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Development and Application of Water and Land Resources Degradation Index (WLDI)

Demetrios E. Tsesmelis [1,2,*], Christos A. Karavitis [2], Kleomenis Kalogeropoulos [3], Andreas Tsatsaris [4], Efthimios Zervas [1], Constantina G. Vasilakou [2], Nikolaos Stathopoulos [5], Nikolaos A. Skondras [2], Stavros G. Alexandris [2], Christos Chalkias [3] and Constantinos Kosmas [2]

1 Laboratory of Technology and Policy of Energy and Environment, School of Science and Technology, Hellenic Open University, Parodos Aristotelous 18, 26335 Patra, Greece; zervas@eap.gr
2 Department of Natural Resources Development & Agricultural Engineering, Agricultural University of Athens, 11855 Athens, Greece; ckaravitis@aua.gr (C.A.K.); vasilakou@aua.gr (C.G.V.); nskondras@aua.gr (N.A.S.); stalex@aua.gr (S.G.A.); ckosm@aua.gr (C.K.)
3 Department of Geography, Harokopio University of Athens, El. Venizelou St, 70, 17671 Athens, Greece; kalogeropoulos@hua.gr (K.K.); xalkias@hua.gr (C.C.)
4 Department of Surveying and Geoinformatics Engineering, University of West Attica, Ag. Spyridonos St, Egaleo, 12243 Athens, Greece; atsats@uniwa.gr
5 Institute for Space Applications and Remote Sensing, National Observatory of Athens, BEYOND Centre of EO Research & Satellite Remote Sensing, 15236 Athens, Greece; n.stathopoulos@noa.gr
* Correspondence: tsesmelis@aua.gr or tsesmelis.dimitrios@ac.eap.gr

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Abstract: Natural resources are gradually coming under continuous and increasing pressure due to anthropogenic interventions and climate variabilities. The result of these pressures is reflected in the sustainability of natural resources. Significant scientific efforts during the recent years focus on mitigating the effects of these pressures and on increasing the sustainability of natural resources. Hence, there is a need to develop specific indices and indicators that will reveal the areas having the highest risks. The Water and Land Resources Degradation Index (WLDI) was developed for this purpose. WLDI consists of eleven indicators and its outcome results from the spatiotemporal performance of these indicators. The WLDI is based on the Standardized Drought Vulnerability Index (SDVI) and the Environmentally Sensitive Areas Index (ESAI). The WLDI is applied for the period from October 1983 to September 1996, considering Greece as a study area. The results of the application of this index reveal the areas with the highest risks, especially in the agricultural sector, with less than the needed water quantities due to extensive periods of droughts. This index could be used by scientists, but also by policy makers, to better and more sustainably manage environmental pressures.

Keywords: decision making; natural resources; WLDI; composite indicators; spatial analysis; Greece

1. Introduction

Integrated water resources management contributes to the appropriate use of surface and groundwater, with the goal of meeting the requirements of urban, agricultural, and industrial needs [1–13]. Water is in abundance in some regions of the world, while in others (especially in developing countries) water resources may be sometimes scarce due to low rainfall, overpopulation, and lack of water specific infrastructure. However, floods, droughts, hydroelectric power generation, and water scarcity have a great impact on the livelihoods of most of the population in most countries [8]. Therefore, there is an urgent need for an adequate and fair distribution of water resources. In addition, the satisfaction of water needs is more difficult due to the high population growth in some regions [14,15]. As available resources (surface and groundwater) play a major role in agricultural production, an increasing share of over-consumption of groundwater is due to the intensification of this sector and mainly due to over-irrigation [16,17]. In arid and semi-arid areas, dependence on groundwater for water supply is significantly higher compared to other areas. It should be mentioned that water users of these areas continue to over-exploit their resources during droughts without sufficiently taking into account their limited availability This lack of appropriate water management further contributes to the environmental degradation of such areas [18–22].

A drought is an "insidious" natural hazard due to the reduction, at an unsuspected time, of the usually expected rainfall in an area [23,24]. This situation may last for months or even years. Water cannot be renewed to the necessary rate for the adequate satisfaction of the needs of both people and the environment. However, droughts are a normal climatic process of certain areas [25–27]. The negative connotation given to droughts is directly related to their adverse effects on humans and the environment, as well as to the complexity and difficulty in recognizing and dealing with this phenomenon. Usually, decision-makers, who are called upon to provide answers and possible solutions to the management of this complex phenomenon, have previously focused on measures and mitigation actions that accompany a drought event. However, the key to effectively deal with a crisis is to study and understand the phenomenon of drought and, subsequently, to draw up preparedness plans in most regions of the world [23,28–33]. In other words, contingency planning is needed.

The primary goal of the pertinent approach is to analyze droughts based on the natural and man-made factors that contribute to their occurrence [23,34–36]. An overview of the concepts, characteristics, and effects of droughts provides the basis for a more complete understanding of this complex natural hazard, including how droughts affect people and society, and vice versa, how the irrational use of natural resources and inadequate policies can worsen vulnerability in droughts [23,25,29,37,38]. A drought is different from other natural hazards for several reasons. Firstly, because it is slow to occur, comparing to floods, fires, earthquakes, etc., it is often described as a "creeping phenomenon" [37]. Secondly, the effects accumulate slowly and for a significant period of time before they are perceived. As a result, it is difficult to determine the onset and end of a drought. Moreover, scientists and policymakers often disagrees on the adequate and necessary measures to address it [22,29,38–41].

Droughts result from the combination of many natural factors, enhanced by anthropogenic influences. The primary cause of any drought is the insufficiency of rainfall and, in particular, the time, distribution, and intensity of this insufficiency in relation to the usually existing stored amount of water, supply and demand. This deficiency results in a lack of water necessary for the functioning of the natural ecosystem and/or for the essential human activities [42–44].

In times of drought, the natural vegetation is suffering and dry areas may be created, runoff is reduced, the water level in lakes, rivers, and reservoirs decreases, and the depth to the groundwater table increases. In cases where a drought persists for a long time, long-term effects may occur such as declining groundwater surfaces, land subsidence, seawater intrusion (a major problem for island areas) and more permanent damage to ecosystems. In contrast to its immediate effects, long-term ones can be more difficult and more costly to manage [45,46].

During droughts, reducing surface water runoff can affect hydroelectric power generation, inland navigation, recreation activities and, of course, can have impacts on aquatic and coastal species. Moreover, there is a close interaction between surface water (watercourses, lakes, reservoirs, wetlands, and estuaries) and groundwater. In contrast to the effects of drought on surface water which are quite immediate, in groundwater there is a time difference in the levels of boreholes and wells, and this difference may appear several months or even years after the onset of drought. Initially, due to the reduced water supply, the water use may increase during a drought and, as a consequence, over-pumping of groundwater may occur. Then, if the resource is pumped at a faster rate than the natural enrichment of the aquifer or the surface sources, its replenishment is challenging, and a deterioration of water quality may take place. Particularly for groundwater, in addition to being an important source of water for lakes and wetlands, it plays a crucial role in maintaining watercourses between rainy events and especially during periods of prolonged drought [47–50].

Land subsidence can occur gradually or suddenly. One reason is from the over-pumping and depletion of aquifers, which may cause permanent damage to groundwater storage. A typical example is the San Joaquin Valley in California, where landslides occur and can lead to serious operational and structural issues in the Mendota Delta Canal. In coastal areas, over-pumping can cause seawater to seep into the aquifer system. Seawater intrusion endangers groundwater quality and can cause serious irrigation soil problems due to salinization [51–54].

To implement an integrated water resources management methodology, a tool, in the form of an index for the recognition of degradation of water and land resources and pertinent vulnerable areas, is developed in the present work. This index is further expanded to produce the connection and similarities between existing droughts and desertification indicators. As Greece is a country prone to drought phenomena, both random and periodical, this index is initially applied to Greece prior its further application to other countries with similar drought issues.

Furthermore, the whole effort analyzes whether there was a relation between drought vulnerability indicators and desertification vulnerability indicators. A statistical analysis with Principal Component Analysis (PCA) based on the Kaiser-Meyer-Olkin (KMO) index was necessary to develop the weights between them to associate these attempts. Based on this assumption, a relationship between drought and desertification vulnerability was surfaced. Finally, the indicators of both procedures were analyzed, and a composite index was created, which shows the water resources and land degradation of a region. The indicators that have occurred in the final equation are Aridity Index, Water Demand, Drought Impacts, Drought Resilience, Water Resources Infrastructure, Land Use Intensity, Parent Material, Rainfall, Slope and Soil Texture. All in all, the final index was applied in Greece for the period from 1983 to 1996. This period was the driest period of the last 100 years (particularly between 1988 and 1993) [22,24,26]. Further on, additional major changes were observed including a shifting water consumption, an increase in the cultivated land area and differences in the rural to urban land distribution. The innovation of the current approach combines two different processes and the simultaneous use of water and land degradation indices in a specific tempo-spatial scale.

2. Materials and Methods

2.1. Study Area

Greece is used as a study area for the development and application of Water and Land Resources Degradation Index (WLDI). Greece is located in the southeast of Europe and almost in the middle of the Mediterranean Sea. Its topography is mostly mountainous. Greece has a very long coastline of almost 14,000 km and a high number of islands (reaching 3000).

The climate is typical Mediterranean one. The highest amount of precipitation (mostly rainfall) occurs between October and March, while the average annual rainfall ranges from 350 mm/year to 2150 mm/yr. The summers are usually very dry in most of the regions [55,56].

Rainfall in Greece, as historically recorded, has the following main characteristics. At the beginning of the wet season, the atmospheric circulation with the west-southwest movement of the barometric systems results in high amounts of rainfall in western Greece. The presence of the mountain range of Pindos is a barrier to the expansion of rainfall in the eastern country. As a consequence, rainfall is selectively located in the islands of the eastern Aegean and in western-northern Greece (mainly Epirus, W. Peloponnese, Macedonia, and Thrace). The gradual shift of circulation to the north during the winter months gives rains to the eastern winds of the mainland and the islands of the Aegean-Crete. With the end of the dry season and the gradual decrease of the passage of barometric systems over the country, the main rainfall contribution to the water balance comes from the afternoon showers, as an expression result of thermal instability with or without dynamic assistance. By their nature, these phenomena concern mainland Greece with emphasis on mountainous areas. Based on this climatic conditions, higher rainfall levels are expected during the rainfall of the wet period in western Greece, but also in the islands of the eastern Aegean (and less in the eastern mainland and the other Aegean islands). During the dry season, most rainfall is expected in the mainland, while the west coast should also have a few rainfalls. Some amounts also occur in the islands of the eastern Aegean and the Dodecanese as a result of the thermal instability of the eastern part of Greece [56].

2.2. Methodology

The methodology followed for the development of Water and Land Resources Degradation Index (WLDI) was based on the "XERASIA" process categorization (Figure 1) [22,57]. According to this scheme, aridity is referred to as a permanent natural condition, representing a stable climatic feature of a given region. Drought may be understood as a temporary, mostly climatic, phenomenon, regular and/or unpredicted. Water shortage is associated mainly with small areas of water deficiency usually caused from human activities. Finally, desertification is principally a man-made phenomenon, where the ecological regime is significantly altered. Nevertheless, whatever the term and the overall context, drought should be associated with its impacts at a given area, with its special technological, environmental, economic and societal traits for the area's vulnerability estimation to various "drought" manifestations. In this regard, the Water and Land Resources Degradation Index (WLDI) is developed including the above four different categories that are important for the initial separation of the types of water deficiencies in relation to natural changes and anthropogenic interventions such as drought, water shortage, aridity, and desertification (Figure 2) [22,23,57].

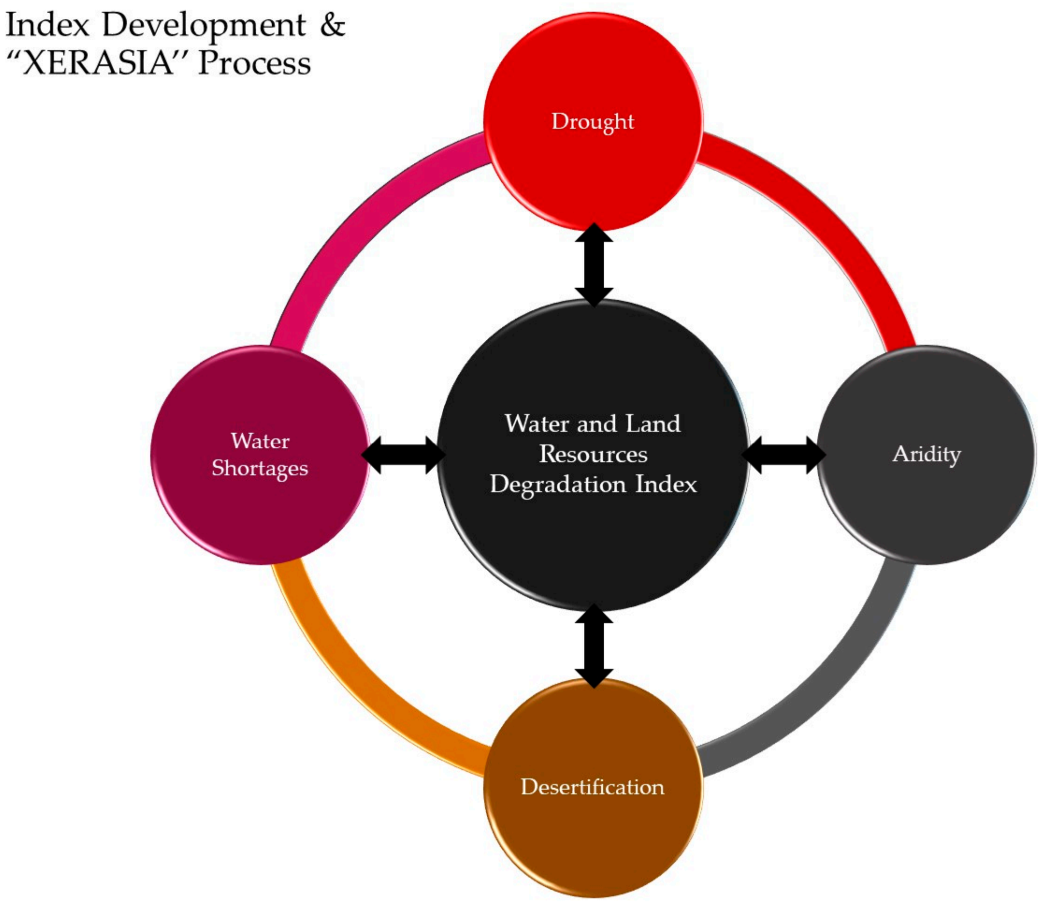

Figure 1. Main scheme of the XERASIA process and the WLDI [22,23,57].

Figure 2. Greece, the main study area.

This section presents the main aspects of the proposed methodology to integrate two already developed indices namely, the Standardized Drought Vulnerability Index (SDVI) and Environmentally Sensitive Areas Index (ESAI) as sub-indices (Table 1), in order to create a new index that will be able to identify spatially degraded-in water and land resources-areas. This new index is the Assessment of Water and Land Resources Degradation Index (WLDI). The methodological steps used a set of indicators, spatial data, and essential GIS spatial analysis functions to assess and map WLDI for Greece. The applied software, throughout the whole process, is ArcGIS 10.8 (ESRI, Redlands, California, CA, USA).

The initial step was gathering data from various databases. In more detail, the climatic parameters were from the National Hellenic Meteorological Service and the National Observatory of Athens [57,58]. Based on these parameters the Standardized Precipitation Index (precipitation), the Aridity Index (precipitation and temperature) and the Rainfall Index (precipitation) were calculated. Then, the transformation from point to spatial distribution was produced by geostatistical methods (Kriging and co-Kriging through ArcGIS 10.8). Data on water demand, water supply, pertinent water infrastructure and drought impacts were gathered from the Water Resources Management Plans of the River Basins of Greece [59]. Impact data have also been acquired from mass media archives, from reduction percentages of the agricultural production for the drought years, and from archive information on various drought impacts and aspects of the corresponding local and national authorities and agencies, all dating from various time intervals. The land-related indicators (Soil Texture, Rock Defragment, Soil Depth, Parent Materials, Drainage and Slope Gradient) were produced from the National Soil Map. Vegetation factors are calculated from CORINE 90s and they related in terms of Fire Risk, the ability to for erosion protection (Erosion Protection) the Drought Resilience, and Plant Cover. Finally, the strategies related to environmental management are classified according to Land Use Intensity and Policy Enforcement.

Table 1. Input Indicators with description and the related values [22,60–64].

Indicators	Description	Value
Soil Texture	L, SCL, SL, LS, CL	1.0
	SC, SiL, SiCL	1.2
	Si, C, SiC	1.6
	S	2.0
Parent Material	Shale, schist, basic, ultra-basic, conglomerates, unconsolidated, clays	1.0
	Marl with natural vegetation	1.7
	Limestone, marble, granite, rhyolite, ignibrite, gneiss, siltstone, sandstone, dolomite marl, pyroclastics	2.0
Rocky fragments (%)	>60	1.0
	20–60	1.3
	<20	2.0
Soil depth (cm)	Deep (>75)	1.0
	Moderate (30–75)	2.0
	Shallow (15–30)	3.0
	Very shallow (<15)	4.0
Drainage	Well drained	1.0
	Imperfectly drained	1.2
	Poorly drained	2.0
Slope (%)	<6	1.0
	6–18	1.2
	18–35	1.5
	>35	2.0
Rainfall (mm/year)	>650	1.0
	280–650	2.0
	<280	4.0
Slope aspect (class)	North, NW, NE, plain	1.0
	South, SW, SE	2.0
Vegetation cover (%)	>40	1.0
	40–10	1.8
	<10	2.0
Fire risk (class)	Bare soils, bedrocks; almonds, orchards, grapevines, olive groves, irrigated annual crops (maize, tobacco, sunflower), horticulture	1.0
	Perennial grasslands, pastures, cereals, annual grasslands, deciduous forests, evergreen forests (with *Quercus ilex*), shrublands, very low vegetated areas	1.3
	Mediterranean maquis	1.6
	Coniferous forests	2.0
Soil erosion protection	vergreen forest (except conifers), mixed Mediterranean maquis, evergreen forests (with *Quercus ilex)*, bedrocks	1.0
	Mediterranean mquis, coniferous forests, perennial grasslands, pastures; olive groves, shrubland	1.3
	Deciduous forests	1.6
	Almonds, orchards	1.8
	Grapevines, annual crops (cereals, maize, rice, oats, barley, grasslands), low vegetated areas, bare ground	2.0
Vegetation resistance to drought	Evergreen forest (except conifers), Mediterranean maquis, evergreen forests (with *Quercus ilex*), bedrocks, bare ground	1.0
	Coniferous and deciduous forests, olive groves	1.2
	Almonds, orchards, grapevines	
	Perennial grasslands, pastures, shrubland	1.7
	Annual crops (annual grassland, cereals, maize, tobacco, sunflower), low vegetated area	2.0

Table 1. *Cont.*

Indicators		Description	Value
Land use intensity	Crop-land	Low land use intensity (LLUI)	1.0
		Medium land use intensity (MLUI)	1.5
		High land use intensity (HLUI)	2.0
	Pasture	ASR < SSR	1.0
		ASR = SSR to 1.5 × SSR)	1.5
		A/S ≥ 1	2.0
	Natu-ral areas	A/S = 0	1.0
		A/S < 1	1.2
		A/S ≥ 1	2.0
	Mining areas	Adequate erosion control measures	1.0
		Moderate control against soil erosion	1.5
		Poor measures against soil erosion	2.0
	Recre-ational areas	A/P < 1	1.0
		1 < A/P < 2.5	1.5
		A/P > 2.5	2.0
Policy Enforcement		Complete (>75% of the area under protection)	1.0
		Partial (25–75% of the area under protection)	1.5
		Incomplete (<25% of the area under protection)	2.0
SPI 6		Wet: ≥1.50	0.0
		Quite Wet: 0.00–1.49	1.0
		Quite Dry: 0.00–−1.49	2.0
		Dry: ≤−1.49	3.0
SPI 12		Wet: ≥1.50	0.0
		Quite Wet: 0.00–1.49	1.0
		Quite Dry: 0.00–−1.49	2.0
		Dry: ≤−1.49	3.0
Water Supply		No Deficits	0.0
		15% Deficits	1.0
		16–50% Deficits	2.0
		>50% Serious Deficits	3.0
Water Demand		No Deficits	0.0
		15% Deficits	1.0
		16–50% Deficits	2.0
		>50% Serious Deficits	3.0
Drought Impacts		None	0.0
		15% Losses	1.0
		16–50% Losses	2.0
		>50% Losses	3.0
Water Resources Infrastructure		Complete	0.0
		15% Deficiency	1.0
		16–50% Deficiency	2.0
		>50% Deficiency	3.0

The second step was the application of the PCA method based on the KMO index for the selected indicators in the final equation. PCA is a technique for reducing the dimensionality of such datasets, increasing interpretability but also at the same time minimizing information loss. In addition, it creates new uncorrelated variables that successively maximize variance. To identify the most important indices, the Kaiser–KMO index was used. KMO statistical index is a comparing tool the magnitudes of the observed correlation coefficients to the magnitudes of the partial correlation coefficients. This index is calculated for all indicators, the values vary from 0.0 to 1.0 and the critical threshold is 0.60 and the ideal is over 0.70 [65–67].

The next step was the sensitivity analysis of WLDI and analysis of the changes in the final values based on the changes in the indicators. The sensitivity analysis of the WLDI results is correlated with the scale range for each indicator. However, these estimations should be independent of the environmental context, and this may reduce the reliability of many sensitivity analyses. Thus, the assessed sensitivity may be observed as the ability to create differences in the model. At this stage, it created the classes of the WLDI [68]. Based on the above results of analyses, the final map of WLDI estimated. Figure 3 presents a conceptual flow chart of the proposed methodology.

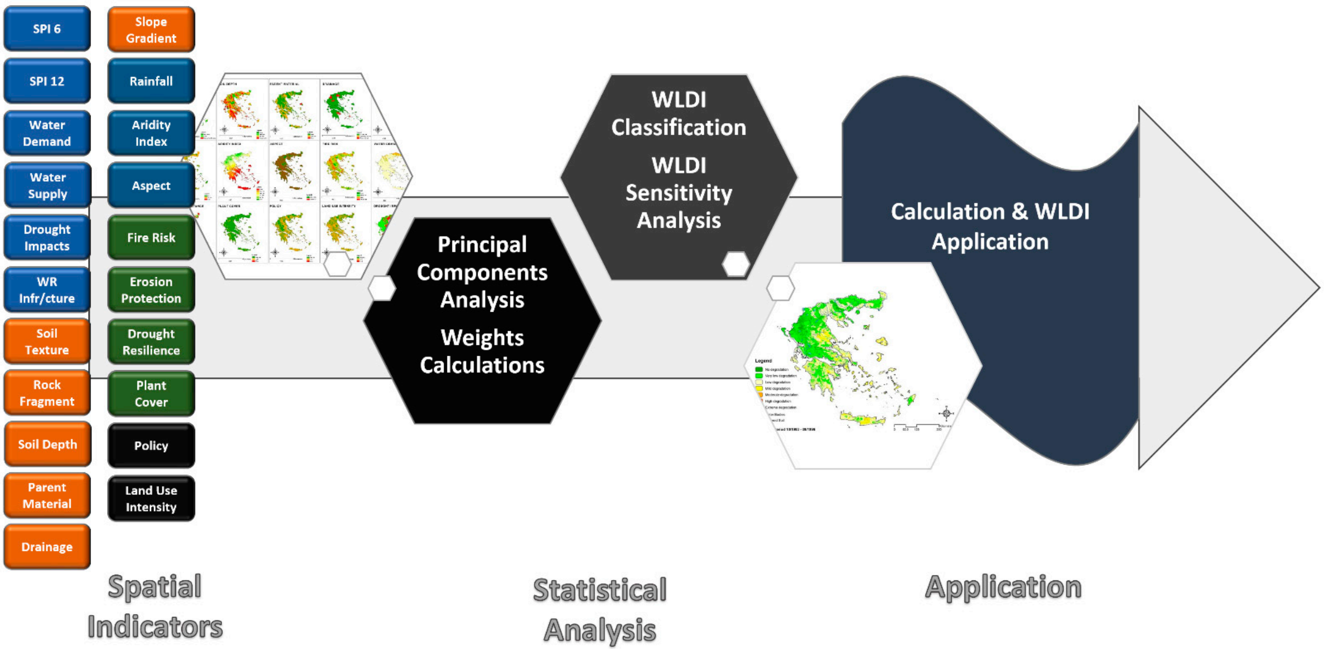

Figure 3. A conceptual model of the proposed methodology.

The SDVI is a composite index developed within the Drought Management Center (DMCSEE project) [22]. SDVI aims to provide a comprehensive measure of drought vulnerability, incorporating all four dimensions of drought: meteorological (SPI6 & SPI12), hydrological (Supply), social, and economic (Demand, Impact and Infrastructure) [22,60,61,67,68].

The ESAI assesses the vulnerability of an area to desertification through the analysis of various parameters such as soil, geology, vegetation, climate, and anthropogenic activities. Each of these parameters is categorized and each factor has weighting factors for each category. The complex index is divided into four categories: soil quality, climate quality, vegetation quality, and management quality. After calculating the four indicators for each quality, each of which consists of 15 sub-indicators, the ESAI is generated. The index is classified into eight classes and grouped into four types. The methodology for calculating vulnerability in desertification was based on the research project MEDALUS, "Mediterranean Desertification and Land Use" [60,69–73].

3. Results

An analysis of all indicators of both procedures (15 of ESAI and 6 of SDVI–Figures 4 and 5) was initially performed with Greece as a study area.

According to the methodology, the examined indicators have been calculated on a spatial scale with spatial resolution equal to 300 m. The calculated indicators based on meteorological data transformed from point to spatial distribution with geostatistical methods (kriging and cokriging). The Land and Management Indicators have estimated based on Soil Unit Sections as created from the National Soil Map. However, the Vegetation and Management Indicators have been produced based on CORINE classes and the classification of each indicator. Water Demand and Supply indicators have developed based on the hydrological basins. Finally, the Drought Impacts define the losses translated in economic values. Based on the PCA and the limitation of the KMO index (0.71), the following 11 indices were selected:

1. Aridity Index,
2. Water Demand,
3. Drought Impacts,
4. Drought Resilience,
5. Infrastructure on Water Resources,
6. Land use intensity,
7. Parent material,
8. Plant cover,
9. Rainfall,
10. Slope, and
11. Soil texture.

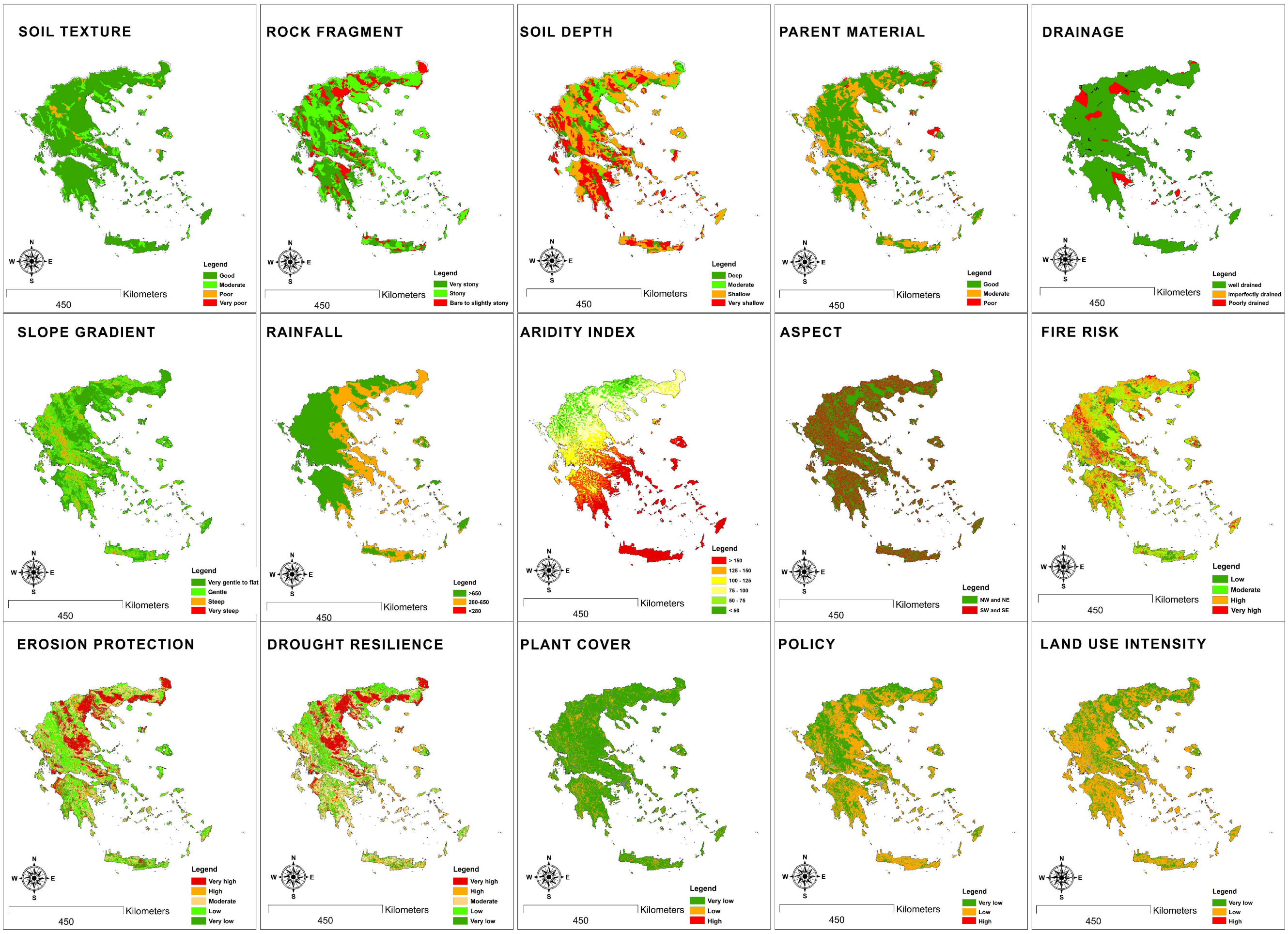

Figure 4. Examined indicators of ESAI for WLDI development and application.

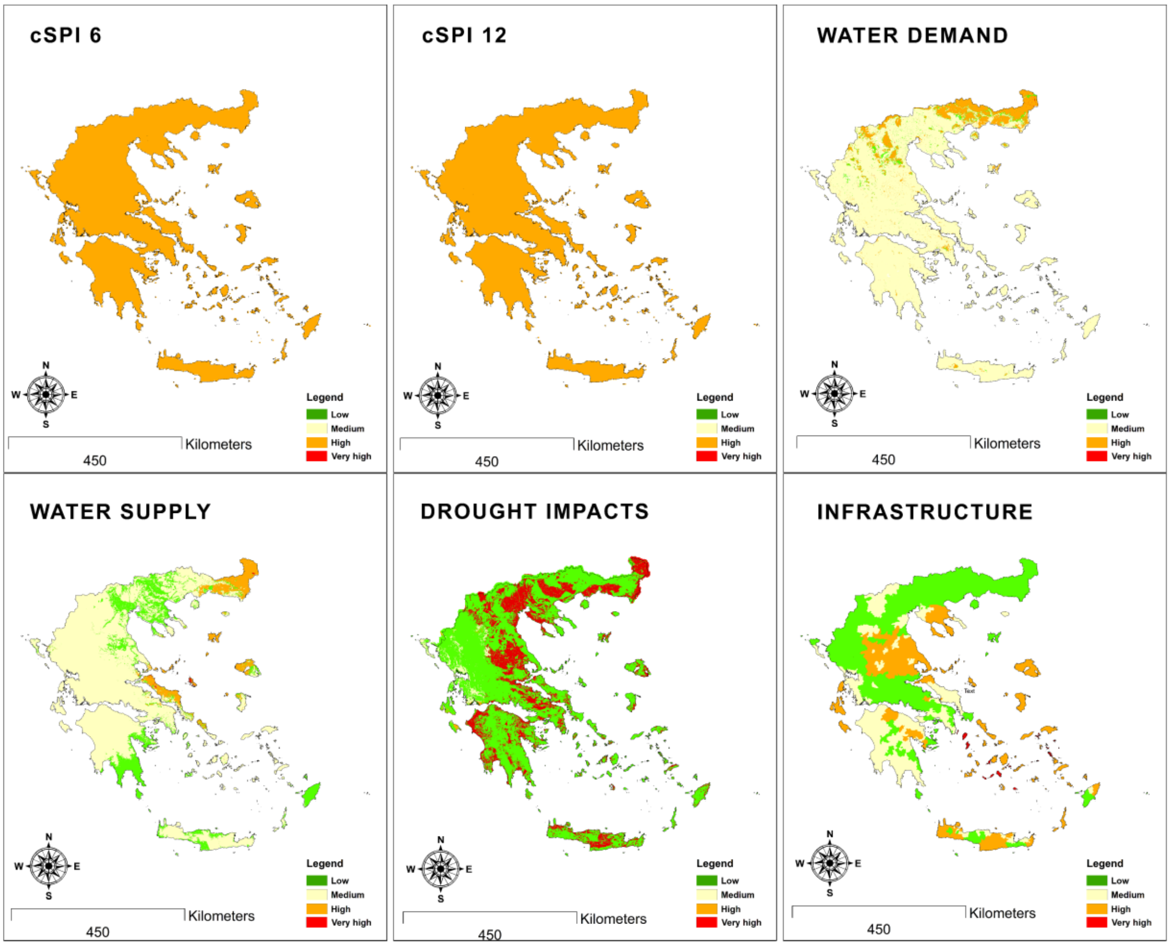

Figure 5. Examined indicators of SDVI for WLDI development and application.

Table 2 shows the correlations of the selected components of PCA between the selected indicators of Water and Land resources Degradation Index. It is noted that all indicators portray a low correlation between them. According to the results of Table 2, there is a relationship between Aridity Index and rainfall, Water Demand and Drought Impacts, Drought resilience and Infrastructure on Water Resources, Land Use intensity, and Plant Cover. These values are low due to fact that the analyses are on a spatial basis.

Table 2. Correlations between all indicators from the two complex indicators.

	Aridity Index	Water Demand	Vegetation Drought Resilience	Drought Impacts	Land Use Intensity	Plant Cover	Rainfall	Soil Texture	Infrastructure on Water Resources	Parent Material	Slope
Aridity Index	1	−0.022	−0.016	−0.024	−0.026	0.005	0.36	0.015	0.013	0.03	−0.06
Water Demand	−0.022	1	−0.048	0.216	−0.002	0.026	−0.079	−0.04	−0.113	−0.039	0.086
Vegetation Drought Resilience	−0.016	−0.048	1	−0.067	0.204	0.117	0.077	−0.003	0.221	0.024	−0.054
Drought Impacts	−0.024	0.216	−0.067	1	−0.008	0.028	−0.085	−0.036	−0.137	−0.078	0.1
Land use intensity	−0.026	−0.002	0.204	−0.008	1	0.51	−0.04	−0.022	−0.001	−0.014	0.005
Plant cover	0.005	0.026	0.117	0.028	0.51	1	−0.045	−0.019	−0.028	−0.007	0.019
Rainfall	0.36	−0.079	0.077	−0.085	−0.04	−0.045	1	0.02	0.05	0.01	−0.076
Soil texture	0.015	−0.04	−0.003	−0.036	−0.022	−0.019	0.02	1	0.007	−0.039	−0.008
Infrastructure on Water Resources,	0.013	−0.113	0.221	−0.137	−0.001	−0.028	0.05	0.007	1	0.062	−0.001
Parent material	0.03	−0.039	0.024	−0.078	−0.014	−0.007	0.01	−0.039	0.062	1	−0.04
Slope	−0.06	0.086	−0.054	0.1	0.005	0.019	−0.076	−0.008	−0.001	−0.04	1

Then, the PCA method was applied using seven components corresponding to 73.06%. This percentage is sufficient for the creation of weights (Figure 6). The final weights are obtained by multiplying the percentage of the variance of each principal component and adding them together.

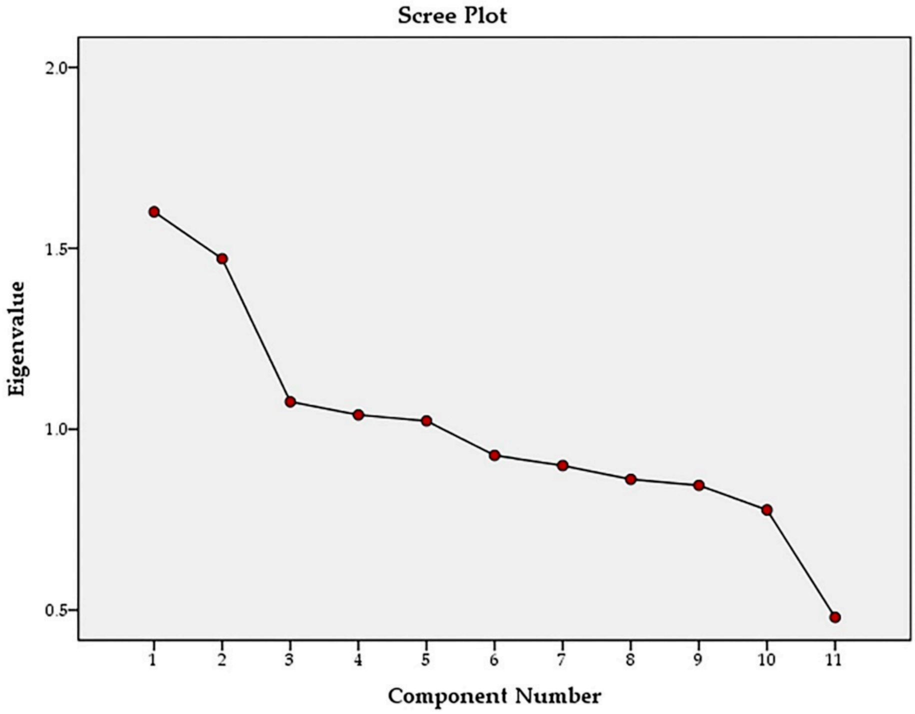

Figure 6. PCA (Scree plot) chart.

Table 3 shows the weights of the new composite Soil and Water resource Degradation Index. The indicators used in the relationship represent climate, soil, vegetation, and anthropogenic interventions. For the climate correspond the indices of Aridity Index, Vegetation Drought Resilience, Rainfall, Land Use Intensity, Drought Impacts, Water Demand, Slope, Parent material, Soil texture, and Infrastructure were used. It is obvious that the indicators used provide information about the environmental conditions of the study area, but also about the way decision-makers manage the natural resources.

Table 3. WLDI weights.

Indicators	Weights
Aridity Index	18.2
Drought Resilience	6.8
Rainfall	7.6
Land Use Intensity	8.0
Drought Impacts	7.2
Water Demand	11.0
Slope	9.4
Parent Material	7.7
Soil Texture	4.1
Infrastructure on Water Resources	9.4
Plant Cover	10.6

Using the data from the SDVI and ESAI indicators, the new composite index was calculated in order to examine the state of the water and land resources of the study area for the specific period. The classification of the produced sub-indices' simulations scores as well as the score of the WLDI to seven (7) classes (Table 4), was developed through

Fisher's Linear Discriminant Analysis, which is a classical method for jointly classification and dimension reduction [68]. The segmentation in seven degradation classes followed the logic of similar indices development in the pertinent literature [22,62,64,74–77].

Table 4. WLDI scaled values of degradation degree [74].

Classes	Values	Description
1	<94	No degradation
2	94–118	Very Low Degradation
3	118–142	Low Degradation
4	142–167	Mild Degradation
5	167–191	Moderate Degradation
6	191–215	High Degradation
7	>215	Extreme Degradation

The results of sensitivity analyses depict that the indicators Aridity, Rainfall, Drought Impacts, and Water Demand are the "key players" of the WDLI. In the first case with random indicators, values were produced using the random numbers, which make numbers derived from a uniform distribution. The sample concerning a spatial application is small but representative to create the classes about the frequency of their occurrence. The composite index was calculated, and the frequencies of the values are depicted in Figure 7 and Table 5. However, it examined three additional scenarios (dry period, land, and vegetation variability) and showed similar patterns of behavior.

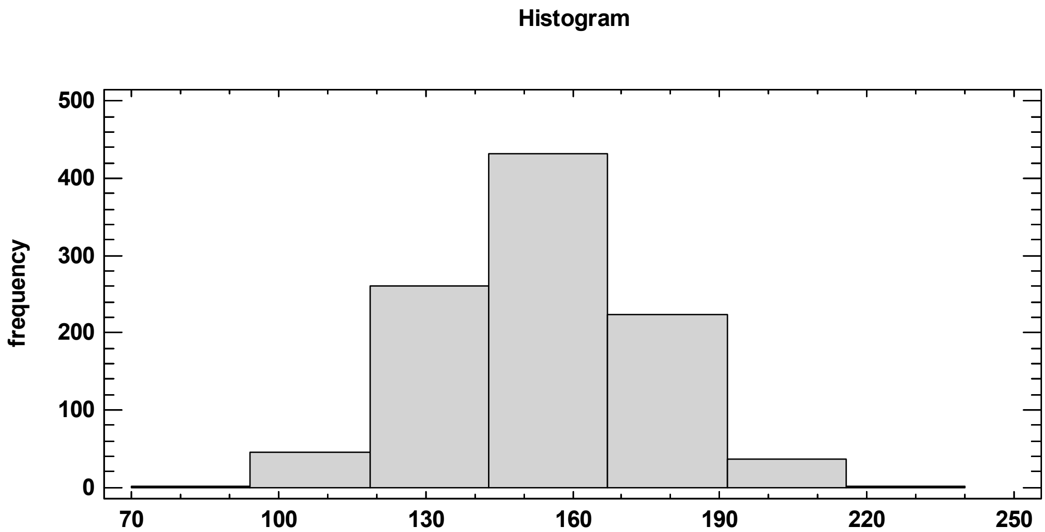

Figure 7. WLDI frequency results of random values.

Table 5. Descriptive statistics of the results of complex indicators.

Descriptive Statistics	WLDI
Mean	118.78
Median	117.75
Std deviation	17.943
Range	121.8
Min	59.7
Max	181.5

The next table (Table 4) shows the descriptive statistics of the sub-indices and the WLDI. The final map of WLDI is shown in Figure 8.

It is observed that the maximum value in the spatial sample value corresponds to the class "moderate" degradation of soil and water resources on a small scale. The areas that present these values are the Thessaly region, Crete, Lesvos, Chios, Kythnos, Kea, Ios and Paros. Areas with the highest agricultural activity show greater degradation in water resources.

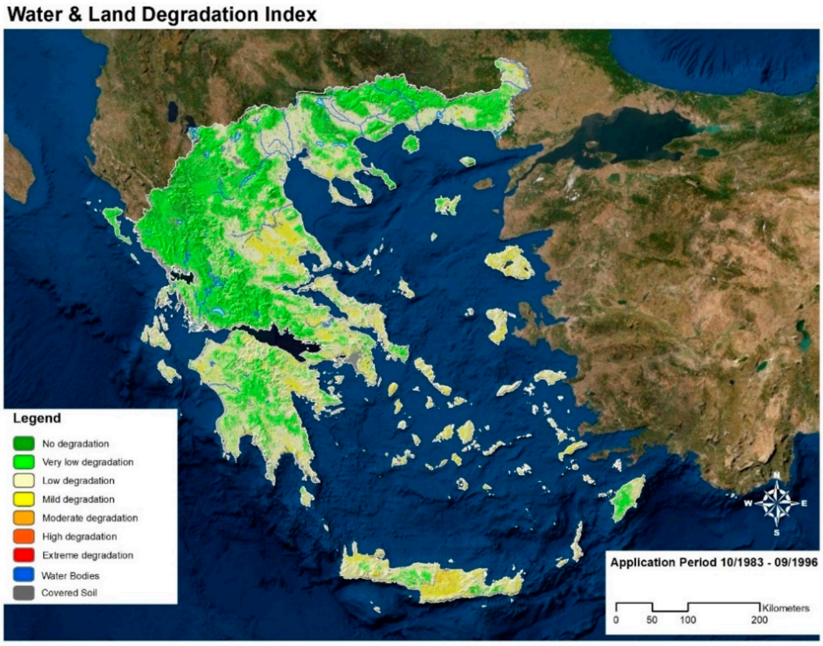

Figure 8. WLDI results for the period October 1983–September 1996.

4. Discussion

Environmental policy-makers face many important problems. They must not ignore the fact that there are continuous problems with water quality due to the excessive use of fertilizers and pesticides, as well as the intrusion of the sea into coastal aquifers. In addition, there is a need to take immediate and indirect measures to soil erosion and desertification. In addition to the aforementioned problems. However, water bodies face a whole host of other related problems, such as:

- Problems of water management and depletion of aquifers.
- Significant delay in surface water exploitation projects, but also projects for the protection of rivers, streams, and watercourses.
- Negative balance of water resources, with significant problems of degradation of aquifers and inadequate and irrational use of water resources, and by not following the guidelines of Directive 2000/60/EC and existing national legislation.
- Pressures on land use and the environment (mainly spatial).
- Degradation of water and soil from their intensive exploitation and the use of pesticides.
- Shortages in infrastructure, such as sewerage networks, wastewater treatment, solid waste treatment, etc.

Another important problem that occurs in Greece as a whole (apart from lack of an extensive network for monitoring of ground and surface systems and a sufficient network of meteorological stations) is related to the provision of good quality data that could effectively contribute to the analysis of problems and the development of solutions for integrated water recourses management. This problem is also observed in the haphazard use of existing technological equipment, such as meteorological stations, since their installation does not usually follow the WMO and FAO protocols.

It is therefore obvious that, for the specific period of the applications of the complex indicators, the water resources managing efforts need more attention concerning the land indicators, especially in areas with intense agricultural holdings, such as Thessaly, Central Macedonia, and the Heraklion prefecture in Crete.

Overall, the spatial application of WLDI for the period from October 1983 to September 1996 shows the following:

Thessaly and Eastern Macedonia are depicted in the medium class which is occupying about 50% in terms of spatial distribution (Larissa, Karditsa, Thessaly, and the region of Evros). This may be attributed to the fact that these areas show intense agricultural activity and, consequently, increased irrigation demand. Eastern Macedonia, Lesbos, and Heraklion of Crete are in the category of moderate class in low spatial distribution. Agriculture is also the main activity in these areas.

On the other hand, Epirus and the rest of Western Greece are the areas with the lowest degradation. These areas have the highest rainfall (e.g., the Pindos Mountain chain), and, at the same time, have no large rural areas (as in Thessaly). In addition, five of the twelve largest dams, as well as the largest reservoir in Greece, were built in this region.

It would seem that the usefulness of WLDI is vital for management as it allows for the precise identification of areas where actions need to take place. This may contribute in avoiding the generalization that usually follows simple indicators or rain data. WLDI may help link rainfall to demand deficits that typically limit and exacerbate water conditions and drought vulnerability. The composite index presented also the possibility of mapping various areas and it followed satisfactorily the fluctuations of vulnerability in Greece concerning the recorded droughts, as well as their impacts.

5. Conclusions

All in all, monitoring WLDI in an area may contribute in the early diagnosis and treatment of water and land degradation in all of its dimensions. However, the data quality should not be overlooked, since if the data themselves are not reliable and in the proper format, there is no point in discussing the quality of the results. Erroneous low rainfall values will result in faulty policies and a decision system resulting in financial discrepancies with respect to local/national budgets. An early drought warning system should also answer the pertinent questions so that it can deliver quality and timely results.

To cope with water and land degradation, the development of a strategy and a master plan for these phenomena is recommended as an effective means of improving the capacity to assess and respond to a variety of hazards using also effective government mechanisms. Pertinent policy objectives indicate also the will of decision-makers for evaluation, mitigation, and impact management programs. In this effort, he objectives of a response plan should be more specific and action oriented. Unanimity between the state, governmental agencies and private and public interest groups is also an important part of the process. The WLDI may help in the early detection of water and land degradation processes and, therefore, in achieving this goal. Furthermore, in combination with forecasting models, a short-term prediction of the phenomenon and its effects may be successfully made so as to allow decision-makers to be better prepared by reducing or minimizing their effects and reaction time to such phenomena. Thus, an important aide in this direction is the promotion and integration of contingency planning though the use of pertinent indicators as the presented one.

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