Abstract: The degradation of natural resources at an intense rate creates serious problems in the environmental systems particularly with the compounding effects of climatic vagaries and changes. On the one hand, desertification is a crucial universal, mostly an anthropogenic environmental issue affecting soils all over the world. On the other hand, drought is a natural phenomenon in direct association with reduced rainfall in various spatial and temporal frames. Vulnerabilities to drought and desertification are complex processes caused by environmental, ecological, social, economic and anthropogenic factors. Particularly for the Mediterranean semi-arid conditions, where the physical and structural systems are more vulnerable, the abuse and overuse of the natural resources lead to their degradation and ultimately, if the current trends continue, to their marginalization. The scope of the current effort is trying to find any common drivers for the pressures of both processes. Thus, the vulnerabilities to drought and desertification are comparing by using the Standardized Drought Vulnerability Index (SDVI) and the Environmentally Sensitive Areas Index (ESAI). The indices are calculated from October 1983 to September 1996 in Greece. Greece is prone to desertification and it is often experiencing intense droughts, thus it presents an almost ideal case study area. The results may indicate that the most important factor for such procedures is the deficits in water resources, either due to lower than usually expected rainfall or to higher societal water demand.

Keywords: integrated water resources management; drought management; contingency planning; drought; desertification; vulnerability; indices comparison

1. Introduction

Natural resources management generally focuses on the implementation, monitoring, control and mitigation of real-world environmental issues (e.g., natural hazards, change of human pressures affecting the environment, etc.) rather than being involved with the abstract theoretical design of such issues causes [1–3]. Although its “marriage” with the environmental contingency planning is desirable, natural resources management is largely dedicated to the understanding of relations between society and environment, leading to the application of science and logic in solving problems. The fact that economic growth and environmental issues should not be approached separately, started to appear
mostly between 1972 (United Nations Conference on the Human Environment, Stockholm) and 1992 (United Nations Conference for the environment and Development, Rio de Janeiro—“The Rio Earth Summit”). Thus, such a fundamental premise became the cornerstone of the current natural resources’ management paradigm.

Nowadays, the degradation of natural resources also creates environmental pressures including water quality and quantity impacts, pollution, soil erosion, desertification, deforestation, potential climate change, overexploitation of water and other natural resources and the reduction of biodiversity particularly in fragile environments. Such degradation is more and more attracting the general concern of the various stakeholders [4–6]. It is also a general concern of the international scientific community that anthropogenic interventions may stress these fragile environments and burden the state of natural resources [7]. Moreover, these human activities may directly affect the well-being, the human health, the safety and the economic affairs and development. Furthermore, they assert continuing pressures to water and soil resources, which support societies through agricultural goods production, as well as providing safe and adequate water for human/animal needs [8–10]. On the other hand, the agricultural sector presents globally the higher consumption of water resources, thus, directly connecting the irrigation water quality with a healthy soil [11,12]. On the other hand, more than often any significant changes in land use or agricultural practices affect the quality of these natural resources [13,14]. Such environmental issues are connected with anthropogenic factors (population density, type of crops, land use intensity, etc.) and natural factors (climate of the area, soil texture, parent material, slope, etc.) [15,16]. In this context, urbanization increases water demand and usually decreases the sustainability of the available water resources. Thus, it is possible for natural resources degradation issues to emerge [17,18].

Drought is an extreme creeping phenomenon, which may occur at any time, in any region regardless of the predominant climate conditions and with undefined duration and unpredicted intensity [19–23]. The phenomenon per se attracts both the scientific and general public interest as it causes a plethora of social, economic and environmental impacts [20,23–25]. According to the Intergovernmental Panel on Climate Change scenarios, the frequency, intensity and duration of droughts are expected to continue growing in various regions around the world, including the Mediterranean basin [26]. However, this reported and expected to happen significant increase in drought patterns has not been observed during the last 60 years [19]. Additionally, it has been shown that for a given period in a particular area, the appearance of an uncertain event, such as drought, can be regarded as a certainty [5,6,12,13]. As a result, drought management plans should always be anticipatory and proactive [22,27–29].

The major challenge for any policy aimed at mitigating the effects of droughts is the development of integrated and effective management plans and the avoidance of crisis management. These plans should be based on contingency schemes having short-term tactics and long-term mitigation strategies including temporally differentiated actions—before, during and after the drought. The implementation of such plans should ideally be based on recording and processing accurate and timely drought data, as well as on using relevant indicators [29–32].

A large number of drought monitoring and evaluation indicators exists in the literature. The most common are: The Standardized Precipitation Index (SPI), the Palmer Drought Severity Index (PDSI) and the Crop Moisture Index (CMI). Choosing the most appropriate indicator per case is mostly based on the availability and validation of pertinent data [33–35]. Greece is an area where droughts occur quite often. During the period of 1989–2009, the phenomenon appeared in strength four times: 1991, 1993, 2000 and 2007 [22,36–38].

At the same time, desertification is characterized as a “silent disaster,” as its diagnosis is difficult especially in the early stages of the process, it only becomes perceptible when the process proceeds in intensity and brings significant problems in the soil [39–42]. It is a phenomenon growing rapidly and as it expands and the cost of restoration/rehabilitation increases until the effects are irreversible. Mitigation measures should be timely placed, before the recovery costs surpasses the soil potential
or before the chance to act is forever lost [43–45]. Therefore, it is a process whereby productive land becomes gradually inhospitable to productive vegetation, thereby creating spots of bared areas with the appearance of the parent rock on the surface [46–48]. In addition, it reduces the capacity for recovery and simultaneously the land productivity, which is neither easy to reverse nor to repair without significant economic interventions [49]. In this regard, defined as a decline of sustainable soil and vegetation use in arid, semi-arid and sub-humid regions, it is caused at least partially by anthropogenic actions. Land degradation and desertification may happen regardless of the climatic conditions and furthermore, the presence or absence of a nearby desert has no direct relationship with the phenomenon per se [50–53].

There are numerous efforts attempting to forecast the future spatial extension of both phenomena. Efforts forecast a gigantic extent of these two problems in association with the projected scenarios of climate change [26,54–56]. If it is predicted that there will be a rise in temperature and a decrease in precipitation in most of the already vulnerable regions, then the water needs will escalate to a level where the available water resources could not satisfy the projected future demands [57–60]. One can understand that if such scenarios prevail, agricultural production and development of a region or country, particularly in the Mediterranean area, will be reduced due to projected future water and soil degradation. It will also increase the imports of agricultural products from other countries which would not have been affected as seriously by the forecasted impacts of climate change [61–64]. In the case that the projected scenarios of IPCC are confirmed in the upcoming decades, then the vulnerability to drought and desertification will correspondingly increase with the consequent significant reduction of Gross domestic product (GDP) [65,66].

The term vulnerability can be expressed as the size of the losses or impacts from a disastrous event [22,66]. It includes the existing values and living standards of a region, as well as the degree of the resistance capacity or defence to a pertinent threat. However, it primarily concerns the extent to which the population, the anthropogenic and natural environment and the associated socio-economic activities are sensitive and susceptible to damage from a natural catastrophic event [67]. Therefore, a drought event also relates to the existing water infrastructure combined with the probability of exposure of a system to it. Such combination can lead to contingency planning in mitigation strategies. Drought Management and moreover Integrated Water Resources Management have to cope with constant changes in values and in the transformation of social structures, as well as to environmental and external changes such as climate anomalies and growing interdependencies. These fundamental changes have created conditions of globalization, high complexity, increased agitation, vulnerability and uncertainty [22,28,38,68]. Karavitis et al., 2014, expressed the Standardized Vulnerability Index Drought (SDVI) by expanding the procedure of the United Nations Office for Disaster Risk Reduction [22,69]. The presented vulnerability analysis composes the social, economic, physical and environmental factors expressed by risk and impacts. This expression also includes susceptibility but sometimes the role of susceptibility is not clear. In other words, the vulnerability of a hazard is meaningless without taking into account the impacts created by it. It is underlined that the risk of an extreme event (flood, drought, etc.), in the engineering literature is most of the times defined as a calculated function of the probability of occurrence of the given phenomenon. However, alternative estimations also exist [35,70]. Thus, in the current approach, the risk function is expressed through the SPI inclusion in the vulnerability index formulation [6].

Overall, the central objective of this work is an effort to find common drivers for the pressures inflicted by drought and desertification. According to the well-known DPSIR framework driving forces are applying pressure on a system [71]. The driving forces consist of any natural or human-induced factors that can direct to environmental pressures. The demand for agricultural land, energy, water, food, transport and housing can serve as examples of driving forces [72–74]. In this context, driving forces indicators may delineate the natural and anthropogenic conditions in a given time frame of a certain area [75]. Thus, the identification of common drivers and their pertinent indicators may come from the induced similar pressures in the systems elements. To this end, the vulnerabilities to
drought and desertification are assessed through the joined calculation of the Standardized Drought Vulnerability Index (SDVI) and the Environmentally Sensitive Areas Index (ESAI) for the common period—October 1983 to September 1996 in Greece. Then, the comparison of the SDVI and ESAI is presented. This step requires the reclassification of these indices to have comparable results. Finally, such procedures were compared spatially, as the ESAI values are subtracted from the SDVI ones and the new maps portray their spatial similarities and differences. Such results are further analysed and the common drivers are delineated, thus linking both processes. The inherent linearity of the presented comparison, it seems that it may not represent a complex non-linear reality of most systems. Potentially an expanded research effort may explore such issues by utilizing an approach embracing complexity in a more detailed fashion, having at the same time the ability to incorporate additional relations among the data arrays [76].

2. Methodology

To achieve the scope of this effort the first phase was the calculation of the Standardized Drought Vulnerability Index (SDVI) and then the vulnerability to desertification by the Environmentally Sensitive Areas Index (ESAI), from October 1983 to September 1996. Such time period was derived based on the common period from all the stations having the full array of the data needed. The data used in this analysis come from 22 weather stations provided by the Hellenic National Meteorological Service [77] and by the National Observatory of Athens [78]. The data used for the calculation of the SPI, as a necessary sub-indicator for the composite SDVI, had no gaps in their time series and they are homogeneous as required [36–38,79]. The indicators Supply and Demand calculated based on the results of AgroHydroLogos GIS hydrological model [80–83] with the simulation period being from October 1970 to September 1996. SDVI is also calculated from October 1983 to September 1996. The indicators for this calculation were cSPI, cSPI 12, Demand, Supply, Impacts and Infrastructure [22,29,84–86]. The ESAI considers the vulnerability of an area to desertification by analysing various parameters, such as the soil, geology, vegetation, climate and human actions. Each of these parameters is categorized and each indicator has different importance for each category. In more detail, the ESAI is divided into four categories: Quality of Soil, Quality of Climate, Quality of Vegetation and Quality of Management [51]. ESAI and SDVI were calculated from October 1983 until September 1996 in Greece. Hellenic National Meteorological Service [77], Hellenic Statistical Service [87,88] and the Hellenic Soil Mapping [89] provided the required data.

The second phase was the reclassification of the SDVI and the ESAI. This was necessary in order to compare the two indices results, since SDVI has a lesser number of classes than ESAI. Namely, SDVI has six classes and ESAI has eight classes. Hence, they were reclassified using three different methods in three common classes as presented in Tables 6 and 7. Based on that, new maps were produced. Such maps visualized the case study areas with a common-scaled degree of vulnerability to drought and desertification. Then, it may be derived which areas have the highest vulnerability to both processes, by subtracting each corresponding class indices values and then derive the common drivers characteristics. The described methodology is depicted in Figure 1.

2.1. Area of Application

The total area of Greece is 131,957 km², the coastlines are 13,676 km and according to the last demographics, the population is 10,815,197 [87]. The country may be divided into three “distinct” geographic units. The mainland unit delimited from the region of Sterea Hellas to the south, to the regions of Epirus, Macedonia and Thrace to the north (the largest unit of the country); the Peloponnese unit, comprised the “island of Peloponnese” south of the Isthmus of Corinth; and the unit of about 6000 larger and smaller islands in the Ionian and Aegean archipelagos. Each unit exhibits specific characteristics which are expressed in the different vulnerability to drought and desertification. Overall, Greece is part of South-Eastern Europe in the Mediterranean region. The Mediterranean region is vulnerable to drought and desertification and it is very sensitive to these phenomena with
sometimes devastating environmental, social and economic impacts. Moreover, natural resources are often degraded and mostly used in an unsustainable way [90]. The climate of Greece is typical northern Mediterranean, with mild and wet winters, relatively hot and dry summers and, generally, long periods of sunshine for the most part of the year. Moreover, in the summer period, the tourism and agricultural sectors are the most significant water users and important for the country’s economic welfare.

### Table 1.

| S/N | Station Name | Elevation (m) | T min (°C) | T max (°C) | T avg (°C) | Precipitation (mm) |
|-----|--------------|---------------|------------|------------|------------|--------------------|
| 1   | Agrinio      | 25            | 9.9        | 22.8       | 16.3       | 76.3               |
| 2   | Alexandroupoli | 3             | 8.8        | 18.9       | 13.9       | 46.3               |
| 3   | Argostoli    | 25            | 14.2       | 21.0       | 17.6       | 69.6               |
| 4   | Chania       | 62            | 14.3       | 21.9       | 18.1       | 49.1               |

In Figure 1a,b appear the spatial distribution of the cumulative annual precipitation and the average annual mean temperature from 1970 to 1996 and in Table 1 portrays the monthly values for temperature (minimum, maximum and average) and monthly precipitation (1970–1996).

Indicatively, on a country scale up to 85 % of the freshwater, predominantly in the mainland unit area, goes into irrigation. Such consumption is dependent on the country’s available water resources. These resources are about $58 \times 10^9$ m$^3$ annually [3,20,21], while, the country’s total water use has been about 12% of the total annual water availability [21,90]. This fact could point out that Greece should not face water shortages or any other water stress related problems [20,29]. In addition, Greece uses extensively groundwater, because it has not developed the proper infrastructure for the storage of the abundant surface water [20,21,28,29]. Furthermore, the extensive use of groundwater affects the aquifers with the sea-water intrusion particularly in the island unit [91,92]. Degradation of groundwater resources also takes place from pollution and contamination due to the disposal of untreated and/or semi-treated wastewater, as well as drainage effluents from agricultural activities containing fertilizers, pesticides and so forth. [93–96]. All such issues make the country highly dependent on the annual rainfall patterns. Thus, any precipitation deficits may often cause significant impacts on the economy, society and the environment. A succession of serious precipitation deficits has befallen during the last decades (e.g., 1989–1990, 1992–1993, 2000, 2003, 2007–2008) portraying Greece as drought prone, exposing its economy to water related hazards and leaving it vulnerable to loss, making the need of drought contingency planning of outmost importance [29,37,38]. Such planning is often relying upon pertinent indicators.

In Figure 2a,b appear the spatial distribution of the cumulative annual precipitation and the average annual mean temperature from 1970 to 1996 and in Table 1 portrays the monthly values for temperature (minimum, maximum and average) and monthly precipitation (1970–1996).
Table 1. Monthly values for temperature (minimum, maximum and average) and monthly precipitation (1970–1996).

| S/N | Station Name   | Elevation (m) | T<sub>min</sub> (°C) | T<sub>max</sub> (°C) | T<sub>avg</sub> (°C) | Precipitation (mm) |
|-----|----------------|---------------|-----------------------|----------------------|----------------------|-------------------|
| 1   | Agrinio        | 25            | 9.9                   | 22.8                 | 16.3                 | 76.3              |
| 2   | Alexandroupoli | 3             | 8.8                   | 18.9                 | 13.9                 | 46.3              |
| 3   | Argostoli      | 25            | 14.2                  | 21.0                 | 17.6                 | 69.6              |
| 4   | Chania         | 62            | 14.3                  | 21.9                 | 18.1                 | 49.1              |
| 5   | Didymoteicho   | 91            | 7.8                   | 18.5                 | 13.2                 | 49.6              |
| 6   | Asteroskopeion | 107           | 13.9                  | 22.1                 | 18.0                 | 32.6              |
| 7   | Hellenicon     | 62            | 14.1                  | 21.6                 | 17.9                 | 32.6              |
| 8   | Heraklion      | 39            | 14.8                  | 21.3                 | 18.1                 | 40.4              |
| 9   | Ioannina       | 484           | 7.5                   | 19.1                 | 13.3                 | 89.4              |
| 10  | Kato Nevrokopion | 652      | 3.7                   | 18.3                 | 11.0                 | 57.1              |
| 11  | Kerkyra        | 4             | 11.7                  | 21.6                 | 16.6                 | 91.9              |
| 12  | Kozani         | 626           | 7.1                   | 17.3                 | 12.2                 | 42.8              |
| 13  | Kythira        | 167           | 15.0                  | 19.7                 | 17.3                 | 40.4              |
| 15  | Larissa        | 74            | 8.4                   | 21.2                 | 14.8                 | 39.0              |
| 15  | Lesvos         | 5             | 13.4                  | 20.6                 | 17.0                 | 56.9              |
| 16  | Melos          | 7             | 14.5                  | 20.3                 | 17.4                 | 34.6              |
| 17  | Naxos          | 10            | 15.0                  | 20.1                 | 17.6                 | 35.3              |
| 18  | Rodos          | 11            | 16.0                  | 21.8                 | 18.9                 | 54.2              |
| 19  | Samos          | 6             | 13.9                  | 22.0                 | 17.9                 | 62.8              |
| 20  | Skyros         | 18            | 13.8                  | 19.5                 | 16.7                 | 42.1              |
| 21  | Thessaloniki   | 32            | 11.0                  | 20.4                 | 15.7                 | 39.1              |
| 22  | Tripoli        | 652           | 7.0                   | 19.3                 | 13.2                 | 66.1              |

2.2. Standardized Drought Vulnerability Index (SDVI)

The SDVI is a composite indicator and aims at integrating the various manifestations of drought (Meteorological, Hydrological, Agricultural, Social and Economic) and the concept of vulnerability into a single value. It comprises six components cSPI<sub>6</sub>, cSPI<sub>12</sub>, Supply, Demand, Impacts and Infrastructure [22,29,97]. As previously stated, the values of cSPI<sub>6</sub> and 12 are calculated on local (meteorological station) scale, while the remaining components are calculated in various scales (e.g., basin/sub-basin/county or other scales) depending on data availability. For example, in a given area (basin/county) the total supply and demand deficits, as well as the resulting impacts, are represented as ratios (proportions) over the total amount of the examined parameters, while the infrastructure component is represented by a weighted average value (ratio) of the infrastructure performance [22].
Continuing, the six components are classified into four vulnerability categories (0–3 scale) according to their performance (Table 2). The final vulnerability value per se is calculated by the average scaled value of the components following Equation (1) \[22,29,86,97,98\]. In this regard, the SDVI adopts the mechanics of the Environmental Vulnerability Index that was developed by the South Pacific Geoscience Commission \[90\]. Worth mentioning is the fact that the SDVI is calculated on a monthly step.

\[
SDVI = \frac{\sum_{i=1}^{N} \text{Scaled Values of the Components}}{\text{Number of Components (N = 6)}}
\]

Table 2. SDVI components vulnerability scale \[22,29,97\].

| Vulnerability Level | cSPI6 and cSPI12 | Supply | Demand | Impact | Infrastructure |
|---------------------|------------------|--------|--------|--------|----------------|
| Less Vulnerable     | 0 Wet            | ≥1.50  | 0 No Deficits | 0 No Deficits | 0 None       | 0 Complete |
| Vulnerable          | 1 Quite Wet      | 0 to 1.49 | 15% Deficits | 15% Deficits | 15% Losses   | 15% Deficiency |
| Highly Vulnerable   | 2 Quite Dry      | 0 to −1.49 | 16–50% Deficits | 16–50% Deficits | 16–50% Losses | 16–50% Deficiency |
| Extremely Vulnerable| 3 Dry            | ≤−1.50 | >50% Deficits | >50% Deficits | >50% Losses  | >50% Deficiency |

Finally, the SDVI results are classified into six vulnerability categories for the vulnerability state per area to be determined (Table 3).

Table 3. SDVI scaled values \[22,29,97\].

| SDVI     | Vulnerability Scale |
|----------|---------------------|
| 0.00–0.49| No Vulnerability    |
| 0.50–0.99| Low Vulnerability   |
| 1.00–1.49| Medium Vulnerability|
| 1.50–1.99| High Vulnerability  |
| 2.00–2.49| Very High Vulnerability |
| 2.50–3.00| Extreme Vulnerability |

2.3. Environmentally Sensitive Areas to Desertification (ESAs)

In MEDALUS project, the vulnerability to desertification method is developed in order to identify pertinent problematic areas \[51\]. The method produced a composite index, comprised by four environmental and anthropogenic factors, the Soil Quality Index (SQI), the Climate Quality Index (CQI), the Vegetation Quality Index (VQI) and the Management Quality Index (MQI). The ESAI estimates the desertification vulnerability and has eight classes (Table 4). Specifically, the equation is described in the following Equations (2)–(6) \[51\].

\[
ESAI = (SQI \times CQI \times VQI \times MQI)^{\frac{1}{3}}
\]

where

\[
SQI = (\text{Soil Texture} \times \text{Rock Fragment} \times \text{Soil Depth} \times \text{Parent Material} \times \text{Drainage} \times \text{Slope Gradient})^{\frac{1}{6}}
\]

\[
CQI = (\text{Rainfall} \times \text{Aridity Index} \times \text{Slope Aspect})^{\frac{1}{3}}
\]

\[
VQI = (\text{Fire Risk} \times \text{Erosion Protection} \times \text{Drought Resistance} \times \text{Plant Cover})^{\frac{1}{3}}
\]

\[
MQI = (\text{Land Use Intensity} \times \text{Policy})^{\frac{1}{3}}
\]

Finally, Table 4 shows the various classes of composite index of Desertification Vulnerability.
Table 4. Types of ESAs and the classes of ESAs index [51].

| Type     | Subtype | Range of ESAI  |
|----------|---------|----------------|
| Critical | C3      | >1.53          |
|          | C2      | 1.42–1.53      |
|          | C1      | 1.38–1.41      |
| Fragile  | F3      | 1.33–1.37      |
|          | F2      | 1.27–1.32      |
|          | F1      | 1.23–1.26      |
| Potential| P       | 1.17–1.22      |
| Non affected | N | <1.17      |

2.4. Comparison Mechanics

The major problem for any meaningful comparison is the difference in scaling classification of the two composite indicators. SDVI is a six-class division while ESAI has eight classes. In order to resolve such issues, the indices were reclassified following three different methods: two empirical and one statistical as shown in Table 6 and then in three common classes. The Empirical methods were derived after extensive literature review, in which the results were given to experts and stakeholders to express their perception and then the new classes formed [80]. The Empirical method one (1) for SDVI formulated three new classes in relation to the original ones (presented in the pertinent parentheses following each new class): Low (no and low vulnerability), Medium (Medium Vulnerability), High (High, Very High and Extreme Vulnerability). The SDVI Empirical two (2) uses: Low (no and low vulnerability), Medium (Medium, High Vulnerability), High (Very High, Extreme Vulnerability). Correspondingly for ESAI the Empirical one (1) is Low (Potential, Non affected), Medium (F1, F2, F3) and High (C1, C2, C3). The ESAI Empirical method two (2) forms Low (Potential, non-affected), Medium (F1, F2, F3 C1), High (C2, C3). The statistical method uses basic statistics such as the minimum value (minV), the maximum value (maxV), the standard deviation (STDEV) and so forth. of the total sample namely the calculated approximately $1.5 \times 10^6$ values of SDVI and ESAI in a 300 by 300 m grid all over the country. Then the following classification scheme applied: Low (minV plus one STDEV), Medium (minV plus two STDEV) and High (maxV minus two STDEV) for both the indices. The classification scheme was also derived after detailed literature review in similar applications. Table 7 presents the resulted new values.

3. Results

3.1. Drought and Desertification Vulnerability

The values of cSPI6 and cSPI12 are calculated on local (meteorological station) scale while the remaining components are calculated in various local also scales (e.g., basin/sub-basin/county) depending on data availability. SDVI is calculated on a monthly step. In a given area (basin/county) the total supply and demand deficits, as well as the resulting impacts, are represented as ratios (proportions) over the total amount of the examined parameters, while the infrastructure component is represented by a weighted average value (ratio) of the infrastructure performance [22,29,84]. The results of the SDVI can be expanded to other regions with similar or different climates since the SDVI is calculated using average values and deviations for the supply, demand and impact sub-indices [22,29,84]. The SDVI results were classified into six vulnerability categories for the vulnerability state per area to be determined [22,29,84]. The SDVI values are calculated spatially using the ArcGIS map-algebra toolbox. Finally, all the obtained data, as well as the SDVI results, were visualized on a GIS environment using geo-statistical techniques, namely ordinary kriging for the SPI components, since it referred to having a better fit for SPI [36–38]. The calculation was performed on a monthly time step for the period October 1983 to September 1996. The average value of each SDVI component during this period is presented for comparison purposes on Figure 3.
The desertification of the Greek land is a phenomenon that was recorded early on by Aristotle and is continued for about three millennia related to the exhaustion of soil productivity and the available water resources [39–41,50]. The extreme deterioration of these two essential natural resources has already spread to more than 20% of Greece’s total area during the last two millennia. The endangered desertification areas amount to 30% of the total area of the country, while 49% is under possible desertification [40,41]. The greatest threat is in Crete, Lesvos, Eastern Sterea and Peloponnese but also in parts of Thessaly, Macedonia and Thrace [40,42]. Despite the prevailing harsh water stress natural conditions in the European Mediterranean area, desertification occurs only if it coexists with the unsustainable soil resources used by human society. Therefore, in Greece as well as in other countries of the region, desertification is found in sensitive areas that are characterized by over-exploitation of land, water and generally natural, resources [51]. This phenomenon evolves very slowly and shows temporal and local discontinuities. Thus, unfortunately, it was not directly perceived by the respective societies and stakeholders until the devastating effects established themselves. The situation has already reached its saturation point and the evolution of the phenomenon has accelerated greatly in the recent years, mostly due to the industrialization of farming practices and over-consumption of water [40,54–56].

Using the four quality indicators (soil, climate, vegetation and management), ESAI calculated also the vulnerability to desertification as pictured. In accordance to the classification of the index, eight categories are presented starting from the areas that are susceptible to desertification, potentially sensitive (F1, F2 and F3) and, finally, the critical areas (C1, C2 and C3), which cannot be restored (especially class C3) [37]. Figure 4 presents the pertinent average values of the ESAI components during the period of October 1983 to September 1996.

Thus, according to the SDVI results (Figure 5), non and less vulnerable are 6.30%, 67.30% are medium vulnerable and 26.5% are categorized in the remaining three classes as highly, exceptionally vulnerable areas. Analysing the ESAI, it is noted that the first class (non-affected) has 8.07% occurrence, with the second class of (potential) being around 11.91%. For vulnerable areas the total value is 53.43% (19.54%, 18.72% and 15.17% for F1, F2 and F3, respectively) and, finally, for critical areas it is 26.59% (10.36%, 14.53% and 1.7% for the C1, C2 and C3, respectively).
Figure 4. Average value of each ESAI Component from October 1983 to September 1996.

Figure 5. Vulnerability to Drought and Desertification in Greece from October 1983 to September 1996.
Regarding the altitudinal, zonation similarities occur in the two indices application. The zones refer to the natural ecosystems and with the application of the indices; they are related to anthropogenic actions and interventions directly associated to the corresponding ecosystems. There are many factors (climate, geomorphology, land use, etc.) such as air temperature, precipitation, parent material, relative humidity, soil texture, solar radiation, altitude and land use are relating for the specifications and categories of the zones [99–102]. The zones with the maximum and minimum values of SDVI and ESAI from the calculated $1.5 \times 10^6$ values of SDVI and ESAI are portrayed in the following Table 5. Both vulnerabilities are decreased in alti-Mediterranean and snow zones, since there are extremely low impacts due to the absence of any significant human activities in these zones [22].

### Table 5. Zonal Statistics for SDVI and ESAI according to the various zones [100].

| Elevation | Zones                  | SDVI Min | ESAI Min | SDVI Max | ESAI Max |
|-----------|------------------------|----------|----------|----------|----------|
| 0–350     | Thermo-Mediterranean   | 0.667    | 0.697    | 2.167    | 1.621    |
| 350–600   | Mesomediterranean      | 0.667    | 0.692    | 2.000    | 1.621    |
| 600–1200  | Super-Mediterranean    | 0.667    | 0.692    | 2.000    | 1.562    |
| 1200–1700 | Montane               | 0.833    | 0.754    | 1.833    | 1.497    |
| 1700–2600 | Alti-Mediterranean     | 0.667    | 0.690    | 1.500    | 1.463    |
| >2600     | Snow Zone             | 0.667    | 0.586    | 1.430    | 1.367    |

### 3.2. Reclassification of SDVI and ESAI

Following the presented approach, the three different classification methods are applied in order to make the comparison of the two Indices. The amplitudes of the categories are reflected in the following table (Table 6).

### Table 6. The new classifications from empirical and statistical methods for SDVI and ESAI.

| Values | Vulnerability | SDVI Empirical 1 | SDVI Empirical 2 | SDVI Statistical | ESAI Empirical 1 | ESAI Empirical 2 | ESAI Statistical |
|--------|--------------|------------------|------------------|------------------|-----------------|-----------------|-----------------|
| 1      | Low          | >1.49            | >1.99            | >1.66            | >1.38           | >1.41           | >1.41           |
| 2      | Medium       | 1.00–1.49        | 1.00–1.99        | 1.16–1.66        | 1.22–1.38       | 1.22–1.41       | 1.26–1.41       |
| 3      | High         | <0.99            | <0.99            | <1.16            | <1.22           | <1.22           | <1.26           |

Figure 6 depicts the maps of composite indicators (SDVI and ESAI) as recalculated in accordance to the new categorization. Tables 6 and 7, reflect the values that appear in each method and for each class. Again, the created samples had a population of about $1.5 \times 10^6$ values of SDVI and ESAI for each method.

### Table 7. Relative frequency of the recalculated values for the SDVI and ESAI according to the methods followed and the new classes.

| Classes | SDVI Relative Frequency (%) | ESAI Relative Frequency (%) |
|---------|-----------------------------|-----------------------------|
| Value   | Empirical 1 | Empirical 2 | Statistical | Empirical 1 | Empirical 2 | Statistical |
| 1       | 6.2         | 6.2         | 31.7        | 8.1        | 17.2        | 29.3        |
| 2       | 67.3        | 93.4        | 52.8        | 68.7       | 67.1        | 55.6        |
| 3       | 26.5        | 0.4         | 15.5        | 23.2       | 15.7        | 15.1        |

It is observed from Table 6 that for both the composite indices (SDVI$_{\text{empirical 1}}$ and ESAI$_{\text{empirical 1}}$) the value of 2 occupies respectively the 67.3% and 68.7%. For the first class, depicting the value of 1 the relative frequency of SDVI is 6.2% while for the ESAI is 8.1% and, finally, the high vulnerability class is 26.5% for SDVI and 23.2% for ESAI. Figure 6, in the first two columns shows that the rural areas in the mainland and the Aegean islands’ units, are more vulnerable to drought. In more detail, Thessaly region raises such problematic areas, as well as the entire Aegean Islands unit. The last unit exhibits also high vulnerability to desertification. In this regard, a first comparison
with Figure 2a suffices to show that all these areas have also low precipitation and the resulting for Greece limited water resources [103]. Eastern Peloponnese, Eastern Sterea Hellas and Euboea. Central and south-eastern Crete, where there is also reduced precipitation, portray critical vulnerability to both drought and desertification. In all these areas, existing information portrays serious drought incidents [20–22,24,29,30,36,38,104] and desertification risk [40–42,51]. The above comparisons may indicate that there is a strong relationship between vulnerability to drought and desertification as represented by the developed indices, especially, regarding water availability and demand. In more detail (Table 3 and Equations (2) to (6)), water demand expressed in both indices either directly as in SDVI or indirectly in ESAI (plant cover, land use intensity) is a crucial characteristic. Furthermore, water availability as expressed through SPI in SDVI and incorporated through the indicators rainfall, aridity index and drought resistance in ESAI, is another signficant common characteristic. Thus, it would seem that both indices point out that water deficits are central drivers’ characteristics for the evolution of both phenomena. The results of the comparison of the two indices in Figure 6 on the third column visualize the difference between SDVI and ESAI. Namely, subtracting in a spatial basis the first procedure’s values from the second. The categorization of this subtraction starts when the difference of classes results in zero. In this regard, it is derived that the region is vulnerable to both droughts and desertification and there is a high potential that any of the processes or both may take place. For positive values (1 and 2), it may be derived that this area is more vulnerable to drought than desertification. Finally, respectively for negative values (−2 and −1) it is pointed out that the area is more vulnerable to desertification than drought.

From Table 8 as well as from column 4 in Figure 6, the empirical approaches exhibit a range from 49.3% to 64.8% that the relevant areas display common values of vulnerability to both drought and desertification, whereas the statistical approach has 42.5% for such a case. More vulnerable to drought with 31.8% and 15.8% are areas according to the two empirical methods, while 28.2% to the statistical approach. Finally, 18.9% 19.3% are reflecting areas more prone to desertification following the empirical approaches and 29.2% according to the statistical one.

### Table 8. Frequencies of the difference between SDVI and ESAI for the three methods.

| Values | Empirical 1 (%) | Empirical 2 (%) | Statistical (%) |
|--------|-----------------|-----------------|-----------------|
| −2     | 1.5             | 1.1             | 4.2             |
| −1     | 17.4            | 18.2            | 25.0            |
| 0      | 49.3            | 64.8            | 42.5            |
| 1      | 29.2            | 15.8            | 24.7            |
| 2      | 2.6             | 0.1             | 3.6             |
| Total  | 100.0           | 100.0           | 100.0           |

Again, eastern Greece is depicted as more vulnerable to both phenomena. This fact is also recorded in the pertinent literature. Furthermore, by comparing all the three methods the first empirical method and the statistical one are representing more closely the recorded conditions [21,22,51,89]. The drought and desertification vulnerable areas in the mainland and the Aegean islands units are both portrayed as such. These results are reinforced by the visualization of the frequencies of the difference between SDVI and ESAI for the three methods as demarcated on Table 8. The second empirical method tends to categorize the resulting values in the larger amplitude of the medium class, thus it misses the severe drought conditions in the mainland and the Aegean islands units, as shown in Figure 6. Overall, the vulnerability to drought and desertification have common characteristics. It seems that one of the most significant ones is the lack of adequate water resources or low rainfall given increased demands and/or low level of demand satisfaction.
4. Conclusions

This effort has focused on the relations between the vulnerability to drought (SDVI) and to desertification (ESAI) indicators. It delineated a process by applying the methodology in Greece to identify the similarities and differences between vulnerability to drought and desertification vulnerability. As an outcome, it delineates how it can adapt to derive policies and strategies to address both issues, in an uncertain future including climate and land use changes. The vulnerabilities to drought and desertification are complex phenomena that are due to a lesser or greater degree to both natural and anthropogenic causes. Particularly, for the arid and semiarid Mediterranean region, where the systems are more fragile, excessive and haphazard use of natural resources leading also to degradation and eventual depletion. Besides human interventions in natural resources, the management approaches to confronting complex natural hazards is of utmost approaches.

According to the main objectives, the vulnerabilities to drought and desertification seem to share common driving forces. The most important of them may be water scarcity, either because of low precipitation/water availability or of higher water demand resulting in higher water use (irrigation, urban and industrial). The results indicated that Eastern Peloponnese, Eastern Sterea Hellas and Euboea. Central and south-eastern Crete and the Aegean Islands present critical vulnerability to both drought and desertification. The presented approach may point towards a relationship of key drivers between vulnerability to drought and desertification, especially, with the second empirical approach and the statistical one and regarding also the altitudinal zonation. Potentially an expanded research effort may explore eliciting issues of non-linearity by utilizing an approach further embracing natural and socio-economic complexity, having at the same time the ability to incorporate additional relations among the pertinent data arrays.

Overall, these results portray a common enabling environmental and driving forces and it seems essential to harmonize based on such premises both drought and desertification mitigation strategies in the guidelines for various stakeholders and International Organizations. Both the indices can
provide useful information to policymakers and may enforce the local adaptation measures to these hazards. The presented methodology may help in demarcating with more clarity complex phenomena, to timely, effectively apply mitigation measures and eventually lead to a contingency planning posture. Finally, the present study demonstrates that a careful comparison of relevant indices may be used to assess drivers of drought and desertification and focus on common environmental, social and economic characteristics to support decisions for mitigation efforts.

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