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Land-use and land degradation processes affecting soil resources: Evidence from a traditional Mediterranean cropland (Greece)

M. Karamesouti [a], V. Detsis [b], A. Kounalaki [a], P. Vasiliou [a], L. Salvati [c], C. Kosmas [a,*]

[a] Agricultural University of Athens, Laboratory of Soils and Agricultural Chemistry, Iera Odos 75, Athens 11855, Greece
[b] Xarokopio University, Department of House Economy and Ecology, El. Venizelou 70, Athens 17671, Greece
[c] Consiglio per la Ricerca e la sperimentazione in Agricoltura (CRA), Via della Navicella 2-4, I-00186 Rome, Italy

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ABSTRACT

Land degradation is a complex process resulting from the permanent interaction between physical and human factors. The effect of changes in land-use and land management on soil erosion and desertification risk has been studied in Messara Valley (Crete, Greece) over the last six decades (1950–2010). Vegetation cover and land-use have been analyzed using representative aerial photographs and ortho-photomaps for representative dates. Soil attributes have been described in a semi-detailed survey in 2010. Soil erosion rates and desertification risk have been assessed for each period using the PESERA and TERON models and the MEDALUS methodology, respectively. Based on distinct socio-ecological characteristics of the area three major time intervals have been identified. Cereals extensively cultivated during the first time interval were progressively replaced by olive plantations and vineyards in the following periods. Soil erosion due to water runoff was important especially in the olive transition period, declining in the olive subsidy period. However, tillage erosion became an important degradation process especially in the olive subsidy period due to mechanization of the agriculture determining soil losses ranging from 0.5 to 30 cm in sloping areas. Desertification risk due to soil erosion and land characteristics has significantly increased during the olive subsidy period.

1. Introduction

Awareness due to the increased environmental stress on natural resources, imposed by the growing human demands, urges the scientific community to define the origins of the problem and to propose practical solutions to restore ecosystem or to mitigate environmental degradation (Millennium Ecosystem Assessment, 2005). The drastic changes in the use of land and the shift of cropland management towards more intense practices, observed at global scale over the last decades, are considered the main driving forces of land degradation (Foley et al., 2005). The intensification of agriculture and unsustainable landscape transformations negatively impacted soil quality in the Mediterranean region (EEA, 2000; Yassoglou and Kosmas, 2001; López-Garrido et al., 2014). Soil erosion and land desertification are recognized as the most common land degradation processes in this region (Kosmas et al., 2000, 2002, 2006; Gordon et al., 2008; Cerdà et al., 2010). These processes are closely interrelated, whereas the human interventions by the appropriate land-use and land management practices can be critical for rehabilitation (Kosmas et al., 1997, 1999a,b; Tsara et al., 2001; EC, 2006; Cerdan et al., 2010).

Soil erosion is a natural process causing limitations to soil productivity, contributing to water quality problems under specific environmental conditions (Gobin et al., 2004; Kirkby et al., 2008). The accelerated erosion rates, due to the synergic action of biophysical and socioeconomic factors, alarmed scholars and politicians in recent decades. As a consequence, a great deal of methodologies and indicators have been developed for the assessment of soil erosion (Gobin et al., 2004; Kapalanga, 2008). Among the most widely used soil erosion models, the PESERA model was developed to provide an explicit assessment of the long-term soil water erosion rate depending on vegetation cover, climate and management characteristics (Kirkby et al., 2008). Furthermore, a wide range of studies focus on tillage erosion, acknowledging the growing human impact on land (Van Oost et al., 2006). The empirical methodology developed by EU TERON project is a useful tool for estimating soil relocation in hilly agricultural areas, where tillage induces higher erosion rates than water or wind (Govers et al., 1994; 1996 Gerontidis et al., 2001). The combination of both water erosion and tillage erosion can provide information about the overall erosion rates affecting hilly agricultural areas.

Similar with soil erosion, land desertification which is considered as a type of advance degradation in the Mediterranean region, affects semi-arid and dry regions where lack of water is the main limiting factor

* Corresponding author.
E-mail addresses: minakaramesouti@gmail.com (M. Karamesouti), detsis@hua.gr (V. Detsis), kounalaki.kate@gmail.com (A. Kounalaki), pennoula_v@yahoo.gr (P. Vasiliou), luca.salvati@entecra.it (L. Salvati), ckosm@aua.gr (C. Kosmas).

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for the soil productivity (Lal, 1927; Kosmas et al., 2003). Desertification is a land degradation process triggered by excessive human activity in areas with unfavorable natural characteristics (Kosmas et al., 1999a,b; Yassoglou and Kosmas, 2001). The Environmentally Sensitive Areas (ESAs) to desertification scheme, originally developed within the MEDALUS project (Kosmas et al., 1999a,b), produced a flexible indicator system for identifying potentially threatened areas.

Research on land degradation, considered as the reduced potential of the land to provide ecosystem services, has highlighted four main pillars, the role of which has undergone significant debate: (i) climate, (ii) vegetation, (iii) social processes and (iv) economic and political processes (Hermann and Hutchinson, 2005). Vegetation and land-use affected by social and economic changes over time are of paramount importance in controlling land degradation due to soil erosion and land desertification (David et al., 2014; Kaplan et al., 2014; Kurothe et al., 2014). Interestingly, agricultural intensification (mechanization, extensive use of agro-chemicals and irrigation) was identified as one of the most relevant processes determining changes in the current use of land in rural areas of the southern Europe. A comprehensive knowledge of transformations in the use of land and in the prevailing land management practice transformations coupled with an in-depth monitoring of the evolution of the main land degradation processes at the local scale contributes to elaborate sustainable land management practices targeting the preservation of soil resources (Zalidis et al., 2002; Novara et al., 2011; Quaranta and Salvia, 2014).

Based on these premises, the objectives of our study are (i) to estimate the effect of land use and land management changes on key land degradation processes, (ii) to describe the evolution of land degradation processes over time coupled with changes in the socioeconomic context at the local scale, and (iii) to assess land degradation processes under alternative land management practices. Based on these premises, the present study has been focused on the evolution of land-use and land management practices in Messara Valley, Crete, and their impact on land degradation processes. The study period refers to the last 60 years (1950–2010) encompassing relevant transformations in the socioeconomic structure of the area together with important changes in cropping systems. Messara Valley is intended here as a paradigmatic case to understand the intimate relationship between environmental, agronomic and socioeconomic factors in rural Mediterranean dry areas experiencing a shift towards crop intensification.

2. Materials and methods

2.1. Study area

The Messara Valley is located in the central-southern part of Crete, about 50 km south of the city of Heraklion (Fig. 1), covering an area of 72,059 ha. The climate of the study area is dry sub-humid, with mild-wet winters and dry-hot summers. The average annual rainfall increases from west to east ranging from 493 mm to 737 mm (three meteorological stations with time period of data 1948–2004). Similarly, average air temperature ranged from 19.1 °C in the western part to 16.6 °C in the eastern part of the valley. The main materials of the upper geological layer are alluvial deposits (mainly in the lower/western part of the valley), marls (mainly in the hilly areas), limestone, flysch (in few hilly areas) and conglomerates. The area is characterized mainly as gently to moderately sloping (areas with slope gradient lower than 12% cover about 47% of the area). In the majority of the study area, elevation is 400 m above sea level. The soils of Messara Valley are mainly moderately deep to deep (soil depth greater than 60 cm characterizes 70% of the study area). In the lower part of the valley recent alluvial soils, classified as Fluvisols, rich in carbonates (15–30%) with clay loam dominant textural class and moderate fertility, were found (Yassoglou et al., 1971). The soils formed on hilly areas are characterized by their advanced degree of erosion with the parent material (mainly marls) exposed to the soil surfaces, classified mainly as Cambisols.

2.2. Changes in the cropping systems of Messara Valley

Messara Valley is one of the most important agricultural regions of Crete undergoing considerable socio-ecological transformations during

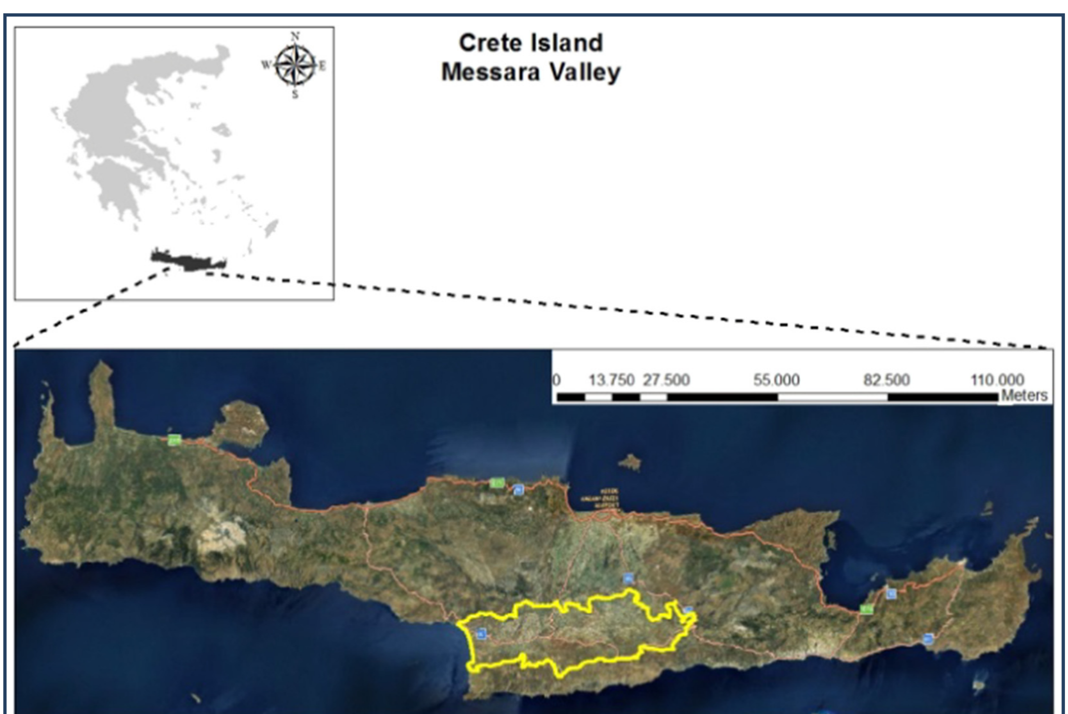

Fig. 1. Location of the Messara study area in Crete, Greece.
Source: Google Earth, elaborated by authors.

the last decades. Although the Messara Valley retains its rural identity, modifications in the land use and cropping systems were observed in the area since the early 1950s.

Up to the early 1970s (when agricultural mechanization replaced the traditional way of land management) cereals, vines and vegetables were the main cultivated species. The area was functionally connected to the Asteroussia Mountains in the south via transhumance practices, according to some accounts (Ispikoudis et al., 2004) also to the Psiloritis massif in the north. More or less traditional labor-intensive practices and low land productivity set the scene. After 1960 major changes occurred in the Greek economy and society that impacted on this region as well. The under occupied labor force that resided in rural areas due to job shortage was channeled to migrating abroad or to urban centers, where industrialization was taking place. In the same time credits became available from banks making investment in mechanization of agriculture possible. State research institutes developed new and more productive crop varieties that lead to increasing harvests. These developments led to the modernization and specialization of the Greek agriculture. The introduction of new cereal varieties has doubled production levels and cereal production in Crete was outcompeted by increased production in the plains of central and northern Greece. As climatic conditions in Messara were marginal for cereal cultivation, farmers started switching to olive cultivation. Furthermore, migration of rural people to urban areas favored the expansion of olive groves since low cultivation management efforts are required. During the same period and especially post-1960 mechanization is gaining ground as well as irrigation.

While the wider Greek and European economic conditions stagnated during the period 1960–1970, the changes initiated in the previous phase accelerated in the study area. After 1970s, the spread of mechanization and irrigation along with a growing use of fertilizers continued. Opportunities created by tourism development along the north coast of Crete as well as the industrialization of the nearby located city of Heraklion have contributed to a significant number of migrants remaining within a limited distance to their place of descent. Non-farmer population also rises within the area along with other economic activities. The combination of the suitability of the area in terms of soils and climate for olive cultivation along with relatively high olive oil market prices promoted the expansion of olive groves. By the early 1980s mechanization has reached current levels and irrigation continued to expand throughout the period. During the 1970s the combination of suitable climatic conditions, the availability of credit, and the improvement of transportation infrastructure have led to the development of greenhouse cultivation in the lowland.

The accession of Greece to the European Union in the 1980s shaped the agricultural system in the area especially with the allocation of CAP subsidies for specific crops. Olive groves expanded all over the study area, replacing annual crops, whereas the surrounding hilly and mountainous areas were partially covered by shrubland and maquis (Stobbelaar et al., 2000; Panagos et al., 2014). The existence of subsidies linked to olive oil production as well as attractive olive oil prices lead to the complete domination of farmland by olive groves and expansion on marginally suitable lands previously covered by natural vegetation. Orange plantations and vegetables growing in greenhouses also expanded in the lowest part of the Messara Valley. Cultivation was further intensified by excessive use of agrochemicals and expansion of irrigation network favored by the availability of relatively easily accessible aquifers and the construction of water reservoirs. The process of intensification took place despite the aging population of the area as incoming immigrants offer cheap labor.

Based on the major socioeconomic events mentioned above, the following three major states (or transition periods) can be distinguished in the study area during the last six decades: (i) the 'cereal modernization' period between the 1950s and 1970s, (ii) the 'olive transition period' between 1970s and mid-1980s, and (iii) the 'olive subsidy' period between the mid-1980s and 2010s. In the first time interval, agriculture was the dominant economic sector in the area, whereas the exploitation of natural resources followed the principles of sustainable agriculture (e.g., contour farming in shallow depth less than 15 cm, limited use of fertilizers, moderate productivity to cover local needs). The second period was characterized by the introduction of agricultural machinery, the increasing productivity demands, leading to land-use changes in Messara Valley from cereals to olive orchards. Finally, during the most recent period the study area was greatly affected by the participation of Greece to the European Union accompanied by significant land-use transformations, wide use of fertilizers, and over-exploitation of natural resources.

2.3. Soil and vegetation mapping

Soil survey has been carried out in 2010 by considering the following soil attributes: soil texture of the surface horizon, percentage of rock fragment cover on the soil surface, depth to bedrock, topography and parent material. All these parameters were described in a network of 208 field observations. The boundaries of the mapping units were drawn on ortho-photomaps (scale 1:30,000) supplied by the Greek Ministry of Agricultural Development and Foods. Each mapping unit included a piece of land with similar soil and topographic characteristics such as soil texture, depth, slope gradient and configuration (e.g., convex, concave, linear slope). Soil textural classes were defined according to the USDA system (Soil Survey Staff, 1975) and were grouped into the following classes: very coarse (S, LS), coarse (SL), medium (L, SiL, Si), moderately fine (SCL, CL, SiCL) and fine (SC, C, SiC). The parent material was described according to the geological map of the area supplied by the Greek National Institute of Geology and Mineral Exploitation (CIGME). Soil depth to unconsolidated bedrock was measured in auger holes or in road cuts. The following classes of soil depth were used: very shallow (depth 0–15 cm), shallow (15–30 cm), moderately shallow (30–60 cm), moderately deep (60–100 cm) deep (100–150 cm), and very deep (>150 cm). Slope gradient was described according to the following classes: nearly level (slope 0–2%), gentling sloping (slope 2–6%), moderately sloping (slope 6–12%), strongly sloping (slope 12–18), moderately steep (slope 18–25%), steep (slope 25–35%) and very steep (slope > 35%).

Vegetation cover maps have been derived by air-photo interpretations of different periods. The following series of aerial photographs supplied by the Greek Army Geographical Service and Ministry of Rural Development and Foods were used with the corresponding periods: (i) aerial photographs of 1947 for the period 1950–1970s, (ii) aerial photographs of 1971 for the period 1970–mid-1980s, and (iii) ortho-photomaps of the year 1995 for the period mid-1980 to 2010 (Table 1). Aerial photographs are taken about every ten years in Greece. Since the quality of the photographs was poor in the middle of the first two study periods, the most proximate in time and best quality series of aerial photographs have been used. Aerial photographs were geo-referenced and converted to standard scale using the ArcGIS™ geo-referencing tool. Vegetation was defined on the basis of the dominant species classified into five main categories: (a) annual crops (cereals, vegetables), (b) perennial crops (vines, olives, citrus), (c) shrubs (natural vegetation), (d) mixed (highly fragmented areas including annual and perennial crops and/or natural vegetation) and (e) other area (urban/artificial area). The following classes of vegetation cover were used: <25%, 25–50%, 50–75%, 75–90%, and >90%.

2.4. Assessing land degradation processes

Soil erosion has been distinguished into water and tillage erosion. Soil erosion due to surface water runoff was estimated using the PESERA model (Pan-European Soil Erosion Risk Assessment: Kirkby et al., 2000, 2004) which implements a full set of 128 input data layers (96 layers with climate data, 25 layers with land-use data, six layers with soil characteristics data, and one layer with topographic data). All layers were converted in grid format, in a 50 m by 50 m cell size, in

Table 1
Parameterization of the erosion models PESERA, TERON and desertification ESA methodology used in the three study periods.

Parameter	Time period	Source
Study period 1950–1970		
Daily rainfall	1957, 1960, 1965	Hellenic Meteorological Service
Monthly air temperature	1957, 1960, 1965	Hellenic Meteorological Service
Vegetation cover	Aerial photographs 1947	Hellenic Military Geographical Service
Soil depth	Derived from soil depth data collected in 2010 and assessing change due to soil erosion	Soil survey last period
Soil texture	Data collected in 2010	Soil survey last period
Topography	Existing topographic maps	Hellenic Military Geographical Service
Study period 1970–mid-1980		
Daily rainfall	1972, 1975, 1979	Hellenic Meteorological Service
Monthly air temperature	1972, 1975, 1979	Hellenic Meteorological Service
Vegetation cover	Aerial photographs 1971	Hellenic Military Geographical Service
Soil depth	Derived from soil depth data collected in 2010 and assessing change due to soil erosion	Soil survey last period
Soil texture	Data collected in 2010	Soil survey
Topography	Existing topographic maps	Hellenic Military Geographical Service
Study period mid-1980–2010		
Daily rainfall	1985, 1995, 2004	Hellenic Meteorological Service
Monthly air temperature	1985, 1995, 2004	Hellenic Meteorological Service
Vegetation cover	Aerial photographs 1995	Hellenic Military Geographical Service
Soil depth	Derived from soil depth data collected in 2010 and assessing change due to soil erosion	Soil survey
Soil texture	Data collected in 2010	Soil survey
Topography	Existing topographic maps	Hellenic Military Geographical Service

order to execute the PESERA_GRID model (Irvine and Kosmas, 2003; Kirkby et al., 2003, 2004). The present model has been calibrated and validated in a previous work using experimental soil erosion data collected under various soils, topographic, and land-use/management characteristics in Greece (Tsara et al., 2005). For the application of the model, meteorological data (provided by the Hellenic National Meteorological Service) were used from the gauging station of Gortina located about in the middle of the study area. Potential evapotranspiration rate (ETo) was calculated from daily values of maximum and minimum air temperature, sunshine duration, air humidity and wind speed, according to the modified Penman equation (Allen et al., 1998). Soil erosion rate was assessed for each study period by running the soil erosion model for three years (representative for the long-term variations in the amount of rainfall observed in the area) and averaging annual erosion rates (Table 1). Based on soil data collected in 2010, soil depth for the previous periods was estimated based on the average soil loss calculated for each period.

Soil erosion due to tillage operations has been assessed using the TERON methodology (Govers et al., 1994; Gerontidis et al., 2001) using the equation:

$$Q_s = D \times BD \times B \times G$$

where: Q_s is the soil displacement (kg m^{-1}), D is the plow depth (m), BD is the bulk density of the topsoil (kg m^{-3}), G is the slope gradient (tan), and B is a coefficient corresponding to plow depth D and estimated as the slope of the linear regression of slope gradient versus soil displacement. An average 25 cm soil depth of plow was considered. Bulk density of the soil has been measured after sampling undisturbed core of soil samples (Klute, 1986). Based on soil data collected in 2010, soil depth for the previous period of 40 years (2010–1970) has been estimated based on the average yearly soil loss due to tillage operations.

Land desertification was estimated according to the Environmentally Sensitive Area (ESA) methodology, originally produced by the MEDALUS project (Kosmas et al., 1999a,b). The assessment involves two stages. In the first step, three partial indicators for soil quality (SQI), climate quality (CQI) and vegetation quality (VQI) are calculated providing a measure of the inherent quality of the physical environment and then the land management quality index (MQI), estimating the human pressure insisting in the area was calculated. In the second step, the three biophysical quality indexes (SQI, CQI and VQI) and the MQI were considered together to identify the various types of ESAs to desertification (Salvati et al., 2013).

3. Results

3.1. Land-use and land cover patterns

Relevant land-use changes, generally characterized as gradual transitions, were observed in the Messara Valley. The term ‘transition’ rather than ‘transformation’ is used here since the area never lost its rural identity. In earlier periods the greater part of the valley was cultivated with annual crops, whereas nowadays olive groves are the dominant vegetation cover type. The analysis of land cover during the ‘cereal modernization’ period (1950–1970s) identified annual crops (mainly cereals and small gardens with vegetables) as the dominant class (Fig. 2), covering 44,711 ha or 62.0% of the study area. Perennials were another important crop (mainly olive trees and vines) covering 13,084 ha or 18.2% of the land, while a significant part of the valley (13,699 ha or 19.0%) was covered by natural vegetation (primarily maquis and garrigues). During the ‘olive transition’ period (1970–mid-1980s), perennial crops (mainly olives and vines) expanded in the area (covering 27,693 ha or 38.4%) replacing annual crops and reduced to 26,616 ha or 36.9% of the area. Natural vegetation has been partially replaced by perennial crops and covered only 10,096 ha or 14.0% of the area. The expansion of perennial crops, mainly olive plantations and citrus in flat areas continued in the ‘olive subsidy’ period by reaching a 65,528 ha or 91% cover of the total area. Natural areas declined to 5228 ha or 7.3% of the investigated land.

The comparison of the land cover changes during the study periods showed that perennials have increased by 584 ha yr^{-1} and 1513 ha yr^{-1} during the ‘olive transition’ period and the ‘olive subsidy’ period, respectively, compared to the ‘cereal modernization’ period. On the contrary, the land covered by cereals has decreased by 723 ha yr^{-1} and 1052 ha yr^{-1} in the ‘olive transition’ period and the ‘olive subsidy’ period, respectively. Areas with natural vegetation have changed to perennial crops in the rate of 114 ha yr^{-1} and 194 ha yr^{-1} in the last two periods.

3.2. Soil erosion

Water erosion is especially important in areas cultivated with vineyards. These areas remain almost bare during fall and early spring due to the removal of annual vegetation by plowing or the application of pesticides (weed control). On the other hand, olive orchard soils are protected from raindrop impact due to rainfall interception by the foliage existing during the whole year. Understory vegetation is especially important in the intermediate area between neighboring trees. Under intensive cultivation management practice, annual vegetation is removed favoring water runoff generation. In both cases, frequent field crossings due to agricultural operations (fertilization, cultivation, harvesting, etc.) cause structural deterioration and compaction to the surface soil layer, reducing soil infiltration rate and increasing soil erosion rate (Kairis et al., 2013).

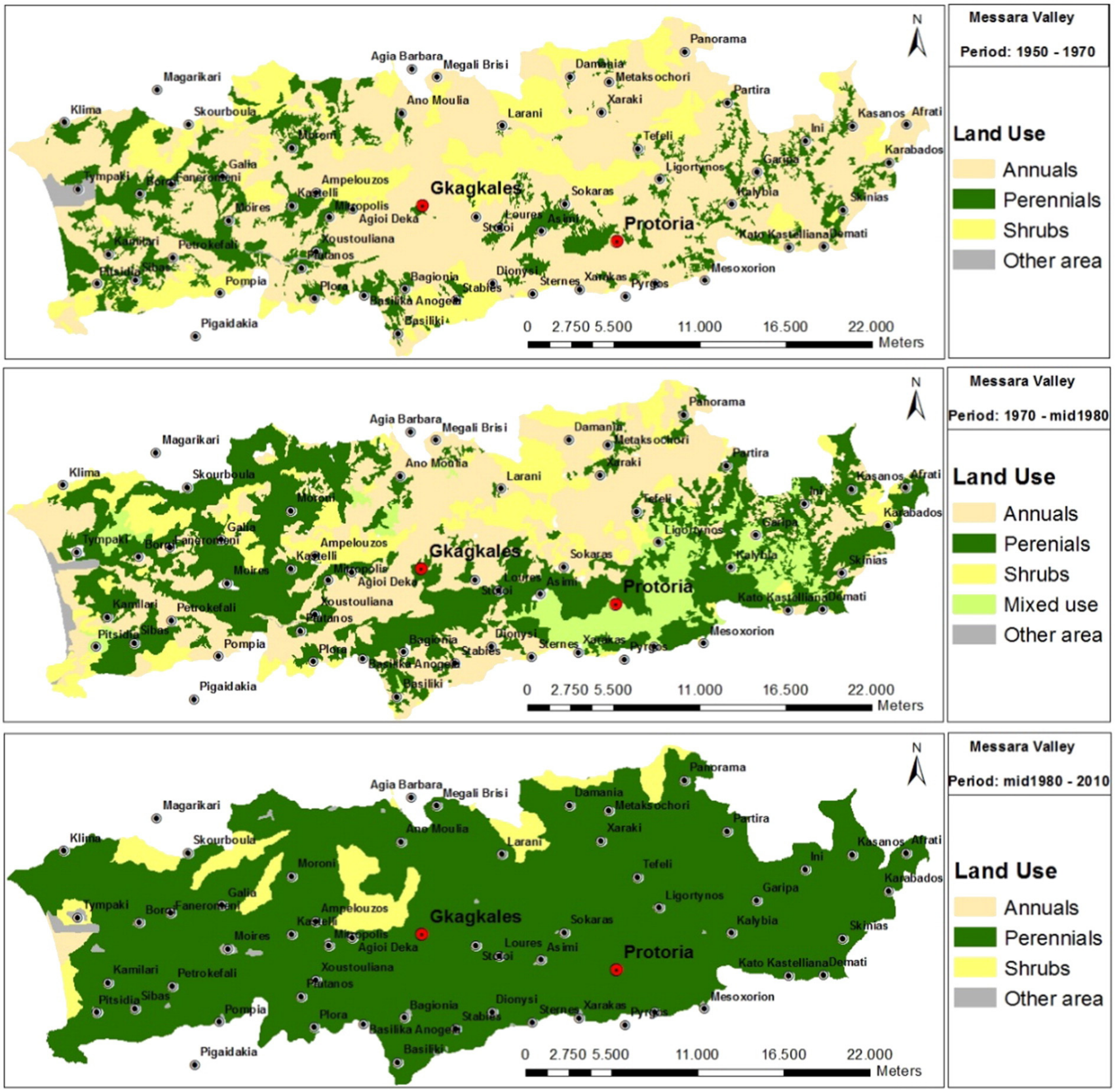

Fig. 2. Land use change during the three study periods in the Messara Valley (1950–1970, upper; 1970–mid-1980, middle; mid-1980–2010, lower).

Soil erosion assessment was carried out for the three study periods considering that before the early 1970s soil erosion was determined primarily by surface water runoff, while after that period, where agriculture was mechanized, soil erosion was caused by both water and tillage operations. During the 'cereal modernization' period (1950–1970s), soil erosion was a key environmental issue in the hilly areas of Messara, mainly located in the northern part of the valley (Fig. 3). Areas with negligible erosion rates (lower than 0.5 t ha^{-1} yr^{-1}) covered 84.4% of the total land (Table 2). The remaining classes of soil erosion (between 0.5–1 and 20–50 t ha^{-1} yr^{-1}) covered smaller areas (ranging between 3.3% and 2.0%). Notably, the estimated soil erosion reported in Table 2 has been calculated using the meteorological data of three representative years with annual rainfall close to the average for the area. However, one extreme rainfall event accompanied with high rain intensity and long duration is able to cause very high soil erosion rate that cannot be compared with the total erosion occurring in the whole study period of twenty years.

Negligible soil erosion rate (lower than 0.5 t ha^{-1} yr^{-1}) was the dominant class during the 'olive transition' period (1970–mid-1980s), covering 72.2% of the total land. The second most important class of soil erosion was that over 50 t ha^{-1} yr^{-1} covering 13.9% of the total area. Under such erosion rates, rills or even gullies are formed in hilly areas with very adverse consequences on soil storage capacity and plant production. The other classes of sediment losses covered small percentages of the area ranging from 1.3% to 3.3% of the total area (Table 2). Intensification of agriculture was characterized by mechanization, use of fertilizers and pesticides favoring in many cases soil erosion. A rapid exploitation of the ground water was mainly initiated during this period and continued into the following one leading to a significant increase in crop production and plant cover reducing raindrop impact and soil erosion. Olive groves expanded in hilly areas by replacing natural shrubby vegetation or cereals favored high erosion rates especially the first three years after the installation of the plantation.

Comparing the first two periods, higher erosion rates occurred in some areas during 'the olive transition' period. This can be attributed to the differences in the intensity and duration of rainfall events that occurred in the second period as well as to (locally reduced) plant cover. Hilly areas under low plant cover due to changes from cereals to olives have favored higher surface water runoff and sediment losses during the first two to three years after installation of the plantation.

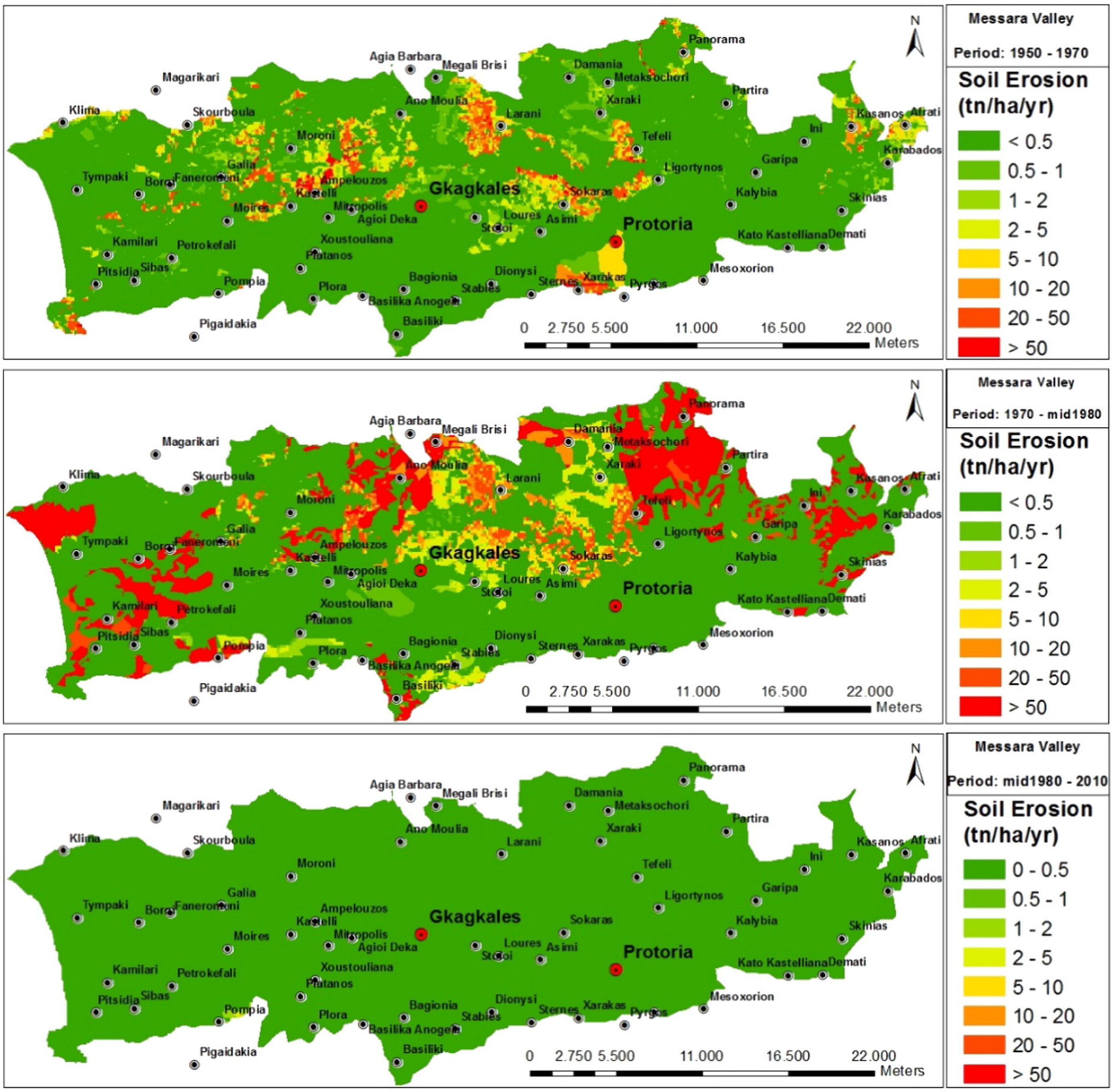

Fig. 3. Spatial distribution of soil erosion rates (due to surface water runoff) estimated for the Messara Valley for the three study periods (1950–1970, upper; 1970–mid-1980, middle; mid-1980–2010, lower).

The estimated soil erosion due to water runoff was greatly reduced during the following 'olive subsidy' period (mid-1980s–2010s) as illustrated in Fig. 3. Negligible erosion rates (<0.5 t ha^{-1} yr^{-1}) have been estimated for the 99.9% of the Messara Valley (Table 2). Similar erosion rates (0.014 to 0.392 t ha^{-1} yr^{-1}) have been measured in an experiment carried out in an olive grove located nearby the study area under various land management practices (Kairis et al., 2013). However, some fields have been identified in the field survey, in which new plantations of olive trees have been installed, with gully erosion features. Such fields are sparsely distributed in the Messara Valley, covering small areas and were not mapped in the semi-detailed survey conducted in the area (scale 1:30,000).

Table 2
Distribution of annual water erosion rates estimated by the PESERA model for Messara Valley during the three study periods.

Sediment loss (t/ha/yr)	Period 1950–1970		Period 1970–mid-1980		Period mid-1980–2010	
	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)
0–0.5	60,795	84.4	52,393	72.7	71,963	99.9
0.5–1	2356	3.3	987	1.4	8	0.0
1–2	1724	2.4	948	1.3	64	0.1
2–5	2239	3.1	2359	3.3	22	0.0
5–10	1685	2.3	1400	1.9	2	0.0
10–20	1431	2.0	1928	2.7	–	–
20–50	1464	2.0	2034	2.8	–	–
>50	365	0.5	10,010	13.9	–	–
Total	72,059	100.0	72,059	100.0	72,059	100.0

As in the previous period, the main issue with respect to soil erosion was intensive cultivation. It had mainly negative impacts causing problems of soil erosion and deterioration of soil physical and chemical properties. However, a new positive response to soil erosion, the so called 'integrated land management' (ILM), has been recently initiated in the area. This response is mainly applied in olive groves and allows for a more sustainable use of natural resources combined with maximum crop production also preserving biodiversity and protecting farmer's health (Greek Ministry of Rural Development and Foods). The ILM practice secures sustainability of natural resources by reducing soil erosion (minimum tillage, enhancing vegetative cover), minimizing ground water pollution (reduction of applied fertilizers), applying the agricultural codes on environmental protection, etc. The application of the ILM is controlled by the local authorities and promoted to the farmers by providing extra payment as subsidies.

Taken together, soil erosion rates due to water runoff during the three study periods shows that erosion was more important especially in the 'olive transition period' (1970–mid-1980s) due to low vegetation cover provided by the new plantations. Water erosion decreased during the 'olive subsidy' period since soils were adequately protected from raindrop splashing by the growing plants. In olive groves the intermediate area between successive olive trees is crucial for generating runoff. In case that olive trees are not adequately grown, high amounts of rain water runoff can be generated in this soil patch and under the condition that understory vegetation has been eliminated by the farmer.

While soil erosion due to water runoff was greatly reduced after 1970s and especially in the last study period, another type of soil erosion became an important issue in the area due to mechanization of agriculture. As Fig. 4 shows, tillage erosion is an important land degradation issue in a great part of the Messara Valley. Tillage erosion has been estimated from less than 0.5 cm up to 30 cm for a period of 40 years (1970–2010) under the prevailing cultivation practices. As Table 3 shows, the majority of the area (61.6% of the total area) is characterized by negligible values of tillage erosion. However, land with tillage erosion rates by 0.5–10 cm and 10–20 cm covers respectively 21.5% and 12.2% of the total area. Erosion rates of 20–30 cm have been estimated in 4.4% of the total area. Similar erosion rates have been measured in the field by measuring the difference in the soil around the tree and the nearby cultivated soil surface. The soil around the tree trunk remains intact since tillage instruments cannot approach there, while the soil some decimeters (20–30 cm) far from the tree is subjected to erosion due to displacement caused by the tillage instruments.

Tillage erosion occurs in hilly areas and in parts of hillslopes. Soil is displaced during plowing operations from the upper convex and linear part of a hillslope and deposited in the lower concave part of the slope. This can be partially explained by the continuous pattern of changes in colors of Fig. 4. The assessment of tillage erosion has been carried out using a digital terrain model of the area identifying both slope gradients and hillslope components (convex, linear and concave).

Tillage erosion rates have been considered as constant for the period 1970–2010, since soil has been cultivated once per year in an average depth of 25 cm. However, water erosion rates have been changed in the study periods depending on the climatic conditions and the land cover type. The following average rates of water erosion 0.014 mm yr^{-1}, 0.072 mm yr^{-1}, and 0.002 mm yr^{-1} were estimated for the 'cereal modernization', 'olive transition', and 'olive subsidy' periods, respectively. The average soil erosion due to tillage in the study area is estimated at 1.018 mm yr^{-1} and exceeds 14 times or more water erosion.

Table 3
Tillage erosion estimated for the last 40 years (after mechanization of cultivation) and for a cultivation depth of 25 cm.

Tillage erosion class (cm)	Area (%)
<0.5	61.6
0.5–10	21.5
10–20	12.2
20–30	4.4
30–40	0.0
>40	0.3
Total	100.0

3.3. Land desertification

Land desertification is another major issue in the Messara Valley. Sensitive areas to desertification are widely expanded in the area during the 'cereal modernization' period (Fig. 5). Potential areas to desertification or non-threatened areas are mainly located in lowlands with deep and well-drained soils. As Table 4 shows, 'fragile' areas to desertification (sub-types F1, F2 and F3) cover 72.2% of the total area with F2 being the dominant sub-type. Such areas are likely to bring about desertification under any change in the delicate balance between natural and human activity. Non-threatened areas to desertification cover only 7.8% of the total area.

Sensitive areas to desertification expanded in the following 'olive transition' period. Sensitive areas to desertification (sub-types F1, F2, and F3) covered 52.4% of the total area with the F2 as the dominant sub-type. Potential ESAs to desertification or non-threatened areas (covering the 24.5% and 19.6% of the total area, respectively) were mainly located in the lowland or in areas of low slope gradient with deep and well-drained soils adequately covered by perennial crops. Critical ESAs to desertification (sub-types C1, C2 and C3) covered 2.1% of the total area.

Comparing the results from the first two examined periods, a decrease in land desertification risk during the second period was clearly observed. Potential and non-threatened ESAs have increased from 23.9% in the first period to 44.1% in the second period. This can be attributed to the change in land-use from cereals to olive plantations. Areas cultivated with cereals are generally more sensitive to desertification than areas covered by olive groves. Furthermore, fragile ESAs have decreased from 72.2% in the period 1950–1970 to 52.4% in the period 1970–mid-1980 (Table 4).

In the 'olive subsidy' period, sensitive areas to desertification expanded in Messara Valley, covering 41.6% of the total area, with the F3 being the dominant sub-type of ESAs to desertification. Such areas are likely to be converted into critical areas if the intensive cultivation of the land will continue. Critical ESAs to desertification (including sub-types C1, C2 and C3) covered the 21.9% of the total area. Such areas

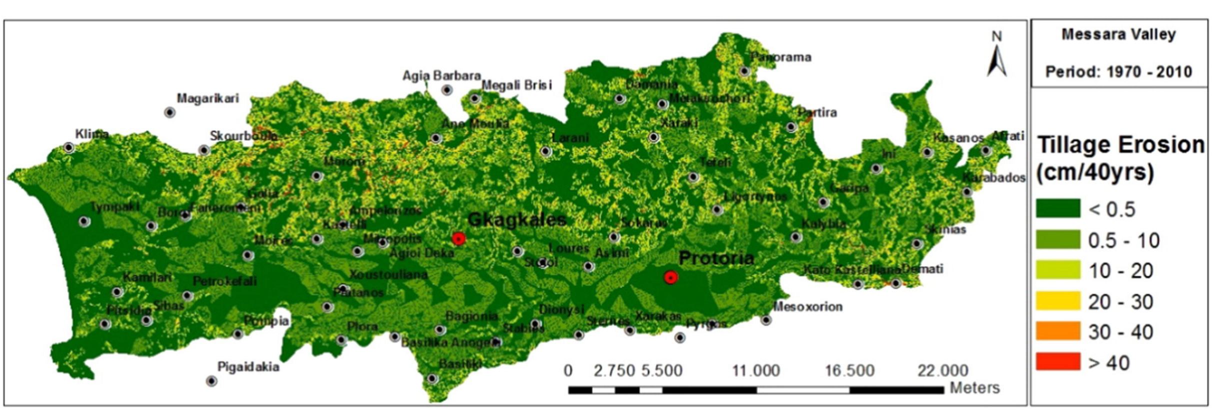

Fig. 4. Spatial distribution of tillage erosion classes for the Messara Valley. (For interpretation of the references to color in this figure, the reader is referred to the web version of this article.)

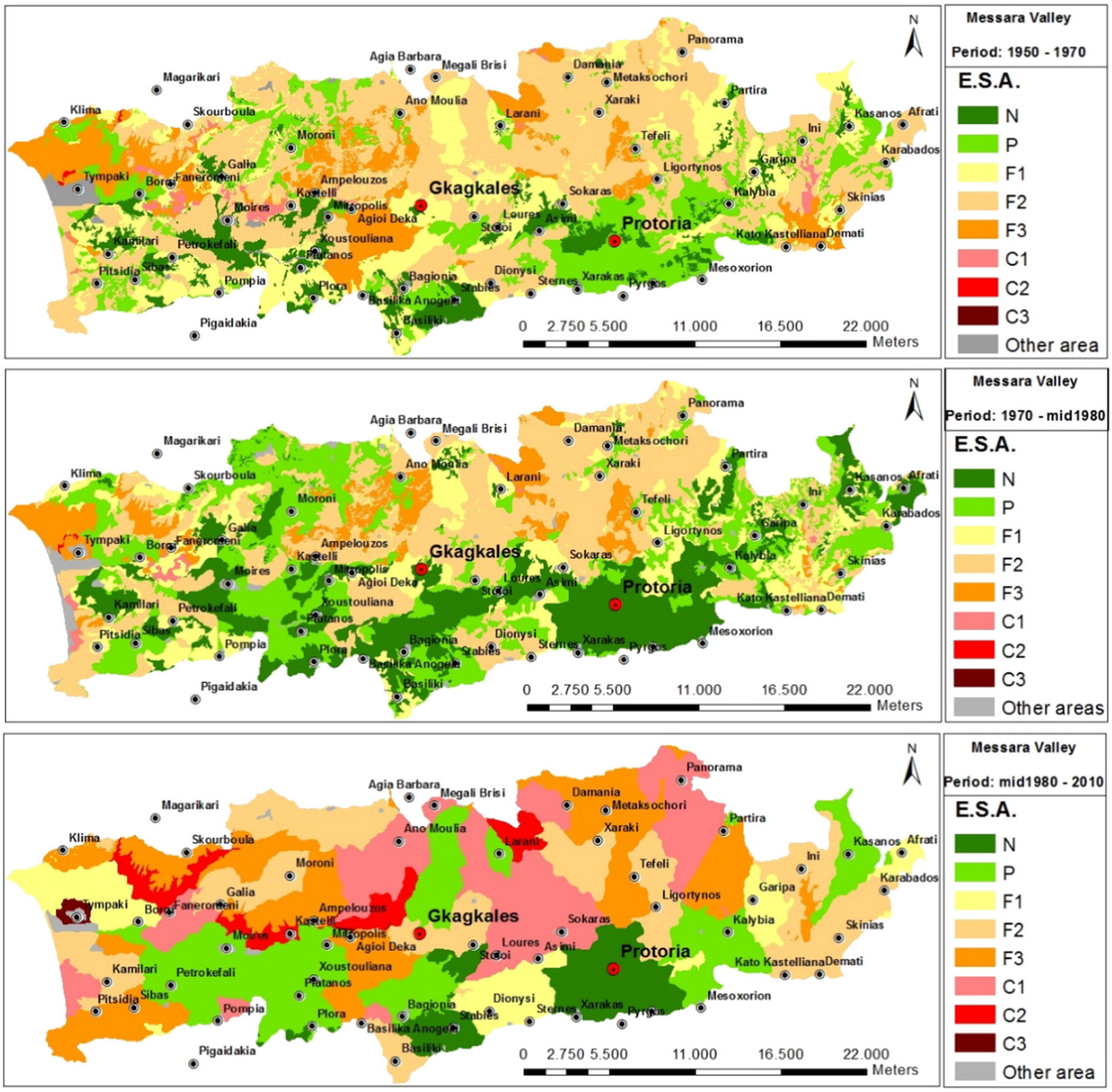

Fig. 5. Spatial distribution of environmentally sensitive areas to desertification of Messara Valley for the three study periods (1950–19790, upper; 1970–mid-1980, middle; mid-1980–2010, lower).

were characterized by high degree of land degradation. Potential and non-threatened ESAs covered 19.5% and 7.5% of the total area, respectively.

Table 4
Distribution of type of environmentally sensitive area to desertification in Messara Valley during the three study periods.

Type of ESA	Period 1950–1970		Period 1970–mid-1980		Period mid-1980–2010	
	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)
Non-affected (N)	5610	7.8	14,096	19.6	5424	7.5
Potentially affected (P)	11,635	16.1	17,681	24.5	14,025	19.5
Fragile (F1)	12,107	16.8	9776	13.6	6352	8.8
Fragile (F2)	30,725	42.6	22,453	31.2	15,144	21.0
Fragile (F3)	9196	12.8	5487	7.6	14,256	19.8
Critical (C1)	1367	1.9	738	1.0	12,693	17.6
Critical (C2)	119	0.2	31	0.0	2918	4.0
Critical (C3)	305	0.4	802	1.1	252	0.3
Other area	995	1.4	995	1.4	995	1.4
Total	72,059	100.0	72,059	100.0	72,059	100.0

The diachronic analysis of the ESAs indicated that several areas, classified as fragile ESAs during the ‘cereal modernization’ period, have been changed to critical ESAs during the ‘olive subsidy’ period mainly due to intensive cultivation of the land resulting in accelerated soil erosion rates due to tillage. Critical ESAs have changed from 2.5% in the ‘cereal modernization’ period to 21.9% in the ‘olive subsidy’ period. Expansion of mechanization and the increasing intensification of agriculture had an adverse consequence on soil resources mainly due to erosion. Soils washed out from the upper parts of a hillslope and deposited in the lower part of the landscape have caused a moderate decline in soil depth. Despite the high vegetation quality during the last study period due to replacement of cereals by olive plantations, soil quality progressively declined. Furthermore, crop intensification accompanied by the low implementation of existing policies on environmental protection has increased the risk for desertification of the Messara Valley in the ‘olive subsidy’ period.

A scenario for the application of the integrated land management (ILM) practice in the Messara Valley has been assessed with respect to soil erosion and land desertification in order to establish whether this approach could remedy the negative impacts of intensive cultivation without compromising production levels. Soil erosion and land desertification risk have been recalculated by changing the input parameters for the PESERA model and the ESA methodology related to the change in land management from intensive cultivation to ILM. The main changes in applying the PESERA model in relation to intensive cultivation was an increase in the understory vegetative cover to 80% during the wet period and a reduction of soil roughness to zero value due to no tillage application.

The estimated soil erosion rates due to surface water runoff are minimized and did not exceed 0.5 t ha^{-1} yr^{-1}. Such erosion rates have been validated in an experimental study in a nearby area cultivated with olives and applying ILM practice (Kairis et al., 2013). The main changes in applying the ESA methodology was in police implementation and land use intensity considered as adequate and low, respectively. The desertification risk decreased significantly; nearly 1% of the study area was classified as critical to desertification, while this class covered 22% of the area under the existing intensive cultivation practice (Fig. 6). Non-affected areas to desertification were almost doubled from 7.5% to 14.6% whereas the majority of areas previously characterized as critical were mainly classified as fragile in the ILM scenario (Table 5).

Table 5
Distribution of type of environmentally sensitive area to desertification in Messara Valley under the land management practices 'intensive cultivation' and 'integrated land management'.

Type of ESA	Intensive cultivation		Integrated land management	
	Area (ha)	Area (%)	Area (ha)	Area (%)
Non-affected (N)	5424	7.5	10,489	14.6
Potentially affected (P)	14,025	19.5	14,332	19.9
Fragile (F1)	6352	8.8	31,553	43.8
Fragile (F2)	15,144	21.0	12,302	17.1
Fragile (F3)	14,256	19.8	1754	2.4
Critical (C1)	12,693	17.6	634	0.9
Critical (C2)	2918	4.0	0	0
Critical (C3)	252	0.3	0	0
Other area	995	1.4	995	1.4
Total	72,059	100.0	72,059	100.0

4. Discussion

The in-depth analysis of the agricultural system in the area within a period of sixty years demonstrates the considerable effect of changes in land-use and land management on soil resources. The present study indicates that human activities contributed to soil deterioration, an outcome that is in accordance with findings of previous research (Blum, 2002; Tóth et al., 2008). The exact mechanism and intensity of the effects of human management on soils was depended on the interplay between local conditions and the underlying driving forces. Up to the early 1960s, securing the cereal provision for the next year was the major issue for such rural communities and a major issue for a cereal importing country like Greece in general. The cereal dominated areas were vulnerable to water erosion but, due to the limited technological means, mechanical erosion and groundwater overuse were rather limited.

Gradually during the 1960s and intensively in the 1970s olives and to a lesser extend vines were replacing cereals. Intensification of cereal production and the growing trade removed the incentive for growing cereals, on the other hand attractive olive oil prices and outmigration further enhanced a land-use suitable for absentee owners, namely olive orchards. In the long term olive orchards were less affected by water erosion than cereal fields. However, during the 'olive transition' period many fields that were planted with new olive trees were extremely vulnerable thus leading to the highest rates of water erosion in the whole study period.

Although olive trees, expanding during the last decades, are well adapted to the specific region, land desertification remains an important threat due to inappropriate agricultural practices. During the 'olive subsidy' period intensive cultivation, including further expansion of irrigation, formed the major practices reflecting a rational adaptation of the farming system to the changing in socioeconomic context. Throughout Greece, and Europe in general, agriculture intensified in suitable areas when the appropriate means (fertilizers, machineries, tools, etc.) became available. This led to increased production and increased income for the Messara farmers as well. However, it led to soil degradation and overexploitation of groundwater. Issues of declining land productivity and, especially, shortage of irrigation water, of varying intensity due to annual fluctuations of weather conditions, seem to have emerged already in some parts of the area.

Interestingly, local stakeholders have realized the importance of reducing land degradation processes as well as improving agricultural productivity. One way to protect soil in rural areas is the adoption of the ILM practice. The main target of ILM is the reduction of human footprint on the environment through the efficient and responsible use of natural resources. Such practices are underway in worldwide campaign for the adoption of sustainable land management practices (Bradford and Peterson, 1999; Lahmar, 2010; FAO, 2012).

The ILM response has already been initiated in the Messara Valley as a response to soil erosion, water pollution, land desertification and processes of natural resources degradation. The strategy was applied mostly in productive fields by medium-to-high income farmers and is limited by the availability of existing technologies and lack in social capital (e.g., common rules, knowledge and skills). If these limitations are overcome and the practice becomes mainstream, many of the misfits

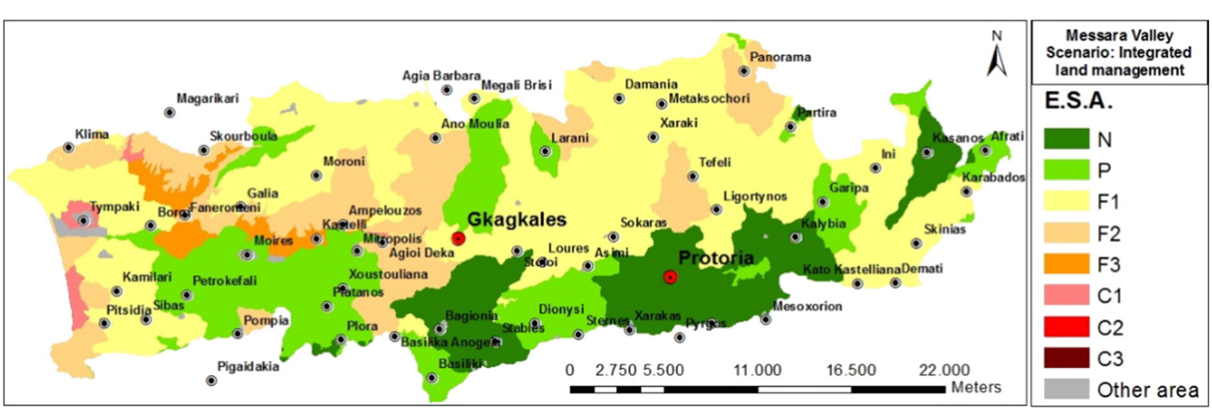

Fig. 6. Spatial distribution of environmentally sensitive areas to desertification of Messara Valley under the condition of applying integrated land management practice.

of intensive cultivation could be alleviated. The implementation of ILM practices can be successfully accomplished under the condition of low application cost, low time consumption, and secure potential for higher economic benefit.

Since soil erosion in the sloping areas of Messara Valley due to water and tillage is a major degradation process, protection of soil water storage capacity can be achieved by applying no-tillage or minimum tillage that allows the understory annual vegetation in olive groves and vineyards to grow. Such management practices, considered as a specific action in the ILM, do not only reduce soil erosion processes but also generate multiple benefits for the soil resources (Kurothe et al., 2014; López-Garrido et al., 2014). Sedimentation of water reservoirs and flooding risk in the lowland of the valley can be partly prevented by retaining adequate plant coverage of soils, especially during the wet period. Policy implementation on protection of soil resources from erosion minimizes desertification risk in the area.

The study of the evolution of land use and land management of the area revealed that changes were shaped through the interplay of processes at higher scales (e.g., rise in cereal productivity, outmigration, introduction of subsidies, tourism growth) with the local conditions (e.g., climate, geomorphology, culture, skills) (Detsis et al. 2010). The outcomes of this evolution with respect to land degradation may go to various directions as this study has shown: for example replacement of cereals by olive trees was positive for protecting natural resources, while mechanization occurring at the same time was negative by enhancing tillage erosion. Up to now, the changes in land use and land management practices were not due to land degradation but to broad socioeconomic changes. Although the risk on land degradation (soil erosion, land desertification) may change by, for example, the adoption of ILM practices, there is a whole interplay of global and local influences that has to be managed in order to steer in the long term the land use system towards a sustainable direction.

5. Conclusions

Monitoring the evolution of land degradation processes in conjunction with socio-ecological transformations in rural areas is a promising useful tool for prevention and/or mitigation of soil erosion and desertification risk. In Messara Valley, a typical rural Mediterranean semi-arid landscape, transformations in land use and land management practices proved to have a significant impact on soil erosion and land desertification risk. The environmental conditions as well as the changes in social and economic characteristics in the study area favored the gradual replacement of annual crops by more attractive (due to higher price of products and cultivation demands) olive trees. Despite the beneficial role of the new vegetation type (olive) to land degradation processes, mechanization and intensification led to a higher sensitivity of land to degradation. With the aim of reducing the drawbacks from the unsustainable land management, possible remedies include the integrated land management strategy. The relevant scenario analysis indicates a significant reduction in the intensity of the prevailing land degradation processes (soil erosion, desertification risk) in the Messara Valley.

Acknowledgments

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