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Clustering or Scattering? The Spatial Distribution of Cropland in a Metropolitan Region, 1960–2010

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Abstract: This article presents empirical results of a multivariate analysis run with the aim to identify (apparent and latent) socioeconomic transformations that shape the distribution pattern of cropland in a metropolitan region of southern Europe (Athens, Greece) over a sufficiently long time interval spanning from 1960 to 2010. The study area is representative of monocentric cities expanding in an unregulated fashion and experiencing sequential cycles of economic growth and recession. Percent share of cropland in total municipal area increased moderately over time. A non-linear relationship with the distance from downtown Athens was also observed, indicating that the highest rates of cropland were observed at a distance ranging between 20 and 30 km from the inner city. A multivariate regression was run by decade at each municipality of the study area using 11 predictors with the aim to identify the factors most associated with cropland decline along urban fringes. Distance from downtown Athens, soil and climate quality, population growth rate, and competing land use were the most relevant factors correlated with cropland expansion (or decline) in the study area. Competing land use was particularly important for cropland decline in a first urbanization phase (1960–1980), while population growth rate—and hence an increased human pressure—was positively associated with agricultural areas in a subsequent phase (1990–2010). In these regards, per capita urban land had a non-linear spatial behavior, being correlated negatively with cropland in 1960 and 1970 and positively in 2010, possibly indicating a moderate change from a monocentric model towards a more dispersed metropolitan configuration impacting distribution of agricultural areas. Empirical findings of this study suggest that effective strategies supporting peri-urban agriculture require a comprehensive knowledge of the local socioeconomic context and relevant biophysical conditions—specifically focusing on the dominant soil and climate attributes.

Keywords: peri-urban agriculture; urban expansion; indicators; multiple regression; Mediterranean Europe

1. Introduction

Rural areas and the related cropping systems play an important role in ecosystem services, improving quality of metropolitan environments [1–4]. Despite the importance of cropland in peri-urban contexts, a progressive reduction in size, production, and functionality has been observed in representative metropolitan regions because of urban spillover [5,6]. Wildland–urban interfaces are particularly vulnerable to cropland decline and physical degradation because of the increasing anthropogenic pressure [7–9]. In Mediterranean Europe, interfaces are particularly rich in animal and plant biodiversity, as well as historical and cultural heritage, being constituted by heterogeneous peri-urban areas with mixed human settlements of different ages and natural-agricultural habitats forming a diversified landscape mosaic [10–12]. Reflecting unsustainable use of land, rural-urban migration, abandonment of cropland, and land marginalization, urban expansion is probably the most impacting factor on cropland, determining landscape transformations and fragmentation of non-urban land use types [2,13,14]. Moreover, land use modifications of fringe land may severely impact cropland, resulting in forest, shrubland, and pasture expansion, due to spontaneous or human-driven processes of re-naturalization [15,16]. However, the main socioeconomic forces at the base of landscape transformations and the underlying mechanisms linking local communities with specific environmental characteristics of rural areas are mostly underrepresented in the Mediterranean basin and still need specific investigation covering both socioeconomic and biophysical issues [17–20].

In such dynamic contexts, identifying relevant factors (and understanding the underlying processes) that drive changes in the use of land is key to sustainable management of fringe land [1,2]. Despite indicators of land take having been extensively developed in recent times [21], only a few studies have analyzed complex interactions between land use and transformations of fringe land driven by urbanization [1,11,13,22,23]. Based on these premises, this article illustrates a comprehensive analysis of cropland distribution over space in a Mediterranean European region (Athens, Greece) from 1960 to 2010. Athens is considered a representative case of (rapidly expanding) Mediterranean cities with a typical monocentric organization and more recent processes of urban sprawl into traditional rural areas [24]. By adopting a multivariate strategy to analyze multi-domain indicators of urban expansion [4], our study identifies clustering or scattering patterns in the spatial distribution of cropland, and the most relevant factors involved in such trends, as a contribution to sustainable land management in expanding metropolitan regions of advanced countries.

2. Materials and Methods

2.1. Study Area

The Athens metropolitan region extends approximately 3000 km^2 and is administered by 114 municipal authorities: 58 urban municipalities belonging to the conurbation of Athens-Piraeus and 56 rural municipalities (Figure 1). The landform consists primarily of uplands and mountains; lowlands are concentrated mainly in the central area of Athens. The prevailing climate regime in the area is Mediterranean dry, with annual rainfall ranging between 400 mm and 500 mm and annual temperatures averaging 18–19 °C. Nowadays, the area is densely populated (4400 inhabitants/km^2). From 1951 to 2011, population density increased by about 2900 inhabitants/km^2 with a more balanced settlement distribution over space and the formation of growing poles outside the consolidated city [25]. After World War II, Athens and Piraeus expanded as the main urban poles thanks to the concentration of service activities (Athens) and industrial functions (Piraeus) [4,26]. Since the early 1990s, the Greater Athens area experienced a process of urban de-concentration, with expansion of discontinuous fringe settlements [1,27]. The development of new urban cores was observed [4,8,9,28–30] in Messoghia (a region centered in the municipalities of Markopoulo Messoghias, and Spata), which is considered the largest sprawling area in Attica [29], and in the Athens north-east district centered in the municipalities of Maroussi and Kifissià, where urban development driven by the 2004 Olympic Games resulted in extensive soil sealing and an increased rate of land consumption [31].

2.2. Land Use Analysis and Cropland Data

The percent share of cropland in total municipal area, taken as the dependent variable in this study, was derived from aggregate data of (i) a land use census held by the Greek Statistical Institute for the years 1960, 1970, 1980, 1990, and 2000; and (ii) Urban Atlas (UA) database referring to 2010. According to Salvati et al. [23], the accuracy of the collected data was evaluated by comparison with additional data sources that provide an independent estimate of cropland expansion (or decline) at a fine grained spatial scale in the study area: (i) a soil map produced by the Institute of Geology and

Soil Chemistry (Piraeus) delimitating the Athens urban area for 1948; (ii) the LaCoast (LC) project database mapping land use in coastal regions of Europe for 1975 [30]; (iii) Corine Land Cover (CLC) maps referring to 1990 and 2000 [32,33]; (iv) the pan-European GlobCorine map referring to 2009 [34]; and (v) prefecture-level data on cropland derived from the Greek National Census of Agriculture for 1961, 1970, 1980, 1990, 1999, and 2009.

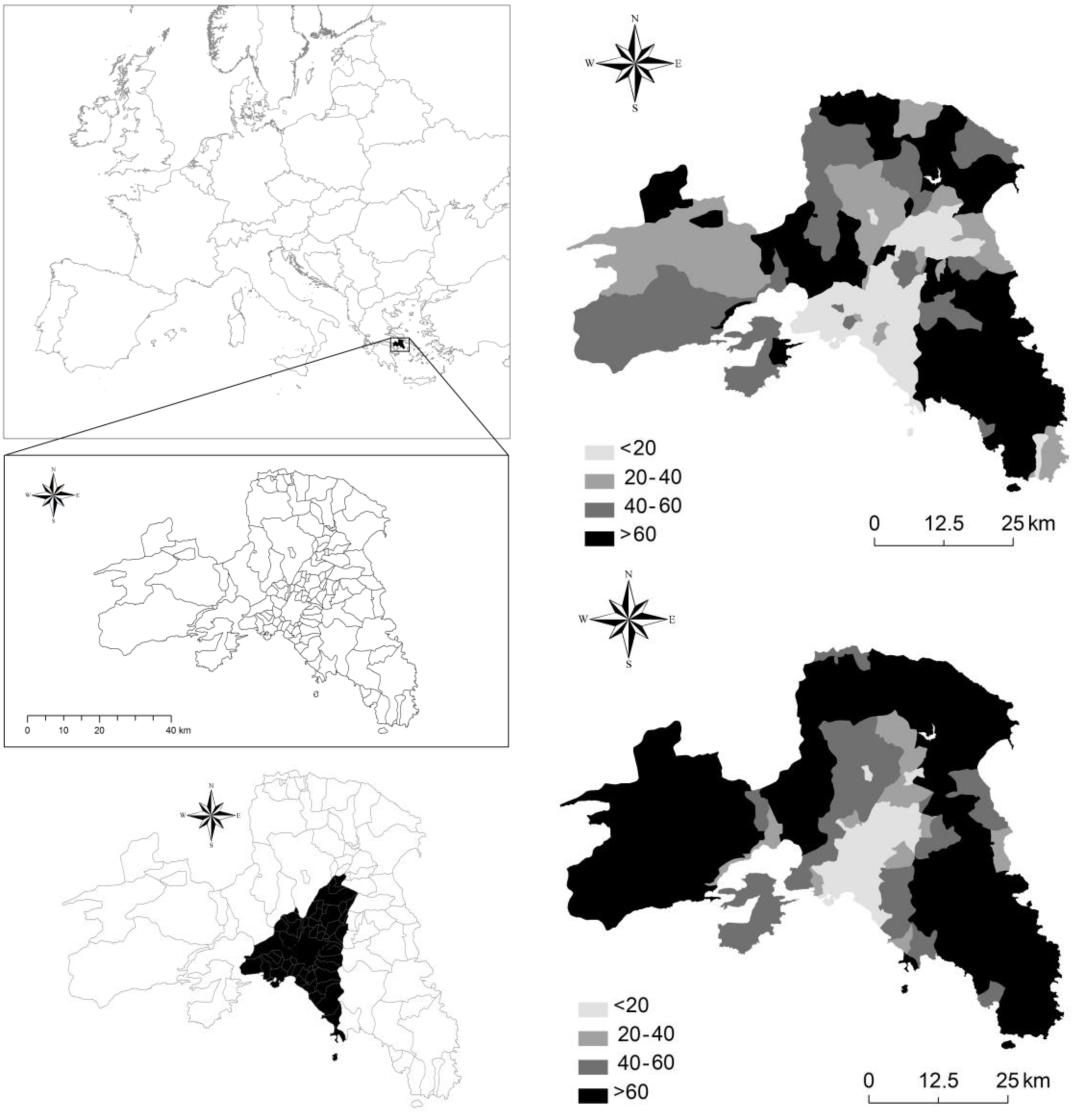


Figure 1. Municipal boundaries in the Athens metropolitan region (**a**), its position in Europe (**b**), and classification of the Athens region in urban (black and rural (white) municipalities (**c**); percent share of cropland in total municipal area by year and municipality (1960: (**d**); 2010: (**e**)).

2.3. Territorial Variables

A total of 11 variables describing population dynamics, topography, urban structure, competing land use (i.e., forest), and climate and soil quality were considered additional context variables in this study and were derived from official statistics (various data sources) at the municipal scale (Table 1). According to Salvati and Serra [35], these variables were considered with the aim to provide a comprehensive assessment of the socioeconomic and territorial characteristics of municipalities in the study area, with a possible (direct or indirect) impact on cropland growth or decline. Following a previous study by Tomao et al. [36], these variables were adopted in regression analysis as predictors of the spatial distribution of cropland over a temporal period spanning from the early 1960s to the early 2010s.

Aggregate data on resident populations (municipal scale) were derived from the National Census of Population carried out by the National Statistical Service of Greece (NSSG) at each decade (1961, 1971, 1981, 1991, 2001, and 2011) and were used to calculate per capita built-up area at the same spatial scale (Urb). According to [37], Urb was considered an indicator of urban land-use efficiency. Population growth (annual percent rate) was considered a proxy of urban expansion. Topographic and territorial variables include specific descriptors of landscape and urban structure (average elevation, proximity to the sea coast, municipal area, and distance to key urban nodes such as Athens, Piraeus, Maroussi, and Markopoulo Messoghias). Topographic variables were measured using ArcGIS software (ESRI Inc., Redwoods, CA, USA). Two variables describing quality of soil and climate were also calculated from a specific dataset released by the European Environment Agency [13]. Soil and climate quality were evaluated with the final aim to ascertain the specific contribution to local-scale land suitability to agriculture [38]. Data on forest areas were derived from computation on land use census for the years 1960, 1970, 1980, 1990, and 2000 and Urban Atlas (UA) map referring to 2010 [36].

Table 1. List of variables considered in the present study (percent share of cropland in total municipal area is the dependent variable in regression models).

Acronym	Variable	Measurement Unit	Source	Time Interval
Agr	Share of cropland in total municipal area	%	Census of land-use	1960–2010
For	Share of forests in total municipal area	I	I	I
Gro	Annual population growth rate	I	Census of population	1961–2011
Area	Municipal surface area	km^2	Territorial statistics	1960–2010
Urb	Per capita built-up area	m^2	Census of land-use	I
Ele	Average municipal elevation	M	Census of population	Once per time
Sea	Proximity to the sea coast	0: internal; 1: coastal	Territorial statistics	I
dAth	Distance from Athens	Km	Our elaboration	I
dPir	Distance from Piraeus	I	I	I
dMar	Distance from Maroussi	I	I	I
dMak	Distance from Markopoulo M.	I	I	I
Cqi	Climate quality index	0–1	Europ. Env. Agency	I
Sqi	Soil quality index	I	I	I

2.4. Exploratory Data Analysis

Data analysis was organized in two steps: (i) exploratory analysis, based on univariate and multivariate approaches, with the objective to analyze long-term changes (50 years) in the spatial distribution of cropland in the study area and (ii) regression models, investigating medium-term changes (10 years) in cropland expansion (or decline) and identifying the main forces at the base of such transformations. Descriptive statistics (including average and median, coefficient of variation, maximum value, coefficient of variation, kurtosis, and asymmetry) describing the spatial distribution of the dependent variable in the municipalities belonging to the study area were calculated at the beginning (1960) and the end of the study period (2010). The relationship between the dependent variable and the linear distance from downtown Athens was illustrated using scatterplots at the same two time points and adapting a square goodness-of-fit polynomial curve to the observations ($n = 114$). A hierarchical clustering (using Ward's agglomeration rule based on a Euclidean distance matrix) was run for the same time points (1960 and 2010) with the aim to group separately (i) variables and (ii) municipalities of the study area on the basis of their similarity patterns [38], thus allowing for the identification of specific territorial profiles associated with high and low levels of percent share of cropland in total municipal area [39]. Based on descriptive and multivariate techniques, a statistical analysis run on aggregate data at the beginning and the end of a long enough time period—as in the present study—may provide an enhanced interpretation of metropolitan transformations with impact on land use distribution [40].

2.5. Regression Analysis

A multiple linear regression analysis based on ordinary least square estimation was finally performed for each time point (1960, 1970, 1980, 1990, 2000, 2010) with Agr as the dependent variable and the 11 predictors reported in Table 1. By using a forward stepwise approach for the selection of un-correlated predictors, this analysis allowed for the identification of changes in the most relevant factors associated with cropland dynamics over time, ranking the individual predictors based on their (direct or indirect) influence on cropland distribution over space and reducing the overall redundancy in the multivariate dataset [35]. All variables were standardized prior to regression analysis. Significant variables were selected fixing F-to-remove and F-to-enter thresholds equal to 3 and 1.5, respectively. Adjusted R^2 was calculated separately for each regression to assess the overall goodness-of-fit of each selected model. Moreover, a Fisher-Snedecor F test with $p < 0.001$ was also run to verify significance against the null hypothesis of a non-significant model. A Durbin-Watson statistic was applied separately to the residuals from the six least squares regressions, testing for serial correlation in the residuals. Values of Durbin-Watson statistics close to 2 (e.g., in the range between 1.5 and 2.5) indicate negligible auto-correlation.

3. Results

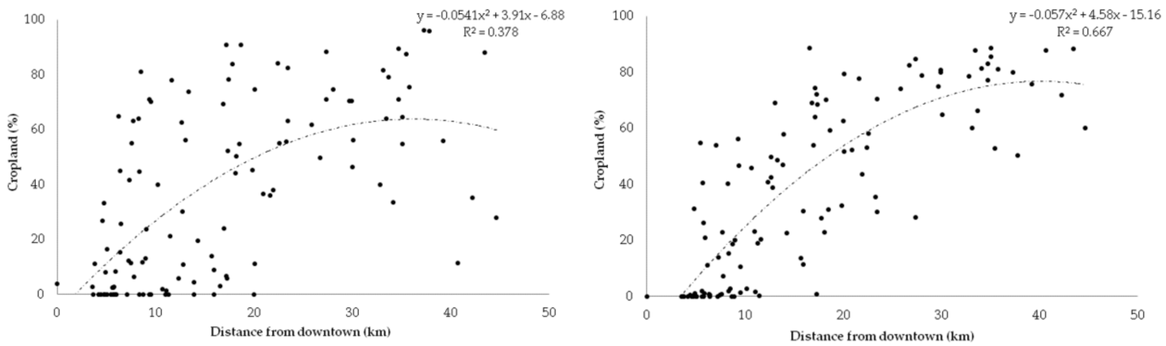
3.1. Descriptive Statistics

Descriptive statistics and maps showing the spatio-temporal evolution of the dependent variable (percent share of cropland in total municipal area) are reported in Figure 1 and Table 2, considering municipalities as the elementary spatial domain. Descriptive statistics outline a moderate increase in cropland surface from 1960 to 2010 (from 37% to 39% on average). Median and average values are rather similar and indicate a substantial regularity in the distribution of the dependent variable over time (Table 2), with a spatial variability decreasing between 1960 and 2010. The maximum value of the dependent variable was decreasing slightly (96% in 1960 and 87% in 2010), although the percent share of municipalities with cropland in total municipalities increased from 84% (1960) to 87% (2010).

Table 2. Descriptive statistics of percent share of cropland in total municipal area by year.

Statistic	1960	2010
Average	36.9	38.6
Median	35.2	40.3
Median to average	0.96	1.04
Coefficient of variation	0.86	0.80
Maximum value	96.0	88.6
Municipalities with cropland (%)	83.6	87.0
Asymmetry	0.27	0.09
Kurtosis	−1.39	−1.47

The spatial distribution of percent share of cropland in total municipal area was mapped in Figure 1, indicating a substantial stability of cropland across the study region. Moderate increases or decreases at a local scale are more likely driven by place-specific socioeconomic factors and/or biophysical conditions. Agricultural areas constituted a buffer to urban expansion, competing with forest land use in more remote places of the metropolitan region. The rural municipalities with the largest cropland surfaces are those situated in traditional agricultural districts such as Megara, Thriasio, Messoghia, and Marathon. Such trends highlight complex transformations of the peri-urban Athens landscape in the last 50 years. The relationship between cropland area and distance from downtown was non-linear, with the highest values observed at a distance ranging between 30 km and 40 km from downtown Athens. The goodness-of-fit of this relationship improved significantly over time, indicating an increased urban-rural polarization at the end of the study period (Figure 2). Only a few municipalities experienced values of the study variable less than 10%, suggesting that cropland is a rather ubiquitous land use not only in rural districts but also in peri-urban marginal areas.



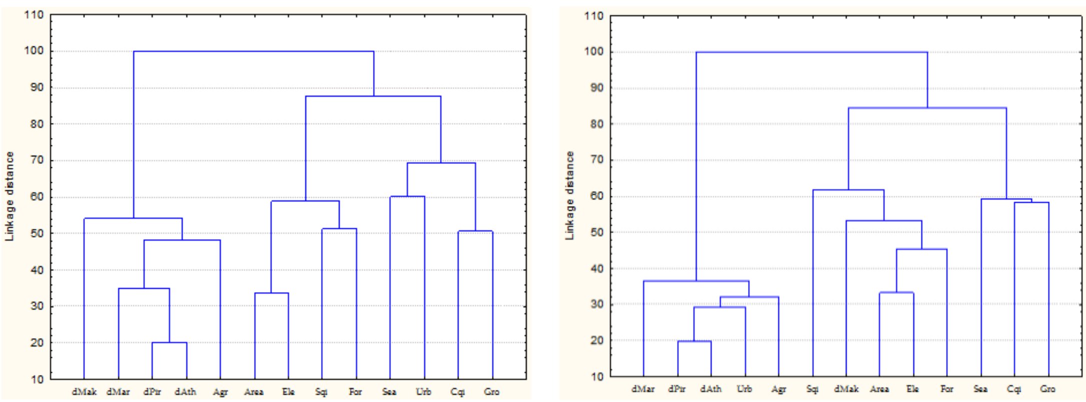
(**a**) (**b**)

(**a**) (**b**)

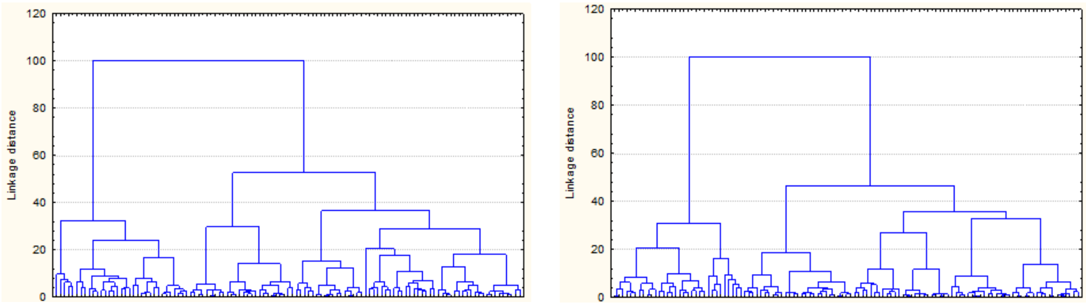
Figure 2. The relationship between percent share of cropland in total municipal area and the distance from downtown Athens (**a**): 1960; (**b**): 2010).

3.2. Hierarchical Clustering

Cluster analysis identified a distinctive similarity pattern for the contextual variables at the beginning and the end of the study period. Cropland clustered together with the distance from all the urban nodes considered in this work (Athens, Piraeus, Maroussi, Markopoulo M.) for 1960, indicating a monocentric structure typically oriented along the urban gradient. Considering 2010 data, cropland clustered together with per capita built-up area and distance from Athens, Piraeus, and Maroussi only. These results suggest a moderate departure from a monocentric structure, outlining instead a more complex spatial interplay between agriculture and low-density settlements that results in a mixed and heterogeneous fringe landscape. Consistently, municipalities in the study area were classified into homogeneous classes (Figure 3) grouping (i) urban municipalities (left side of each graph)—primarily belonging to the Greater Athens area—and (ii) mixed peri-urban and rural municipalities (right side of each graph). Strictly rural municipalities, located over 30 km from downtown Athens and with a share of cropland in total municipal area systematically over 50%, were grouped into a specific class (dashed circle, right side of each graph). Only minor differences in hierarchical clusters were detected for 1960 and 2010.



(**a**) (**b**)



(**c**) (**d**)

Figure 3. Hierarchical clustering of variables (**a**) and municipalities (**b**) in the study area ((**left**): 1960, (**right**): 2010); dotted circles indicate strictly urban municipalities (**c**) and mixed peri-urban/rural municipalities (**d**).

3.3. Multiple Regression

Forward stepwise multiple regression (Table 3) identified (and ranked the impact of) the most relevant predictors influencing the dependent variable (Agr) at each time point investigated in this work. The model's goodness-of-fit increased over time, reaching a particularly high adjusted R^2 (0.75) for 2010. Cropland area increased with the distance from downtown Athens for the whole time period investigated in this study. However, the impact of this predictor was largely variable over time, being the highest in 1960 and decreasing progressively in the following decades thanks to emerging suburbanization processes. A new increase of the regression coefficients was observed for the early 1990s in parallel with a period of huge urban expansion and a final moderate decrease was observed for the early 2010s. The distance from Piraeus explained some of the additional variance observed in selected models and may indicate the period of maximum consolidation of the monocentric model (1970, 1980). The spatial relationship between forests and cropland was negative and significant only for the first decades under investigation (1960, 1970, 1980). Lower regression coefficients indicate a progressive reduction in land use competition between forests and cropland, because of the huge decline of forests in the study area. Population growth rate was positively associated with cropland since the early 1990s; this result is reflected in fringe landscapes where expanding settlements and cropping systems frequently coexist. Distance from Markopoulo Messoghias was negatively associated with the dependent variable for 1970 and 1980, indicating the period of maximum expansion of cropland in a traditional rural district such as Messoghia. Suburbanization-driven landscape transformations in a period immediately following the 1980s may explain the non-significant impact of this predictor in the following decades. Distance from Maroussi (the modern business district of Athens, expanding with the Olympic Games) was relatively less important and significant only for the 1960 and 2000 models. Climate quality had a role in explaining a high level of cropland at the municipal scale only in specific years (1960, 1990, 2000). Soil quality was associated with a higher level of cropland in the last two decades (2000, 2010). Finally, municipal size was occasionally associated with cropland area, significantly impacting the dependent variable only for 1970 and 1980.

Table 3. Results of forward stepwise multiple regressions with percent share of cropland in total municipal area as the dependent variable (see Table 1 for acronyms).

Variable	Beta	Std. Error	*t*-Statistic	*p*-Level
1960: Adj-R^2 = 0.590, $F_{(5,109)}$ = 33.9, $p < 0.001$; D-W test = 1.87				
dAth	1.302	0.135	9.6	0.000
For	−0.497	0.071	−7.0	0.000
dMar	−0.603	0.128	−4.7	0.000
Cqi	0.155	0.065	2.4	0.018
Urb	−0.128	0.062	−2.1	0.042
1970: Adj-R^2 = 0.594, $F_{(6,108)}$ = 28.8, $p < 0.001$; D-W test = 1.74				

dAth	0.418	0.163	2.6	0.012
For	−0.467	0.070	−6.7	0.000
dPir	0.507	0.151	3.4	0.001
Area	0.157	0.072	2.2	0.031
dMak	−0.165	0.075	−2.2	0.030
Urb	−0.134	0.066	−2.0	0.044
1980: Adj-R^2 = 0.546, $F_{(5,109)}$ = 28.4, $p < 0.001$; D-W test = 1.64				
dAth	0.396	0.171	2.3	0.022
For	−0.374	0.074	−5.1	0.000
dPir	0.410	0.158	2.6	0.011
Area	0.219	0.076	2.9	0.005
dMak	−0.144	0.078	−1.9	0.050
1990: Adj-R^2 = 0.656, $F_{(3,111)}$ = 73.5 $p < 0.001$, D-W test = 1.92				
dAth	0.743	0.060	12.5	0.000
Gro	0.204	0.059	3.5	0.001
Cqi	0.136	0.056	2.4	0.017
2000: Adj-R^2 = 0.693, $F_{(5,109)}$ = 52.6, $p < 0.001$; D-W test = 2.05				
dAth	0.980	0.116	8.4	0.000
Gro	0.155	0.060	2.6	0.011
Sqi	0.167	0.055	3.1	0.003
Cqi	0.113	0.054	2.1	0.041
dMar	−0.226	0.111	−2.0	0.044
2010: Adj-R^2 = 0.749, $F_{(4,110)}$ = 86.0, $p < 0.001$; D-W test = 2.00				
dAth	0.565	0.080	7.1	0.000
Sqi	0.305	0.048	6.3	0.000
Gro	0.251	0.048	5.2	0.000
Urb	0.272	0.080	3.4	0.001

4. Discussion

Our study proposes an integrated analysis of cropland distribution over space and land use changes in a metropolitan region, providing a relevant knowledge base with implications for urban studies, agricultural policy, and regional planning [3,6,10,22,34,41–45]. Specific socioeconomic and biophysical factors influencing cropland distribution have been identified through an original procedure based on multivariate exploratory statistics [2,4]. Despite massive urban expansion, our results showed a moderate (and spatially-heterogeneous) increase in cropland over time, mainly at the expenses of forest areas [46–48]. Fringe landscapes became more heterogeneous and mixed, reflecting a latent interplay between low-density settlements and medium-small farms specialized in tree and garden crops [1,14]. Cropland constituted a relevant part of fringe land, and its transformations have a direct impact on the structure of natural-based infrastructures surrounding Athens.

Earlier studies have clearly evidenced how suburbanization has negatively affected the structure of landscapes, reducing the overall environmental quality of the region [13,49]. An increasing polarization in fringe mixed areas and more remote districts was observed during the investigated time period. The monocentric model typical of the study area has influenced markedly the spatial distribution of cropland, evidencing the importance of traditional agricultural systems as a latent urban-forest interface [14,16,50]. At the same time, urban sprawl impacted cropland directly by fragmenting agricultural utilized area and partly disconnecting pristine agricultural-natural districts. Various forms of infrastructure (including the Athens International Airport built-up in the traditional agricultural district of Messoghia) were also important in this process.

As far as factors associated with changes in land use are concerned [51], the results from the multivariate analysis allow for the evaluation of where, when, and how increasing complexity occurred in Athens' landscape over time. Basically, the distance from downtown Athens remained one of the most relevant predictors of the spatial distribution of cropland in the study area. Considering the spatial legacy of a compact and monocentric urban form—only partly altered by recent suburbanization—Athens is a representative example for other European cities experiencing similar development patterns [14,22].

In these regards, our study clarifies the relationship between land use and the local context [26,52,53], identifying the variables most associated with cropland [54]. The significance of the empirical findings of this study for future land use decisions within the local context (considering current economic, political, and soil/climate trends) lies exactly in this issue. Results of our study confirm that the Athens metropolitan region is sensitive to environmental degradation [8,9,55] because of the progressive urbanization of rural fringe [38]. This suggests the role of multi-scalar sustainable land management policies [56–61] in reducing the impact of urban sprawl on cropland [2,13,17,24]. At the same time, a more effective protection of traditional agriculture is required, especially for rural and remote districts [62]. Although the study may represent a good reference either in methodological and results direction for further appraisal of the investigated approach in other European contexts, further studies are required to provide a better understanding of biophysical drivers that are not directly considered in this study, such as wildfires. Moreover, the adopted variables could be integrated with some additional economic indicators, especially related to the regional agriculture system and related market relations. An extensive investigation of methodological limitations and potential sources of error considering the selected indicators and omitted variables is also relevant to advance landscape and regional studies. In this regard, a specific approach based on spatially-explicit models (e.g., considering spatial autocorrelation) is a possible solution for overcoming the implicit problems related with geographical data. Finally, considerable efforts are still needed to design tools capable of guiding decision makers towards the sustainable use of land [63]. Identification and long-term monitoring of urban-cropland interfaces is the basis for a more effective strategy of sustainable land management and planning.

5. Conclusions

In a framework of growing metropolization processes and related land use change that affects Europe, this article allows an original interpretation of land use change, based on understanding the impact of local-scale (socioeconomic and biophysical) contexts on cropland distribution over space in a Mediterranean urban region. The empirical findings of this study contribute towards highlighting two fundamental points in landscape studies: (i) despite huge expansions of residential settlements in rural areas, cropland increased moderately in Athens, demonstrating a strong relevance of agricultural functions compared to other non-urban land uses such as forests (e.g., woodland); (ii) cropland expansion in fringe land may reflect new forms of urban-rural mixes, requiring innovative monitoring approaches, dedicated spatial planning, and specific development policies. The analysis clarifies the multi-faceted (agri-environmental) role of cropland in metropolitan contexts (e.g., providing together ecosystem services, fresh food, and leisure activities). Supporting that role with innovative food policies and regional agricultural market enhancement is imperative in rapidly evolving metropolitan regions.

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