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Land degradation and metropolitan expansion in a peri-urban environment

Vito Imbrenda^a , Giovanni Quaranta^b, Rosanna Salvia^b, Gianluca Egidi^c, Luca Salvati^d, Marcela Prokopová^e, Rosa Coluzzi^a and Maria Lanfredi^a

^aInstitute of Methodologies for Environmental Analysis – Italian National Research Council (IMAA-CNR), Potenza, Italy; ^bDepartment of Mathematics, Computer Science, and Economics, University of Basilicata, Potenza, Italy; ^cDepartment of Agriculture and Forestry Sciences (DAFNE), Tuscia University, Viterbo, Italy; ^dDepartment of Economics and Law, University of Macerata, Macerata, Italy; ^eGlobal Change Research Institute, Czech Academy of Sciences, České Budějovice, Czech Republic

ABSTRACT

The couple rapid urbanization and policy failure in controlling urban expansion was sometimes associated to soil and land degradation phenomena in both developing and developed countries. This work points to investigate the link between exurban development and soil/land degradation in the region of Athens (Greece) as a typical semiarid Mediterranean area experiencing a shift from a land-saving compact urban form to a dispersed, low-density urban expansion. The examined area is among the most populated areas in the Mediterranean basin showing an enormous population growth during the last 60 years. While low-density, dispersed urban settlements mainly developed over the decade (2000–2010) in the investigated area occupied mostly land classified at poor soil quality, the overall assessment of vegetation, climate and soil quality layers renders a complex picture in which exurban development consumed high-quality land that were classified as non-vulnerable to land degradation. On the contrary, compact urban settlements prevail in land with intermediate (or even high) soil quality but with inadequate climatic and vegetation conditions, which are classified as highly vulnerable to land degradation. Urban planning should integrate multi-dimensional indicators of soil, climate and vegetation quality to evaluate the environmental impact of exurban development.

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Exurban development; land degradation risk; urban planning; sustainable land management; peri-urban areas

Introduction

Spatial mapping addresses the need of differentiating areas with respect to detrimental/beneficial phenomena and processes on the basis of specific natural and anthropic features of the involved areas (Heidkamp 2008).

CONTACT Rosa Coluzzi rosa.coluzzi@imaa.cnr.it

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Until recently, the lack of tools able to achieve spatial analyses has prevented spatial variability from becoming a usual mean in various types of assessments.

With the emergence of geographic information system tools (GIS) and remote sensing techniques, spatial mapping has undergone a striking acceleration, spreading widely in many disciplinary fields.

As far as environmental degradation is concerned, it is common knowledge that its causes and effects are spatially distinct, thus it is very advisable to adopt spatial mapping to facilitate environmental analyses.

Land degradation, defined as the long-term loss of ecosystems services (MEA 2005), is more appropriately called desertification in drylands (Reynolds et al. 2011; Xie et al. 2020). This complex phenomenon originates from an ill-fated mix of natural and human drivers affecting worldwide different environments at various latitudes (Lambin et al. 2002; Adamo and Crews-Meyer 2006; Wang et al. 2012; Vu et al. 2014; Torres et al. 2015; Gibbs and Salmon 2015; Martínez-Valderrama et al. 2016; Ferrara et al. 2016; Jiang et al. 2019; Quaranta et al. 2020). Deterioration of soil properties through unsustainable management in combination with changing climate can lead to a fall in productivity beyond the point of no return with devastating effects on ecosystem services (Alados et al. 2011; Trnka et al. 2016; Huang et al. 2020). In order to calibrate suited actions inspired to the principles of sustainable management of resources and pursuing the target of land degradation neutrality (Vogt et al. 2011; Akhtar-Schuster et al. 2017; Gonzalez-Roglich et al. 2019), it is crucial to implement a holistic approach adopting as a milestone the land use and also encompassing all the relevant variables (meteorological, ecological, pedological, hydrological and geomorphological) contributing to the vulnerability to land degradation (Salvati and Zitti 2008; Salvati and Zitti 2009; Bajocco et al. 2012; Lanfredi et al. 2015; Coluzzi et al. 2019; Dave et al. 2019; Xu et al. 2019).

Given these premises, spatial analysis takes on great significance in indicating where and what actions should be undertaken to prevent, reduce or restore affected zones (Santini et al. 2010).

The persistent increase of population and its concentration in cities (Angel et al. 2011) which by 2050 is expected to be at 68% (United Nations Publications 2018) was recently amplified by an increased interconnection among urban areas due to high social productivity and market economy (Teaford 2006). This implies inevitable repercussions on the quality and quantity of natural resources (soil, vegetation, groundwater and water bodies, traditional landscapes) with metropolitan areas that are particularly impacted (Dutta et al. 2020) determining loss or reduction of ecosystem services (biodiversity, crop production, water and air quality, soil functions, etc., see Rahman et al. 2011).

In this context, peri-urban areas attract major attention from planners because their role is critical in causing soil loss/degradation that impact or reduce natural capital (Graves et al. 2015; D'Emilio et al. 2018; Cheng et al. 2018). Planning policies have developed significantly since the first half of nineties to address the complex question of designing and managing new urban areas while preserving natural resources (Barbosa et al. 2007).

The centre gravity of this issue is certainly the land, i.e., the 'place' where different soil uses compete and that is the most impacted by urban growth (Portnov and

Safriel 2004). The obvious example is an impact of peri-urban land use change implying trade-off between maintaining local agriculture and economic and social benefits of urbanization (Dolley et al. 2020). Urban expansion results in increasing pressures on natural resources, on agricultural land and causes degradation of ecosystem services as cities expand (Dolley et al. 2020; Parnell 2016; Seto et al. 2017). Among the most influential drivers of disturbance, urbanization, especially when its pace is rapid, represents an important anthropogenic process affecting worldwide peri-urban areas (Telesca et al. 2009; Zambon et al. 2017; Abubakar et al. 2020; Alipbeki et al. 2020). In most parts of Europe, urbanization, urban sprawl and growing demand for land cause increasing soil sealing (Prokop et al. 2011; Barbero-Sierra et al. 2013; Gardi et al. 2015; Cuadrado-Ciuraneta et al. 2017; Delfanti et al. 2016), soil degradation (Colantoni et al. 2015; Erisman et al. 2016), decreasing performance of natural functions such as biomass production, water storage and filtering or soil quality regulation (Gardi et al. 2015). It is also associated with other negative aspects such as loss of habitats and land fragmentation and water/air pollution (Erisman et al. 2016), reduced evapotranspiration (Carlson and Arthur 2000), increased overland flow and streamflow (Fletcher et al. 2013; Miller et al. 2014) and considerable precipitation changes associated with ‘heat island’ effect (Kalnay and Cai 2003). These changes contribute to food security threat (Ceccarelli et al. 2014; Glaesner et al. 2014) because it decreases productivity and tends to occur on the most fertile soils (Nizeyimana et al. 2001). These pressures are further intensified by climate change (Foley et al. 2005; Chapin et al. 2010).

The main reasons for exurban development phenomena are ascribable to decentralization of economic activities, building of new transport infrastructures, and research of improved living conditions (e.g. Salvati et al. 2019; Ponstingel 2020). Furthermore, the rising urban expansion is increasingly decoupled from population trends (growth of urban covers in areas showing stable or declining resident population) contributing to ‘declare’ cities as the great consumers of land (Hill et al. 2008; Petrov et al. 2009).

Unmeasured and unplanned urbanization observed in both developed and developing countries has been more and more connected to the concept of land degradation/desertification (Feng et al. 2015). The recent establishment of strategic objectives at global or European level (e.g. Zero Net Land Degradation by 2030, Zero Net Land Take by 2050, see UNCCD 2012; Stavi and Lal 2015; Gardi 2015), responding to the need for more respectful land management practices (Fleskens and Stringer 2014; Giger et al. 2018), widely testifies the strict interconnections between the mentioned phenomena. Particularly, for the Mediterranean Basin the United Nations Convention to Combat Desertification (UNCCD) developed the special Annex IV containing some sobering facts concerning how land degradation is linked to social disparities between north/south and coastal/inland areas (Sommer et al. 2011; Salvati et al. 2016; Briassoulis 2019).

This Annex is focused on protection/preservation measures for facing land degradation phenomena in rural areas, while peri-urban areas are identified as potential target for land degradation mitigation (Salvati et al. 2012; Pili et al. 2017; Capozzi et al. 2018). Paradoxically, this approach is refutable due to the wide literature testifying

the different pressure observed along the urban-rural gradient in both environmental and socio-economic terms. Starting from climate, it is ascertained that peri-urban districts suffer a drier and hotter local climate in comparison with neighboring rural areas by virtue of global/regional climate changes effects (temperature increase, changes in seasonality rainfall patterns, higher frequency of extreme events, see e.g. Caloiero et al. 2018; Lanfredi et al. 2020; Spinoni et al. 2016) and local warming phenomena (urban heat islands, see e.g. Hamin and Gurran 2009; Zhao et al. 2020). At the same time, also peri-urban soil and vegetation exhibit similar behaviours (Salvati et al. 2013; Su et al. 2014).

Lastly, it is evident that these areas bear a higher anthropic level of disturbance in comparison with surrounding rural areas causing harmful effects on soil, water, wetland and biodiversity (e.g. Monarca et al. 2009; Imbrenda et al. 2018). This is further magnified by the fact that socioeconomic factors in peri-urban regions have deep and more rapid impact on environmental matrices with respect to rural areas (Özgülner et al. 2012). In particular, as regards Mediterranean and Middle East regions, cities have changed their growth pattern: from compact expansion to low-density, dispersed development (see Patacchini et al. 2009; Salvati et al. 2013; Díaz-Pacheco and García-Palomares 2014; Masoumi 2014; Serra et al. 2014; Carlucci et al. 2017; Zambon et al. 2018; Duvernoy et al. 2018; Guastella et al. 2019). This phenomenon can be observed in other cities scattered all over the world (Salvati et al. 2018; Mortoja and Yigitcanlar 2020; Anees et al. 2020) and may cause high pressure on natural resources and vulnerable landscapes. On the basis of these observations, research investigations should better explore the intimate link between exurban development and land degradation in the perspective to support regional and local policies to prevent/mitigate desertification risk in new and growing peri-urban lands (Pessarakli et al. 2019).

In this work, the relationship between exurban development and land degradation is analysed taking as a paradigmatic case for the Mediterranean urban region the metropolitan area of Athens (Attica, Greece, see e.g. Salvati and Serra 2016) notoriously considered an area vulnerable to land degradation due to both natural (climate and geotopographical factors) and anthropogenic drivers (e.g. urban growth). In particular, the rapid urbanization in the rural-urban fringe of this region has showed a critical shift from a land-saving compact form to a dispersed, low-density urban expansion with detrimental effects on the neighbouring arid landscapes (Salvati et al. 2012). More in details, a notable part of Greece (about 30%) is considered as highly vulnerable to land degradation/desertification (Karamesouti et al. 2015; Kosmas et al. 2016; Karamesouti et al. 2018). The Attica region encompasses some features that make it a hotspot of degradation as a result of a semi-arid climate expected to be drier and warmer in the next decades (Giannakopoulos et al. 2011) and the great population density which is one of the highest in the Mediterranean Basin. This condition is further exacerbated by several natural predisposing factors such as low-quality soils prone to erosion, sparse and often stressed vegetation (Yassoglou 2004).

The socio-economic dynamics attributable to human interventions have contributed to increase the vulnerability especially through policies of diffused planning deregulation (Chorianopoulos et al. 2010). In the light of this, Athens' region can be legitimately conceived as a useful laboratory where the development of integrated

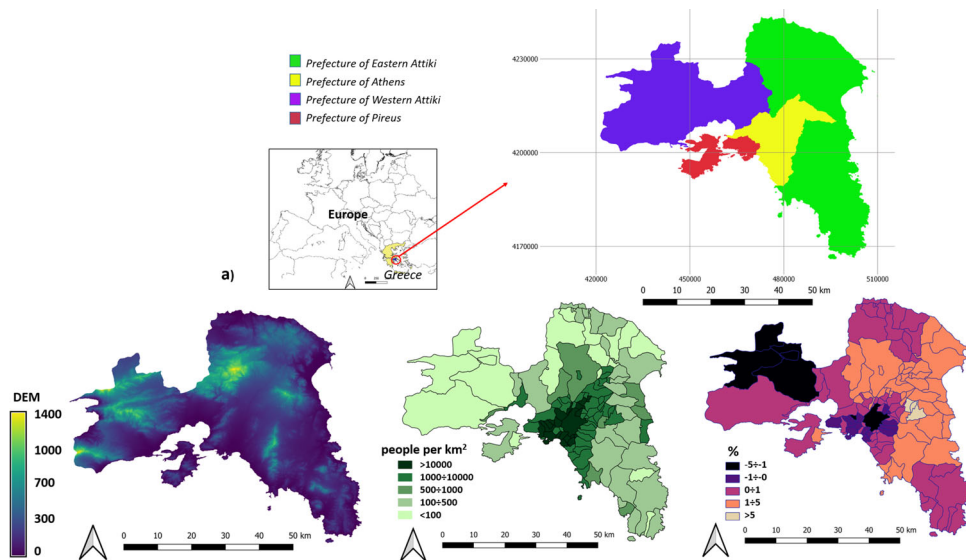


Figure 1. The study area of Attica (a) location of four prefectures of Attica (Greece); (b) EU-DEM (European - Digital Elevation Model, see Gras D. 2014); (c) population density in 2011; (d) annual rate of population growth (%) in the period 2001–2011.

urban planning and sustainable land management investigations can help to address land degradation issues, since these matters are common to all the peri-urban areas of the Mediterranean Basin.

The purpose of this work is to achieve a quantitative assessment of the vulnerability level to land degradation/desertification to be then encapsulated in a proper and sustainable strategy of land planning aimed at limiting adverse effects of low-density urban expansion. Starting from an appropriate land classification founded on four criteria encompassing biophysical (climate, soil and vegetation) and anthropic (land management) components, the paper estimates relative values of vulnerability to land degradation. Quantitative findings can provide local authorities with prioritization of intervention in affected areas, verifying simultaneously if the recent urban sprawl of Athens has occupied low or high-quality lands according to the above-mentioned criteria. Finally, we discuss the role of multi-criteria evaluation of land quality in the perspective of supporting sustainable plans of development at regional/local scale including strategies of mitigation for land degradation phenomena connected to low-density urban growth.

Methodology

Study area

Attica region, located in central Greece, extends for nearly 3000 km² and is subdivided in four prefectures (Athens, Pireaus, western Attica and, eastern Attica) consisting of 84 communes and 30 local communities (for a total of 114 municipalities) before the local authority reform enforced in law in 2011 (Figure 1). The region is characterized by a semi-arid Mediterranean climate, with dry and hot summer

periods and mild and relatively wet winters. Athens is surrounded by four mountains (Parnitha, Penteli, Imitos and Egaleo) reaching the maximum elevation of 1413 m at the sea level. Sloping lands occupy a significant part of the area with soils formed mainly on limestone, shale, marble and alluvial deposits.

Assessment of land degradation vulnerability

The land degradation vulnerability analysis was done following the original scheme of MEDALUS project (Kosmas et al. 1999; Ferrara et al. 2020) based on four sets of basic indicators inserted in the environmentally sensitive area (ESA) procedure: climate quality index (CQI), soil quality index (SQI), vegetation quality index (VQI) and management quality index (MQI) (see e.g. Imbrenda et al. 2013; Mohamed 2013; Imbrenda et al. 2014; Salvati et al. 2016; Právělie et al. 2017; Perovic et al. 2021). This methodology has been widely validated at regional scale (see Lavado et al. 2009).

Soil parameters influencing land status were analysed through six basic variables: texture, depth, parent material, rock fragments, drainage and slope. The Soil Association Map of Greece (scale 1:850,000), the EU-DEM 1.1 (Digital Elevation Model) (EU Copernicus Programme 2016) and soil cartography from the EU Joint Research Centre of Ispra (Yassoglou 2004) were jointly used to build a synthetic indicator of SQI.

The CQI is related to the impact of climate variation on land. In this work, it was obtained by combining three variables: aridity index, average annual rainfall and the aspect of sloping land. These data are derived from 97 meteorological stations, rather homogeneously distributed over Greece, providing data for the time span 1950–1990. Specifically, the mainland Attica hosts more than 10 stations. From a methodological point of view, data from the stations were spatially interpolated following two steps. First, Thiessen polygons were created to delimit the area of influence of each meteorological station. Data were then correlated to elevation, with a step of 200 m difference in altitude.

The VQI was analysed based on four variables of the standard MEDALUS method, i.e. fire risk, soil erosion protection, drought resistance and plant cover. The 2000 Corine Land Cover (CLC) map (scale 1:1,000,000) has been adopted to derive the abovementioned variables. CLC maps have been developed by the European Environment Agency within the COoRdinate Information and Environment programme (Büttner et al. 2002). Its core is an inventory of 44 land cover/land use classes referring to urban areas, cropland, forests and pastures, water bodies and wetlands that have been mapped throughout Europe. For each one of the above-mentioned variables, a vulnerability score was associated to each land cover class according to the MEDALUS methodology (Kosmas et al. 1999). Finally, also the more direct contribution of the human component (MQI) is taken into account by means of a land-use intensity index, considered as a proxy of anthropic pressure. It was computed for the whole examined area together with an index of land protection policy enforcement based on the extent of protected areas of national or regional parks.

SQI, CQI, VQI and MQI have been derived as the geometric average of the relative considered variables:

$$\text{SQI} = (\text{Rock Fragments} * \text{Drainage} * \text{Parent material} * \text{Texture} * \text{Soil depth} * \text{Slope})^{1/6}$$

$$\text{CQI} = (\text{Rainfall} * \text{Aridity} * \text{Aspect})^{1/3}$$

$$\text{VQI} = (\text{Fire risk} * \text{Erosion protection} * \text{Drought resistance} * \text{Vegetation cover})^{1/4}$$

$$\text{MQI} = (\text{Land use intensity} * \text{Policy enforcement})^{1/2}$$

To define the simple, final index ESAI index (ESAI), able to identify areas with different degrees of vulnerability to land degradation, the geometric mean was applied to four equally-weighted sub-indices abovementioned.

The ESAI is classified in a standard score range from 1 (very little vulnerability) to 2 (highly vulnerable).

According to the MEDALUS method (Kosmas et al. 1999), there are four vulnerability classes based on the stage of land degradation phenomena (Basso et al. 2000; Lavado et al. 2009; Salvati et al. 2012; Izzo et al. 2013): (i) areas unaffected by land degradation ($\text{ESAI} < 1.17$), (ii) areas potentially affected by land degradation ($1.17 < \text{ESAI} < 1.22$), (iii) 'fragile' areas ($1.23 < \text{ESAI} < 1.37$) and (iv) 'critical' areas ($\text{ESAI} > 1.37$). The 'fragile' and 'critical' classes have been subsequently divided in three sub-classes: F1 ($1.23 < \text{ESAI} < 1.26$), F2 ($1.27 < \text{ESAI} < 1.32$), F3 ($1.33 < \text{ESAI} < 1.37$), C1 ($1.38 < \text{ESAI} < 1.41$), C2 ($1.42 < \text{ESAI} < 1.53$) and C3 ($\text{ESAI} > 1.53$).

Assessment of metropolitan growth

The different land uses identified in Attica have been extracted from the Urban Atlas (UA) classification (European Environment Agency 2011). The UA is a high-resolution database at pan-European scale offering comparable land-use and land cover information for Large Urban Zones (populated by more than 100,000 inhabitants) as defined by the Urban Audit programme, which is a geo-referenced source providing reliable and comparative information on different urban areas located within European Union and in the Candidate Countries. Land use is sorted according to around 30 hierarchical classes grouped into several main categories. Based on the expected population density (UA code in brackets), the 20 UA land-use classes observed in Attica have been divided into three wider categories: (i) urban areas characterized by dense and compact settlements including continuous urban fabric (with surface land $> 80\%$, see 11,100 class), industrial, commercial, public, military and private units (12,100 class), and port areas (12,300 class); (ii) urban areas with moderately dense settlements including discontinuous dense urban fabric (Surface Land between 50% and 80%, see 11,210 class), discontinuous medium density urban fabric (Surface Land. Between 30% and 50%, see 11,220 class), mineral extraction and dump sites (13,100 class), green urban areas (14,100 class), sports and leisure facilities (14,200 class) and airports (12,400 class); (iii) low-density urban areas including discontinuous low density urban fabric (Surface Land between 10% and 30%, see 11,230 class), discontinuous very low density urban fabric (Surface Land $< 10\%$: 11,240), isolated structures (11,300 class), fast transit roads and associated land (12,210 class), other roads and associated land (12,220 class), railways and associated land (12,230 class), construction sites (13,300 class), and land without current use (13,400 class). The other land-use categories, present in the study area include: agricultural, semi-

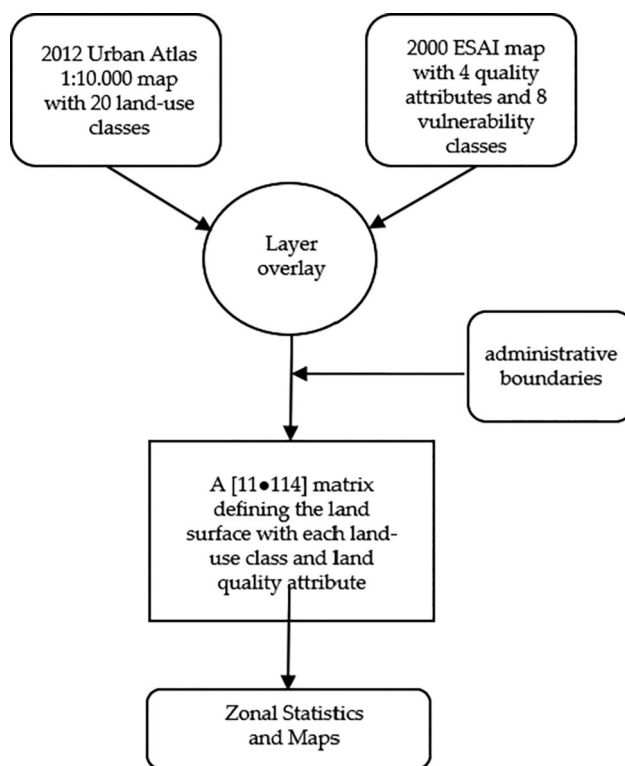


Figure 2. The flow chart representing the procedure adopted in this work.

natural areas and wetlands (20,000 class), forests (30,000 class) and water bodies (50,000 class).

Statistical analysis

A first descriptive analysis was performed to correlate the ESAI with a selection of variables including elevation, closeness to the sea and proximity to sealed lands (see [Figure 1](#)). More specifically, we overlaid the ESAI 2000 map with the UA 2012 map to extract information on the environmental conditions possibly leading to land degradation in areas characterized by low-density dispersed urban expansion. Extent of areas showing given land qualities (according to the above described indicators: SQI, CQI, VQI, MQI and ESAI) within each land-use class has been computed by intersecting the UA map with land-use polygons and the ESAI map polygons using spatial statistics tools of the free and open-source desktop GIS software QGIS version 3.14 (<http://qgis.osgeo.org>). A flowchart describing the procedure adopted in this study is in [Figure 2](#).

Results

The structure of Athens' metropolitan region

From a demographic point of view, the case of the Attica region is striking because in the face of covering only 3% of the Greece surface, Attica is one of the most

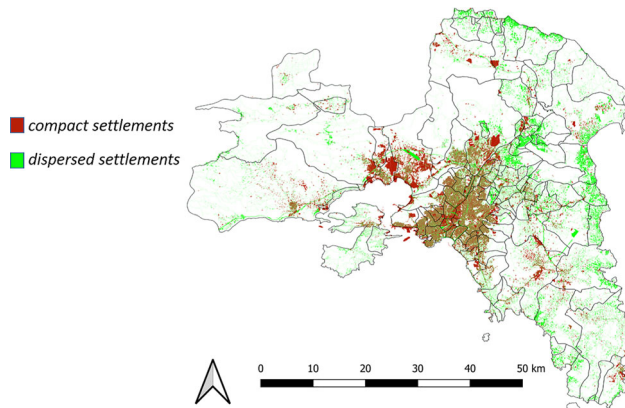


Figure 3. The 2010 urban footprint of Attica: compact and dispersed urban settlements. The zone where red and green areas are mixed indicates the metropolitan area of Athens.

populated regions in Europe showing a population density of about 1250 inhabitants/km² compared to the European average density (close to 120 inhabitants/km²). Particularly, the highest values of population density were observed in the urban prefectures of Athens and Pireaus. Due to exurban development, eastern Attica population grew at the highest rate followed by Western Attica. The joint analysis of the UA land-use map and demographic statistics suggests that the urban structure of Attica can be considered predominantly compact and dense. However, the presence of low-density, dispersed settlements around Athens is concentrated in Eastern and Western Attica prefectures. Rural areas persist at the boundaries of the region especially in the proximity of mountains (Figure 3) where the main land uses are cropping and forestry.

A brief outline of the driving forces determining vulnerability to land degradation in Attica

The information collected to built-up the ESAI has been used to describe the main factors determining the level of vulnerability of the study area (Figure 4). The dominant parent material of the area is limestone, mostly in areas with slopes exceeding 10%. Such a combination favours soil erosion phenomena. While only 4% of Attica soils shows poor textural quality, a large part of the investigated lands (about 70%) exhibits shallow to very shallow soil depth. Areas characterized by gentle slopes occupy half of the Attica, whereas slope is greater than 18% in more than one-third of study area with consequent severe soil erosion facilitated by sparse vegetation cover due to recurrent forest fires. The average SQI obtained for the study area (1.35) suggests the prevalence of moderate to low-quality soils, mainly concentrated in the prefecture of western Attica. Notably, as far as vegetation, only 41% of the Attica is covered by vegetation species providing an acceptable level of protection from soil erosion phenomena.

The average rainfall in Attica is rather scarce especially in lowland areas (350 mm/year), whereas mountain areas experienced larger amounts of rainfall (more than

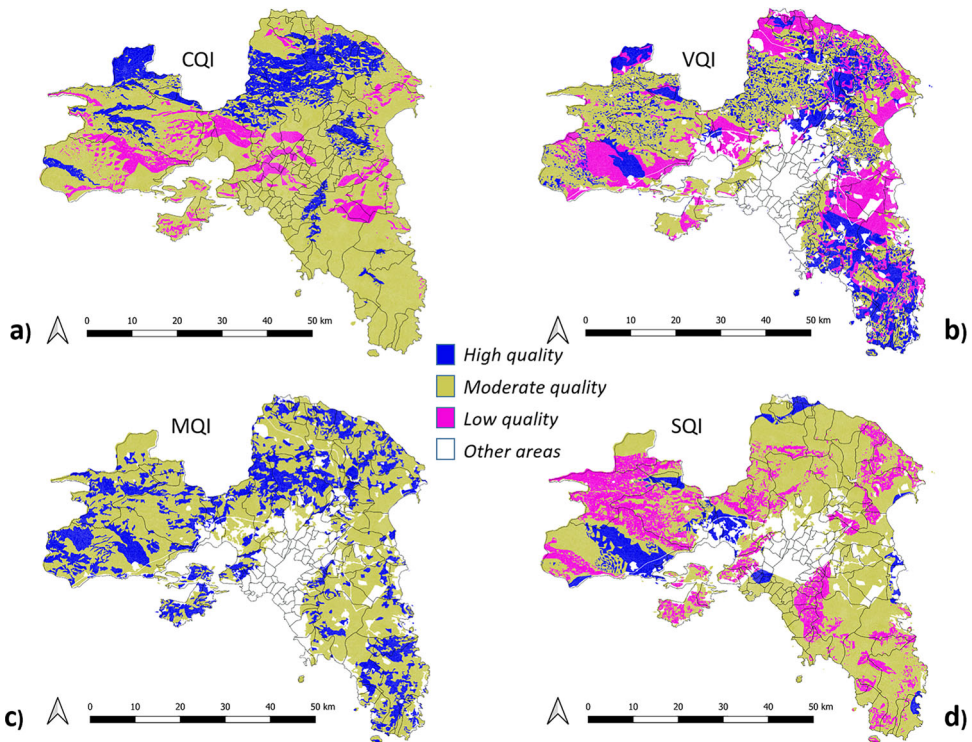


Figure 4. Classification in quality levels of the four thematic indicators composing the ESAI in Attica.

600 mm, with intense precipitation events during autumn and spring). According to Bagnouls-Gausson index, a large part of the area can be labelled as arid. On the whole, the observed average CQI of the area is 1.46 meaning moderate-to-low level of climate quality. The poor climate quality is substantially due to low rainfall amounts together with a high aridity index. About 55% of the study area harbours vegetation types that ensure moderate soil protection against drought, which is a typical phenomenon occurring in Attica. The most vulnerable soils to drought fall within non-irrigated arable land and natural grasslands, which occupy almost 24% of the area.

Attica is strongly affected by fires events due to the large presence of pine and maquis communities. A considerable part of the study site (about 43%) is occupied by non-forest areas including mainly pastures showing a moderate proneness to fire risk, while forestlands, the more vulnerable class to fire risk, covers only 10% of whole surface area. Areas covered by vegetation at low fire risk are mainly devoted to cropping and occupy only 4% of Attica. Overall, the averaged value of VQI (1.25) suggests that the quality of the Attica vegetation is moderate. Clustered areas showing poor vegetation quality are largely located in the south-eastern part of Eastern Attica (where vineyards dominate) and the south-western part of Western Attica (high presence of heterogeneous agricultural crops).

Last, looking at the MQI, we find out that a significant part of the area (almost 70% of the area) is subject to a moderate land use intensity Policy implementation towards environmental protection measures appears to be partial only in 65% of the area. On the

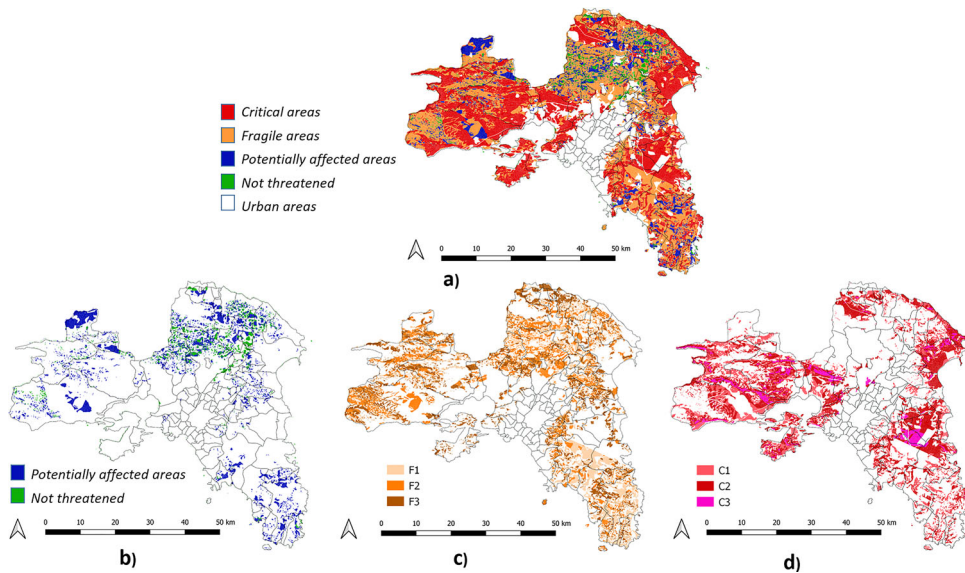


Figure 5. The spatial distribution in Attica of non-affected, potentially affected, fragile and critical areas according to the ESAI classification. The last two classes are further subdivided into three sub-classes (letters c) and d)) with increasing levels of vulnerability to land degradation.

whole, the spatial analysis of the ESAI suggests that the prevailing class in Attica is ‘fragile’ and ‘critical’ to desertification (Figure 5). Generally, areas with higher vulnerability values concentrate in the prefectures of Piraeus and Western Attica.

The relationships among the ESAI, urban expansion and the demographic component

A quick comparative analysis of the ESAI with the features of urban settlements in Attica indicates that ESAI decreases as the distance from the centre of Athens increases. Climatic conditions appear to be decisive to ‘declare’ highly vulnerable areas experiencing compact urban development, despite the fact that these areas showed higher soil quality values compared to land covered by moderately dense and low-density settlements during the period 2000–2010 (Table 1). Vegetation quality is crucial in determining the vulnerability level to land degradation in those areas characterized by poor climatic conditions. At the same time, areas with fertile soils unfavourable climatic conditions and poor land management practices are the main drivers of land degradation risk (Table 2). This pattern has been generally found in areas experiencing low-density urban expansion. Lastly, correlations between the demographic component and the ESAI are not statistically significant neither in a linear way (Pearson’s correlation coefficient) nor in a not linear way (Spearman’s correlation coefficient).

Discussion

This study explores the link between the notable urban growth observed in the decade (2000–2010) in the metropolitan region of Athens and the geography of

Table 1. Average scores of the four thematic indicators and the ESAI reported for the Attica by selected variables.

Variable	CQI	SQI	VQI	MQI	ESAI	Area (km ²)
Athens' metropolitan region (grand total)	1.46	1.35	1.25	1.40	1.35	3040
Land-use type						
11,100 – Continuous Urban Fabric (S.L.>80%)	1.59	1.28	1.29	1.44	1.39	108
11,210 – Discontinuous Dense Urban Fabric (S.L.: 50–80%)	1.53	1.32	1.31	1.43	1.39	125
11,220: Discontinuous Medium Density Urban Fabric (S.L.: 30–50%)	1.48	1.30	1.31	1.43	1.37	95
11,230 – Discontinuous Low Density Urban Fabric (S.L.: 10–30%)	1.46	1.29	1.32	1.42	1.37	75
11,240 – Discontinuous Very Low Density Urban Fabric (S.L.<10%)	1.46	1.28	1.33	1.43	1.37	11
11,300 – Isolated structures	1.41	1.33	1.26	1.40	1.34	20
12,100 – Industrial, commercial, public, military and private units	1.52	1.29	1.27	1.43	1.36	131
12,210 – Fast transit roads and associated land	1.62	1.30	1.32	1.44	1.40	7
12,220 – Other roads and associated land	1.45	1.37	1.26	1.39	1.35	141
12,230 – Railways and associated land	1.56	1.33	1.28	1.41	1.37	3
12,300 – Port areas	1.50	1.31	1.24	1.38	1.38	13
12,400 – Airports	1.76	1.20	1.45	1.47	1.46	13
13,100 – Mineral extraction and dump sites	1.50	1.38	1.27	1.40	1.38	15
13,300 – Construction sites	1.56	1.29	1.32	1.42	1.39	6
13,400 – Land without current use	1.53	1.26	1.30	1.47	1.38	7
14,100 – Green urban areas	1.48	1.26	1.25	1.41	1.33	28
14,200 – Sports and leisure facilities	1.46	1.31	1.25	1.42	1.35	19
20,000 – Agricultural + Semi-natural areas + Wetlands	1.43	1.37	1.24	1.41	1.35	1917
30,000 – Forests	1.34	1.39	1.22	1.34	1.31	293
Elevation class (m)						
0 – 200	1.58	1.33	1.31	1.41	1.40	1513
201 – 400	1.40	1.35	1.22	1.41	1.34	798
401 – 600	1.22	1.39	1.19	1.40	1.29	383
601 – 800	1.16	1.43	1.19	1.40	1.28	203
801 – 1000	1.13	1.42	1.18	1.39	1.27	100
>1000	1.12	1.39	1.20	1.32	1.25	32
Distance from the sea (km)						
0 – 1	1.47	1.35	1.29	1.40	1.34	484
1 – 2	1.49	1.35	1.30	1.40	1.38	370
2 – 3	1.47	1.34	1.29	1.40	1.37	311
3 – 5	1.46	1.35	1.26	1.40	1.35	556
>5	1.48	1.34	1.23	1.42	1.33	1317
Distance from impervious land (m)						
0 – 100	1.49	1.34	1.27	1.41	1.36	1883
101 – 200	1.42	1.38	1.24	1.39	1.35	409
201 – 500	1.38	1.40	1.22	1.40	1.34	479
501 – 1000	1.30	1.41	1.20	1.41	1.32	178
>1000	1.22	1.43	1.17	1.43	1.29	91

Table 2. Average ESAI, SQI, CQI, VQI and MQI values for the Prefectures of the Attica region.

Region	ESAI			Average				Area (km ²)
	Average	CV	Max–min	SQI	CQI	VQI	MQI	
Prefecture of Eastern Attiki	1.341	0.076	1.103–1.638	1.34	1.41	1.24	1.39	1521.091
Prefecture of Athina	1.343	0.071	1.111– 1.586	1.41	1.52	1.20	1.41	354.139
Prefecture of Western Attiki	1.360	0.077	1.100–1.638	1.36	1.49	1.26	1.39	1003.362
Prefecture of Piraeus^a	1.436	0.044	1.207– 1.620	1.43	1.55	1.23	1.24	147.087

^aonly mainland of Attiki and Salamina, islands are not included.

vulnerability to land degradation of these areas. This is achieved through the integration of high-resolution land-use maps and multi-criteria environmental indicators supported by spatial analysis and zonal statistics. The impressive enlargement of Athens urban areas in the time span 2000–2010 is attributable to sprawling patterns mainly due to the development of infrastructural facilities having heavy repercussions

on the landscapes located within the urban fringe belt (Salvati et al. 2012). This circumstance is rather common in similar peri-urban areas belonging to different developing countries (Johnson and Lewis 2007; Terfa et al. 2020), with particular reference to northern Africa and middle East regions (Masoumi et al. 2018; Capozzi et al. 2018; Riad et al. 2020).

Findings obtained from the analysis carried out in this article support the idea that Attica can be regarded as a paradigmatic case study of the strong linkage existing between exurban growth and land degradation phenomena. What emerges is that vulnerability to land degradation is certainly influenced by a set of variables that reflect complex socio-economic and territorial contexts in which anthropogenic pressure likely drives the level of vulnerability at municipal scale but it does not seem to be directly connected with demographic pressure (i.e. settlement) or with its increase over time both for medium-short and for longer periods explored synergistically as in this work.

Although a preliminary analysis demonstrates that low-density, dispersed urban settlements developed during 2000–2010 occupied land with poor-quality soils, a more in-depth reflection, embracing an overall assessment of vegetation, climate and soil, illustrates how exurban development happens at expense of high-quality land. On the contrary, compact urban settlements rest on land with intermediate (or even high) soil quality levels coexisting with low-quality conditions of climatic and vegetation layers which confer to the area a high vulnerability to land degradation.

Specifically, the study furnishes evidence that there is a possible mismatch between the targets of urban planning and the conservation of land quality. The evaluation of land take features in Athens' region can lead to very different results depending on the considered variables: (a) single parameter connected to land degradation processes; (b) complex and all-embracing indicator like the ESAI. Interpretations of data based on single parameters (climate aridity in state of soil depth or vegetation density) may mislead inducing to affirm that high-quality soils are not associated to the recent development of low-density, dispersed settlements in Attica.

Multi-criteria indices are able to evaluate land vulnerability levels efficiently and in a more thorough way than single indicators of land quality. The issue of spatial expansion of built-up areas with potential consumption of high-quality land resources should be addressed in a 'holistic' perspective especially for the fragile peri-urban areas. The management of peri-urban areas with high or low environmental quality should be treated differently. Soil with high-quality pedological features should be preserved from chaotic forms of urban development and subjected to stricter conservation policies, whereas it is admissible that soil with poor qualities (and vulnerable to land degradation) can be occupied by medium-density contiguous residential settlements possibly intermixed with green areas (urban parks, gardens, etc.) to preserve landscape functionality and connectivity and reduce biodiversity loss (Portnov and Safriel 2004; Aronson et al. 2017).

In this perspective, focusing on abandoned lands located at the fringe as target areas could be an effective strategy to reach a right trade-off between landscape supply capacities and society demands. These areas, in fact, are the most vulnerable to land degradation, falling in the 'critical' classes of the ESAI, due to a mix of causes

(local climate conditions, poor edaphic properties of soil horizons, high anthropic pressure, see Salvati et al. 2013). Being not far from functional sterility conditions, these areas are not able to sustain an economically and ecologically sustainable production for agricultural, forestry or livestock purposes. Given these premises, planning processes in rapidly growing Mediterranean cities could take into consideration the possibility of ‘sacrificing’ these lands to the settlement of semi-compact urban land uses, respecting the principle of “the lesser of evils”. Nonetheless, planning policies are problematic in these complex areas due to various environmental components (soil, climate and vegetation) which are not spatially correlated, as testified by the findings of the multivariate analysis applied in this study. The analysed case, undoubtedly, lends itself to an ambiguous interpretation with regard to the optimal criteria for regional planning and sustainable land management, putting in evidence the existence of a complex picture needing of a comprehensive planning approach which takes into account multiple dimensions concurrently.

From a planning point of view, analyses incorporating the estimation of land degradation vulnerability are still lacking especially in developing countries (Greiving et al. 2006). Generally, land degradation and its more severe form, desertification, are still conceived as phenomena affecting mainly agricultural areas provoking loss or deterioration of crop quality/quantity. Also natural and semi-natural covers surrounding cities are, actually, experiencing a drastic worsening of environmental conditions (Louwagie et al. 2016; Wang et al. 2018).

The present work strives to provide useful strategies to limit side effects of exurban growth in a very fragile Mediterranean area (combination of soil degradation, local effects of climate change and landscape fragmentation in a troubled socioeconomic milieu) through the adoption of a consolidated methodology (Li et al. 2018). The used framework MEDALUS is useful in providing a synthetic index of land degradation vulnerability accounting the quality of different layers (climate, soil, vegetation and anthropic pressure). Here, it is profitably adopted to estimate how urban growth affects proximate areas (both vulnerable and not vulnerable to degradation processes) undermining their environmental conditions at the regional scale (Bestelmeyer et al. 2015). This methodology is suggested as a practical tool to evaluate over time and space the quality of basic land features that could be considered as relevant targets in a strategy aimed at containing desertification risk in Mediterranean areas with a special focus on the critical peri-urban regions (Salvati et al. 2013).

Once determined, the target areas thanks to the presented procedure it can be possible to characterize the sites of interest for subsequent actions of mitigation/restoration.

In fact, site characterization is an essential step in ecological restoration actions of landscapes at desertification risk. The decisions to restore are taken at landscape level by using models that do not take into account the micro-site variability. Non-spatial models are prone to the negative effects of spatial dependence, which can result in unreliable and potentially misleading results. Such adverse effects can be reduced by adopting geostatistics techniques and multivariate spatial regression to compute spatial regression parameters and to characterize site conditions without recurring to the oversampling.

Most of the restoration actions implies the evaluation of suitable conditions and plant species. However, very often the planting is not appropriate because it is not

spatially targeted. The common and consolidated way is to adopt afforestation measures over large areas. In particular, regarding soil erosion, several specific approaches are suggested and some of which are also spatially targeted (e.g., buffer strips) even if they are rarely encapsulated in an integrated and consistent manner within the whole catchment.

Even though land degradation is a global concern, it has to be managed on a local and regional scale where the measures have to be undertaken. Land planners and landowners are responsible for restoration management actions; however, they are often unaware of their role in the larger-scale process. As an example, in the case of erosion phenomena simulation modelling for predicting soil erosion under different conditions of soil management and land use may be integrate by land managers to locate erosion hot-spots and consider site-specific sustainable interventions. Through this wide approach, the specific decision taken imposes stricter regulations involving mitigation/conservation/restoration measures to provide aid to landowners. However, it is still important to consider how these individual decisions fit together at landscape scale and whether spatial interactions have effects on functioning or have detrimental impacts down system.

Conclusions

Expansion of urban settlements has been enlarging worldwide. Therefore, urbanites demand for natural areas has expanded, and it is now considered a key environmental issue. These phenomena overlaid to climate change, especially in some parts of the world.

The next few years will see an increase of 2.3 billion people in the world, and the urban areas will have an average population increase of about 30%. This is happening not only in developing countries characterized by continuous economic development, but it is also taking place in the Old Continent, where by 2050, 80% of population will be urban (United Nations 2019).

In this regard, land take for urban growth and the immediate worsening of environmental conditions in natural and semi-natural areas must be included among the most important side effects of urbanization. In particular, vegetated areas surrounding urban settlements (kitchen gardens, crops, grasslands, sparsely vegetated areas, shrublands, etc.) are the preferred targets of urban expansion inducing often a complete loss or a serious worsening of their quality resulting in incoming or enhanced land degradation phenomena.

This translates into a paradoxical competition between land for housing and land for food, thus leading to a heavy reduction of soil storage functions of carbon and water and an increase of interface area between urban and rural areas, amplifying the possibility of occurrence of other damaging events (e.g. fires, floods). Definitely, what emerges is the need to embrace a new approach in making land-use policies, orienting decisions towards more sustainable strategies based on effective tools providing quantitative estimations of current states of environmental conditions and ongoing trends of land transformations.

This study goes in this direction definitely pointing out the key role of ecological, social and economic factors influencing land degradation and exurban development in the metropolitan area of Athens. A multi-criteria assessment of these dimensions informs spatially balanced developmental policies. Sustainable land management at the urban-rural interface is particularly important in the territorial contexts where planning strategies are not considering the dynamic interactions among these components.

The challenge is containing the adverse impacts of human activities on environmental matrices, while keeping unaltered the socio-economic benefits deriving from them and promoting the development of more resilient communities.

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ORCID

Vito Imbrenda  <http://orcid.org/0000-0002-1846-7704>

Rosa Coluzzi  <http://orcid.org/0000-0003-0420-082X>

Maria Lanfredi  <http://orcid.org/0000-0003-4659-5233>

Data availability statement

The data that support the findings of this study are available from the coauthor Luca Salvati upon reasonable request. Please contact the corresponding author Rosa Coluzzi for this request.

References

- Abubakar GA, Wu J, Shahtahmassebi AR, Wang K. 2020. Necessity of a multifaceted approach in analyzing growth of impervious surfaces. *Sustainability*. 12(10):4109.
- Adamo SB, Crews-Meyer KA. 2006. Aridity and desertification: exploring environmental hazards in Jachal, Argentina. *Appl Geography*. 26(1):61–85.
- Akhtar-Schuster M, Stringer LC, Erlewein A, Metternicht G, Minelli S, Safriel U, Sommer S. 2017. Unpacking the concept of land degradation neutrality and addressing its operation through the Rio Conventions. *J Environ Manage*. 195(Pt 1):4–15.

- Alados CL, Puigdefábregas J, Martínez-Fernández J. 2011. Ecological and socio-economical thresholds of land and plant-community degradation in semi-arid Mediterranean areas of southeastern Spain. *J Arid Environ.* 75(12):1368–1376.
- Alipbeki O, Alipbekova C, Sterenharz A, Toleubekova Z, Aliyev M, Mineyev N, Amangaliyev K. 2020. A spatiotemporal assessment of land use and land cover changes in Peri-Urban areas: a case study of Arshaly district, Kazakhstan. *Sustainability.* 12(4):1556.
- Anees MM, Mann D, Sharma M, Banzhaf E, Joshi PK. 2020. Assessment of urban dynamics to understand spatiotemporal differentiation at various scales using remote sensing and geospatial tools. *Remote Sens.* 12(8):1306.
- Angel S, Parent J, Civco DL, Blei A, Potere D. 2011. The dimensions of global urban expansion: estimates and projections for all countries, 2000–2050. *Prog Plann.* 75(2):53–107.
- Aronson MF, Lepczyk CA, Evans KL, Goddard MA, Lerman SB, MacIvor JS, Nilon CH, Vargo T. 2017. Biodiversity in the city: key challenges for urban green space management. *Front Ecol Environ.* 15(4):189–196.
- Bajocco S, De Angelis A, Salvati L. 2012. A satellite-based green index as a proxy for vegetation cover quality in a Mediterranean region. *Ecol Indic.* 23:578–587.
- Barbero-Sierra C, Marques MJ, Ruíz-Pérez M. 2013. The case of urban sprawl in Spain as an active and irreversible driving force for desertification. *J Arid Environ.* 90:95–102.
- Barbosa O, Tratalos JA, Armsworth PR, Davies RG, Fuller RA, Johnson P, Gaston KJ. 2007. Who benefits from access to green space? A case study from Sheffield, UK. *Landscape Urban Plann.* 83(2–3):187–195.
- 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(1):19–35.
- Bestelmeyer BT, Okin GS, Duniway MC, Archer SR, Sayre NF, Williamson JC, Herrick JE. 2015. Desertification, land use, and the transformation of global drylands. *Front Ecol Environ.* 13(1):28–36.
- Briassoulis H. 2019. Combating land degradation and desertification: the land-use planning quandary. *Land.* 8(2):27.
- Büttner G, Feranec J, Jaffrain G. 2002. Corine land cover update 2000. Technical guidelines. technical report 89. Copenhagen, Denmark: European Environment Agency.
- Caloiero T, Veltri S, Caloiero P, Frustaci F. 2018. Drought analysis in Europe and in the Mediterranean basin using the standardized precipitation index. *Water.* 10(8):1043.
- Capozzi F, Di Palma A, De Paola F, Giugni M, Iavazzo P, Topa ME, Adamo P, Giordano S. 2018. Assessing desertification in sub-Saharan peri-urban areas: case study applications in Burkina Faso and Senegal. *J Geochem Explor.* 190:281–291.
- Carlson TN, Arthur ST. 2000. The impact of land use — land cover changes due to urbanization on surface microclimate and hydrology: a satellite perspective. *Global Planet Change.* 25(1–2):49–65.
- Carlucci M, Grigoriadis E, Rontos K, Salvati L. 2017. Revisiting a hegemonic concept: long-term ‘Mediterranean Urbanization’ in between city re-polarization and metropolitan decline. *Appl Spatial Anal.* 10(3):347–362.
- Ceccarelli T, Bajocco S, Perini L, Luca Salvati L. 2014. Urbanisation and land take of high-quality agricultural soils – exploring long-term land use changes and land capability in Northern Italy. *Int J Environ Res.* 8(1):181–192.
- Chapin FS, Carpenter SR, Kofinas GP, Folke C, Abel N, Clark WC, Olsson P, Smith DMS, Walker B, Young OR, et al. 2010. Ecosystem stewardship: sustainability strategies for a rapidly changing planet. *Trends Ecol Evol.* 25(4):241–249.
- Cheng L, Lu Q, Wu B, Yin C, Bao Y, Gong L. 2018. Estimation of the costs of desertification in China: a critical review. *Land Degrad Dev.* 29(4):975–983.
- Chorianopoulos I, Pagonis T, Koukoulas S, Drymoniti S. 2010. Planning, competitiveness and sprawl in the Mediterranean city: the case of Athens. *Cities.* 27(4):249–259.

- Colantoni A, Ferrara C, Perini L, Salvati L. 2015. Assessing trends in climate aridity and vulnerability to soil degradation in Italy. *Ecol Indic.* 48:599–604.
- Coluzzi R, D’Emilio M, Imbrenda V, Giorgio GA, Lanfredi M, Macchiato M, Ragosta M, Simoniello T, Telesca V. 2019. Investigating climate variability and long-term vegetation activity across heterogeneous Basilicata agroecosystems. *Geomat Nat Hazards Risk.* 10(1): 168–180.
- Cuadrado-Ciuraneta S, Dura-Guimera A, Salvati L. 2017. Not only tourism: unravelling suburbanization, second-home expansion and rural sprawl in Catalonia, Spain. *Urban Geograph.* 38(1):66–89.
- D’Emilio M, Coluzzi R, Macchiato M, Imbrenda V, Ragosta M, Sabia S, Simoniello T. 2018. Satellite data and soil magnetic susceptibility measurements for heavy metals monitoring: findings from Agri Valley (Southern Italy). *Environ Earth Sci.* 77(3):1–7.
- Dave V, Pandya M, Ghosh R. 2019. Identification of desertification hot spot using aridity index. *Ann Arid Zone.* 58(1–2):39–44.
- Delfanti L, Colantoni A, Recanatesi F, Bencardino M, Sateriano A, Zambon I, Salvati L. 2016. Solar plants, environmental degradation and local socioeconomic contexts: a case study in a Mediterranean country. *Environ Impact Assess Rev.* 61:88–93.
- Díaz-Pacheco J, García-Palomares JC. 2014. Urban sprawl in the Mediterranean urban regions in Europe and the crisis effect on the urban land development: Madrid as study case. *Urban Stud Res.* 2014:1–13.
- Dolley J, Marshall F, Butcher B, Reffin J, Robinson JA, Eray B, Quadrianto N. 2020. Analysing trade-offs and synergies between SDGs for urban development, food security and poverty alleviation in rapidly changing peri-urban areas: a tool to support inclusive urban planning. *Sustain Sci.* 15(6):1601–1619.
- Dutta D, Rahman A, Paul SK, Kundu A. 2020. Estimating urban growth in peri-urban areas and its interrelationships with built-up density using earth observation datasets. *Ann Regional Sci.* 65:67–82.
- Duvernoy I, Zambon I, Sateriano A, Salvati L. 2018. Pictures from the other side of the fringe: urban growth and peri-urban agriculture in a post-industrial city (Toulouse, France). *J Rural Stud.* 57:25–35.
- Erisman JW, van Eekeren N, de Wit J, Koopmans C, Cuijpers W, Oerlemans N, Koks BJ. 2016. Agriculture and biodiversity: a better balance benefits both. *AIMS Agriculture and Food.* 1(2): 157–174.
- EU Copernicus Programme. 2016. European digital elevation model (EU-DEM), version 1.1. European environment agency. 2011. Mapping guide for a European urban atlas. Copenhagen, Denmark: EEA.
- Feng Q, Ma H, Jiang X, Wang X, Cao S. 2015. What has caused desertification in China? *Sci Rep.* 5:15998.
- Ferrara A, Kelly C, Wilson GA, Nolè A, Mancino G, Bajocco S, Salvati L. 2016. Shaping the role of “fast’ and ‘slow’ drivers of change in forest-shrubland socio-ecological systems.” *J Environ Manage.* 169:155–166.
- Ferrara A, Kosmas C, Salvati L, Padula A, Mancino G, Nolè A. 2020. Updating the MEDALUS-ESA framework for worldwide land degradation and desertification assessment. *Land Degrad Dev.* 31:1593–1607..
- Fleskens L, Stringer LC. 2014. Land management and policy responses to mitigate desertification and land degradation. *Land Degrad Develop.* 25(1):1–4.
- Fletcher TD, Andrieu H, Hamel P. 2013. Understanding, management and modelling of urban hydrology and its consequences for receiving waters: a state of the art. *Adv Water Resour.* 51:261–279.
- Foley JA, DeFries R, Asner GP, Barford C, Bonan G, Carpenter SR, Chapin FS, Coe MT, Daily GC, Gibbs HK, et al. 2005. Global consequences of land use. *Science.* 309(5734):570–574.
- Gardi C. 2015. Toward zero net land take by 2050: an EU perspective. In: Fregolent L, Tonin S, editors. *Growing compact.* Milano, Italy: FrancoAngeli; p. 177–190.

- Gardi C, Panagos P, van Liedekerke M, Bosco C, de Brogniez D. 2015. Land take and food security: assessment of land take on the agricultural production in Europe. *J Environ Plan Manag.* 58(5):898–912.
- Giannakopoulos C, Kostopoulou E, Varotsos KV, Tziotziou K, Plitharas A. 2011. An integrated assessment of climate change impacts for Greece in the near future. *Reg Environ Change.* 11(4):829–843.
- Gibbs HK, Salmon JM. 2015. Mapping the world's degraded lands. *Appl Geogr.* 57:12–21.
- Giger M, Liniger H, Sauter C, Schwilch G. 2018. Economic benefits and costs of sustainable land management technologies: an analysis of WOCAT's global data. *Land Degrad Dev.* 29(4):962–974.
- Glaesner N, Helming K, de Vries W. 2014. Do current European policies prevent soil threats and support soil functions? *Sustainability.* 6(12):9538–9563.
- Gonzalez-Roglich M, Zvoleff A, Noon M, Liniger H, Fleiner R, Harari N, Garcia C. 2019. Synergizing global tools to monitor progress towards land degradation neutrality: trends. *Earth and the World Overview of Conservation Approaches and Technologies sustainable land management database.* *Environ Sci Policy.* 93:34–42.
- Gras D. 2014. EU-DEM statistical validation report. Per citare l'EU-DEM che sostituirà la figura in questione. Copenhagen, Denmark: European Environment Agency.
- Graves AR, Morris J, Deeks LK, Rickson RJ, Kibblewhite MG, Harris JA, Farewell TS, Truckle I. 2015. The total costs of soil degradation in England and Wales. *Ecol Econ.* 119:399–413.
- Greiving S, Fleischhauer M, Wanczura S. 2006. Management of natural Hazards in Europe: the role of spatial planning in selected EU member states. *J Environ Plann Manage.* 49(5):739–757.
- Guastella G, Oueslati W, Pareglio S. 2019. Patterns of urban spatial expansion in European cities. *Sustainability.* 11(8):2247.
- Hamin EM, Gurran N. 2009. Urban form and climate change: balancing adaptation and mitigation in the U.S. and Australia. *Habitat Int.* 33(3):238–245.
- Heidkamp CP. 2008. A theoretical framework for a 'spatially conscious' economic analysis of environmental issues. *Geoforum.* 39(1):62–75.
- Hill J, Stellmes M, Udelhoven T, Roder A, Sommer S. 2008. Mediterranean desertification and land degradation: mapping related land use change syndromes based on satellite observations. *Glob Planet Change.* 64(3–4):146–157.
- Huang J, Zhang X, Zhang Y, Guan X, Wei Y, Guo R. 2020. Global desertification vulnerability to climate change and human activities. *Land Degrad Dev.* 31(11):1380–1391.
- Imbrenda V, Coluzzi R, Lanfredi M, Loperte A, Satriani A, Simoniello T. 2018. Analysis of landscape evolution in a vulnerable coastal area under natural and human pressure. *Geomatics Nat Hazards Risk.* 9(1):1249–1279.
- Imbrenda V, D'Emilio M, Lanfredi M, Macchiato M, Ragosta M, Simoniello T. 2014. Indicators for the estimation of vulnerability to land degradation derived from soil compaction and vegetation cover. *Eur J Soil Sci.* 65(6):907–923.
- Imbrenda V, D'Emilio M, Lanfredi M, Ragosta M, Simoniello T. 2013. Indicators of land degradation vulnerability due to anthropic factors: tools for an efficient planning. *Sustainable practices: concepts, methodologies, tools, and applications.* Hershey (PA): IGI Global; p. 1400–1413.
- Izzo M, Araujo N, Aucelli PPC, Maratea A, Sánchez A. 2013. Land sensitivity to desertification in the Dominican Republic: an adaptation of the ESA methodology. *Land Degrad Dev.* 24(5):486–498.
- Jiang L, Jiapaer G, Bao A, Kurban A, Guo H, Zheng G, De Maeyer P. 2019. Monitoring the long-term desertification process and assessing the relative roles of its drivers in Central Asia. *Ecol Indic.* 104:195–208.
- Johnson DL, Lewis LA. 2007. *Land degradation. Creation and destruction.* Lanham (MD): Rowman & Littlefield.
- Kalnay E, Cai M. 2003. Impact of urbanization and land-use change on climate. *Nature.* 423(6939):528–531.

- Karamesouti M, Detsis V, Kounalaki A, Vasiliou P, Salvati L, Kosmas C. 2015. Land-use and land degradation processes affecting soil resources: evidence from a traditional Mediterranean cropland (Greece). *Catena*. 132:45–55.
- Karamesouti M, Panagos P, Kosmas C. 2018. Model-based spatio-temporal analysis of land desertification risk in Greece. *Catena*. 167:266–275.
- Kosmas C, Karamesouti M, Kounalaki K, Detsis V, Vassiliou P, Salvati L. 2016. Land degradation and long-term changes in agro-pastoral systems: an empirical analysis of ecological resilience in Asteroussia - Crete (Greece). *Catena*. 147:196–204.
- Kosmas C, Kirkby M, Geeson N. 1999. Manual on key indicators of desertification and mapping environmentally sensitive areas to desertification. Bruxelles, Belgium: European Commission, Energy, Environment and Sustainable Development, EUR 18882, 87.
- Lambin EF, Downing TE, Kerven C, Kleidon A, Leemans R, Lüdeke M, Prince SD, Xue Y. 2002. The interplay between international and local processes affecting desertification. In: Reynolds JF, Stafford SDM, editors. *Global desertification: do humans cause deserts?* Berlin, Germany: Dahlem University Press; p. 387–401.
- Lanfredi M, Coluzzi R, Imbrenda V, Macchiato M, Simoniello T. 2020. Analyzing space–time coherence in precipitation seasonality across different European climates. *Remote Sens.* 12(1):171.
- Lanfredi M, Coppola R, Simoniello T, Coluzzi R, D’Emilio M, Imbrenda V, Macchiato M. 2015. Early identification of land degradation hotspots in complex bio-geographic regions. *Remote Sens.* 7(6):8154–8179.
- Lavado CJ, Schnabel S, Gutiérrez AG, Fernández MP. 2009. Mapping sensitivity to land degradation in Extremadura. *Land Degrad Dev.* 20(2):129–144.
- Li X, Yang L, Ren Y, Li H, Wang Z. 2018. Impacts of urban sprawl on soil resources in the Changchun–Jilin Economic Zone, China, 2000–2015. *Int J Environ Res Public Health.* 15(6): 1186.
- G. Louwagie, J. Morris, M. Kibblewhite. Soil resource efficiency in urbanised areas. Analytical framework and implications for governance EEA Report no 7/2016 (2016), 10.2800/020840, Luxembourg, 94p
- Martínez-Valderrama J, Ibáñez J, D, Barrio G, Sanjuán ME, Alcalá FJ, Martínez-Vicente S, Puigdefábregas J. 2016. Present and future of desertification in Spain: implementation of a surveillance system to prevent land degradation. *Sci Total Environ.* 563:169–178.
- Masoumi HE, Hosseini M, Gouda AA. 2018. Drivers of urban sprawl in two large Middle-eastern countries: literature on Iran and Egypt. *Hum Geograph.* 12(1):55–79.
- Masoumi HE. 2014. Urban sprawl in mid-sized cities of MENA, evidence from Yazd and Kashan in central Iran. *Manag Res Practice.* 6(2):25–41.
- [MEA] Millennium Ecosystem Assessment. 2005. *Ecosystems and human well-being: desertification synthesis.* Washington (DC): World Resources Institute.
- Mohamed ES. 2013. Spatial assessment of desertification in north Sinai using modified MEDLAUS model. *Arab J Geosci.* 6(12):4647–4659.
- Monarca D, Cecchini M, Guerrieri M, Colantoni A. 2009. Conventional and alternative use of biomasses derived by hazelnut cultivation and processing. *Acta Hort.* 845(845):627–634.
- Mortoja M, Yigitcanlar T. 2020. Local drivers of anthropogenic climate change: quantifying the impact through a remote sensing approach in Brisbane. *Remote Sens.* 12(14):2270.
- Nizeyimana EL, Petersen GW, Imhoff ML, Sinclair HR, Waltman SW, Reed-Margetan DS, Levine ER, Russo JM. 2001. Assessing the impact of land conversion to urban use on soils with different productivity levels in the USA. *Soil Sci Soc Am J.* 65(2):391–402.
- Özgüner H, Eraslan Ş, Yilmaz S. 2012. Public perception of landscape restoration along a degraded urban streamside. *Land Degrad Dev.* 23(1):24–33.
- Parnell S. 2016. Defining a global urban development agenda. *World Dev.* 78:529–540.
- Patacchini E, Zenou Y, Henderson JV, Epple D. 2009. Urban sprawl in Europe. *Brookings-Wharton papers on urban affairs.* p. 125–149. USA:Brookings Institution Press

- Perović V, Kadović R, Đurđević V, Pavlović D, Pavlović M, Čakmak D, Mitrović M, Pavlović P. 2021. Major drivers of land degradation risk in Western Serbia: current trends and future scenarios. *Ecol Indic.* 123:107377.
- Pessaraki M, Moradi E, Mirdeilami SZ. 2019. The role of local settlements in combating desertification of Isfahan's desert rangelands. *J Rangeland Sci.* 9(3):202–218.
- Petrov L, Lavallo C, Kasanko M. 2009. Urban land use scenarios for a tourist region in Europe: applying the MODAL model to Algarve, Portugal. *Landscape Urban Plann.* 92(1): 10–23.
- Pili S, Grigoriadis E, Carlucci M, Clemente M, Salvati L. 2017. Towards sustainable growth? A multi-criteria assessment of (changing) urban forms. *Ecol Indic.* 76:71–80.
- Ponstingel D. 2020. The impact of exurban development on forested areas in Kurgan City, Russia. *Land Use Policy.* 94:104485.
- Portnov BA, Safriel UN. 2004. Combating desertification in the Negev: dryland agriculture vs. dryland urbanization. *J Arid Environ.* 56(4):659–680.
- Prăvălie R, Săvulescu I, Patriche C, Dumitrașcu M, Bandoc G. 2017. Spatial assessment of land degradation sensitive areas in southwestern Romania using modified MEDALUS method. *Catena.* 153:114–130.
- Prokop G, Jobstmann H, Schönbauer A. 2011. Overview of best practices for limiting soil sealing or mitigating its effects in EU-27; Brussels, Belgium: European Commission, DG Environment; European Communities. Publications/Files/WUP2018\$-KeyFacts.pdf.
- Quaranta G, Salvia R, Salvati L, De Paola V, Coluzzi R, Imbrenda V, Simoniello T. 2020. Long-term impacts of grazing management on land degradation in a rural community of Southern Italy: depopulation matters. *Land Degrad Dev.* 31(16):2379–2394.
- Rahman A, Aggarwal SP, Netzband M, Fazal S. 2011. Monitoring urban sprawl using remote sensing and GIS techniques of a fast growing urban centre, India. *IEEE J Sel Top Appl Earth Observ Remote Sens.* 4(1):56–64.
- Reynolds JF, Grainger A, Stafford Smith DM, Bastin G, Garcia-Barríos L, Fernández RJ, Janssen MA, Jürgens N, Scholes RJ, Veldkamp A, et al. 2011. Scientific concepts for an integrated analysis of desertification. *Land Degrad Dev.* 22(2):166–183.
- Riad P, Graefe S, Hussein H, Buerkert A. 2020. Landscape transformation processes in two large and two small cities in Egypt and Jordan over the last five decades using remote sensing data. *Landscape Urban Plann.* 197:103766.
- Salvati L, Ciommi MT, Serra P, Chelli FM. 2019. Exploring the spatial structure of housing prices under economic expansion and stagnation: the role of socio-demographic factors in metropolitan Rome, Italy. *Land Use Policy.* 81:143–152.
- Salvati L, Gemmiti R, Perini L. 2012. Land degradation and the Mediterranean urban areas: an unexplored link with planning? *Area.* 44(3):317–325.
- Salvati L, Sateriano A, Bajocco S. 2013. To Grow or to Sprawl? Evolving Land Cover Relationships in a Compact Mediterranean City Region. *Cities.* 30(1):113–121.
- Salvati L, Serra P. 2016. Estimating rapidity of change in complex urban systems: a multidimensional, local-scale approach. *Geogr Anal.* 48(2):132–156.
- Salvati L, Zamboni I, Chelli FM, Serra P. 2018. Do spatial patterns of urbanization and land consumption reflect different socioeconomic contexts in Europe? *Sci Total Environ.* 625: 722–730.
- Salvati L, Zitti M, Perini L. 2016. Fifty years on: long-term patterns of land sensitivity to desertification in Italy. *Land Degrad Dev.* 27(2):97–107.
- Salvati L, Zitti M. 2008. Regional convergence of environmental variables: empirical evidences from land degradation. *Ecol Econ.* 68(1–2):162–168.
- Salvati L, Zitti M. 2009. Assessing the impact of ecological and economic factors on land degradation vulnerability through multiway analysis. *Ecol Indic.* 9(2):357–363.
- Santini M, Caccamo G, Laurenti A, Noce S, Valentini R. 2010. A multi-component GIS framework for desertification risk assessment by an integrated index. *Appl Geogr.* 30(3):394–415.
- Serra P, Vera A, Tulla AF, Salvati L. 2014. Beyond urban-rural dichotomy: exploring socioeconomic and land-use processes of change in Spain (1991–2011). *Appl Geogr.* 55:71–81.

- Seto KC, Golden JS, Alberti M, Turner BL. 2017. Sustainability in an urbanizing planet. *Proc Natl Acad Sci USA*. 114(34):8935–8938.
- Sommer S, Zucca C, Grainger A, Cherlet M, Zougmore R, Sokona Y, Hill J, Della Peruta R, Roehrig J, Wang G. 2011. Application of indicator systems for monitoring and assessment of desertification from national to global scales. *Land Degrad Dev*. 22(2):184–197.
- Spinoni J, Naumann G, Vogt J, Barbosa P. 2016. Meteorological droughts in Europe: events and impacts: past trends and future projections. Luxembourg: Publications Office of the European Union; p. 134.
- Stavi I, Lal R. 2015. Achieving zero net land degradation: challenges and opportunities. *J Arid Environ*. 112:44–51.
- Su S, Wang Y, Luo F, Mai G, Pu J. 2014. Peri-urban vegetated landscape pattern changes in relation to socioeconomic development. *Ecol Indic*. 46:477–486.
- Teaford JC. 2006. The metropolitan revolution: the rise of post-urban America. New York (NY): Columbia University Press.
- Telesca L, Coluzzi R, Lasaponara R. 2009. Urban pattern morphology time variation in Southern Italy by using Landsat imagery. *Geocomputation and urban planning*. Berlin, Heidelberg, Germany: Springer; p. 209–222.
- Terfa BK, Chen N, Zhang X, Niyogi D. 2020. Urbanization in small cities and their significant implications on landscape structures: the case in Ethiopia. *Sustainability*. 12(3):1235.
- Torres L, Abraham EM, Rubio C, Barbero-Sierra C, Ruiz-Pérez M. 2015. Desertification research in Argentina. *Land Degrad Dev*. 26(5):433–440.
- Trnka M, Bales J, Štěpánek P, Zahradníček P, Možný M, Eitzinger J, Žalud Z, Formayer H, Turňa M, Nejedlík P, et al. 2016. Drought trends over part of Central Europe between 1961 and 2014. *Clim Res*. 70(2):143–160.
- UNCCD. 2012. Zero net land degradation a sustainable development goal for Rio + 20. UNCCD Secretariat policy brief. <http://www.unccd.int>.
- United Nations Publications. 2018. World urbanization prospects: the 2018 revision. New York (NY): UN. <https://population.un.org/wup/>.
- United Nations, Department of Economic and Social Affairs, Population Division. 2019. World population prospects 2019: highlights (ST/ESA/SER.A/423). USA:Brookings Institution Press
- Vogt JV, Safriel U, Bastin G, Zougmore R, von Maltitz G, Sokona Y, Hill J. 2011. Monitoring and assessment of land degradation and desertification: towards new conceptual and integrated approaches. *Land Degrad Dev*. 22(2):150–165.
- Vu QM, Le QB, Frossard E, Vlek PL. 2014. Socio-economic and biophysical determinants of land degradation in Vietnam: an integrated causal analysis at the national level. *Land Use Policy*. 36:605–617.
- Wang LY, Xiao Y, Rao EM, Jiang L, Xiao Y, Ouyang ZY. 2018. An assessment of the impact of urbanization on soil erosion in Inner Mongolia. *Int J Environ Res Public Health*. 15(3):550.
- Wang T, Yan CZ, Song X, Xie JL. 2012. Monitoring recent trends in the area of aeolian desertified land using Landsat images in China's Xinjiang region. *ISPRS J Photogramm Remote Sens*. 68:184–190.
- Xie H, Zhang Y, Wu Z, Lv T. 2020. A bibliometric analysis on land degradation: current status, development, and future directions. *Land*. 9(1):28.
- Xu D, You X, Xia C. 2019. Assessing the spatial-temporal pattern and evolution of areas sensitive to land desertification in North China. *Ecol Indic*. 97:150–158.
- Yassoglou N. 2004. Soil map of Greece. Athens: National Committee against Desertification, Agricultural University of Athens.
- Zamboni I, Benedetti A, Ferrara C, Salvati L. 2018. Soil matters? A multivariate analysis of socioeconomic constraints to urban expansion in Mediterranean Europe. *Ecol Econ*. 146:173–183.
- Zamboni I, Serra P, Sauri D, Carlucci M, Salvati L. 2017. Beyond the Mediterranean city: socioeconomic disparities and urban sprawl in three Southern European cities. *Geografiska Ann B–Hum Geograph*. 99(3):319–337.
- Zhao C, Jensen JL, Weng Q, Currit N, Weaver R. 2020. Use of local climate zones to investigate surface urban heat islands in Texas. *GI Sci Remote Sens*. 57(8):1083–1101.