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Soil Quality and Peri-Urban Expansion of Cities: A Mediterranean Experience (Athens, Greece)

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Abstract: Soil loss and peri-urban settlement expansion are key issues in urban sustainability, with multi-disciplinary implications that go beyond individual ecological and socioeconomic dimensions. Our study illustrates an assessment framework diachronically evaluating urbanization-driven soil quality loss in a Southern European metropolitan region (Athens, Greece). We tested the assumption that urban growth is a process consuming high-quality soils in a selective way analyzing two spatial layers, a map illustrating the diachronic expansion of settlements at five time points (1948, 1975, 1990, 2000, and 2018), and a geo-database reporting basic soil properties. The empirical results showed that the urban expansion in the Athens region took place by consuming higher- quality soil in fertile, mostly flat, districts. It entailed a persistent soil quality decrease over time. This trend globally accelerated in recent years, but in a heterogeneous way. Actually, newly built, more compact areas expanded on soils with lower erosion risk than in the past. Besides, low-density land take is likely to be observed in soils with moderate-high or very-high qualities. These evidences reflect the need for a comprehensive evaluation of complex processes of land take informing spatial planning for metropolitan sustainability.

Keywords: land take; urban sprawl; compact settlements; indicators; Mediterranean

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1. Introduction

Soil is a dynamic, environmental matrix, assuring necessary support to any form of life on Earth and needing strict protection regulations [1]. The notion of "soil quality" (often known as "soil health") is the ability of soil to work as a "living system", since it plays an active role in shaping the interaction between the biotic component (such as animals and plants) and the abiotic component (e.g., light, rocks, water, and air) of ecosystems [2–4]. Soil quality is intended as "the capacity of a soil to function, within land use and ecosystem boundaries, to sustain biological productivity, maintain environmental quality, and promote plant, animal, and human health" [5] (p. 4). Preserving soil quality is therefore essential to guarantee the balance between human intervention and the resilience of natural systems [6–8]. Soil conditions not only affect the overall functioning of the ecological infrastructure they belong to [9], but also food and hydrogeological safety, the protection of biodiversity, the effects of climate change, and trade deriving from ecosystem services [10].

Soil is, by definition, a fragile resource, since its health depends on physical conditions, environmental context, and the interlacing of inevitable natural processes (including extreme weather conditions: constant strong wind, heavy rain, floods, etc.), in relation to the intensity of human interventions, e.g., urbanization, industrialization, and local contamination [7]. These factors expose soils to intense and constant degradation processes, such as the deterioration of physical, chemical, and biological properties [11] that includes erosion, landslides, floods, salinization, decrease in biodiversity and organic matter, compaction, sealing, acidification, desertification, increased global warming and heat islands, loss of fertile soils in rural areas, as well as impairment of valuable landscapes [2,12,13]. The irreversible loss of natural soil—capable of providing environmental services—is related to different components that act simultaneously and contribute to further compromising its "quality".

Urbanization-driven soil sealing is one of the most pervasive mechanisms of degradation of fertile land around cities [14–16] in Europe [17–19]. According to an interdisciplinary study, Western Europe stands out for the huge threats associated with the sealing of soils through urbanization [20]. The widespread urbanization in peri-urban areas was demonstrated to proceed at a speed four times faster than the sealing of urban areas [21–23]. This phenomenon exerts negative effects on agricultural production, resulting in reduced soil fertility; loss of continuity, variation, and quality of crops; increased severity and frequency of hydrogeological instability; and habitat fragmentation of the ecological network, resulting in loss of biodiversity and green areas, low-soil carbon stocks, as well as increasing energy costs and services [18,24–28]. Various motivations indicate Mediterranean Europe as an interesting case study for understanding long-term dynamics of land consumption [29–31]. Although urban planning is nowadays inspired by the European Spatial Planning Perspective guidelines provided by the European Commission in 1999 (e.g., [32–34]), deregulation and, in some cases, informality have inspired policies regulating urban growth and the economic development in the entire region [35]. Finally, the European Mediterranean landscape is recognized worldwide as a hotspot for bio-diversity, rural traditions, and a millenary interaction between humans and nature. Mediterranean landscapes and soils can be considered, at the same time, as ecologically fragile because of dry climate, a generally steep terrain reflecting a locally restricted availability of land for edification or agriculture, poor vegetation cover, important soil degradation (erosion, salinization, compaction, and pollution), and increased human pressure.

In this context, it was hypothesized that urban growth may concentrate on soils with the highest capability for agriculture, thus determining a net loss in the natural resource base at the regional scale. However, this assumption needs a more intense field verification based on long-term studies. Zambon, et al. [36] proposed a logical framework for the assessment of urbanization-driven soil consumption and applied this methodology to a specific case study to evaluate if edification was consuming the highest quality available soils [36]. There is a definite need to enlarge and adapt this approach to monitor soil consumption in larger (metropolitan) regions, and to evaluate the effect of settlement expansion in peri-urban and rural contexts characterized by infrastructural development and intense restructuring of the economic base. From this perspective, an accurate assessment of soil sealing in mixed urban–rural landscapes characterized by intermediate-low soil imperviousness rates is particularly effective for large-scale quantification of the possible soil resource loss due to edification. Earlier studies indicate that standard land-use maps (e.g., Corine Land Cover maps), together with topographic and building maps, can allow a dynamic evaluation of soil sealing [37].

Based on these premises, the aim of this study is to illustrate an assessment framework evaluating long-term soil consumption by edification. Compared with earlier studies, this work focuses on an urban region in Southern Europe (Athens, Greece) that has experienced rapid urban growth since the late 1940s. Interestingly, this process involved both fringe areas and agricultural/forestry-specialized areas progressively further away from the main city. The expanding discontinuous and low-density settlements were mainly associated with the road network and pre-existing villages. This study hypothesizes that urban expansion consumes high-quality soil in a larger proportion than soils of a lower quality, possibly altering the spatial distribution of the soil resource base. This assumption was verified through the analysis of two spatial layers: a map illustrating urban settlements at five points in time (1948, 1975, 1990, 2000, and 2018), and a map evaluating basic properties of soils. Results indicate trends over time in soil consumption and form the base for long-term monitoring approaches to inform policies for the preservation of high-quality soils in peri-urban areas. Such knowledge may inform design of specific strategies to mitigate the environmental impact of soil sealing at vastly different scales, from local to national.

2. Materials and Methods

2.1. Spatial Analysis

The area encompasses the Athens' Metropolitan Region (AMR), extending more than 3000 km^2 in the administrative region of Attica, Central Greece [38]. All mainland municipalities, including those belonging to Salamina island, close to Piraeus harbour, were included in this study (Figure 1). While mostly consisting of mountains bordering the flat area occupied by the Greater Athens' (GA) district, three coastal plains (Messoghia, Marathon, and Thriasio) are located in Attica. Climate is characterized by a Mediterranean semi-arid regime, with average annual rainfalls amounting to 400 mm and a mean annual temperature of about 19 °C [39]. A continuous, radio-centric expansion of settlements was characteristic of the Athens' urban history since the First World War [40]. Settlements initially irradiated from the main centres of Athens and Piraeus, diffusing across the whole GA district since the 1950s [41–43]. Compact urban expansion, based on dense/semi-dense settlement growth—mostly residential and industrial—was mainly observed between the late 1940s and the late 1980s, although with different characteristics at the local scale [44]. The early 1990s acted as a sort of breakpoint from a (more or less) compact model of urban expansion to a more evident dispersed pattern, losing the main feature of mono-centrism while being unable to follow a purely polycentric-model of growth [45]. Before the economic crisis, the city was aiming to attract enough foreign investment to sustain peri-urban growth [46]. The 2004 Olympics have had a major impact on the development of the city in terms of investment and infrastructure [47]. Overall, population density in the study area doubled from 1500people per km^2 in 1951 to 3000people per km^2 in 2011 [48].

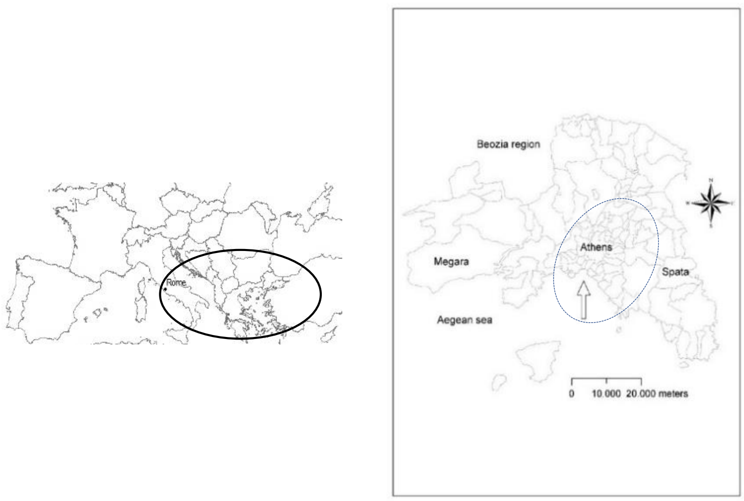


Figure 1. Maps of the study area illustrating the position of the investigated region in Mediterranean Europe (**left**) and municipal boundaries in the Athens' metropolitan region—downtown Athens as white arrow, Greater Athens bonded by a dashed blue line (**right**).

2.2. Elementary Data

Urban settlements were mapped at five years (1948, 1975, 1990, 2000, and 2018) on the base of a census and surveys mapping at polygons level. Given our context of possibly heterogenous patterns of urban settlement, this methodology has been preferred to sampling point procedure. Mapping has been carried out according to homogeneous sources covering the whole region: (i) a comprehensive soil map of Attica realized by the Institute of Pedology and Chemistry (Piraeus, Greece) in 1948 at 1:100,000 scale that includes a spatial layer representing urban settlements (polygons representing urban areas were digitalized from a geo-referenced high-resolution TIFF image provided by Joint Research Centre, Ispra); (ii) the LaCoast (LC) digital cartography available for 1975 at 1:100,000 scale appropriately integrated with other information sources, including the results of agricultural, population, and building censuses at the regional scale in Attica); (iii–iv) the Corine Land Cover (CLC) pan-European digital cartography available at the same resolution scale for 1990, 2000, and 2018. The first-level land-use class, coded 1, "urban settlements", which incorporated the various 1.xx classes of the third hierarchical level of the CLC nomenclature system, was adopted to map settlements. A raster map referring to 2015, disseminated by the GMES Land Copernicus initiative and illustrating built-up and non-built-up areas with a continuous degree of soil sealing ranging from 0% to 100% in aggregated spatial resolution (100 × 100 m), was used to assess the current degree of soil imperviousness in the study area.

To monitor soil quality loss, the following indicators were adopted in the present study to stress the complexity and the multidimensional definition of a concept such as soil degradation: (i) a standard soil erosion risk, (ii) soil depth, (iii) a composite index of Soil Quality (SQI), and (iv) a Climate Quality Index (CQI) as a control variable. Soil erosion and depth were derived from a digital topographic map of Greece delineating a number of soil properties at 1:50,000 spatial resolution [39]. According to their intrinsic characteristics, soils have been grouped into seven classes of land capability, specifically addressing agriculture, forestry, and pasture requirements. The erosion risk index has classified soils in 7 classes (ranging from 1: low risk to 7: high risk). Soil depth has also been classified into 7 classes (ranging from 1: the highest depth to 7: the lowest depth in the area). The Soil Quality Index (SQI), realized by the European Environment Agency, was considered here and computed using the information contained in the European Soil Database produced by the Joint Research Centre, Ispra (www.jrc.eu (accessed on 1 February 2021)). This index was widely used in the Environmentally Sensitive Area (ESA) framework to assess the level of sensitivity to soil and land degradation [36]. Based on data provided by [15], the SQI is based on four variables: parent material, soil depth, texture, and slope angle. A set of sensitivity scores derived from fieldwork and statistical analysis was assigned to each of the four analyzed variables. The SQI was thus estimated as the geometric mean of the different scores attributed to the four selected variables and ranges from 1 (the highest soil quality) to 2 (the lowest soil quality). Additionally, climate quality—determining a supposedly higher level of sensitivity to land degradation—was investigated based on the Climate Quality Index (CQI) derived from the same information source of the SQI. Intended as a control variable, CQI is an aridity index based on the ratio of average annual precipitation to the average potential evapotranspiration. The index showed positive values increasing with wetness. An arid climate is generally depicted by a value of the index below 0.5 [36].

2.3. Spatial Analysis

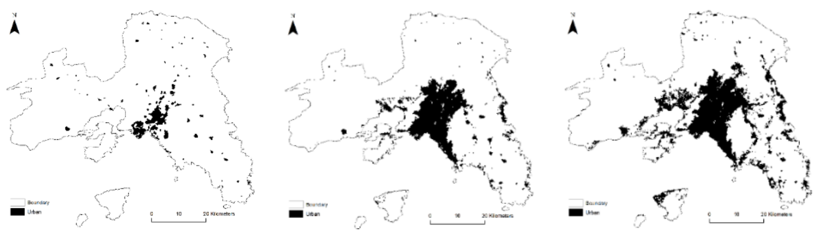
The polygon layer of each of the five settlement maps (1948, 1975, 1990, 2000, and 2018) has been overlaid to the soil map described above. The ArcGIS (ESRI Inc., Redwoods, USA) "zonal statistics" tool was adopted to calculate an average score for each indicator (i–iv, see above), separately, associated with urban settlements for each study year. Changes over time in the distribution of the indicators between 1948 and 2018 were analyzed through a non-parametric Mann–Whitney U statistic testing against a "no-change" null hypothesis at $p < 0.05$. The "zonal statistics" tool was also used to calculate an average score for SQI and CQI at increasing degrees of soil imperviousness (from 0% to 100% by a 1%step), by overlapping the SQI (or CQI) map with the soil imperviousness layer map (Section 2.2). The pair-wise correlation between soil-sealing intensity and SQI (or CQI) was evaluated using Pearson correlation coefficients and testing for statistical significance at $p < 0.05$.

3. Results

Built-up areas in the Athens' region expanded from 53 km^2 (1948) to 794 km^2 (2018), displaying the highest growth rate between 1948 and 1975. Table 1 illustrates basic characteristics of soils (erosion risk, depth, and soil quality) progressively converted to urban use and finally built-up between 1948 and 2018 as shown in Figure 2. Soil quality decreased continuously over time (−2.5%), reflecting settlement expansion on soils with significantly higher quality; decline rates accelerated during the most recent time intervals. The statistical distribution of the SQI was significantly different between 1948 and 2018 (Mann–Whitney U test, $p < 0.05$). At the same time, newly built-up areas expanded on soils with lower erosion risk than in the past. This process is an indirect confirmation of soil consumption in fertile, mostly flat, districts. In line with this trend, our analysis indicates how deep soils were especially consumed when Athens grew. Conversion of high-quality soils to urban use was relatively heterogeneous over time: less intense conversion rates have been observed in the first time interval (1948–1975) corresponding to huge, compact, and mostly radio-centric expansion of Athens. More intense conversion rates were recorded in recent periods, in parallel with low-density, dispersed urban expansion.

Table 1. Classification of built-up land considering a soil quality index, soil erosion rate, and soil depth by year in the study area.

Year	Built-Up Area (km^2)	Soil Quality Index	Soil Erosion Risk	Soil Depth
		Absolute values		
1948	53.1	1.629	2.39	3.77
1975	392.9	1.618	2.27	3.22
1990	496.1	1.612	2.16	3.22
2000	577.5	1.602	2.23	3.37
2018	794.0	1.590	1.96	3.23
		Per cent annual change		
1948–1975	23.8	−0.03	−0.19	−0.54
1975–1990	1.8	−0.02	−0.32	−0.01
1990–2000	1.6	−0.06	0.32	0.47
2000–2018	2.1	−0.04	−0.67	−0.23
		Per cent change—whole time period		
1948–2018	19.9	−0.03	−0.26	−0.21



1948 1990 2018

Figure 2. Maps of the study area illustrating urban expansion in the Athens metropolitan region at selected years, 1948–2018.

Correlations between soil sealing intensity and soil quality (or climate quality) have been illustrated in Figure 3 and delineate results in line with earlier evidence of this study.

Similar findings were derived from the analysis of climate and soil quality: compact settlements (high sealing rate) were built-up on lower-quality soils with higher rates of climate aridity. The reverse pattern was observed for dispersed settlements with medium-low (or low) sealing rate built-up mainly on soil with moderate-high or very-high qualities. The relationship between soil quality and sealing rate was found to be linearly and statistically significant, empirically confirming how compact urban growth consumed soils mostly with lower environmental quality.

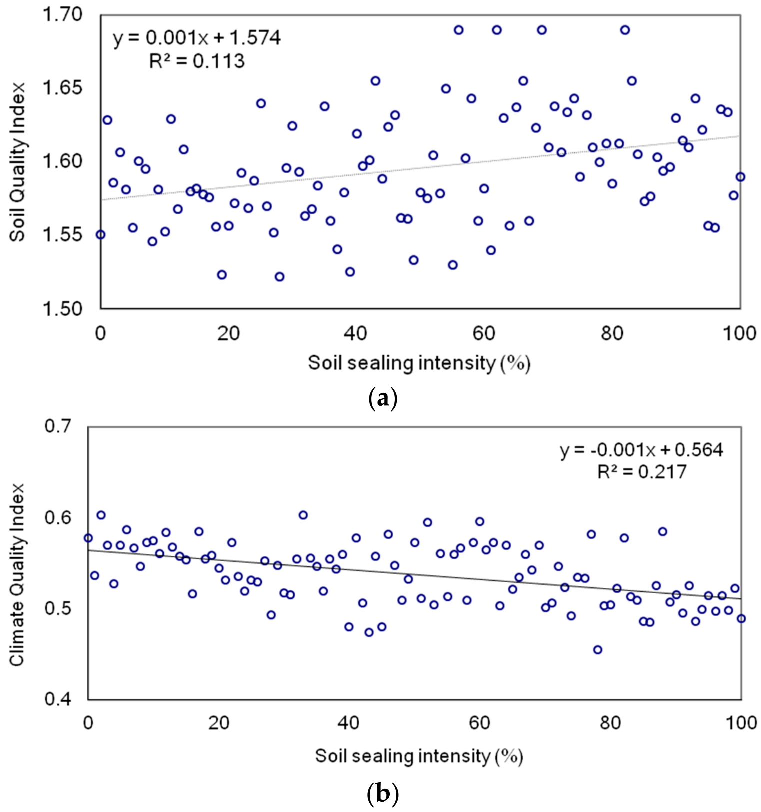


Figure 3. The relationship between land take (estimated as sealing intensity, %) and quality of soils (**a**) and climate (**b**) in the Athens metropolitan region.

The reverse correlation was found between soil sealing rate and climate quality. Compact settlements (with high sealing rates) were built-up mainly on land classified as low climate quality (i.e., dry, semi-arid, or arid lands). Conversely, dispersed settlements (with low sealing rates) expanded into lands classified as higher climate quality (i.e., less arid soils). Taken together, these findings confirm the empirical evidence of Table 1 and delineate the negative impact of recent urban expansion on land with high-quality soils (less arid, deep soils with high fertility and low erosion risk). In other words, urban settlements have selectively consumed the soils with the highest available quality in the study area.

4. Discussion

The key ecological role of soils is demonstrated by the long list of ecosystems services they provide, including (i) support (e.g., main biomass container and storage of a quarter of the planet's biodiversity), (ii) provisioning (e.g., supplier of 95% of the food income), (iii) regulating (e.g., main natural carbon sink after the oceans, regulator of 3.8 million liters of water in a non-urbanized hectare), and (iv) preservation of cultural and archaeological heritage [49–53]. Assuming soil as a slowly renewable natural resource resulting from complex actions and interactions of ecological processes in time and space, the present paper evaluates the impact of urban expansion on soil quality in a large Mediterranean urban region. Assuming urban expansion in fringe land as a threat for soil quality—in relation with habitat loss and landscape fragmentation—a spatial analysis evaluating the quality of soil consumed by the city's development was implemented into a Geographic Information System interface using diachronic land-use maps and a high-resolution soil geo-database.

Results of the present study provide empirical demonstration of the working hypothesis that urban expansion consumes soils with high land capability and low susceptibility to soil degradation that is mostly represented by water (or wind) erosion in the study area. Moreover, the inverse relationship observed between soil-sealing intensity and soil quality (or climate quality) indexes suggests how compact and dense settlements represent a more sustainable urban model in the study area compared to discontinuous, dispersed settlements. In the long term, dispersed settlements may consume soils with the highest quality in the region, impacting landscape resilience and altering ecosystem stability at the regional scale [21]. This phenomenon can be more intense in peri-urban Mediterranean regions undergoing climate aridification and increasing anthropogenic pressure [54–57]. The empirical findings of our work confirm earlier evidence on urban growth as a factor of degradation and physical loss of soil [58–61]. In most socioeconomic contexts typical of advanced countries, consensus has been reached on the assumption that settlement expansion may concentrate on soils with high suitability for agriculture (e.g., [62–65]), determining cropland reduction and loss of approximately 2% of the world's current arable land [66]. Negative consequences on a social, economic, and environmental level as regards, e.g., food security, hydrologic systems, habitat fragmentation and its impact on ecosystem services [67], biodiversity (with very likely introduction of invasive species), and urban sustainability have been also delineated [68].

Recent transformations in Greek landscape due to (uncontrolled) settlement pattern are a concern for policy makers since they will have repercussions on the natural and cultural heritage of the Athens' area and the region of Attica as a whole. This is a place that constitutes an important tourist destination that attracts (national and foreign) visitors. This context raises the issue of pursuing and managing Sustainable Urban Tourism activities and development [69]. Earlier studies that looked at sustainable tourism implementation highlighted that local and central government should play a relevant role in managing, including financially, tourism flows. They enjoy huge influence on related policy areas that affect land take and spatial planning, such as (tourism) infrastructure, real estate pressure or residentialism, transport and smartization, planning of natural areas and parks, as well as recreational economic zoning for the region [56,70,71]. Thus, land use planning assumes tourism as an integral factor of sustainable development. Furthermore, sustainable tourism practices can also be achieved by promoting community management, with commitment and cooperation at multiple levels, leveraging visitors and residents' attitudes toward sustainability in the realm of reducing waste, overconsumption, and education toward preservation of the natural and cultural heritage that, ultimately, can promote a more environmental use of soil [72–74].

These results consolidate basic knowledge on the intrinsic relationship between land take and soil quality, an increasingly topical and urgent issue, and the containment of its negative effects [75]. The goal is to inform sustainable regional planning and development policies with an in-depth quantification of soil loss due to different phases of urban expansion [76–78]. Land-saving urban forms should be especially promoted for their indirect, beneficial effects on soil conservation [79–81]. Moving toward this direction means that, in addition to triggering an accurate investigation to estimate current soil loss rates, important steps should be taken to introduce soil loss estimates based on a monetary quantification of ecosystem services [50]. Besides being a valuable and equitable approach, it could bring practical recommendations about, for instance, building new settlements where it has less impact from several points of view (e.g., economic, agronomic, social, territorial, political, and ecological), stimulating urban containment and preventing sprawl in other contexts. It may also represent a viable solution to reconnect valuation of existing ecosystem services at a certain location to sustainability on a larger regional level.

The establishment of an information system is key to developing a dynamic assessment of soil resource depletion [82–84]. In these regards, sensitivity of land to degradation is not a static attribute and it needs permanent monitoring [85]. In addition to measuring the effects of soil sealing, one of the most complicated aspects of the problem is the ability to control and manage the process through policies, regulatory frameworks, plans, and specific actions [37,57,86]. This occurs in the Mediterranean region, where there is a partial lack of tools evaluating land take risk by urban growth [42,56,87]. It adds to the failure of procedural initiatives for soil protection and to the resulting insolvency of the instruments responsible for monitoring land take [88–91]. The integrated political-administrative and planning territorial system of monitoring land take is still full of (cognitive) gaps, (regulatory) contradictions, and (strategic) delays and limitations. It therefore requires a strong effort of fine tuning with field knowledge and evidence from mainstream scientific literature [12,92–94].

5. Conclusions

The metropolitan area of Athens has undergone a vast growth process since 1948. This study showed that peri-urban settlements have been consuming the highest quality available soils, thus determining a net loss in the natural resource base of the entire region. An inverse relationship between land take intensity, and soil and climate quality indexes, provides evidence that compact and dense settlements can be considered a more sustainable urban growth model than discontinuous, dispersed settlements. Assuming soil is a slowly renewable natural resource resulting from complex actions and interactions of ecological processes in time and space, an overall reduction in the provision of ecosystem service of soil is expected. These threats necessitate an active policy implementation, including actions towards urban tourism sustainability, to contain negative effects and to restore environmental sustainability in the long run. The empirical results of our study definitively outline the importance of a comprehensive assessment of ecological-economic factors associated with loss of soil quality in peri-urban areas. The quality, reproducibility, and precision of such assessments may limit the operational/planning activity of decision-makers, on which the sustainability of the choices and the resulting actions depend substantially. Introducing practices of identification and monetary quantification of ecosystem services may prove highly successful in containing soil degradation in a specific location. Overall, implementation of forecasting policies for the control of soil quality loss is imperative in peri-urban areas; this would involve focusing on the resolution of locally- based "territorial issues" rather than on activities that are generalizable to broader contexts but not completely pertinent to the peculiarity of the specific area.

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