Article

Urban Growth and Land-Use Structure in Two Mediterranean Regions: An Exploratory Spatial Data Analysis

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Abstract

The present study develops an Exploratory Spatial Data Analysis (ESDA) with the aim to assess changes over time in the distribution of selected uses of land in two Mediterranean urban regions (Rome and Athens) with different morphology and economic functions. The study uses global and local Moran's indexes of spatial autocorrelation to describe the land-use structure observed in the two cities in mid-1970s and late-2000s, and debates on the divergent contribution of compact growth and scattered urban expansion to changes in land use. The analysis identifies fringe landscapes as a key target for urban containment policies in sprawling cities.

Keywords

exurban development, land-use changes, indicators, spatial analysis, Mediterranean region

Introduction

The urban–rural gradient is traditionally defined as an ordering of sites based on the predominance of buildings and infrastructure, coupled with dense (or semi-dense) population, in contrast with sites having sparse infrastructure, dispersed settlements, and low population density. A number of criteria have been set up to operationally define urban gradients depending on the environmental and socioeconomic specificity of each investigated region (Alberti, 2005; Allen, 2003; Antrop, 2004; Jomaa, Auda, Abi Saleh, Hamzé, & Safi, 2008; Soliman, 2004). Measurements of physical, biological, and environmental variables or socioeconomic indicators dealing with consumption, finance, transportation, dependence on agriculture, or management of natural resources have been used to contrast urban and rural sites (e.g., Hahs & McDonnell, 2006). These measures usually include a gradient based on the distance from the urban center or a population-density-based gradient or a combination of both variables (Sinclair, 1967). This issue, however, deserves special attention as a potential cross-cutting research field and as a specific topic within planning, regional economics, and urban geography.

While, as a general rule, urban–rural gradients can be found as continuous lines from an old downtown through suburbs, and ending in agricultural and forested areas, the structure of metropolitan areas and their fringes consists of a variety of components, ranging from totally built environments to natural or semi-natural areas with a low imperviousness degree (Shrestha, York, Boone, & Zhang, 2012). The urban gradient is therefore an excellent example of a coupled human–environmental system that cannot be well understood without an integrated approach incorporating aspects of both the socioeconomic and ecological subsystems (Briassoulis, 2001). The spatial distribution of land uses along this gradient definitely reflects the complexity of human–landscape interactions (Serra, Pons, & Saurí, 2008).

In the most recent years, suburbanization has determined important changes in land-use structures on the regional scale by altering the socioecological relationships between urban and the surrounding rural areas (Brueckner, 2000; Bruegmann, 2005; Richardson & Chang-Hee, 2004). Regarded as a multifaceted research and policy issue with controversial aspects in both spatial configuration and territorial processes (Couch, Petschel-held, & Leontidou, 2007), suburbanization contributes to the formation of mixed and hybrid landscapes, which dilute at progressively larger distances from the inner city (Alphan, 2003; Cakir et al., 2008; Catalàn, Sauri, & Serra, 2008; Chorianopoulos, Pagonis, Koukoulas, & Drymoniti, 2010; Paul & Tonts, 2005).

The differentiation of peri-urban areas from both urban and rural areas relies on specific attributes dealing with environmental characteristics and socioeconomic features

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(European Environment Agency, 2006). While land cover change research has mainly focused on rural and natural environments, peri-urban land-use changes have received less attention, and urban land uses have often been lumped together in such a way that "urban" itself means little more than "non-rural" (e.g., Detsis, Ntasiopoulou, Chalkias, & Efthimiou, 2010; Feranec, Jaffrain, Soukup, & Hazeu, 2010; Geri, Amici, & Rocchini, 2010). On the contrary, peri-urban areas have their own socioeconomic, political, and ecological functions affecting ecosystem services (Aguilar, 2008; Jomaa et al., 2008; Sinclair, 1967; Soliman, 2004; Walker, 2004).

In Europe, an increasing proportion of rural, high-quality land experienced changes in use and cover due to dispersed urbanization, with implications on landscape structure, quality, and diversity (Frondoni, Mollo, & Capotorti, 2011; Ioannidis, Psaltis, & Potsiou, 2009; Kasanko et al., 2006; Weber, Petropoulou, & Hirsch, 2005). It was hypothesized that changes in land use along the urban gradient can be influenced by the specific morphology observed in each city (Salvati, Sateriano, & Bajocco, 2013). Salvati and Sabbi (2011) showed how the spatial relationship among land uses can be modified by different "sprawl" patterns (in terms of both settlement morphology and socioeconomic functions) reflecting different processes on the landscape scale (Paul & Tonts, 2005; Polyzos, Christopoulou, Minetos, & Leal Filho, 2008; Schneider & Woodcock, 2008). Especially in southern Europe, highly varied rural landscapes experiencing exurban development may evolve into a low-diversity model, dominated by impervious land and poor-quality woodlands or semi-natural cover classes (e.g., Frondoni et al., 2011). Socioeconomic dynamics leading to landscape transformations definitely indicate that land-use changes may involve wider regions in the future. This scenario points out the importance of monitoring tools and planning solutions for the sustainability of peri-urban areas (Bruegmann, 2005).

Based on these premises, the evolving spatial relationships among land uses in peri-urban areas should be further investigated (Carruthers, Hepp, Knaap, & Renner, 2012). The assessment of landscape structures and land-use changes contributes to inform urban planning and socioeconomic policies for sustainable development. Landscape studies were primarily oriented toward a geo-ecological approach based on metrics quantifying size, shape, connectedness, fractality, and fragmentation of the investigated patches at both class and landscape levels (Alphan, 2003; Antrop, 2004; Feranec et al., 2010; Jomaa et al., 2008, among others). Approaches based on the study of (changing) spatial relationships between landscape types over time, for example, based on Exploratory Spatial Data Analysis (ESDA), are relatively scarce (e.g., Polyzos et al., 2008; Salvati, Sateriano, et al., 2013) and need methodological improvements and a comparative analysis of paradigmatic case studies (Walker et al., 2004).

ESDA techniques are aimed to detect the existence of spatial structures in the data analyzed on different geographical scales by considering the degree of similarity (or dissimilarity) of the observed values of a given variable in neighboring locations, or by considering deviations from the hypothesis of randomness in the distribution of the variable itself (Haining, 1990). ESDA techniques are widely used in regional economics, urban geography, and quantitative sociology, among others (examples can be found in Anselin, 2001; Ertur, Le Gallo, & Baumont, 2006; Li & Haynes, 2011; Longhi & Nijkamp, 2007; Patacchini & Rice, 2007).

As an original contribution to landscape studies, the ESDA may provide an *in-depth* assessment of the interplay among different land-use classes by quantifying spatial clusters and evaluating spatial autocorrelation functions on a regional scale. Local autocorrelation indexes may complement this general picture providing an assessment of long-term trends at both class and landscape levels. This output can be contrasted with independent socioeconomic variables to assess their role in the transformation of fringe landscapes (Shrestha et al., 2012). By specifying thresholds and evaluation rules, the ESDA approach proved to be useful to identify objectively and to characterize urban gradients from both landscape and urban planning perspectives (Hahs & McDonnell, 2006).

By using a simplified ESDA approach, the present study investigates the spatial distribution of basic land-use classes along the urban gradient in two expanding southern European regions, Rome (Italy) and Athens (Greece), at two points in time (mid-1970s and late-2000s) representing different phases of the urban expansion of both cities. The 1970s were characterized by rapid population growth and compact urban expansion, while the 2000s represented a period of discontinuous urban growth and population decline in the central city. The spatial organization of the two regions progressively diverged from mono-centricity and compactness to different levels of settlement scattering (Salvati & Sabbi, 2011; Salvati, Sateriano, et al., 2013). The proposed approach is therefore aimed at verifying, based on the results derived from an ESDA, if landscape structure and the spatial distribution of selected uses of land along the urban gradient in the two cities change over time as a consequence of dispersed urbanization. The analysis identifies processes of changes in specific classes of land use that could be considered in a comprehensive strategy reducing landscape fragmentation and containing urban expansion in originally compact and dense cities. From this perspective, approaches based on the ESDA can be considered as original contributions to regional planning, urban studies, and environmental management.

Method

Study Area

The two investigated regions correspond to the urban area of Rome and Athens, two Mediterranean cities characterized by different settlement morphology and an economic structure

mainly centered on commerce, tourism, public sector, and construction industry. In Rome, the study area covers the entire Nomenclature of Units for Territorial Statistics, level 3 (NUTs-3) European province with 121 municipalities and a surface area of 5,355 km^2. The municipality of Rome, one of the biggest in Europe (1,285 km^2), was subdivided into smaller districts, with a size comparable with the remaining municipalities of the prefecture. The investigated area was therefore partitioned into a total of 235 spatial units forming a complex topography consisting of 30% lowlands, 50% uplands, and 20% mountains.

Athens' area extends for nearly 3,000 km^2 and covers a large part of the NUTs-2 region of Attica coinciding with the Athens metropolitan area considered in the Urban Atlas initiative (European Environment Agency, 2010). The investigated area was subdivided into 115 mainland municipalities (including Salamina Island) of which 58 formed the compact urban area covering 430 km^2 (the spatial asset of the urban region was recently changed by the "Kallikratis" law that reduced the number of municipalities to nearly 60). The region mostly consists of mountains bordering the urban area of Athens and three coastal plains (Thriasio, Marathona, and Messoghia) located outside the compact urban area (Salvati, Sateriano, et al., 2013).

Land-Use Data and Maps

The surface area covered by basic land-use classes was assessed at 2 years (1974 or 1975 and 2006 or 2009) in Rome and Athens, respectively, based on digital maps covering the investigated regions. In Rome, data were obtained from elaboration of two compatible digital land cover maps: the Corine Land Cover (CLC)–like "Agricultural and forest map of Rome province" (scale 1:50,000) dated 1974 and the 1:100,000 CLC map dated 2006 (Salvati & Sabbi, 2011). In Athens, the CLC-like LaCoast (LC) digital cartography available for 1975 at 1:100,000 scale (Perdigao & Christensen, 2000) and the GlobCorine (G-CLC) cartography, a pan-European land-use map available in 2009 and providing a resolution of 300 m with a compatible CLC legend (see http://due.esrin.esa.int/prjs/prjs114.php for technical details), have been used for analysis.

The LC project consisted in a quantitative analysis of changes in land cover over a 10-km wide coastal strip around the countries of Europe performed through a comparison of the CLC-Level 3 database (44 classes at 1:100,000 scale) of 1987-1990 with Landsat-MultiSpectral Scanner (MSS) satellite images dated 1975, and the creation of a land-use/land cover database for the year 1975. For a restricted number of municipalities in Attica where the coverage of the LC map is partial, data were complemented with information derived from the 1980 land-use census carried out every 10 years by National Statistical Service of Greece (see Salvati, Sateriano, et al., 2013 for further details) and from the CLC map dated 1987 to 1990. GlobCorine is a European Space Agency

(ESA) project based on an automatic service that generates in a consistent way land-use/land cover maps and land change indicators based on a CLC-compatible legend. GlobCorine project delivered a land-use/land cover map covering the pan-European area (including the Mediterranean basin and the European Russia) and using full-year 2009 remote sensing data.

Six and five land-use classes in Rome and, respectively, Athens have been selected for analysis, including (a) built-up areas (URB), (b) tree crops (TRE), (c) sparse natural vegetation (SPA), (d) arable land (ARA), (e) heterogeneous crops (HET), and (f) forests (FOR) in Rome and (g) URB, (h) rain crops (RAI), (i) FOR, (j) HET, and (k) SPA in Athens. These classes were chosen to provide a comprehensive description of the landscape found in the two study areas (see Salvati & Sabbi, 2011; Salvati, Sateriano, et al., 2013 for further details on landscape structure in Rome and Athens, respectively). The analysis of land-use composition was carried out separately for the two time periods (referring to mid-1970s and late-2000s periods). Only cross-section variables were used while time changes were derived separately from the statistical output for each year.

The Spatial Unit of Analysis

The selection of the elementary spatial unit of analysis is a key issue in urban studies. Quantitative research usually relies on administrative boundaries that have been largely used as the denominator for demographic, socioeconomic, and land-use analysis (Garcia & Riera, 2003; Muñiz, Galindo, & Angel Garcia, 2003; Tsai, 2005). Although administrative boundaries depict arbitrary spatial units with regard to the urban landscape, the use of municipalities, districts, or local administrative units allows a detailed diachronic analysis of a number of different indicators derived from official statistics (Salvati, Gargiulo, Rontos, & Sabbi, 2013). While data at lower spatial resolutions (e.g., census tracts and enumeration district units) were made available only recently and with heterogeneous territorial coverage, municipal data allow cross-country and within-region reliable comparisons along relatively long time intervals. As a matter of fact, municipalities (NUTS-5 or European Local Administrative Units, level 2 [LAU-2]), represent, in both Italy and Greece, the minimum mapping unit (i.e., the smallest spatial domain) of most statistical surveys and are also easily interpretable by policy-makers, planners, and other local stakeholders. In both countries, municipalities are a key institution in the decision process about land destination, building volume, settlement size, and other factors affecting urbanization, landscape structure, and land-use changes (Salvati & Sabbi, 2011; Salvati, Sateriano, et al., 2013; but see also Chorianopoulos et al., 2010). Based on these premises, municipalities are regarded as a meaningful unit of analysis from both statistical and planning perspectives.
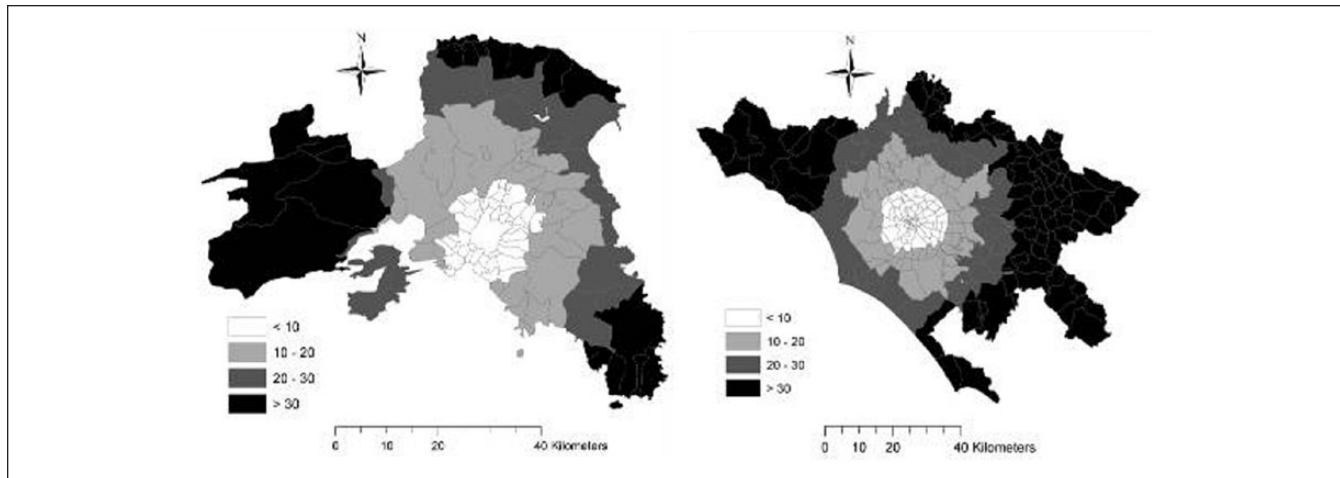
Figure 1. Distance of each municipality from the inner city of Athens (left) and Rome (right).

Evaluating the Urban–Rural Divide in the Use of Land

By using the ArcGIS "create centroid" function, a centroid for each elementary spatial unit was derived from the shapefiles depicting the geometry of municipality's boundaries provided for Athens and Rome, respectively, by the Hellenic Statistical Authority (EL.STAT) and the Italian National Institute of Statistics (ISTAT) at the 1:10,000 scale. A place in downtown Rome and Athens was selected to represent the position of the inner city. The selected place in both Athens and Rome (Plateia Syntagmatos in Athens and Piazza Barberini in Rome) was considered one of the most representative places in the historical center with high density of services, public institutions, commercial activities, and resident population (Salvati, Gargiulo, et al., 2013). The proximity of each municipality to the inner city was determined by calculating the linear distance between the municipality centroid and the central place determined as described above (see also Figure 1). By considering municipalities within the same urban region, linear distances are a simplified but reliable tool to explore the spatial organization of cities and the possible impact on landscape structure on the regional scale (Salvati & Sabbi, 2011).

ESDA

The land-use composition of each spatial unit of analysis was estimated in the 2 years as the percentage surface area of the above-mentioned classes on the total surface area by using the "intersect" tool provided by ArcGIS software (ESRI, Inc., Redwoods, USA) after the overlap between each land-use map and the shapefile depicting the municipality's boundaries. The subsequent analysis was developed using municipalities (and urban districts in Rome) as the minimum mapping unit and land-use classes as target variables. Percentage class area represents a well-known and largely

used proxy for landscape composition and land-use changes on the local scale (see Salvati & Sabbi, 2011 and references therein). Although alternative computational solutions can be implemented, the percentage class area was preferred to other statistical figures as it provides readers with an intuitive description of landscape composition and an exhaustive mapping of prevailing land uses.

The assessment of both global and local spatial autocorrelation processes characterizing landscape composition was carried out in this study through Moran's statistics (Cliff & Ord, 1981). By using the "spatial statistics" tool provided with ArcGIS, the global Moran's index of spatial autocorrelation was calculated for each year and class of land use at eight fixed distances (d = 2, 5, 10, 15, 20, 30, 40, and 50 km). For each d, the standardized z value for each global Moran's index, $z(I)$, was reported together with the associated level of significance assuming the (asymptotic) distribution of I is normal (Anselin, 1995). The analysis was aimed to identify a partition of each investigated area grounded on the properties of the stochastic process generating the observed spatial pattern of each target variable. By increasing d incrementally, it is possible to assess how far the links between spatial units extend (Patacchini, 2008). Also, by varying d (and thus considering alternative definitions of neighborhoods), the analysis of spatial dependence conveys information about the association pattern that maximizes the intensity of interactions between areas. The definition of proximity is therefore important in these analyses. For each investigated spatial unit, a relevant neighboring set should be defined in terms of those spatial units that potentially interact with it. A spatial weight matrix based on the Euclidean distances between the centroids of each municipality was used in the present study as a standard approach to define proximity (Patacchini & Rice, 2007).

Moran's I statistic is intended as a global statistic, in the sense that the overall pattern in the data is summarized in a single value indicating different spatial relationships for a

given subset of data. To assess spatial dependence in a particular subregion of the sample, the local Moran's index (z score) was calculated for each municipality, year, and class of land use, producing a number of spatial autocorrelation maps for both cities that are examined and commented in the following "results" chapter. The local Moran's statistic measures the correlation between the value for a given area and that for its neighbors; a positive and significant value of the local Moran's statistic indicates spatial clustering of similar (high or low) values, whereas a negative and significant value indicates spatial clustering of dissimilar values between an area and its neighbors. Based on these premises, values of the Moran's z score higher than 1.96 and lower than −1.96 were highlighted in the maps to indicate the two cases described above. Local Moran's statistics were computed using the spatial weight matrix based on the distance at which the spatial linkages between areas seem to be strongest (Patacchini, 2008).

Correlation Analysis

The local Moran's z score for the URB class was correlated (separately for each city and reference year), to (a) the distance of each municipality from the inner city and (ii) the share of urban areas to the total municipal area. This exercise, together with the results of the previous analyses, is aimed at identifying changes over time in the urban landscape structure through each investigated region. Due to the exploratory approach of the present study, two separate regression analyses were carried out to assess the distribution of the local Moran's z scores along the urban gradient using the two independent variables described above. The best-fit polynomial model was selected in both cases by checking for the highest adjusted R^2 statistic.

As this study uses an elementary unit of analysis based on administrative boundaries, the Modifiable Areal Unit Problem (MAUP) might influence the results of certain statistical analyses, for example, the correlation analysis. The MAUP is a source of statistical bias that can affect the results of statistical hypothesis tests when point-based measures of spatial phenomena are aggregated into modifiable areal units. Consequently, the resulting summary values can be influenced by the choice of unit boundaries (Openshaw, 1984). However, the approach here developed is mainly exploratory and was not aimed at testing specific hypotheses in the spatial distribution of the investigated variables. Moreover, based on the considerations reported in the section "The Spatial Unit of Analysis," the selected spatial domain appears as a reliable analysis unit for urban studies and geography. Although the methodology proposed can be applied to data available on various spatial scales (e.g., census tracks, economic districts, administrative boundaries, physiographic zones), the use of the local administrative scale allows for a comparative, multitemporal analysis of the landscape structure and the relationships among different uses of land (Salvati, Gargiulo, et al., 2013) at a spatial scale, which is relevant for urban planning and sustainable land management.

Results

Land-Use Distribution and Changes in Rome and Athens (Mid-1970s–Late-2000s)

As illustrated in Table 1, the most relevant landscape changes in both cities are linked with urban expansion (increasing by 10% and 6% in Athens and Rome, respectively). URB covered, respectively, the 13% and the 26% of the total area in Rome and Athens in the most recent study year. Urbanization consumed both agricultural areas (reduced by 7% during the investigated time interval) and natural and semi-natural habitats (−3%) in Athens but not in Rome, where natural and semi-natural habitats decreased by 12% in parallel with an increase in agricultural areas (+6%). The predominant land-use classes in Rome were ARA and FOR in both years. Heterogeneous crop mosaic and FOR covered the majority of Athens' region, but a moderate decline between 1975 and 2009 was observed for both uses.

Exploratory Spatial Analysis of Land-Use Distribution at the Regional Scale

Table 2 reports the global Moran's index by year, land-use class, and distance from the inner city. Overall, spatial autocorrelation in land-use distribution showed a typical inverted U-shaped pattern, with distance in both cities increasing up to a peak observed at intermediate distances and then declining more or less rapidly. Despite the relevant increase in URB, the maximum global Moran's index for this class was observed in Athens at 20 km distance being stable in both years, while in Rome, Moran's index reached the maximum score at 10 km distance in 1974 and at 20 km in 2006. This contrasting pattern suggests that urbanization occupied mainly fringe areas in Athens with few dispersed settlements at larger distance from the city. This expansion mode consolidated the mono-centric, dense, and compact structure typically observed in Athens' urban area. By contrast, urbanization in Rome occurred not only on fringe areas but also around subcenters far away from the inner city. This development mode altered the semi-compact and continuous urban structure contributing to the shift toward settlement scattering. These results indicate that in Athens the spatial structure of urban settlements changed only moderately over time in contrast to what was observed in Rome.

Interestingly, FOR showed the opposite pattern: in Rome, the maximum global Moran's index was found in the 30-km distance zone in both years, despite a moderate score decline in 2006 compared with 1974. In Athens, the peak value of Moran's index was observed at 10 km and 20 km in 1975 and 2009, respectively. These results indicate a substantial stability of the forest cover in Rome in terms of both landscape composition and spatial structure, while in Athens the reduction in

Table 1. Land-Use Composition (%) in Athens and Rome by Year and Class.

Land-use class	1975[a]	2009[b]	% change
Athens			
Rain-fed cropland (RAI)	16.5	10.1	−6.4
Heterogeneous agricultural areas (HET)	43.5	43.4	−0.1
Total of Agricultural areas	*60.0*	*53.5*	*−6.5*
Forests (FOR)	22.0	20.4	−1.6
Sparsely vegetated areas and bare land (SPA)	2.1	0.4	−1.7
Water bodies	0.1	0.1	0.0
Total of Natural areas	*24.2*	*20.9*	*−3.3*
Built-up areas (URB)	15.8	25.6	9.8
Rome			
Arable land (ARA)	29.7	29.5	−0.2
Heterogeneous agricultural areas (HET)	12.2	20.2	8.0
Tree crop (TRE)	9.3	7.9	−1.4
Total of Agricultural areas	*51.2*	*57.6*	*6.4*
Forests (FOR)	20.0	20.0	−0.0
Sparse vegetation (SPA)	19.9	7.9	−12.0
Water bodies	1.6	1.6	0.0
Total of Natural areas	*39.9*	*27.9*	*−12.0*
Built-up areas (URB)	7.3	12.9	5.6

Note. Acronyms indicate the classes analyzed within the ESDA framework. ESDA = Exploratory Spatial Data Analysis.
[a]1974 in Rome.
[b]2006 in Rome.

forest area was reflected in a marked spatial rearrangement with concentration at larger distances from the city.

In contrast with the trends analyzed above, the spatial distribution of SPA showed a comparable trend in the two cities, with the autocorrelation index increasing at higher distances. As a matter of fact, the maximum global Moran's index was observed in 1975 at 5 km and 10 km distance in Rome and Athens, respectively, while shifting at 30 km and 20 km in the most recent period. These changes indicate a higher dispersion of sparse vegetation with the reduction of the polarities observed in the mid-1970s. Results also reflect peculiar urbanization dynamics leading to the consumption of the Mediterranean fringe landscape typically formed by poor-quality sparse vegetation, pastures, and isolated farming areas.

Heterogeneous agricultural areas featured a comparable autocorrelation structure along the urban gradient in both cities. The maximum global Moran's index was observed at 20 km in both years with comparable scores in Athens and Rome, possibly indicating stability over time and spatial dispersion. The autocorrelation structure for the remaining two agricultural classes (TRE and ARA) was found relatively stable over time in Rome (the maximum global Moran's scores were observed, respectively, at 20 km and 10 km), while a shift in the maximum score Moran's index for RAI (observed at 15 km in 1975 and 20 km at 2009) was found in Athens. Despite moderate increases, these findings

indicate a substantial stability in the spatial structure of croplands in Rome. More relevant changes occurred in Athens where a decline in this class' area was observed (see Table 1).

Evaluating Changes in the Spatial Structure of Land Uses at the Regional Scale

Figure 2 illustrates the distance-weighted average of the global Moran's index for each land-use class in Rome and Athens by year. The analysis focuses on possible shifts in the landscape spatial structure highlighting concentration (or dispersion) processes for each class due to urbanization-driven landscape transformations. In both cities, the average Moran's score of URB decreased markedly indicating a shift toward more diffused spatial patterns. This result is in line with previous findings observed by Salvati and Sabbi (2011) in Rome and Salvati, Sateriano, et al. (2013) in Athens and reflects the dispersed, medium- and low-density settlement expansion observed in the two cities over the last three decades. As far as the remaining classes are concerned, different patterns were observed. The average Moran's index decreased for FOR and TRE in Rome, being stable for ARA and sparse vegetation and increasing moderately for heterogeneous agricultural areas. In Athens, the average global Moran's index increased for FOR, was stable for HET, and declined weakly for sparse vegetation and RAI. These

Table 2. Exploratory Spatial Data Analysis (Global Moran's Index: z(I)*) of the Distribution of Each Examined Class of Land Use by Year and Different Values of *d* (see Paragraph "Evaluating the Urban–Rural Divide in the Use of Land") in Athens (a) and Rome (b).
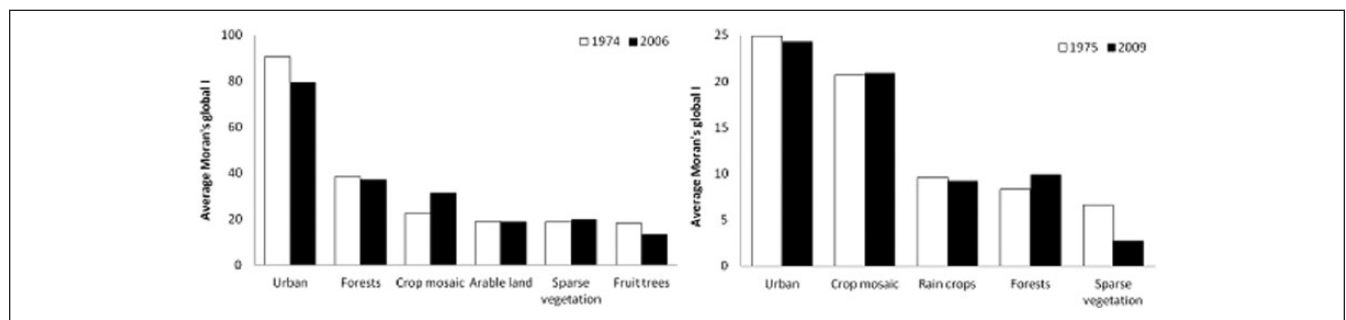
(a) Athens

d (km)	URB 1975	URB 2009	RAI 1975	RAI 2009	FOR 1975	FOR 2009	HET 1975	HET 2009	SPA 1975	SPA 2009
2	7.4	6.2	4.3	2.1	3.1	1.8	5.5	5.4	3.8	0.4
5	15.8	14.3	6.6	6.8	6.8	4.4	12.0	12.1	6.3	2.8
10	23.9	22.3	9.4	9.1	8.6	7.9	19.2	19.5	7.4	2.3
15	27.5	26.6	10.6	9.9	8.2	10.1	23.1	22.9	6.9	2.3
20	27.9	27.9	10.6	10.2	8.2	11.1	24.3	23.7	6.6	3.1
30	26.3	26.2	10.1	9.5	8.5	10.8	22.1	22.4	7.0	2.8
40	24.7	23.9	9.4	9.1	8.4	10.1	20.1	20.7	6.9	2.6
50	24.4	23.5	9.4	9.0	8.3	9.9	20.0	20.3	6.2	2.7

(b) Rome

d (km)	URB 1974	URB 2006	TRE 1974	TRE 2006	SPA 1974	SPA 2006	ARA 1974	ARA 2006	HET 1974	HET 2006	FOR 1974	FOR 2006
2	51.1	35.0	3.9	2.6	14.3	3.3	10.2	9.9	7.7	12.9	7.1	6.6
5	80.8	59.9	11.3	7.4	20.7	8.8	19.1	18.0	14.2	22.5	16.7	16.1
10	93.3	77.7	17.4	12.7	18.6	14.1	20.4	20.1	19.7	30.1	28.8	27.9
15	93.0	83.0	19.6	15.0	18.1	18.0	17.4	17.6	22.7	34.3	36.1	35.0
20	92.3	83.7	19.7	15.6	18.6	20.4	17.2	17.2	23.7	34.6	40.3	38.9
30	91.9	82.5	18.9	13.9	18.5	22.7	18.9	18.6	23.5	33.0	42.9	41.2
40	90.6	79.8	18.3	12.8	19.0	21.9	19.8	19.5	22.7	31.2	41.3	39.8
50	90.2	78.4	17.9	12.9	19.1	20.3	20.0	19.7	22.0	30.2	38.8	37.2

Note. URB = built-up areas; RAI = rain crops; FOR = forests; HET = heterogeneous crops; SPA = sparse natural vegetation; TRE = tree crops; ARA = arable land.
*In both cities, z(I) values were found always significant at $p < .01$.

Figure 2. Changes over time in the spatial autocorrelation structure (distance-weighted average Moran's global index) of each examined land-use class in Rome (left) and Athens (right).

dynamics reflect the different impact urban morphology exerts on the distribution of non-urban classes.

Exploring the Spatial Structure of Land Uses on the Local Scale

The distribution of the *z* score Moran's local index of spatial autocorrelation in each unit of Rome's and Athens' regions is shown in maps prepared for each class of land use (Figure 3). The spatial distribution of the local Moran's index for the urban class in Athens confirms the results illustrated above, identifying a gradient from urban to rural areas both characterized by positive autocorrelation regimes. This pattern was more evident in 2009 than in 1975, although the autocorrelation structure remained quite stable on the regional scale. Areas characterized by a low (or negative) autocorrelation
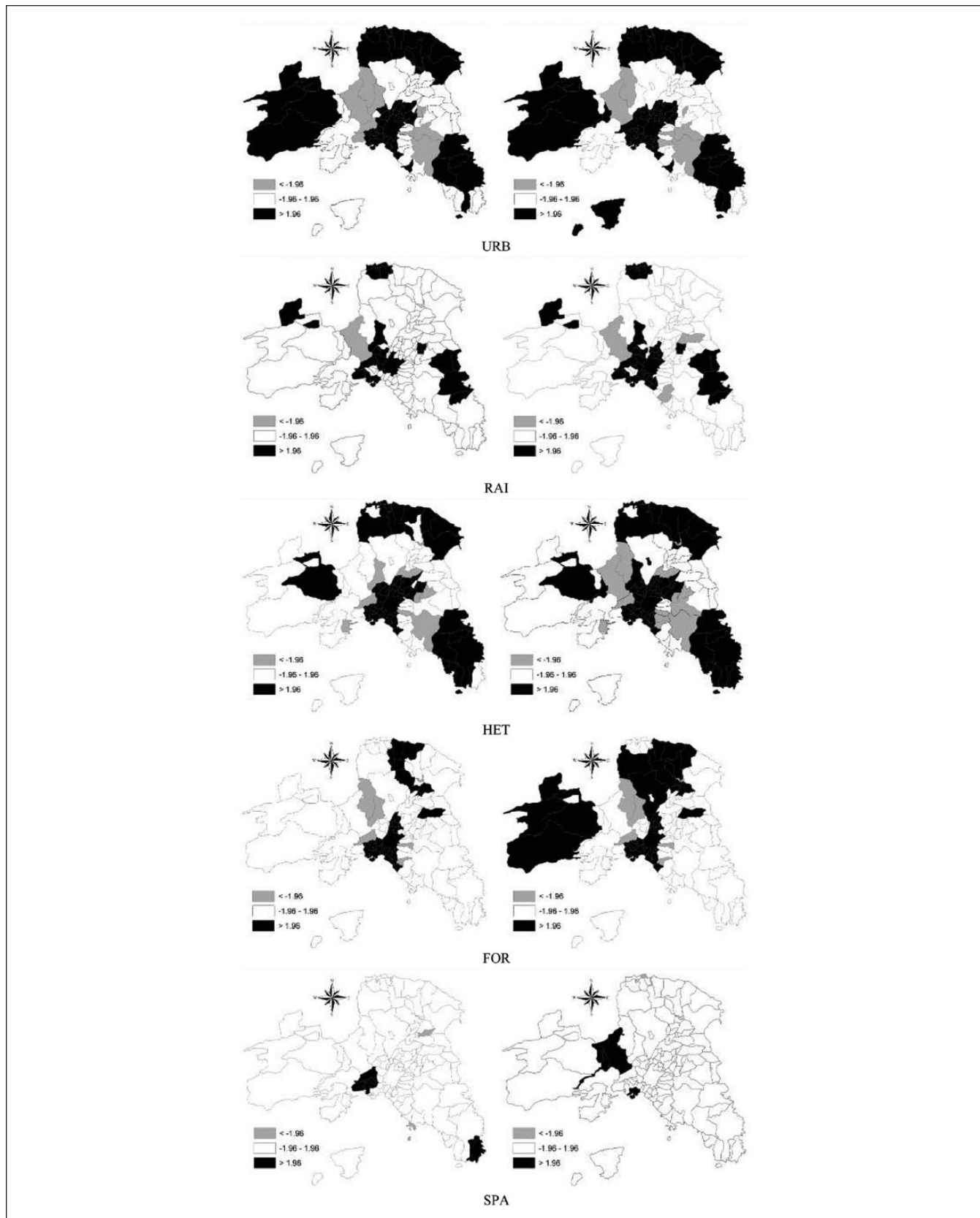
Figure 3. Local Moran's index by land-use class and municipality in Attica (left: 1975; right: 2009).
Note. Class abbreviations are reported in the section "Land-Use Data and Maps."

regime were mainly observed in peri-urban spaces placed *in between* urban and rural areas. These areas featured rapid population and urban expansion, important landscape transformations (e.g., from FOR to agriculture), and an increased spatial heterogeneity in the distribution of land uses on the local scale, which is reflected in the low autocorrelation regime.

The local Moran's index for FOR showed a different spatial pattern with a marked concentration found in 2009 compared with 1975, when this class was quite homogeneously distributed throughout the region. Results indicate an increasing polarization in class distribution for urban areas and FOR, possibly due to urbanization-driven landscape restructuring along the distance gradient. Heterogeneous agricultural areas characterized by crop mosaic followed the pattern observed for URB, showing increasing disparities between central and peripheral areas in Attica. Interestingly, the number of municipalities classified at low autocorrelation regime increased in 2009, especially in peri-urban areas. This confirms the existence of landscape heterogeneity processes and the emergence of a mixed and disordered landscape on the fringe. Rain-fed crops and sparse vegetated areas showed a moderate polarization in class distribution with no relevant changes over time.

In Rome, marked changes in the spatial structure were observed for all land-use classes except for ARA (Figure 4). As observed in Athens, the polarization in urban and rural areas (both characterized by the high autocorrelation regime for the built-up class) in 1974 was evident in Rome and increased in 2006 because of the city expansion. Areas with a low autocorrelation regime reflecting the increase of peri-urban spaces with a fragmented and heterogeneous landscape surrounded the municipality of Rome in 1974 and expanded in 2006, with a similar spatial structure.

A polarization in high and low autocorrelation regimes was observed for sparsely vegetated areas, TRE, and FOR, possibly indicating a process of land-use rearrangement in Rome's region. The expansion of municipalities classified at high autocorrelation regime is particularly evident over the study period for sparsely vegetated areas and FOR (with a polarization in "urban" and "marginal" municipalities both characterized by high autocorrelation).

On the contrary, heterogeneous agricultural areas showed a shift in the autocorrelation regime from the western to the eastern area surrounding Rome's municipality, possibly indicating a complex process of landscape rearrangement. Finally, ARA showed a substantial stability in the autocorrelation pattern with a high regime observed in the flat area west of Rome and in marginal hilly areas east of Rome. ARA is a traditional use of land in Rome's region showing a modest variation in class area over time.

The Structure of Spatial Autocorrelation Along the Urban Gradient

The relationship between the local Moran's z score for the built-up class and the proportion of urban areas observed in
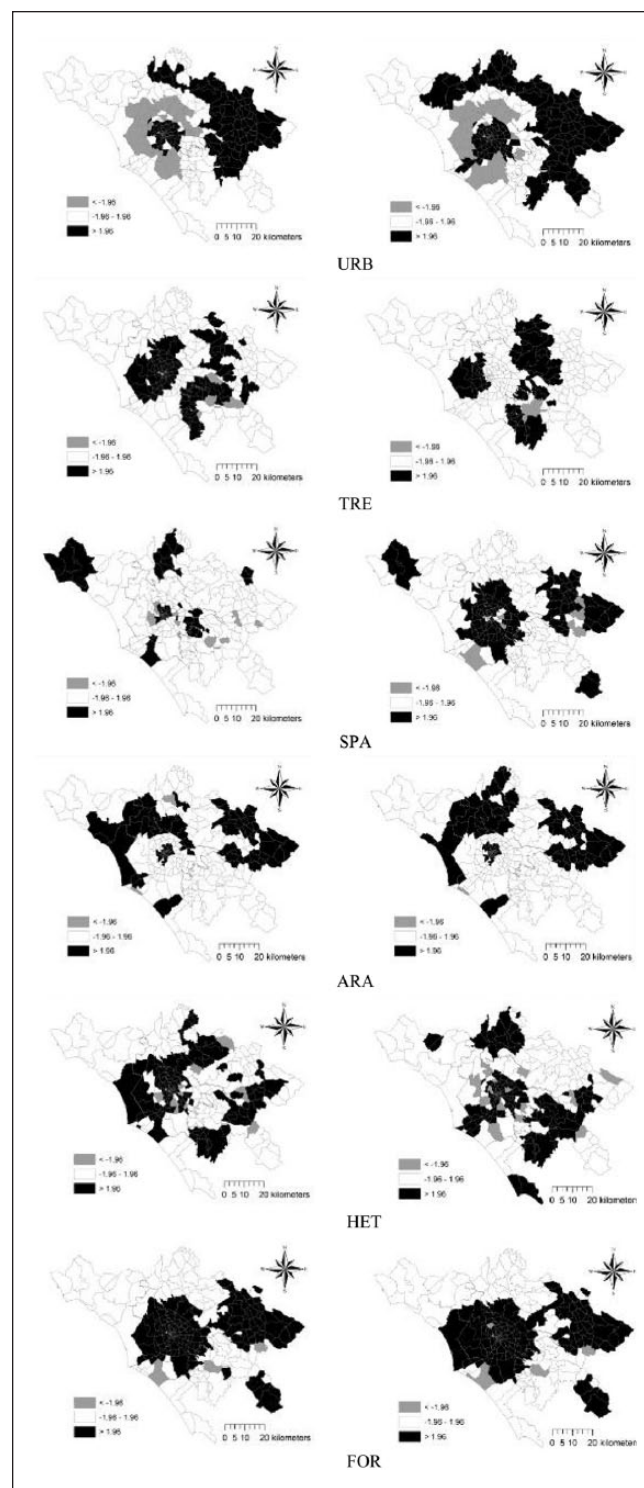

Figure 4. Local Moran's index by land-use class and municipality in Rome's province (left: 1974; right: 2006).
Note. Class abbreviations are reported in the section "Land-Use Data and Maps."

each spatial unit in both Rome and Athens is illustrated in Figure 5 by year. As expected, positive autocorrelation regimes were observed primarily in municipalities with a
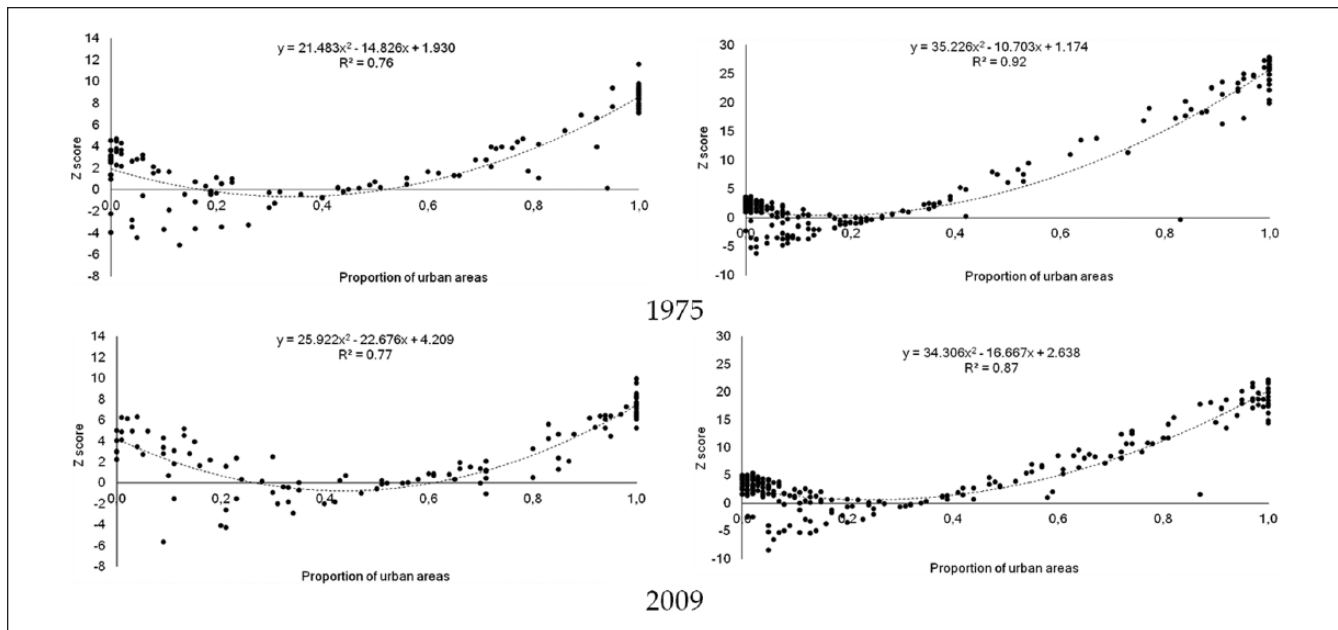
Figure 5. The relationship between the local Moran's z score and the proportion of urban areas in each municipality of Athens (left) and Rome (right) regions by year.
Note. 1974 and 2006 for Rome

share of URB to the total municipal area higher than 0.8. However, in both cities, the best-fit regression model was less steep in the most recent period, possibly indicating a less polarized urban landscape likely due to the processes of settlement dispersion observed during the last 30 years.

Figure 6 illustrates the relationship between the local Moran's z score and the distance from the inner city in each municipality of the two study areas. Two different patterns were observed in Rome and Athens. In the first time point, high autocorrelation regimes were observed in urban municipalities close to Rome (<10 km far away from the city center) and rural areas with a distance ranging from 30 km to 50 km. A low autocorrelation regime was also observed in peri-urban municipalities at distances around 20 km from the inner city. Interestingly, this pattern was less evident in the final year, providing an indirect proof to urban scattering. In Athens, high autocorrelation regimes were observed at distances <10 km and >30 km from the inner city reflecting the polarization in urban and rural areas. Interestingly, municipalities with a low autocorrelation regime are few and stable over time, suggesting that the mono-centric spatial organization of the whole region was only moderately altered by processes of urban diffusion observed in the last 30 years.

Discussion

The present study explores the spatial relationship in selected land-use classes observed along the urban–rural gradient in two cities characterized by different morphology and contrasting socioeconomic settings. The novelty of our research

is in the use of a spatial exploratory framework based on classical autocorrelation indexes (traditionally applied to the analysis of socioeconomic variables, such as income, employment, labor productivity, and industrial concentration) to the study of land-use structure. This approach, providing information—on both the regional and the local scales—about concentration (or diffusion) dynamics in each investigated class, can supplement standard geo-ecological approaches based on landscape metrics. From the statistical point of view, the approach developed in this study is deliberately simple to allow easy interpretation of results for non-technical users such as practitioners and planners.

Results pointed out the usefulness of multitemporal, comparative analyses of land-use spatial relationships in peri-urban regions (Longhi & Musolesi, 2007; Turok & Mykhnenko, 2007). The landscape rearrangement observed in Rome's and Athens' regions was reflected in changing autocorrelation regimes, especially for URB, FOR, and agricultural classes. In the first study period, the values of Moran's index reflect the complex "succession" in the use of land traditionally observed along the Mediterranean urban-to-rural gradients. A more simplified landscape structure was observed in the most recent period, which resulted to be poorly correlated with the distance from the inner city and more associated with elevation, the level of land protection (e.g., national or regional parks), and the distance from the infrastructural network (Salvati, Sateriano, et al., 2013). At the regional scale, diverging regimes in the autocorrelation structure of specific classes (mainly URB and FOR) in Rome and Athens may indicate the different impact of city's
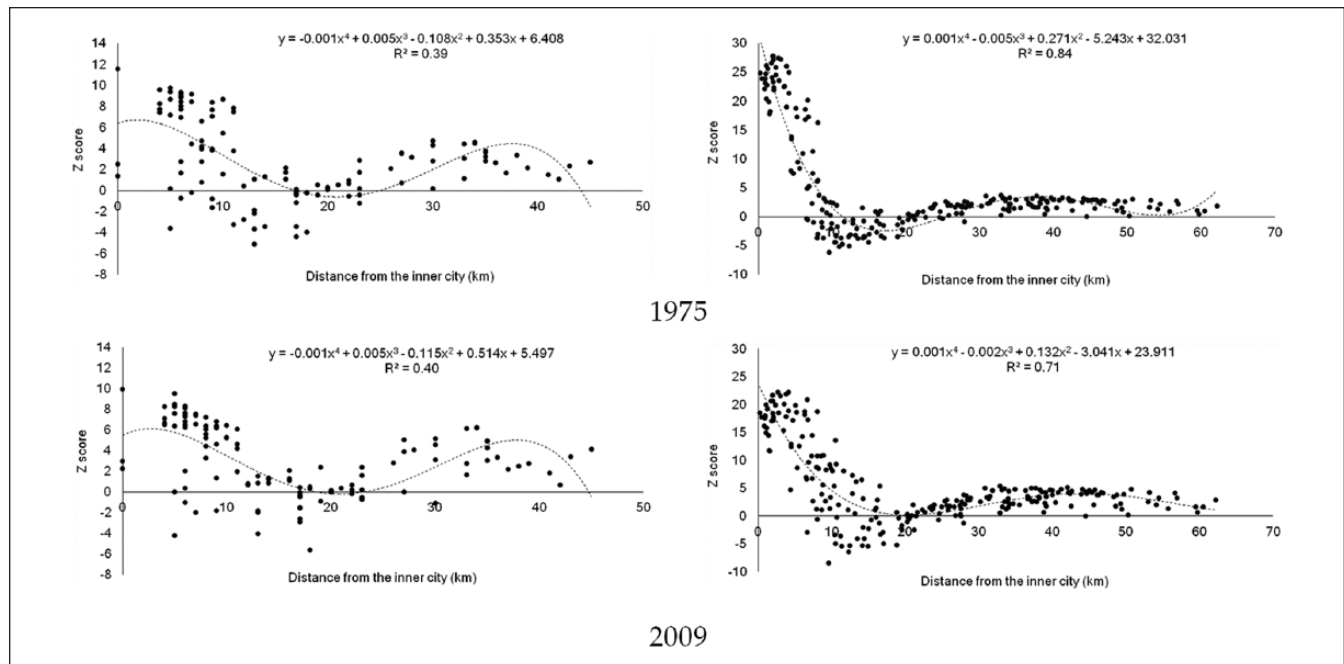
Figure 6. The relationship between the local Moran's z score and the distance from the inner city in each municipality of Athens (left) and Rome (right) regions by year.
Note. 1974 and 2006 for Rome

morphology (fragmented and dispersed in Rome, compact and dense in Athens) on landscape transformations. As a matter of fact, findings of this study confirm the consolidation of a mono-centric spatial structure in Athens, while a more scattered urban expansion at higher distances from the inner city was observed in Rome, with implications in the autocorrelation structure of both natural/semi-natural and agricultural classes.

Preserving a diversified landscape structure along the urban-to-rural gradient should be considered in a strategy promoting land-saving urban forms and conserving the environmental quality of the Mediterranean peri-urban regions (Paul & Tonts, 2005). Coupled with urban containment policies, the preservation of landscape diversity requires differentiated sustainable land management measures (Frondoni et al., 2011) according to the distance from the inner city and the morphology of each urban region (e.g., Shrestha et al., 2012). While promoting general measures for forest preservation and the conservation of some traditional cropland, the recent planning strategy in Rome and Athens seems to neglect the importance of a diversified land-use structure and the consequences of the discontinuous, low-density urbanization on landscape quality. The impact of forest fires on the spatial distribution of specific land-use classes (such as woodland, scrublands, and sparse vegetation/pastures) should be also considered in both cities (Salvati, Sateriano, et al., 2013).

Although in both regions, the recent Master Plans referred to a "moderately polycentric" vision aimed at balancing the territorial gap between the central city and the surrounding areas in a reasonably short time, the recent urbanization patterns contributed to increase land consumption rates and landscape simplification determining a more scattered settlement structure (Salvati, Gargiulo, et al., 2013). The environmental measures promoted in the two cities (e.g., dealing with the formation of peri-urban green belts) stimulated important transformations along the urban gradient, possibly consolidating the traditional polarization in less-fragmented, natural, or semi-natural (e.g., forest, scrubland, pasture) landscapes concentrated in marginal areas and mixed agricultural uses of land with simplified structure and spatial relationships concentrated in fringe areas (Salvati & Sabbi, 2011; Salvati, Sateriano, et al., 2013).

Conclusion

This study indicates the progressive simplification in the structure of land uses on the regional scale in both Rome and Athens and underlines the crucial role of urban morphology in shaping the spatial relationships among non-urban uses of land at the local scale. Taken together, results indicate a shift from complex spatial relationships among land uses to a more polarized and simplified peri-urban space in both cities. The analysis of specific socioeconomic indicators (e.g., evaluating changes over time in the distribution of service and industry activities) may complement the methodological framework adopted in this study with the aim to assess the impact of scattered settlements and discontinuous urban morphologies on landscape structures at the regional scale.

Exploratory approaches and comparative analysis of paradigmatic cases, like those proposed in this study, integrated with a more traditional assessment based on landscape metrics (e.g., Shrestha et al., 2012), land-use change detection analysis (e.g., Pontius et al., 2013) and spatial analysis of statistical indicators (e.g., Carruthers et al., 2012) are considered as relevant tools for producing a comprehensive assessment of land-use transformations in areas with different urban form and territorial characteristics.

Declaration of Conflicting Interests

Funding

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