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RESEARCH ARTICLE

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Detection of areas susceptible to land degradation in Cyprus using remote sensed data and environmental quality indices

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Abstract

This study is an effort to adapt the general principles, methodological tools, and equations of a widely used Mediterranean desertification and land use approach (MEDALUS approach) in order to detect environmental sensitive areas susceptible for land degradation in Cyprus. For this scope, different remote sensed data and products (Landsat multispectral imagery and ASTER Digital Elevation Model) were used as well as demographic information, taken from the Socioeconomic Data and Applications Center. Four quality indices were calculated (Climate Quality Index, Demographic Index, Soil Quality Index, and Vegetation Quality Index) and combined in order to provide at final stage, the Environmental Sensitivity Area Index (ESAI) with which the environmental status is described. The use of remote sensed data of 30-m spatial resolution and the calculation of different indices to extract the environmental stress at regional scale can be considered as innovative characteristics of this study. According to this ESAI, it was found that 9.68% of the Cyprus Island is at environmental risk, strictly related to the land degradation potential. The spatial distribution of the ESAI values shows that the environmental risk is most significant in Paphos district and Limassol, following the Larnaca and the Famagusta districts. Nicosia and Kyrenia districts are found slightly less problematic. In addition, large parts of Troodos Mountain (especially in its low altitudes), which is one of the most vegetated areas of the Island, seem to be at notable environmental stress.

KEYWORDS

Cyprus Island, environmental index, GIS, land degradation, remote sensed data

1 | INTRODUCTION

The land degradation is considered a major problem for the environmental quality and sustainability, affecting many regions worldwide. This phenomenon can be triggered or enhanced by the climatic changes and from the continuous increase of human-induced activities upon land. Among the direct consequences of the land degradation included are the decrease of the vegetation, the loss of the natural fertility, soil erosion, the pollution of water resources, and the extreme weather events driven by the thermal disturbances that are caused from the changes in surface characteristics (Chen, Ma, & Zhao, 2017; J. Gao, Xue, & Wu, 2013; Hammad & Tumeizi, 2012; Omar, Abdi, Glover, & Luukkanen, 2013; Paix, Lanhai, Xi, Ahmed, & Varenyam, 2013; Tang et al., 2016).

Regarding climate change, the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (2014) denotes significant warming trends during the summer season in south-eastern Europe and the Mediterranean along with a decrease of the mean annual precipitation (Christensen & Christensen, 2007; Giannakopoulos et al., 2009). The increasing trend of temperature and the decreasing trend of precipitation can lead gradually to an arid environment in many parts of the Mediterranean region (e.g., X. Gao & Giorgi, 2008; Giorgi, 2006). All these consequences are considered major threats to biodiversity and ecosystems sustainability, extending beyond the local scale. Moreover, human health can be significantly affected by land degradation through water and food-induced diseases and by atmospheric dust from soil erosion and other air pollutants which can cause respiratory diseases (Chivian & Bernstein, 2008; Collins, 2001; Myers et al., 2013; Ostfeld, Keesing, & Eviner, 2008; Speldewinde, 2006).

Many regions around the Mediterranean basin are characterized highly vulnerable regarding the drought due to climatic changes (Cook, Anchukaitis, Touchan, Meko, & Cook, 2016; Giannakopoulos et al., 2009). Additionally, according to the United Nations Convention to Combat Desertification (2010) and the international bibliography (e.g., Behrens, Georgiev, & Carraro, 2010; Camille et al., 2013; Giorgi & Lionello, 2008; Hoerling et al., 2012; Kythreotou & Mesimeris, 2014; Lelieveld et al., 2012), many parts of the Mediterranean are very sensitive to climate changes which, in turn, can intensify the phenomenon of drought and land degradation (e.g., Blondel, Aronson, Bodiou, & Boeuf, 2010; European Environmental Agency, 2015; Evans, 2009; Giorgi, 2006). The greater area of Cyprus is considered one of them, having one of the most severe and long-term drought periods recently (2004–2008), as referred by Zachariadis (2016) and also having the highest water stress level all over Europe (Raso, 2013). Moreover, the continuous increase of population and mainly tourism leads to an increase of water demands (Sofroniou & Bishop, 2014) and urbanization of the study area. Such factors are considered of major importance for evaluating the state and trends of land degradation.

Nevertheless, the land degradation is a multifold issue which is not only affected by the climate change and the population. The shape and the growth rate of the urban fabric, its structure and the population density, the agricultural sector (e.g., types of crops, fertilizers, tools, and methods in the agricultural production), and the livestock (which is frequently linked with overgrazing) are considered worldwide key factors for the environmental status of a region, leading gradually to the land degradation (e.g., Vetter & Bond, 2012; Wang & Batkhishig, 2014; Nkonya, Mirzabaev, & Von Braun, 2015; Kairis, Karavitis, Salvati, Kounalaki, & Kosmas, 2015).

The majority of the key factors for the land degradation are changing in time and space. Nowadays, the contiguous increasing plethora of high-quality spatial data and products with the synergy of the modern polar-orbiting satellite data (having spatial resolution equal or significantly smaller than 30 m) have been already proved essential in the analytic and reliable study of the land degradation, worldwide. Additionally, the tools and the methods of the spatial analyses through geographic information systems are catalytic in studying environmental issues such as land use/land changes, land degradation, and desertification.

The aim of this study is to detect areas vulnerable to land degradation over the whole island of Cyprus and assess their dynamics so that to provide useful informational background for an environmentally sustainable spatial planning and decision making at regional level in Cyprus.

Main novelty of this study can be considered the extensive use of remote sensed data, products, and spectral indices based on Landsat satellite imagery. Moreover, all the final indices are provided in the spatial resolution of 30 m, which coincides with the Landsat images spatial accuracy. It is the first time in the international bibliography where the environmental sensitivity for the whole Cyprus Island is recorded in such detailed spatial resolution. At this point, it is mentioned that the information provided from satellites is not estimations and simulations (such as model outputs) but real multispectral information which is impossible to be recorded for the whole study area with other instrumentation or by using ground data. These data combined with the general principles and formulas of a widely used and reliable methodology (Mediterranean desertification and land use or briefly “MEDALUS” approach) for studying the environmental sensitivity and land degradation constitute a modern and integrated approach to monitor environmental issues. Finally, it has to be noted that the findings of this study are essential, depicting the situation in the island, and they can operate as a driver to a future planning for the protection and conservation of the unique Cyprus landscape and biodiversity.

2 | DATA AND METHODS

2.1 | Area of study

Cyprus is located in the eastern Mediterranean Sea (Figure 1) and is the third largest Mediterranean island after Sardinia and Sicily. It has a total areal extent of 9.251 km^2 and neighbors with Turkey, Syria, Egypt, and Greece. According to the Ministry of Agriculture, Rural Development and Environment of Cyprus, its climate is characterized by generally mild winters and warm summers partly because of the Persian Trough affection. Nevertheless, the land–sea distribution and the local topography can lead to a wide range of temperature differences which vary from 14 °C (coastal areas) to 18 °C (inland areas), annually. The mean annual precipitation varies between 400 and 500 mm, having a tendency to decrease in the near future (e.g., Giannakopoulos, Hadjinicolaou, Kostopoulou, Varotsos, & Zerefos, 2010). Only 5% of the mean annual precipitation occurs during summer. The wet period is mainly between November and March, annually. Water resources and demands is another specific characteristic of the Cyprus Island. There are continuously increasing water demands but limited water resources. These needs are covered mostly by the continuous construction of water dams and reservoirs. Characteristically is referred that nowadays, are used over 100 water dams and surface reservoirs on a daily basis at the Island of Cyprus (Sofroniou & Bishop, 2014), to cover the water demands and refill the diminishing volume of both groundwater and surface water storages.

According to the National Statistical Service of Cyprus, the agricultural sector consists of annual and permanent crops. Annual crops are mainly constituted by cereals, legumes, industrial crops, forage crops, and vegetables, whereas permanent crops are constituted primarily by vineyards, citrus, fruit crops, nuts, olives, and locust trees. The vast majority of the cultivated area in Cyprus is occupied by cereals, forage crops, olives, and locust trees. Another interesting statistic for Cyprus is that less than 25% of its total land area is farmland (one of the smallest percentages across European Union countries) and has the lowest income by agricultural activities among the European Union countries (Coyette & Schenk, 2013). On the other hand, livestock numbers in Cyprus were found consistently higher (across all types of animal) in 2011 than in 1990, with a 4.0% increase

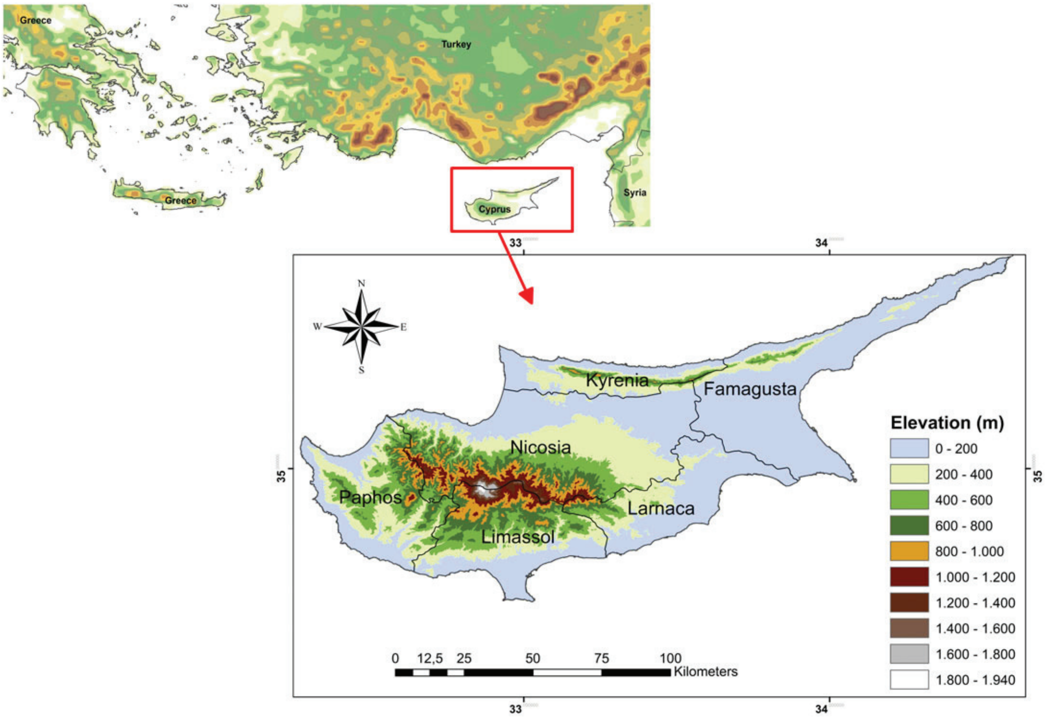

FIGURE 1 The area of study (Cyprus Island). The elevation and the different districts are also shown [Colour figure can be viewed at wileyonlinelibrary.com]

in the number of cattle, a 14.8% increase in the number of sheep, and a 58.0% increase in the number of pigs (Coyette & Schenk, 2013).

The population of Cyprus is increasing steadily during the examined period (2000–2016). More specifically, according to official statistics from the World Bank, during the period between 2000 and 2016, Cyprus had a mean annual population growth rate of 1.35%. Nowadays, the total population of Cyprus is 1,172,071 habitats. Concerning tourism, the National Statistical Service of Cyprus for the period 2000–2016 reports that the average number of tourist arrivals in Cyprus comes up to 2,472,802 persons/year, having a mean annual growth rate of 1.85% in the same period.

Furthermore, it is noteworthy pointing out that Cyprus, although it is very small areal extent in comparison with the whole European continent, hosts 6% of the total number of species (animals and plants) that can be found in all of Europe. A significant number of such species is endemic, and a 10% of them is considered to be threatened at European level (Pino del Carpio, Sánchez, Nieto, & Bilz, 2013).

All the above-mentioned characteristics highlight the environmental importance and, in parallel, the environmental fragility of Cyprus Island, making necessary to carry out analytic studies dealing with land degradation.

2.2 | Datasets and data preprocessing

All the initially collected data for the study area, at first, are organized in order to be used for the calculation of a set of indices, which are analytically described in the following. These data were also used for the production of secondary products, which were necessary for the indices calculation. Analytic description of all the data and products were used is provided in the Tables 1–4. More specifically, all the different datasets were converted (where was needed) at gridded format and resampled at a spatial resolution of 30 m which coincides with the spatial resolution of the Landsat imagery. The Landsat images are core compound for this study because they were used to calculate many secondary products such as land use/land cover (LULC) types of the Cyprus Island (Tables 1–3). Before the extraction of the final image products of the Landsat imagery, a set of basic preprocessing procedures were performed. More analytically, the surface radiance per pixel was first calculated using the mathematic formulas that are referred in the study of Kolios and Stylios (2013). Additionally, the atmospheric correction was performed to all the Landsat image scenes, using the dark object subtraction method (Chavez Jr, 1996; Teillet & Fedosejevs, 1995). At this point, it must be noted that two different image scenes were needed to cover the whole study area in both of the years 2000 and 2016 (the exact dates for the Landsat scenes acquisition are 05/04/2000 and 05/11/2000 and 07/19/2016 and 07/26/2016, respectively). These Landsat image scenes were chosen because they were cloud-free and, in parallel, in short-time distance from one to another regarding their acquisition dates. The time difference between image scenes of the year 2000 and 2016 is slightly larger than 2 months. Nevertheless, from May to July, the amount of precipitation is almost the same and not affect the seasonal vegetation of the island. Also, the vast majority of the vegetation is sclerophyll and evergreen including brushwood, shrubs, and conifers, and there are extended areas of olive trees. All these types of vegetation are not seasonal and are not changing the chlorophyll levels at regional scale, during this period (May to July). Conclusively, in order to eliminate any possible and small seasonal changes in the vegetation profile of Cyprus among the examined image scenes and deteriorate the different illumination conditions which are slightly different at monthly basis, the remote sensing technique of the histogram matching (Lillesand, Kiefer, & Chipman, 2015) was performed.

TABLE 1 The parameters used to calculate the Climate Quality Index

Parameter	Categorization	Score	Description
Precipitation (mm)	<27.4 27.4–38.8 >38.8	2.0 1.5 1.0	Tropical Rainfall Measuring Mission monthly data sets (3B43 satellite product) with 0.25° spatial resolution Date/period: 2000–2015
Aspect	S, S–W, S–E N, N–W, N–E	2.0 1.0	The "Thermal Emission and Reflection Radiometer" (ASTER) Global Digital Elevation Model Version 2 was used to calculate the Aspect (30 m spatial resolution)
Normalized Difference Water Index (NDWI)	0–1	1–2	The ranges of values of the NDWI that represent the different vegetation classes are reclassified according to the sensitivity to land degradation. The following formula (B. C. Gao, 1996) was applied to calculate the NDWI values using the surface radiances of the Landsat channels in the relative spectral regions $NDWI = \frac{R_{NIR} - R_{SWIR}}{R_{NIR} + R_{SWIR}}$ Date/period: 2000 and 2016 image scenes

Note. The score values assigned to parameter values and the basic information about the parameters are also provided.

TABLE 2 The parameters used to calculate the Demographic Index

Parameter	Categorization	Score	Description
Population density (Number of people per km^2)	<20 20–60 60–100 100–150 150–200 >200	1.0 1.2 1.4 1.6 1.8 2.0	Gridded data (1-km spatial resolution) from the Socioeconomic Data and Applications Center, which provide estimates of population density, globally (the initial gridded data resampled at 30 m). Date/period: 2000–2015
Population growth rate (%)	<0 0–10 5–10 10–20 20–30 >30	1.0 1.2 1.4 1.6 1.8 2.0	Gridded data from the Socioeconomic Data and Applications Center, which provide estimates of population density, globally (the initial raster data resampled at 30 m) Date/period: 2000–2015

Note. The score values assigned to parameter values and the basic information about these parameters are also provided.

TABLE 3 The parameters used to calculate the Soil Quality Index

Parameter	Categorization	Score	Description
Soil moisture (kg/m^2) Average 0–10 cm layer	<21.9 21.9–23.1 >23.1	2 1.5 1	Monthly data sets from Global Land Data Assimilation System Version 2 with 0.25° spatial resolution (Bi, Ma, Zheng, & Zeng, 2016; Rodell et al., 2004; Zawadzki & Kędzior, 2014) Date/period: 2000–2015
Slope (°)	<5.0 5.0–15 15–35 >35	1 1.2 1.5 2	The "Thermal Emission and Reflection Radiometer" (ASTER) Global Digital Elevation Model Version 2 was used to calculate the slope (30-m spatial resolution)
Average surface temperature (K)	<291.5 291.5–294.6 >294.6	1 1.5 2	Monthly data sets from Global Land Data Assimilation System Version 2 with 0.25° spatial resolution (Rodell et al., 2004). Date/period: 2000–2015
Bare Soil Index (BSI; normalized)	[0, 1]	[1, 2]	The ranges of values of the BSI, which represent the different vegetation classes, are reclassified according to sensitivity to land degradation. The following formula (Jamalabad & Abkar, 2004) was applied to calculate the BSI values using the surface radiances of the Landsat channels in the relative spectral regions $BSI = \frac{(R_{SWIR} + R_{Red}) - (R_{NIR} + R_{Blue})}{(R_{SWIR} + R_{Red}) + (R_{NIR} + R_{Blue})}$ Date/period: 2000 and 2016 Landsat image scenes

Note. The score values assigned to parameter values and the basic information about the parameters are also provided.

This analysis aims to homogenize the different illumination conditions which can affect the surface radiance of the used channels. As a result, the calculation of Normalized Difference Vegetation Index (NDVI) and every index related to the vegetation was directly comparable among the slightly different acquisition dates of the Landsat imagery. At this point, it is also mentioned that the dates of the year 2016 were

TABLE 4 The parameters used to calculate the Vegetation Quality Index

Parameter	Categorization	Score	Description
Land use/land cover	Urban fabric–road network	1.0	Different classes calculated from the classification procedure conducted using the available channels of Landsat scenes for 2000 and 2016. Different score values were given to each class, according to sensitivity to land degradation.
	High-density vegetation (forested areas conifer & deciduous, oaks, dense areas with fruit & olive trees)	1.2	
	Highly reflective ones (e.g., sandy & limestone areas)	1.4	
	Low vegetation (cultivated areas, pastures, low-to-medium height irrigated crops, grain, and among others)	1.6	
	Sparse vegetation in rocky areas (e.g., shrublands and nonirrigated areas with low and sparse vegetation)	1.8	
	Bare ground and particularly loamy areas with sparse shrubs and low vegetation	2.0	
	Water surface–wetlands	1.0	
Fire risk	Urban fabric–road network	1.0	Different classes calculated from the classification procedure conducted using the available channels of Landsat scenes for 2000 and 2016. Different score values were given to each class, according to sensitivity to land degradation.
	High-density vegetation (forested areas conifer & deciduous, oaks, dense areas with fruit & olive trees)	2.0	
	Highly reflective ones (e.g., sandy & limestone areas)	1.2	
	Low vegetation (cultivated areas, pastures, low-to-medium height irrigated crops, grain, and among others)	1.8	
	Sparse vegetation in rocky areas (e.g., shrublands and nonirrigated areas with low and sparse vegetation)	1.6	
	Bare ground and particularly loamy areas with sparse shrubs and low vegetation	1.4	
	Water surface–wetlands	1.0	
Drought resistance	Urban fabric–road network	1.0	Different classes calculated from the classification procedure conducted using the available channels of Landsat scenes for 2000 and 2016. Different score values were given to each class, according to sensitivity to land degradation.
	High-density vegetation (forested areas conifer & deciduous, oaks, dense areas with fruit & olive trees)	1.2	
	Highly reflective ones (e.g., sandy & limestone areas)	1.6	
	Low vegetation (cultivated areas, pastures, low-to-medium height irrigated crops, grain, and among others)	1.8	
	Sparse vegetation in rocky areas (e.g., shrublands and nonirrigated areas with low and sparse vegetation)	1.4	
	Bare ground and particularly loamy areas with sparse shrubs and low vegetation	1.2	
	Water surface–wetlands	1.0	
NDVI (normalized)	[−1, 0,1)	1.0	The values of the NDVI, which represent the different vegetation classes, are reclassified according to sensitivity to land degradation. The following formula (e.g., Roderick, Smith, & Lodwick, 1996; Rouse, Haas, Schell, & Deering, 1974) was applied to calculate the NDVI values using the surface radiances of the Landsat channels in the relative spectral regions $NDVI = \frac{R_{NIR} - R_{Red}}{R_{NIR} + R_{Red}}$ Date/period: 2000 and 2016 Landsat image scenes
	[0,1–0,2)	1.8	
	[0,2–0,4)	1.6	
	[0,4–0,6)	1.4	
	[0,6–1]	1.2	

Note. The score values assigned to parameter values and the basic information about the parameters are also provided. NDVI: Normalized Difference Vegetation Index.

selected to be after the large forest fire broken out from June 19 to 22 in Cyprus, in the Troodos Mountain. Thus, the multispectral satellite image of the year is considered as one of the most representative image scenes throughout the year 2016, in terms of that it is including the most recent large-scale changes in land surface of Cyprus Island. Next, mosaics of every used channel were created, and a set of indices (Normalized Difference Water Index [NDWI], Bare Soil Index, and NDVI) were calculated to provide additional information. Finally, a supervised classification procedure was performed in order to categorize different LULC types of the Cyprus Island. The used Landsat 7 and 8 images concern the same channels in the visible, near infrared, and shortwave spectral wavelengths (channel codes for the Enhanced Thematic Mapper Plus “ETM+”: 1, 2, 3, 4, 5, 7, and Operational Land Imager “OLI”: 2, 3, 4, 5, 6, and 7). The overall classification accuracy was achieved using the support vector machine classifier and is 92.98% for the classified image of the year 2000 and 93.05% for the classified image of the year 2016. It is noteworthy to point out that different classifiers were tested regarding their overall accuracy, but the support vector machine classifier provided the highest overall accuracy. The high accuracy of this classifier is also referred in many other studies (e.g., Kolios & Stylios, 2013; Petropoulos, Kontoes, & Keramitsoglou, 2011; Srivastava, Han, Rico-Ramirez, Bray, & Islam, 2012). The number and the class types of the classification procedures are given analytically in Table 4. At this point, it is noteworthy to be mentioned that by using Landsat imagery, we manage to produce LULC maps for the years 2000 and 2016, providing fully updated information for the scopes of the study at the spatial resolution of 30 m. This spatial resolution can be considered suitable for the detailed mapping of the study area and the extraction of useful conclusions.

2.3 | Environmental sensitivity

As the exclusive scope of the study is to detect susceptible areas to land degradation, the analytic calculation of the Environmentally

Sensitive Areas Index (ESAI) was chosen to depict such areas across the study area. The use of the ESAI to depict environmental sensitive areas and thus susceptible to land degradation is considered efficient, well-tested ,and has been already used in several similar studies (e.g., Contandor, Schnabel, Gutierrez, & Fernandez, 2009; Bouabid, Rouchdi, Badraoui, Diab, & Louafi, 2010; Parvari, Pahlavanravi, Nia, Dehvari, & Parvari, 2011; Salvati & Bajocco, 2011; Jafari & Bakhshandehmehr, 2013; Symeonakis, Koukoulas, & Panagopoulos, 2014; Vieira et al., 2015). Furthermore, the use of the ESAI except for its reliability, especially at regional scales, is performed for the first time in the entire Cyprus Island. The ESAI was also chosen because the computations of this method are not affected by the number of data layers used in every quality index (QI) at the first level; meaning that the importance of a QI is not determined by the number of data layers used but according to their relevance to the environmental sensitivity (Basso et al., 2000). It is noted that the whole methodology used to depict susceptible areas to land degradation in this study was based on general principles of the MEDALUS methodology, proposed by Kosmas, Kirkby, & Geeson, 1999, where different types of environmental indicators were used. All these indicators are grouped into a final index representing the possible vulnerable areas for land degradation. The final index, as abovementioned, is called ESAI. The Equations (1) and (2), describe mathematically the calculation of the used indices (indicators):

$$QI_{ij} = \left(V_{1ij} \times V_{2ij} \times \ldots \times V_{nij}\right)^{\frac{1}{n}}, \tag{1}$$

where QI_{ij} represents pixel values of the QI, V_{nij} is the score value of a pixel in the position ("*i*, *j*") regarding the reclassified parameter, and "*n*" is the number of the used parameters define each QI (Tables 1–4). It is noted that the range of the score values represents the level of the environmental sensitivity and varies from 1 (*minor sensitivity*) to 2 (*major sensitivity*), according to the MEDALUS methodological approach.

$$ESAI_{ij} = \left(QI_{1ij} \times QI_{2ij} \times \ldots \times QI_{nij}\right)^{\frac{1}{n}}, \tag{2}$$

where $ESAI_{ij}$ is the pixel value of the final index, whereas QI_{nij} represents pixel values of each of the defined QIs, and "*n*" is the number of the QIs were used to calculate the ESAI.

According to the availability of spatial data and the specific characteristics of the study area, four different categories of environmental indices were defined. More specifically, four indices (indicators) are chosen for the calculation of the ESAI in Cyprus, based on the Equations (1) and (2). These indices are named as Climate Quality Index (CQI), Demographic Index (DI), Soil Quality Index (SQI), and Vegetation Quality Index (VQI). Similar indices and parameters were used in other relative studies (e.g., Parvari et al., 2011; Sepehr, Zucca, & Nowjavan, 2014; Symeonakis et al., 2014; Trotta, Menegoni, Massimo, Frattarelli, & Iannetta, 2014; Vieira et al., 2015). More specifically, four parameters are chosen to represent the CQI. These parameters are listed in Table 1 and include the precipitation, the aspect, and the NDWI as proposed by B. C. Gao (1996) which is considered a drought sensitive index (Ceccato, Flasse, & Gregoire, 2002; Gu, Brown, Verdin, & Wardlow, 2007). Table 1 provides the score values which are linked to the different ranges of values for each parameter and a short description about the data sets used. The population density and the population growth rate (Table 2) were used to define the DI. The spatial distribution of the index values for the years 2000 and 2016 and their difference values (at pixel basis) can be seen in Figure 2. At this point, it is mentioned that the population data are estimates of population density provided from a data center in NASA's Earth Observing System Data and Information System which is called Socioeconomic Data and Applications Center (SEDAC). These datasets are widely used, worldwide, and considered of satisfactory accuracy. The SQI was calculated using the score values of four parameters (Table 3). The results of the SQI values in the years 2000 and 2016 can be seen in Figure 3 and Table 5. The VQI was calculated using the score values of four different parameters that are provided in Table 4.

3 | RESULTS AND DISCUSSION

In this study, we have used, as abovementioned, the ESAI index to detect and highlight vulnerable areas to land degradation all over the Cyprus Island. As a consequence, in following, the results of every index which used to calculate the ESAI (Figures 1–3) and the ESAI spatial variations in the period 2000–2016 (Figure 5) are described.

3.1 | Climate Quality Index

The image products of the CQI can be seen in Figure 2, highlighting the climatic profile for Cyprus in the years 2000 and 2016. The range of values in these image products was categorized into four classes, equal in range, representing different levels of sensitivity (Figure 2 and Table 5). The image difference (CQI_{2016} − CQI_{2000}) is also provided in order to highlight areas of increasing climatic sensitiveness (Figure 2c). Figure 2c makes apparent that large areas of the Cyprus Island have positive values in the image of difference indicating a slight (small positive values) but notable increase of climate stress across the study area. It is mentioned that significant role for the spatial distribution of the CQI is playing the NDWI. The precipitation and the aspect have slightly smooth spatial variations, but the abrupt changes of NDWI which depict the increased water stress between 2000 and 2016 affect the CQI changes (Figure 2c) significantly. This is more evident especially in agricultural areas such as the inland of Paphos and Kyrenia, in the greater suburbs of Nicosia, and around the borders between Larnaca and Famagusta districts.

Additionally, it is noteworthy pointing out that a little less than half of the total area of study belongs to the "high" climatic sensitivity class (46.38% and 45.59% in the years 2000 and 2016, respectively), as it is defined in Table 5. Such results are in general accordance with the climatic conditions and scenarios regarding Cyprus and the eastern Mediterranean which report a continuous decrease in precipitation and increase of air temperature, leading gradually to a dry and arid environment (e.g., Bruggeman et al., 2011; Giannakopoulos et al., 2009; Hochstrat & Kazner, 2009; Lelieveld et al., 2012; Zachariadis, 2016). In other words, the long-term climatic tendencies in the greater area are in accordance with the results of the CQI. The areas where the highest CQI values are located include the coastal area of

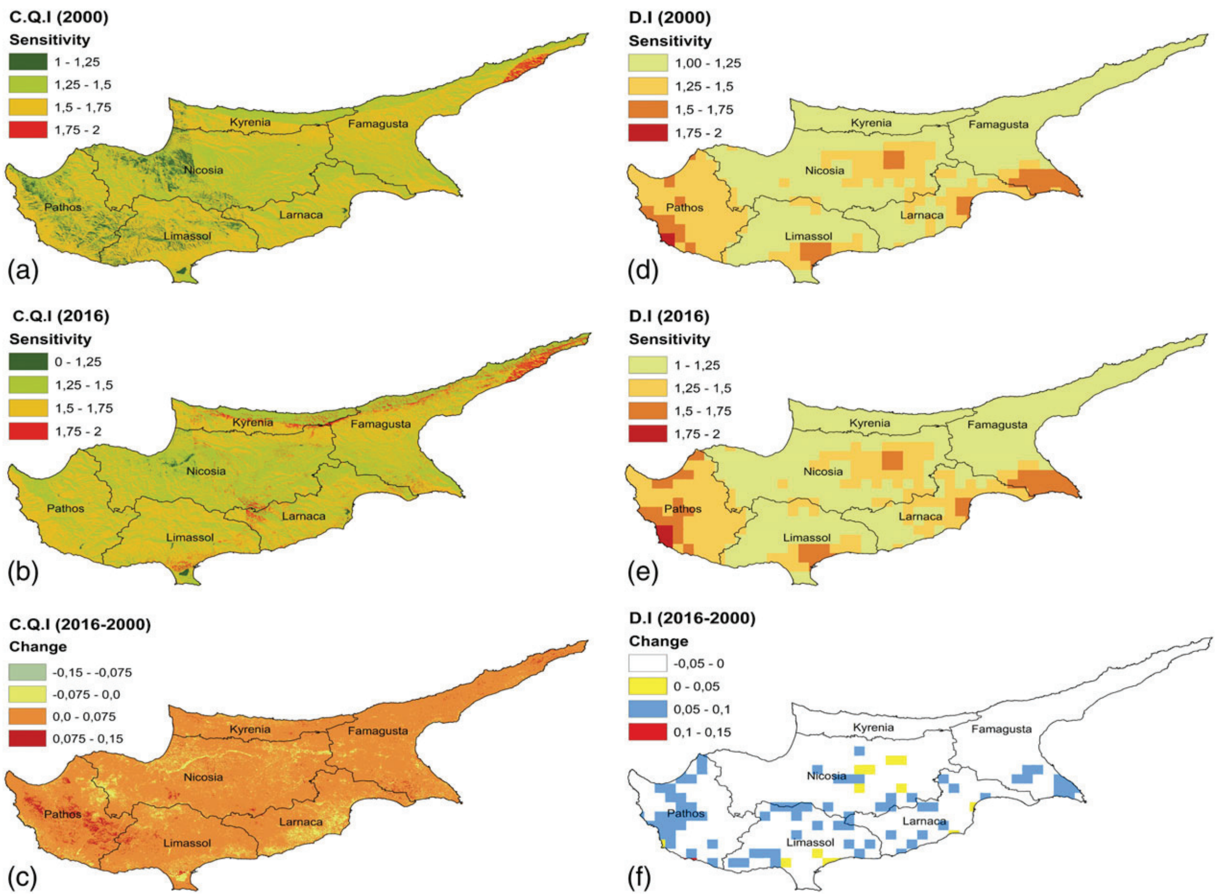

FIGURE 2 Climate Quality Index (CQI) spatial distribution in (a) 2000 and (b) 2016. The image difference is also shown (c). Demographic Index (DI) spatial distribution in (d) 2000 and (e) 2016 and their image difference (f). The four different colored ranges of values represent four sensitivity stages ("very low," "low," "high," and "very high" from the minimum to the maximum range of values) [Colour figure can be viewed at wileyonlinelibrary.com]

Limassol, a significant part of Larnaca, the mountain ridge of Kyrenia, and the northern parts of Famagusta district. In the year 2016 (Figure 2b), these areas are more spatially extended as compared with the same areas in the year 2000 (Figure 2a), depicting the most climatic sensitive areas on the Island.

3.2 | Demographic Index

The spatial distribution of the index values for the years 2000 and 2016 and their difference values (at pixel basis) can be seen in Figure 2. At this point, it is mentioned that the population data are estimates of population density provided from a data center in NASA's Earth Observing System Data and Information System, which is called SEDAC. These datasets are widely used, worldwide, and considered of satisfactory accuracy.

As can be seen in Table 5 and Figure 2d,e, there is a small increasing trend in the DI values in many parts of the study area which is due to the increasing growth rate of the population. More specifically, the population is slightly increasing but is concentrating in parallel around the coastal parts of Cyprus and around the large cities. This is a possible reason that could cause an increase in the DI values (where exist). Indeed, small increase of the DI is depicted in the southwestern parts of Famagusta and in central Nicosia (Figure 2f). An increase of the DI values is also noted especially around the coastal and the most touristic areas of the Island which are located at the coastal zone of the southern and western part of Cyprus (Paphos, Limassol, and Larnaca). From the Figure 2f, it is also evident that the districts of Kyrenia and Famagusta as well as notable parts of Nicosia present a slight decrease of the DI values. A significant factor which contributes to the decrease of the DI values can be considered the emigration (the mean number of emigrants during the period 2000–2014 is 6,787 people according to the Statistical Service of Cyprus). The emigration may be partly owed to the recent economic crisis in Cyprus which caused reduction of jobs, salaries, working opportunities, and perspectives.

3.3 | Soil Quality Index

In the Figure 3a–c, can be seen that the most sensitive areas according to the SQI (and thus the most vulnerable to soil erosion) are located in Paphos district. Large areas with high sensitivity to soil quality are also found in inland of Larnaca and Famagusta districts in both the years 2000 and 2016 (Figure 3a,b). An additional notable result from Figure 3 is that in the year 2016, high values of the SQI exist along the Troodos and Kerynia mountain ridges in opposition to the year 2000. According to the quantitative statistics of Table 5, there is a shift in the sensitivity level from the low values (in the year 2000) to the high ones (year 2016). In other words, the "very low" and "low"

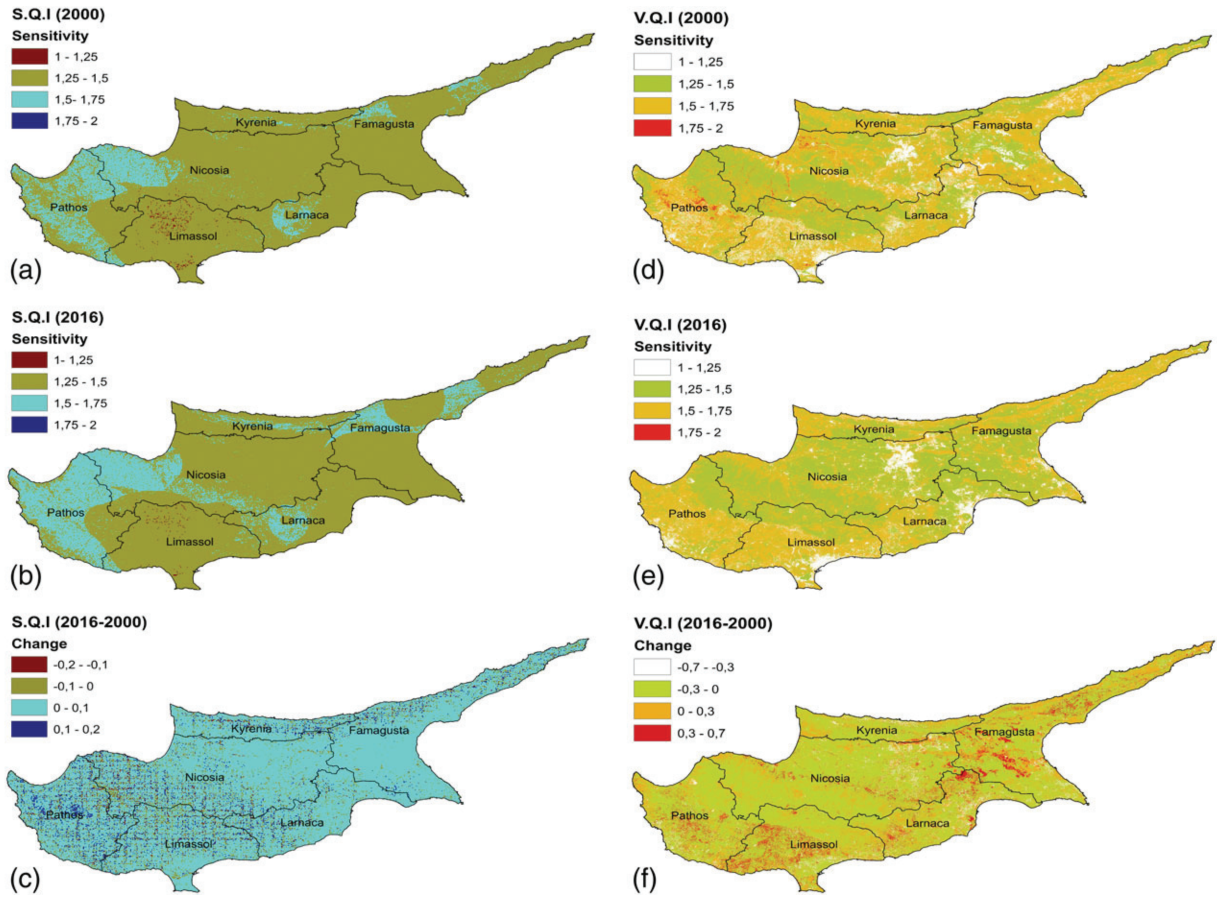

FIGURE 3 Soil Quality Index (SQI) spatial distribution in (a) 2000 and (b) 2016. The image difference is also shown (c). Vegetation Quality Index (VQI) spatial distribution in (d) 2000 and (e) 2016 and their image difference (f). The four different colored ranges of values represent four sensitivity stages ("very low," "low," "high," and "very high" from the minimum to the maximum range of values) [Colour figure can be viewed at wileyonlinelibrary.com]

TABLE 5 Percentage of total area of Cyprus in different score value classes for environmental sensitivity

Quality index	Class (Sensitivity)	Area 2000 (%)	Area 2016 (%)	Class difference (%) (2016–2000)
Climate Quality Index	1.0–1.25 (very low)	8.31	2.13	−6.18
	1.26–1.5 (low)	44.78	51.18	6.4
	1.51–1.75 (high)	46.38	45.59	−0.79
	1.76–2.0 (very high)	0.53	1.1	0.57
Demographic Index	1.0–1.25 (very low)	64.58	62.68	−1.9
	1.26–1.5 (low)	28.17	28.47	0.3
	1.51–1.75 (high)	6.95	8.25	1.3
	1.76–2.0 (very high)	0.3	0.6	0.3
Soil Quality Index	1.0–1.25 (very low)	0.44	0.16	−0.28
	1.26–1.5 (low)	85.39	78.53	−6.86
	1.51–1.75 (high)	14.17	21.31	7.14
	1.76–2.0 (very high)	0	0	0
Vegetation Quality Index	1.0–1.25 (very low)	11.06	8.72	−2.34
	1.26–1.5 (low)	43.12	51.5	8.38
	1.51–1.75 (high)	45.18	39.78	−5.4
	1.76–2.0 (very high)	0.64	0	−0.64

Note. The column "class difference" refers to the areal difference considering the range of values in each class as a single value.

sensitivity levels decreased 0.28% and 6.86%, respectively, whereas the high sensitivity class increased 7.14%. A notable contribution to these changes has mainly the slope spatial variations and the BSI. More specifically, the slope values are depicting abrupt changes in the mountainous regions and mainly around Troodos Mountain that comprises a significant part of the inland Paphos district. The BSI values are also have increased values in 2016 compared with the relative ones of 2000. This is especially evident in agricultural areas that is consistent with the significant decrease of the agricultural sector and the parallel increase of livestock in Cyprus (Coyette & Schenk, 2013). These factors can increase the total surface of the bare soil and consequently can increase the signs of land degradation (high SQI values).

Conclusively, according to the spatial distribution of the SQI values, it can be said that the largest part of Cyprus is suffering from a gradually increasing soil sensitivity which is especially evident in Paphos, but it can also be depicted, dispersed all over the Island (Figure 3c).

3.4 | Vegetation Quality Index

The results of the VQI values in the years 2000 and 2016 can be seen in the Figure 3d,e and Table 5. The VQI presents a total increase of almost 11% for the very low and low classes (Table 5), and there is a total decrease of 6% in the other two classes which represent the high and "very high" sensitivity. The most influential factors are the LULC changes and the NDVI (Table 4) because it was found to have the largest variations values spatially and temporarily and the highest values among all the other parameters which were used to calculate the VQI. The highest values (score values of sensitivity) of these two parameters are included mainly in the agricultural areas of Paphos, Larnaca, and Famagusta. This is consistent with the significant decrease of the agricultural sector and, in parallel, a notable increase of livestock in Cyprus (Coyette & Schenk, 2013). Indeed, the parallel reduction of the total cultivated area and the increasing livestock can reduce vegetation cover and gradually lead to land degradation.

The image difference of the VQI (Figure 3f), which is referred to the differences in actual VQI values at pixel basis, is considered indicative of the spatial distribution and the size of VQI changes. From this figure, it can be seen that highly positive difference values are mainly located in central Paphos, at the western part of Limassol, and at the northern part of Larnaca. In these districts, there are also dispersed areas with highly positive difference of the VQI values in many of their coastal parts. Nevertheless, the most extended areas with highly positive difference of the VQI values are located in Famagusta district. Regarding Kerynia, it is the district with the smaller changes of the VQI values, whereas in Nicosia, the majority of these areas are mainly located along the edges of the Troodos Mountain. Regarding the coastal areas of Paphos, Limassol, and Larnaca, a major factor of such changes can be considered the continuous development of the touristic sector which can lead to LULC changes, urbanizing gradually these areas. This factor is consistent with the parallel reduction (or abandonment) of the agricultural production and the movement of the population around the coastal areas, which can lead partly to a restoration of vegetation, inland. The existence of water dams may also contribute to the decrease of sensitivity (vegetation restoration) which is noted in many inland parts of the study area, due to the improvement of water management and availability. In reference with the increase of sensitivity in Troodos Mountain, the most influential factor can be considered the forest fires and the LULC changes which are caused especially during the construction of the increase of the number of water dams in the greater area after 2000 (Evangelidou, 2011).

3.5 | Environmental Sensitivity Area Index

The ESAI was calculated using the score values of four indices mentioned before, using the Equation (2). Figure 4 represents schematically, how the ESAI was calculated.

In Figure 5, the final image result of the ESAI for the years 2000 and 2016 (Figure 5a and Figure 5b, respectively) and their image difference (Figure 5c) can be seen. As a general result, it can be mentioned that the susceptible areas for land degradation are dispersed all over the study area but mainly in its southern part. Indeed, the highest values of the ESAI, which represent areas highly vulnerable to land degradation, can be seen in both of the years 2000 and 2016 mainly in the district of Paphos, in the coastal areas of Limassol, in the largest part of Larnaca district, in the greater suburbs of Nicosia, and in the southern part of Famagusta. Comparing the images in the two examined years (Figure 5a,b), it is also evident that practically, areas of very high sensitivity (values of the ESAI above the threshold value 1.75) do not exist. Nevertheless, there are large areas which belong to the high sensitivity class (values of the ESAI between 1.5 and 1.75) in both the

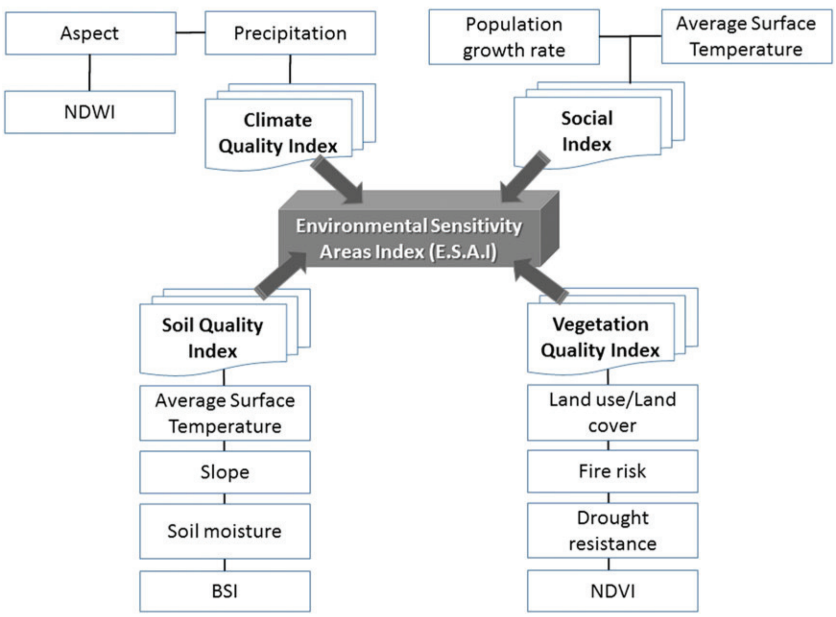

FIGURE 4 Schematic flowchart showing determination of the ESAI. BSI: Bare Soil Index; NDVI: Normalized Difference Vegetation Index; NDWI: Normalized Difference Water Index [Colour figure can be viewed at wileyonlinelibrary.com]

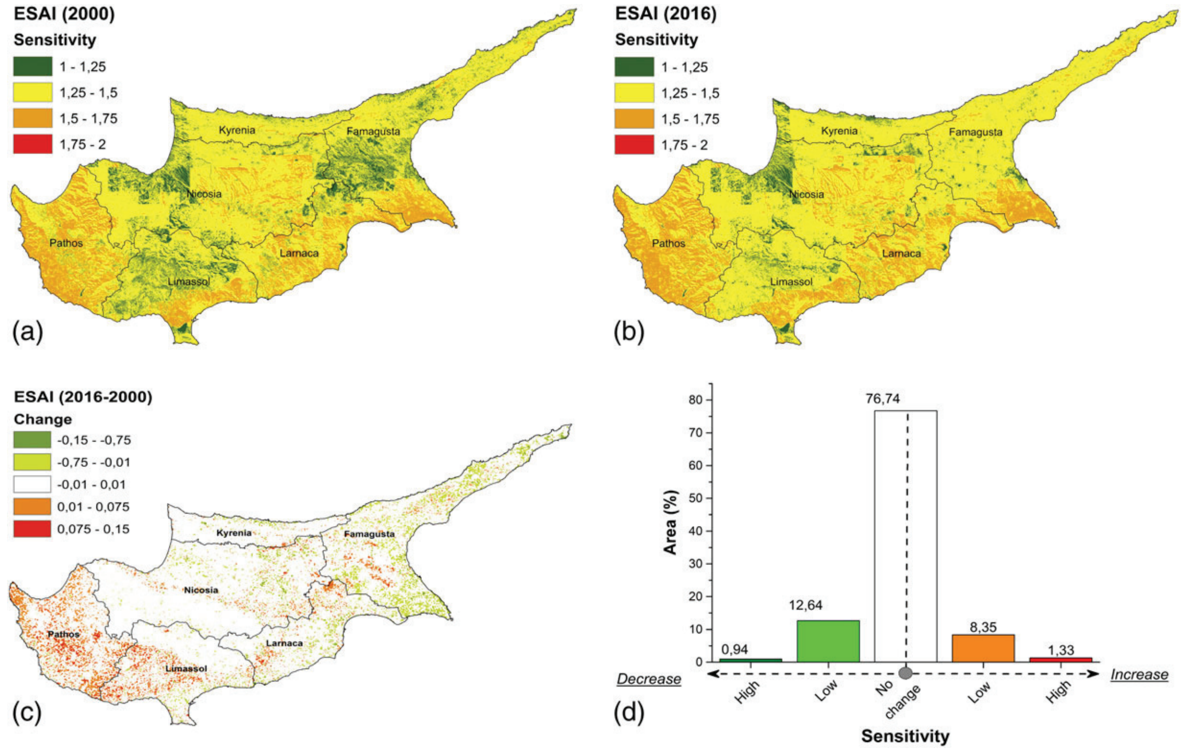

FIGURE 5 Environmental Sensitivity Area Index (ESAI) spatial distribution in 2000 and 2016. The image difference is also shown. The four different colored ranges of values represent four sensitivity stages ("high decrease," "low decrease," "low increase," and "high increase" from the minimum to the maximum range of values) [Colour figure can be viewed at wileyonlinelibrary.com]

examined years (Figure 5). These areas include a large area between Paphos City and Coral Bay, the greater area of Limassol and Episkopi Bay, the greater area of Larnaca, the southern part of Famagusta, and the central lowland part of Nicosia.

Although the ESAI score values are found to be high in specific areas, in both of the examined years, the image difference of the ESAI (Figure 5c) provides slightly different results because we have chosen to highlight only the most important values of difference and not the negligible ones. More specifically, the small ESAI values of difference are mostly owed to the roundings during the calculation procedures. Thus, only the ESAI score values of difference, larger ±0.01, are considered as notable and satisfactory enough to characterize areas susceptible to land degradation (Figure 5c). According to this approach, 76.74% of the total area of Cyprus was found practically unchanged during the examined period (white colored areas in the Figure 5c). Nevertheless, 9.68% of the total surface of Cyprus was found to have an increase of the sensitivity, with 1.33% (Figure 5d) to be at the highest levels of increase regarding the risk sensitivity to land degradation. The areas of positive difference of the ESAI and, consequently, of increasing vulnerability to land degradation are located mainly in Paphos district and in the central and western part of Limassol around the lowest parts of Troodos mountain ridge. Notable areas of positive ESAI difference values were also found in the western and the northeastern part of Larnaca district as well as in the central part of Famagusta. In Nicosia, the increase of sensitivity is dispersed along the edges of the Troodos Mountain where the forested areas gradually diminish, and the livestock/agricultural activities are usually present. Also, small semimountainous areas with positive ESAI difference values are located in the borderline which separates Kyrenia and Nicosia districts (Figure 5c). In Kyrenia, although the construction sector bloom in the recent years, the sensitivity to land degradation seems to be unchanged in the largest part of the district. Also, the expansion of urban fabric seems to have no significant effect on the land degradation of this region. This may be owed to the smooth development (absence of dense urban fabric at least in the majority of areas with bloom of construction sector), the construction of green places, and the development of organized and irrigated cultivation areas which may have been gradually contributed to the decrease of the land degradation signs. In Famagusta, except its central part, where positive values of the ESAI difference exist, there are large parts with negative values which depict a decrease in the sensitivity risk. This may be owed to changes in the types of cultivation but mainly to the abandonment of the agriculture. Also, the economic situation of people in this district may enforce many of them to immigrate to other places of the island, where there are many job opportunities (especially tourism related). These factors may gradually lead the people to abandon the agriculture and the livestock which in turn decrease the risk sensitivity to the land degradation in this district.

Another interesting finding of Figure 5c,d is that the 13.58% of the total study area presents negative ESAI difference values. This means that the 13.58% of the whole Cyprus Island present a decrease of in the risk sensitivity regarding land degradation. The areas where these score values exist are mainly cultivated areas, and more specifically, they are located in the poorest parts of the island. This finding can be owed to the existence of a huge number of water dams and reservoirs which can support arable farming and irrigation processes. Furthermore, the gradual restoration of burnt areas of the year 2000

($3.34\ km^2$ burnt areas) can contribute to the existence of negative values of the ESAI difference values. Also, important can be considered the contiguous increase of tourism Sector. Such increase, usually enhances the tourism-related jobs, making in parallel the people to abandon the land cultivation which in turn can gradually decrease the risk sensitivity of land degradation due to agriculture sector.

4 | CONCLUSIONS

This study constitutes an effort to detect and evaluate the current environmental status of Cyprus and to identify susceptible areas for land degradation using exclusively remote sensed data and products. The initial datasets were preprocessed and used to produce a series of quality indices to identify areas at environmental risk and, consequently, at potential land degradation. The general concept of MEDALUS approach was performed for this scope, which is considered reliable at least for regional scale studies and is widely used nowadays.

More specifically, four indices (indicators) were calculated (CQI, DI, VQI, and SQI) and analyzed (Figures 2 and 3 and Table 5). Finally, the ESAI was computed for both the epochs of interest (Figure 5). The use of the ESAI considers a set of many different parameters, grouped in different types of indices (Figure 4). All these parameters are equally weighted which is important to highlight the most influential factors for the environmental quality over Cyprus at regional level. These characteristics provide a multidimensional approach which is useful to study the role of specific parameters in the environmental quality of a region.

Evaluating the environmental indices, the CQI reveals a general increase in its values which constitute a notable contribution of climatic factors in the environmental vulnerability (Table 5). The areas where the most abrupt changes, regarding the CQI, took place are located mainly in Paphos and Limassol as well as in disperse areas in the southern and northern parts of Famagusta district.

The DI shows a small increase especially around the most urbanized districts of Cyprus (Figure 2). This increase can be linked with the population shift to the coastal zone and the expanding of the touristic and commercial sector in the coastal areas, which increase population growth around coastal cities, but on the other hand, there is a reduction of the agricultural production and population, mainly in inland parts of the study area. Based on these observations, it is depicted environmental stress in coastal areas according to the LULC changes and restoration of the vegetation cover in the areas where the population is decreasing.

Concerning the SQI, high percentage of the total area of study was found to be environmentally sensitive and consequently characterized as susceptible to land degradation, in terms of our analysis (Table 5).

About the VQI, the highest values of this index are located mainly at the districts of Limassol and Paphos, but significant parts of high sensitivity regarding vegetation quality are also found in Famagusta and Larnaca (Figure 3d,e). Furthermore, in these districts, there are large areas with an increase of sensitivity between the years 2000 and 2016. An additional characteristic regarding the VQI is that the most abrupt positive changes which are connected with the increase of the stress in the vegetation cover are covering large parts of all the districts except Kyrenia and Nicosia, where the smallest areas of positive VQI difference are found. It is also noteworthy pointing out the increase of vegetation sensitivity (meaning vegetation degradation) in large parts of the most vegetated region of the Cyprus Island, which is the Troodos Mountain, extending mostly from southwest to south of the Nicosia district.

Regarding the final product of this study, which is the calculation of ESAI for the study area, the main conclusion is that according to the values of the ESAI (Figure 5d), a large area of the Cyprus Island (9.68%) was found to be susceptible to land degradation. The susceptible areas are mainly located in Paphos and Limassol districts (Figure 5). Significant parts of Larnaca and of the central and southern Famagusta districts also belong to the high susceptibility areas (Figure 5). Dispersed areas mainly in the eastern part of Nicosia and near the edge of the mountain of Troodos, which is one of the most vegetated areas, are also found susceptible to land degradation.

In conclusion, the quantitative results are based on the exclusive use of remote sensed data and products, which are high quality datasets, with a satisfactory spatial resolution appropriate for regional scale studies. This study provides a clear evidence of the environmental dynamics and highlights the potential for land degradation in Cyprus. Moreover, the used methodology based on the use of environmental quality indices based and basic principles of the MEDALUS methodology, constitutes an integrated approach to identify, describe, and highlight at a regional scale the environmentally sensitive areas in the Island of Cyprus.

Although some local changes are difficult to be recorded, the scope of the study is to detect and present tendencies of the environmental quality for the whole Cyprus Island, at regional level, operating as a driver for further studies at different spatial scales and a triggering mechanism to establish good practices and policies for a sustainable future of the Cyprus Island. More specifically, the final results can be useful for future studies because highlight susceptible regions for land degradation in Cyprus. The accurate detection of such regions can constitute a driver for future actions to protect and promote the environmental sustainability of Cyprus. More specifically, considering the results of the study, it is considered highly important to promote an environmentally sustainable tourism sector and to enhance modern solutions in the livestock and agriculture. Also, it is considered of crucial importance the protection of the physical ecosystems and the forested areas and the environmentally sustainable urban planning in order to deteriorate the vulnerability to the land degradation in Cyprus.

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REFERENCES

Basso, F., Bove, E., Dumontet, S., Ferrara, A., Pisante, M., Quaranta, G., & Taberner, M. (2000). Evaluating environmental sensitivity at the basin scale through the use of geographic information systems and remotely sensed data: An example covering the Agri basin (Southern Italy). *Catena*, *40*, 19–35. https://doi.org/10.1016/S0341-8162(99)00062-4

Behrens, A., Georgiev, A., & Carraro, M. (2010). Future impacts of climate change across Europe. Center for European Policy Studies (CEPS) Working Document No. 324, Brussels. DOI: 978–92–9079-972-6

Bi, H., Ma, J., Zheng, W., & Zeng, J. (2016). Comparison of soil moisture in GLDAS model simulations and in situ observations over the Tibetan Plateau. *Journal of Geophysical Research*, *121*(6), 2658–2678. https://doi.org/10.1002/2015JD024131

Blondel, J., Aronson, J., Bodiou, J. Y., & Boeuf, G. (2010). *The Mediterranean region: Biological diversity in space and time* (2nd ed.). Oxford, UK: Oxford University Press. ISBN: 978-0-19-955798-1.

Bouabid, R., Rouchdi, M., Badraoui, M., Diab, A., & Louafi, S. (2010). Assessment of land desertification based on the MEDALUS approach and elaboration of an action plan: The case study of the Souss River Basin, Morocco. In *Land degradation and desertification: Assessment, mitigation and remediation* (pp. 131–145). https://doi.org/10.1007/978-90-481-8657-0_10

Bruggeman, A., Hadjinicolaou, P., Lange, M. A., Zoumides, C., Pashiardis, S., & Zachariadis, T. (2011). Effect of climate variability and climate change on crop production and water resources in Cyprus. The Cyprus Institute, Cyprus University of Technology, Cyprus Meteorological Service. https://doi.org/10.1.1.458.4104

Camille, A., Guilhaumon, F., Leprieur, F., Ben Rais Lasram, F., Somot, S., Aznar, R., … Mouillot, D. (2013). Projected climate change and the changing biogeography of coastal Mediterranean fishes. *Journal of Biogeography*, *40*, 534–547. https://doi.org/10.1111/jbi.12013

Ceccato, P., Flasse, S., & Gregoire, J. M. (2002). Designing a spectral index to estimate vegetation water content from remote sensing data: Part 2. Validation and Applications. *Remote Sensing of Environment*, *82*, 198–207. https://doi.org/10.1016/S0034-4257(02)00036-6

Chavez, P. S. Jr. (1996). Image-based atmospheric corrections revisited and improved. Radiometric calibration of Landsat Thematic Mapper multispectral images. *Photogrammetric Engineering and Remote Sensing*, *62*, 1025–1036. DOI: 0099-1112/96/6209-1025S3.00/0

Chen, L., Ma, Z., & Zhao, T. (2017). Modeling and analysis of the potential impacts on regional climate due to vegetation degradation over arid and semi-arid regions of China. *Climatic Change*, *144*(3), 461–473. https://doi.org/10.1007/s10584-016-1847-2

Chivian, E., & Bernstein, A. (2008). *Sustaining life: How human health depends on biodiversity*. New York: Oxford University Press. ISBN: 978–0195175097.

Christensen, J. H., & Christensen, O. B. (2007). A summary of the PRUDENCE model projections of changes in European climate by the end of this century. *Climate Change*, *81*, 7–30. https://doi.org/10.1007/s10584-006-9210-7

Collins, A. E. (2001). Health ecology, land degradation and development. *Land Degradation and Development*, *12*(3), 237–250. https://doi.org/10.1002/ldr.436

Contandor, J. F. L., Schnabel, S., Gutierrez, A. G., & Fernandez, M. P. (2009). Mapping sensitivity to land degradation in Extremadura. SW Spain. *Land Degradation and Development*, *20*, 129–144. https://doi.org/10.1002/ldr.884

Cook, B. I., Anchukaitis, K. J., Touchan, R., Meko, D. M., & Cook, E. R. (2016). Spatiotemporal drought variability in the Mediterranean over the last 900 years. *Journal of Geophysical Research-Atmospheres*, *121*(5), 2060–2074. https://doi.org/10.1002/2015JD023929

Coyette, C., & Schenk, H. (2013). *EuroStat pocketbooks: Agriculture, forestry and fishery statistics*. Luxembourg: European Union. ISBN: 978–92–79-33005-6.

European Environmental Agency. (2015). Countries and regions—Mediterranean Sea region. European Environment — State and Outlook 2015 (SOER 2015). Available at: https://www.eea.europa.eu/soer-2015/countries/mediterranean

Evangelidou, S. (2011). Dams of Cyprus and their environment. Energy, Environment and Water Research Center (EEWRC). The Cyprus Institute. Available at: http://www.cyi.ac.cy/system/files/Evangelidou_Dams_of_Cyprus_and_their_Environment_Sep2011a.pdf

Evans, J. P. (2009). 21st century climate change in the Middle East. *Climatic Change*, *92*(3–4), 417–432. https://doi.org/10.1007/s10584-008-9438-5

Gao, B. C. (1996). NDWI—A normalized difference water index for remote sensing of vegetation liquid water from space. *Remote Sensing of Environment*, *58*, 257–266. https://doi.org/10.1016/S0034-4257(96)00067-3

Gao, J., Xue, Y., & Wu, S. (2013). Potential impacts on regional climate due to land degradation in the Guizhou Karst Plateau of China. *Environmental Research Letters*, *8*(4). https://doi.org/10.1088/1748-9326/8/4/044037

Gao, X., & Giorgi, F. (2008). Increased aridity in the Mediterranean region under greenhouse gas forcing estimated from high resolution simulations with a regional climate model. *Global and Planetary Change*, *62*, 195–209. https://doi.org/10.1016/j.gloplacha.2008.02.002

Giannakopoulos, C., Hadjinicolaou, P., Kostopoulou, E., Varotsos, K. V., & Zerefos, C. (2010). Precipitation and temperature regime over Cyprus as a result of global climate change. *Advances in Geosciences*, *23*, 17–24. https://doi.org/10.5194/adgeo-23-17-2010

Giannakopoulos, C., Le Sager, P., Bindi, M., Moriondo, M., Kostopoulou, E., & Goodess, C. M. (2009). Climatic changes and associated impacts in the Mediterranean resulting from a 2°C global warming. *Global and Planetary Change*, *68*(3), 209–224. https://doi.org/10.1016/j.gloplacha.2009.06.001

Giorgi, F. (2006). Climate change hot-spots. *Geophysical Research Letters*, *33*. https://doi.org/10.1029/2006GL025734

Giorgi, F., & Lionello, P. (2008). Climate change projections for the Mediterranean region. *Global and Planetary Change*, *63*, 90–104. https://doi.org/10.1016/j.gloplacha.2007.09.005

Gu, Y., Brown, J. F., Verdin, J. P., & Wardlow, B. (2007). A five-year analysis of MODIS NDVI and NDWI for grassland drought assessment over the central Great Plains of the United States. *Geophysical Research Letters*, *34*. https://doi.org/10.1029/2006GL029127

Hammad, A. A., & Tumeizi, A. (2012). Land degradation: Socioeconomic and environmental causes and consequences in the eastern Mediterranean. *Land Degradation & Development*, *23*(3), 216–226. https://doi.org/10.1002/ldr.1069

Hochstrat R, & Kazner C. (2009). Flexibility in copying with water stress and integration on different measures: Case study report Cyprus. TECHNEAU project report. Available at: https://www.techneau.org/fileadmin/files/Publications/Publications/Deliverables/D1.3.4.pdf

Hoerling, M., Eischeid, J., Perlwitz, J., Quan, X., Zhang, T., & Pegion, P. (2012). On the increased frequency of Mediterranean drought. *Journal of Climate*, *25*, 2146–2161. https://doi.org/10.1175/JCLI-D-11-00296.1

Intergovernmental Panel on Climate Change, (2014). Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Available at: https://www.ipcc.ch/pdf/assessment-report/ar5/syr/SYR_AR5_FINAL_full.pdf

Jafari, R., & Bakhshandehmehr, L. (2013). Quantitative mapping and assessment of environmentally sensitive areas to desertification in central Iran. *Land Degradation and Development*, *27*, 108–119. https://doi.org/10.1002/ldr.2227

Jamalabad, M. S., & Abkar, A. A. (2004). Forest canopy density monitoring, using satellite images. XXth ISPRS Congress, July 12–23, Istanbul, Turkey. Available at: http://www.isprs.org/proceedings/XXXV/congress/comm7/comm7.aspx

Kairis, O., Karavitis, C., Salvati, L., Kounalaki, A., & Kosmas, K. (2015). Exploring the impact of overgrazing on soil erosion and land degradation in a dry Mediterranean agro-forest landscape (Crete, Greece). *Arid Land Research and Management*, *29*(3), 360–374. https://doi.org/10.1080/15324982.2014.968691

Kolios, S., & Stylios, C. (2013). Identification of land cover/land use changes in the greater area of the Preveza peninsula in Greece using Landsat satellite data. *Applied Geography*, *40*, 150–160. https://doi.org/10.1016/j.apgeog.2013.02.005

Kosmas, C., Kirkby, M. J., & Geeson, N. (1999). Manual on key indicators of desertification and mapping environmentally sensitive areas to desertification. European Commission Publication EUR 18882. Available at: http://cordis.europa.eu/result/rcn/25074_en.html.

Kythreotou, N., & Mesimeris, T. (2014). National Communication and Biennial report under the UNFCCC. Department of Environment Ministry of Agriculture, Natural Resources and Environment.

Lelieveld, L., Hadjinicolaou, P., Kostopoulou, E., Chenoweth, J., El Maayar, M., Giannakopoulos, C., … Xoplaki, E. (2012). Climate change and impacts in the Eastern Mediterranean and the Middle East. *Climatic Change*, *114*, 667–687. https://doi.org/10.1007/s10584-012-0418-4

Lillesand, T., Kiefer, R. W., & Chipman, J. (2015). *Remote sensing and image interpretation* (7th ed.). United States: Wiley & Sons. ISBN: 978–1–118-34328-9.

Myers, S. S., Gaffikinc, L., Golden, C. D., Ostfeldd, R. S., Redforde, K. H., Ricketts, T. H., … Osofskyh, S. A. (2013). Human health impacts of ecosystem alteration. *Proceedings of the National Academy of Sciences of the United States of America*, *110*(47), 18753–18760. https://doi.org/10.1073/pnas.1218656110

Nkonya, E., Mirzabaev, A., & Von Braun, J. (2015). *Economics of land degradation and improvement—A global assessment for sustainable development*. Springer Book. DOI: https://doi.org/10.1007/978-3-319-19168-3

Omar, A., Abdi, O. A., Glover, E. K., & Luukkanen, O. (2013). Causes and impacts of land degradation and desertification: Case study of the Sudan. *International Journal of Agriculture and Forestry*, *3*(2), 40–51. https://doi.org/10.5923/j.ijaf.20130302.03

Ostfeld, R., Keesing, F., & Eviner, V. T. (2008). *Infectious disease ecology: The effects of ecosystems on disease and of disease on ecosystems*. Princeton University Press. ISBN: 9780691124858.

Paix, M. J., Lanhai, L., Xi, C., Ahmed, S., & Varenyam, A. (2013). Soil degradation and altered flood risks as a consequence of deforestation. *Land Degradation & Development*, *24*(5), 478–485. https://doi.org/10.1002/ldr.1147

Parvari, S. H., Pahlavanravi, A., Nia, A. R. M., Dehvari, A., & Parvari, D. (2011). Application of methodology for mapping environmentally sensitive areas (ESAs) to desertification in dry bed of Hamoun Wetland (Iran). *International Journal of Natural Resources and Marine Sciences*, *1*(1), 65–80.

Petropoulos, P. G., Kontoes, C., & Keramitsoglou, I. (2011). Burnt area delineation from a uni-temporal perspective based on Landsat TM imagery classification using support vector machines. *International Journal of Applied Earth Observation and Geoinformation*, *13*, 70–80. https://doi.org/10.1016/j.jag.2010.06.008

Pino del Carpio, A., Sánchez, S., Nieto, A., & Bilz, M. (2013). Cyprus biodiversity at risk, International Union for Conservation of Nature. European Union Representative Office. Availble at: https://cmsdata.iucn.org/downloads/cyprus__biodiversity_at_risk_fact_sheet_may_2013.pdf

Raso, J. (2013). Updated report on wastewater reuse in the European Union; European Commission: Brussels, Belgium. DOI: 10.2779/603205

Rodell, M., Houser, P. R., Jambor, U., Gottschalck, J., Mitchell, K., Meng, C. J., … Toll, D. (2004). The global land data assimilation system. *Bulletin of the American Meteorological Society*, *8*(3), 381–394. https://doi.org/10.1175/BAMS-85-3-381

Roderick, M., Smith, R., & Lodwick, G. (1996). Calibrating long-term AVHRR-derived NDVI imagery. *Remote Sensing of Environment*, *58*(1), 1–12. https://doi.org/10.1016/0034-4257(96)00035-1

Rouse, J. W., Haas, R. H., Schell, J. A., & Deering, D. W. (1974). Monitoring vegetation systems in the Great Plains with ERTS. Third Earth Resources Technology Satellite-1 Symposium- Volume I: Technical Presentations. NASA SP-351. Available at: https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19740022614.pdf

Salvati, L., & Bajocco, S. (2011). Land sensitivity to desertification across Italy: Past, present, and future. *Applied Geography*, *31*(1), 223–231. https://doi.org/10.1016/j.apgeog.2010.04.006

Sepehr, A., Zucca, C., & Nowjavan, M. R. (2014). Desertification status using factors representing ecological resilience. *British Journal of Environment and Climate Change*, *4*(3), 279–291.

Sofroniou, A., & Bishop, S. (2014). Water scarcity in Cyprus: A review and call for integrated policy. *Water*, *6*, 2898–2928. https://doi.org/10.3390/w6102898

Speldewinde, P. (2006). Environmental degradation and human health in Western Australia. ISEE/ISEA 2006 Conference 17 **(6):** 435–453. DOI: 00001648-200611001-01165

Srivastava, P. K., Han, D., Rico-Ramirez, M. A., Bray, M., & Islam, T. (2012). Selection of classification techniques for land use/land cover change investigation. *Advances in Space Research*, *50*, 1250–1265. https://doi.org/10.1016/j.asr.2012.06.032

Symeonakis, E., Koukoulas, S., & Panagopoulos, G. P. (2014). Monitoring sensitivity to land degradation and desertification with the environmentally sensitive index: The case of Lesvos Island. *Land Degradation and Development*, *27*, 1562–1573. https://doi.org/10.1002/ldr.2285

Tang, Z., An, H., Deng, L., Wang, Y., Zhu, G., & Shangguan, Z. (2016). Effect of desertification on productivity in a desert steppe. *Scientific Reports*, *6*. https://doi.org/10.1038/srep27839

Teillet, P. M., & Fedosejevs, G. (1995). On the dark target approach to atmospheric correction of remotely sensed data. *Canadian Journal of Remote Sensing*, *21*, 373–387. https://doi.org/10.1080/07038992.1995.10855161

Trotta, C., Menegoni, P., Massimo, F., Frattarelli, M., & Iannetta, M. (2014). Assessing desertification vulnerability on a local scale: The Castelporziano study area (central Italy). *Rendiconti Lincei*, *26*, 421–450. https://doi.org/10.1007/s12210-014-0362-5

United Nations Convention to Combat Desertification, (2010). Fourth national report to the United Nations Convention on Biological Diversity Department of Environment Ministry of Agriculture, Natural Resources and Environment. Available at: https://www.cbd.int/doc/world/cy/cy-nr-04-en.pdf

Vetter, S., & Bond, W. J. (2012). Changing predictors of spatial and temporal variability in stocking rates in a severely degraded communal rangeland. *Land Degradation and Development*, *23*(2), 190–199. https://doi.org/10.1002/ldr.1076

Vieira, R. M. S. P., Tomasella, J., Alvalá, R. C. S., Sestini, M. F., Affonso, A. G., Rodriguez, D. A., … Santana, M. O. (2015). Identifying areas susceptible to desertification in the Brazilian northeast. *Solid Earth*, *6*, 347–360. https://doi.org/10.5194/se-6-347-2015

Wang, Q., & Batkhishig, O. (2014). Impact of overgrazing on semiarid ecosystem soil properties: A case study of the Eastern Hovsgol Lake Area, Mongolia. *Journal of Ecosystem and Ecograph*, *4*, 140. https://doi.org/10.4172/2157-7625.1000140

Zachariadis, T. (2016). *Climate change in Cyprus. Impacts and outline of an adaption strategy*. Springer. ISSN: 2191-5555. DOI: https://doi.org/10.1007/978-3-319-29688-3

Zawadzki, J., & Kędzior, M. A. (2014). Statistical analysis of soil moisture content changes in Central Europe using GLDAS database over three past decades. *Central European Journal of Geosciences*, *6*(3), 344–353. https://doi.org/10.2478/s13533-012-0176-x

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