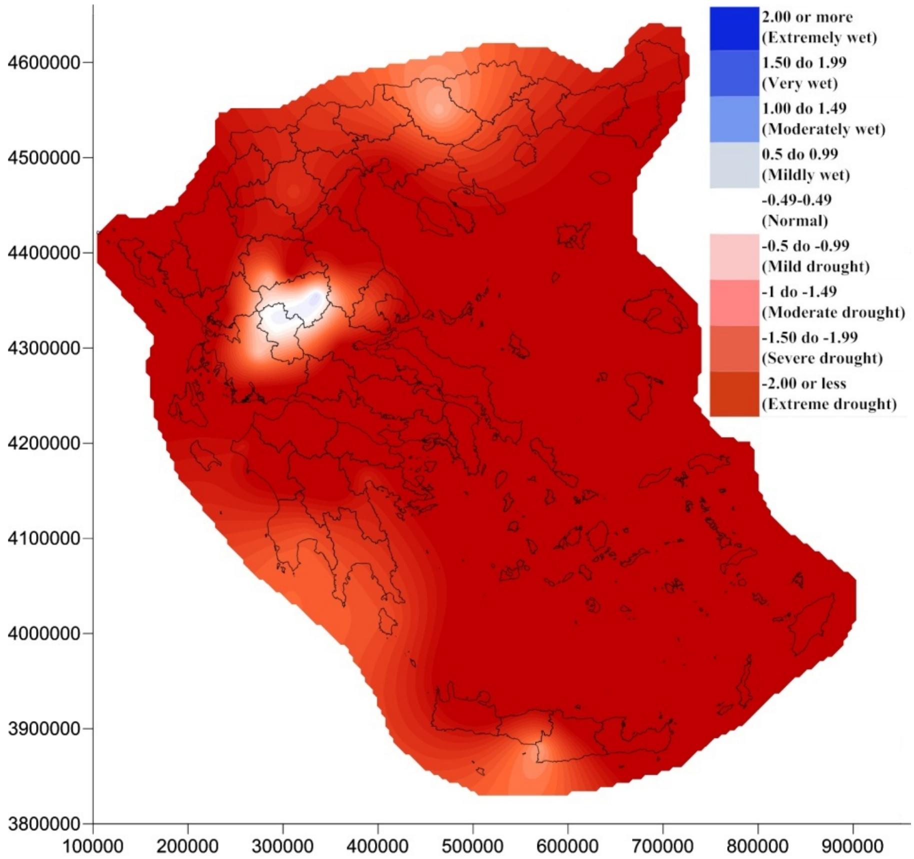


Figure 9. SPI 12 month time scale June/1990.

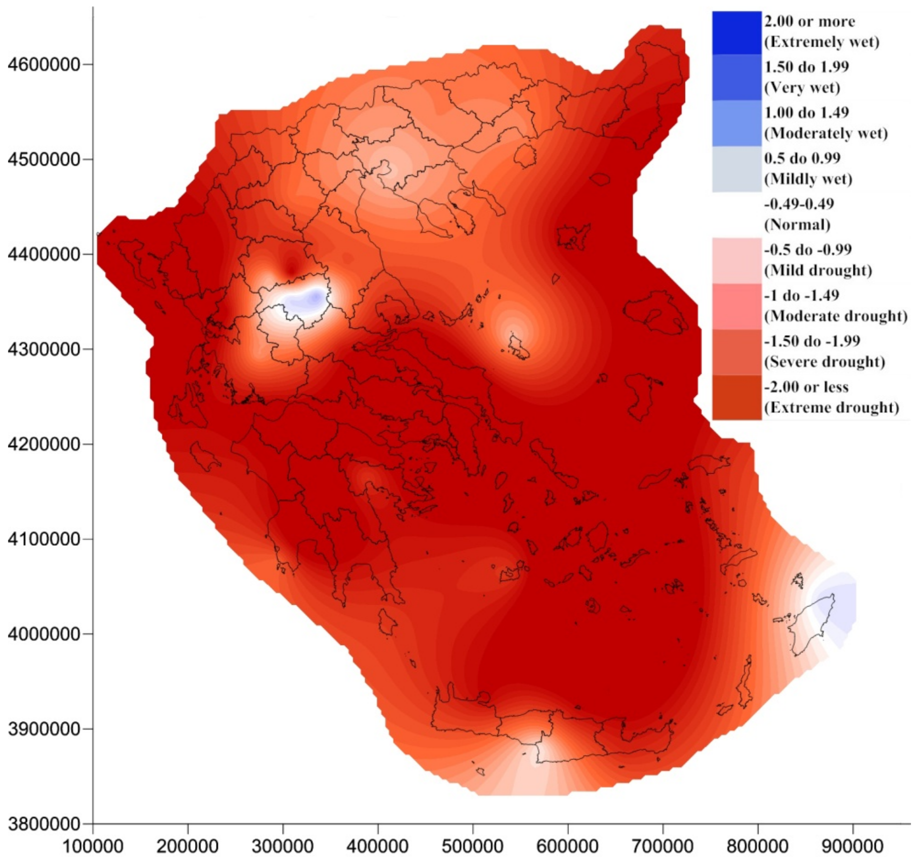


Figure 10. SPI 6 month time scale January/1993.

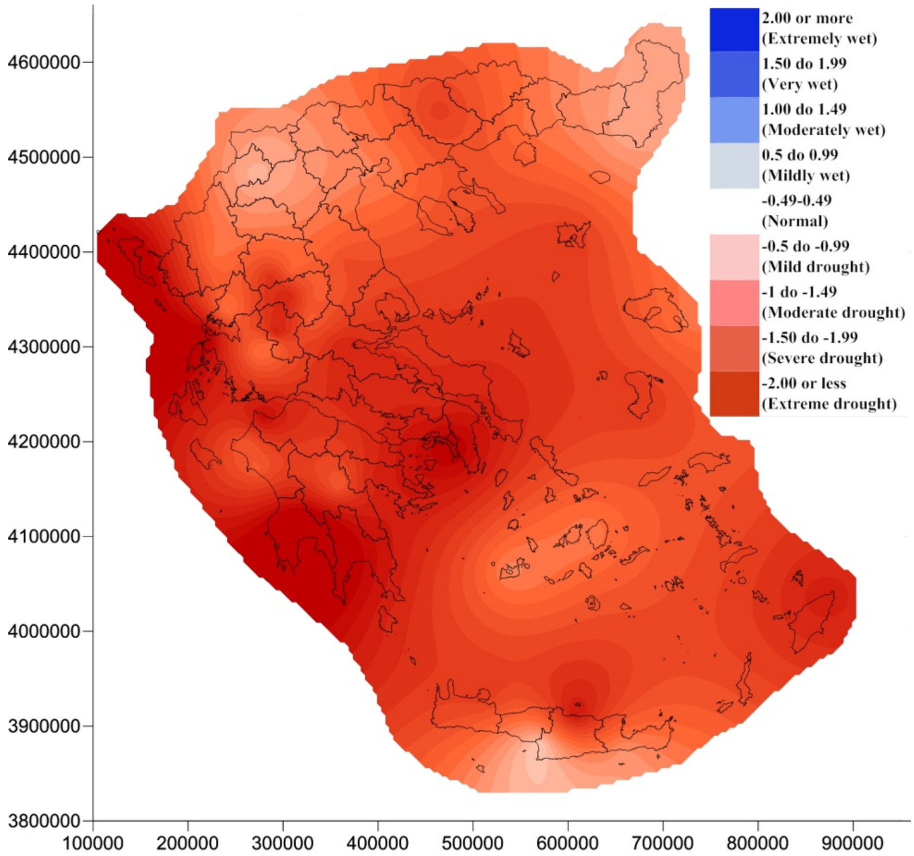


Figure 11. SPI 12 month time scale January/1993.

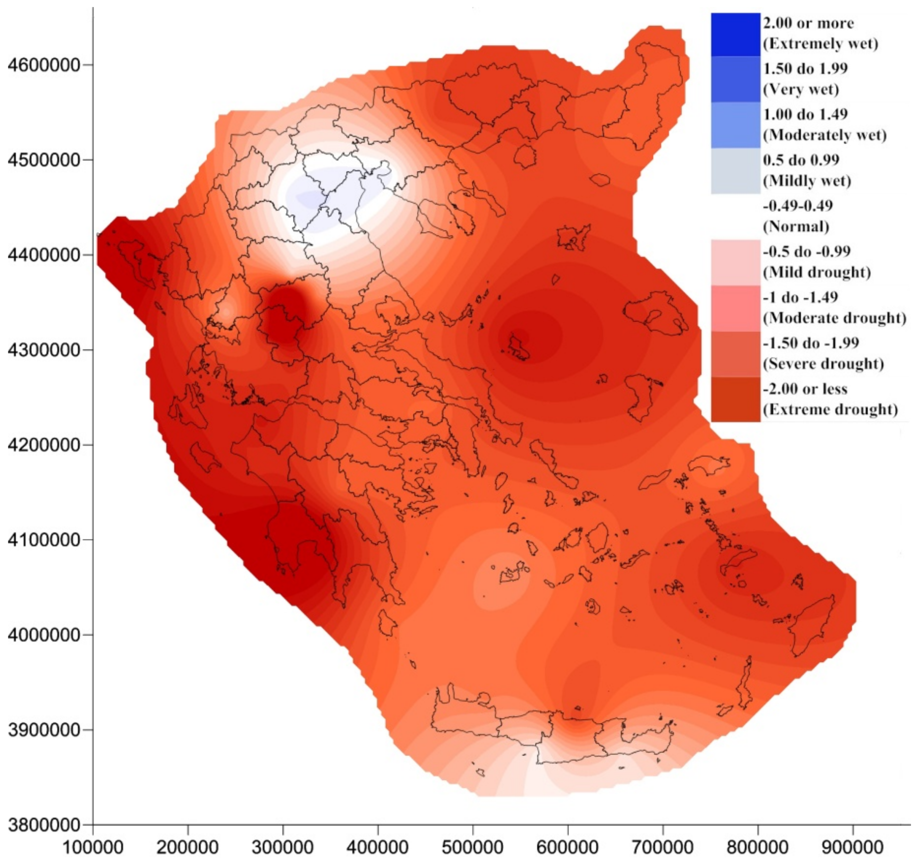


Figure 12. SPI 6 month time scale January/2000.

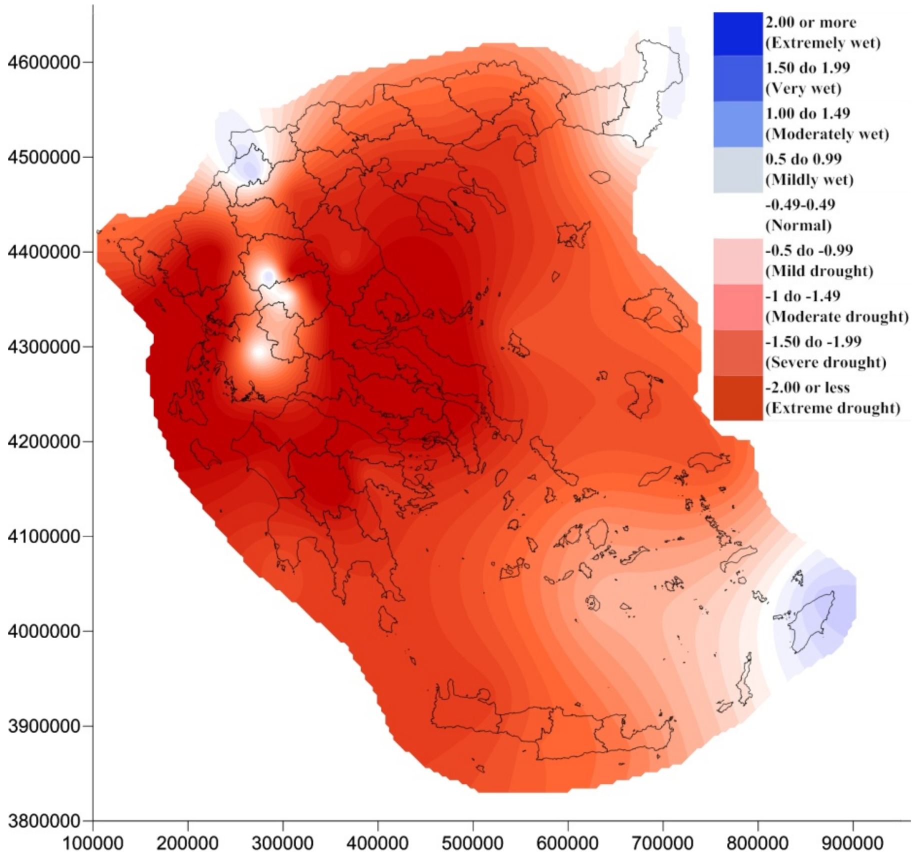


Figure 13. SPI 12 month time scale December/2000.

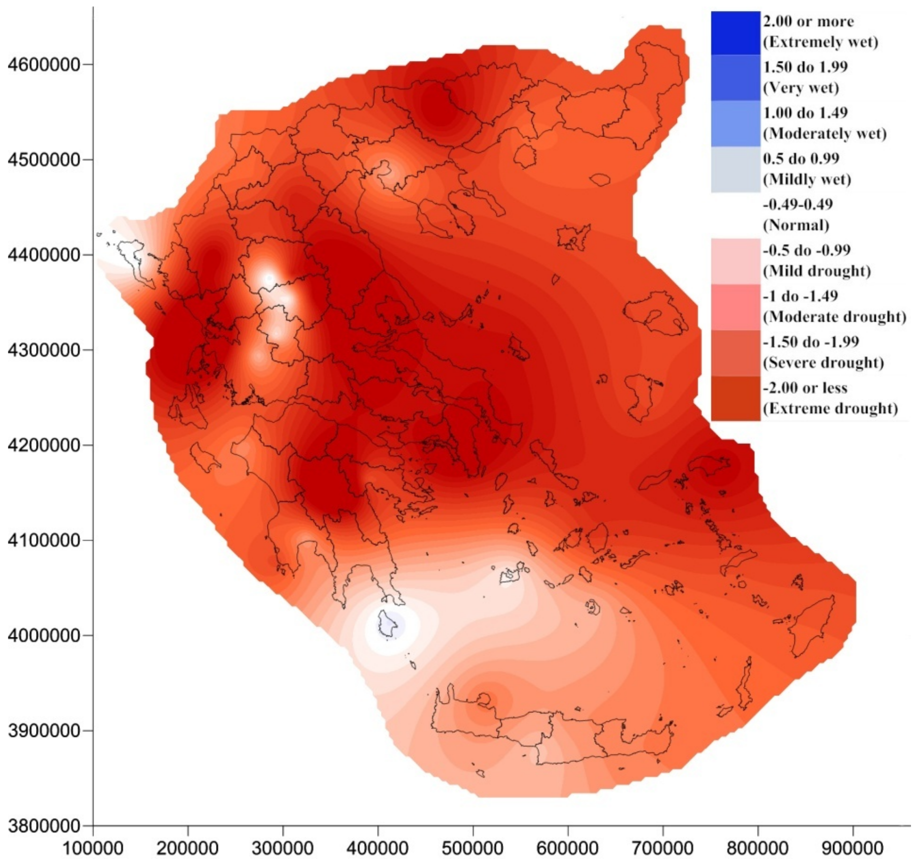


Figure 14. SPI 6 month time scale May/2004.

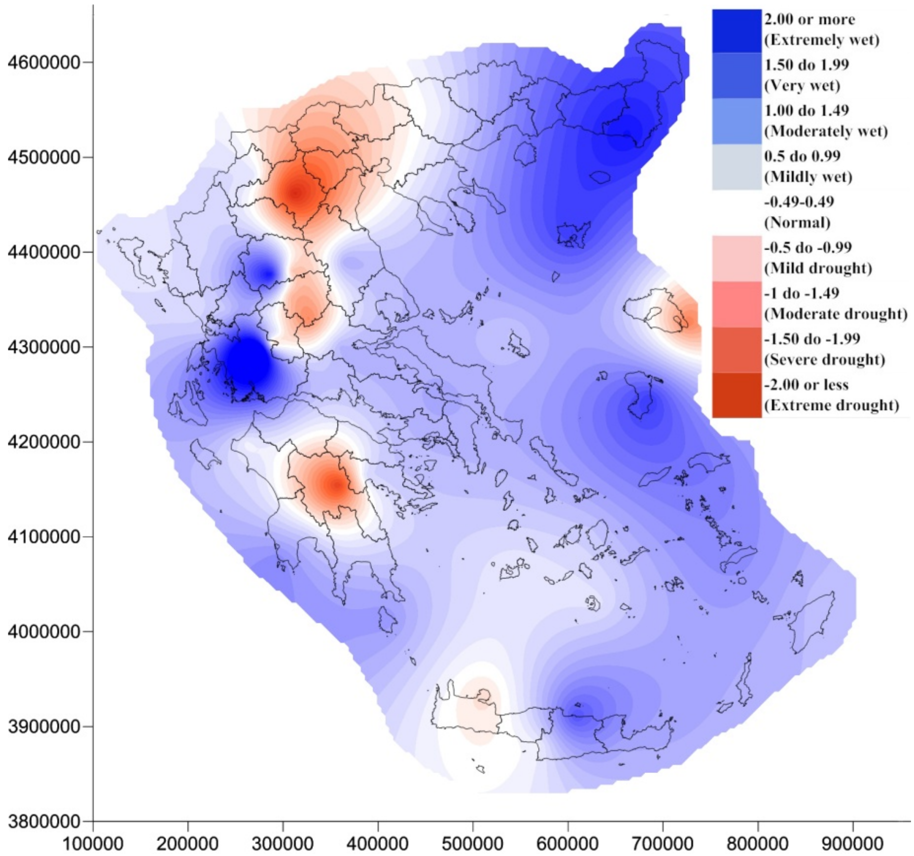
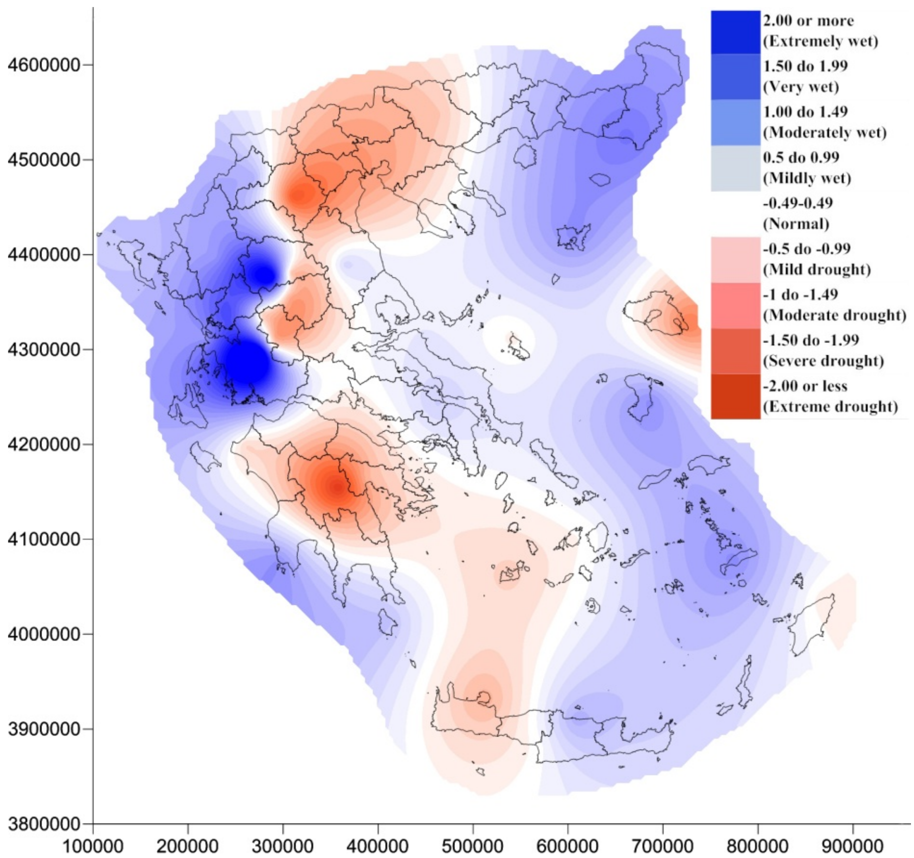


Figure 15. SPI 12 month time scale May/2004.



5. Conclusions

Overall, SPI described well the drought conditions in Greece. The indicator established the onset, the ending, and the severity levels of exceptional drought events, in the Greek conditions and by extension to other similar parts of the world facing such problems. The spatial SPI visualization provided a stakeholder oriented tool for immediate drought categorization. At the same time it could depict drought conditions all over the Greek territory incorporating the most vulnerable insular environments, a vital part of the country's economy. However, due to specific climatic conditions and the resulting precipitation patterns, a more populated meteorological network with the inclusion of as many as possible of the existing stations—incorporating areas with high elevation such as Mount Olympus, or/and more islands—would have contributed to the approach. This effort though, presents certain obstacles due to the fragmentation of the meteorological information management entities and the resulting difficulties in obtaining the pertinent data. Nevertheless, this inclusion may point toward a continuous temporal online SPI application that would also serve as a drought alert mechanism. Furthermore, drought contingency plans generally call for certain measures to be initiated when a drought indicator reaches a predefined level. Trigger levels can be refined through computer modeling or other decision making aids to strike an acceptable balance between the frequency of drought declarations and the effectiveness of an early response. Combined with drought contingency planning, this may lead to holistic drought management strategies**.** Therefore, drought management strategies should include sufficient capacity for contingency planning before the onset of drought, and appropriate policies to reduce vulnerability and increase resilience to drought. Effective information and early warning systems based on indicators such as the SPI are the foundation for overall effective drought adaptation plans.

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