Int. J. Environ. Res., 9(4):1325-1332, Autumn 2015
ISSN: 1735-6865

Swimming Pools as Indicator of Urban Sprawl: An Exploratory Analysis in a Mediterranean City

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Received 11 Nov. 2014; Revised 24 Feb. 2015; Accepted 1 March 2015

ABSTRACT: Studies relating form and functions of cities indicate sprawl as an intriguing research issue, especially for certain typologies of cities. Although with inherent differences on a local scale, Mediterranean cities offer a kaleidoscopic overview of sprawl morphologies that require dedicated monitoring tools. The present study provides an original assessment of recent urbanization processes in the Mediterranean region by considering swimming pools as a 'sprawl landmark'. Two indicators ('pools per population' and 'pools per area') are derived from digital interpretation of Google Earth diachronic imagery at two points in time (early 2000s and early 2010s) in a compact Mediterranean city (Athens, Greece) which is actually evolving towards urban scattering. The spatial distribution of swimming pools in Athens is strongly polarized with the 'pools per population' indicator being associated to low-density, isolated settlements and the 'pools per area' indicator growing in medium-low density, discontinuous settlements. Both indicators were validated through correlation with independent variables assessing sprawl patterns on a municipal scale. The indicators proposed respond to basic criteria such as easy computation and graphical representation, flexibility, cheapness and comprehensibility to non-technical stakeholders.

Key words: Land-use structure, Urban expansion, Permanent monitoring, Indicators, Southern Europe

INTRODUCTION

Urban growth is usually assessed using sophisticated models that take into account several factors including economic performances and specialization, socio-spatial structures, institutional and cultural variables together with territorial characteristics (Musterd & Ostendorf, 1998; Kazepov, 2005; Cassier & Kesteloot, 2012). Urban sprawl is a recent development model which involves social, economic and environmental factors that lead to new settlement patterns and morphologies (Burchell *et al.,* 1998; Brueckner, 2000; Galster *et al.,* 2001; Frenkel & Ashkenazi, 2008; Orenstein *et al.,* 2013). Sprawl can be identified in areas where low-density settlements replace cropland and forests, forming a mixed landscape dominated by detached houses, and where the resident population is highly dependent on private transportation (Burchell *et al.,* 1998; Tsai, 2005; Torrens, 2008).

Sprawl processes have generated economic advantages together with environmental and social costs and result to be a challenge for sustainable land management and regional planning (Hasse & Lathrop, 2003). The lack of high-resolution spatial data in both emerging countries and some wealth regions (Frenkel & Ashkenazi, 2008) prevents the in-depth analysis of sprawl patterns. Cross-country databases containing relevant information at the very local scale, allow international comparisons aimed at identifying sprawl typologies in different socioeconomic contexts. Recently the European Commission promoted initiatives to monitor urban expansion that have produced maps on a fine spatial scale, e.g. the Urban Atlas (UA) initiative and the pan-European soil sealing map (Salvati *et al.,* 2013a). The UA program produced high-resolution land-use maps covering nearly 300 urban areas during 2008-2010; a soil sealing intensity spatial database was also developed on behalf of the European Environment Agency (2006) monitoring program to cover the

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entire continent at 100m resolution. Remote-sensing data need financial resources to be updated and possibly adapted to the peculiarity of the different local contexts being crucial to the analysis of urban growth and sprawl patterns in Europe,. Moreover, their in-depth, comparative analysis requires technical expertise e.g. in Geographic Information Systems, and adequate calculation power.

In Europe, the differentiation in homogeneous groups of cities with specific forms and functions is great. Mediterranean cities, as instance, share distinctive morphologies stratified over their long-term history, with unique urban landscapes reflecting the interplay of economic, demographic, political and cultural factors (King *et al.,* 1997). After a mostly deregulated and compact expansion, typical of the 1960s and the 1970s (Catalán et al., 2008; Chorianopoulos *et al.,* 2010; Salvati *et al.,* 2013a), southern European cities have undergone a rapid transition towards a more dispersed morphology (Schneider & Woodcock, 2008), with distinct patterns compared to northern and western European cities and similar traits shared with non-European Mediterranean urban areas (Gargiulo Morelli & Salvati, 2014). This makes the pan-European assessment of sprawl dynamics more prone to confusion.

Effective indicators assessing sprawl patterns over time are thus required for Mediterranean urban areas. Sprawl indicators have to respond to basic criteria (Jaeger *et al.,* 2010), such as easy computation and graphical representation, flexibility, cheapness and comprehensibility to non-technical stakeholders. The present study introduces and validates two indicators derived from the spatial distribution of residential swimming pools intended as reliable proxies of sprawl. Swimming pools can be seen as a typical architectural element of de-localized sprawl landscapes with settlements physically decoupled from core cities and overcoming the urban-rural dichotomy (Vidal *et al.*, 2011). The empirical verification was carried out in a compact urban area (Athens, Greece) taken as a prototype of Mediterranean cities recently experiencing discontinuous urban expansion.

MATERIALS & METHODS

The study area (3,000 km2) is located in Attica, Greece (Fig. 1), and is divided in 115 municipalities forming Athens' metropolitan area (AMA) which concentrated 3.8 million inhabitants in 2011 (Salvati *et al.*, 2013a). The area coincides with the boundaries of the 'Urban Atlas' region and consists of plateaus and mountains that border the flat area occupied by the consolidated city. The AMA was divided into four prefectures: (i) greater Athens and (ii) greater Piraeus, both with compact and dense urban settlements, (iii) eastern Attica, a former rural area now transforming to a mixed and fragmented landscape with various settlement patterns including sprawl (Couch *et al.,* 2007; Chorianopoulos et al., 2010) and (iv) western Attica, a mainly rural prefecture with some compact urban centres and dispersed settlements in Salamina island (Salvati *et al.,* 2013a).

Swimming pools in the AMA were mapped according to the approach proposed by Vidal et al. (2011). Although official data on pool spatial distribution are restricted and difficult to obtain from manufacturers, they can be derived from integration of aerial photos and satellite images and even from Google Earth imagery. A census of all residential swimming pools in each municipality of the AMA was carried out at two points in time (early 2000s and early 2010s). According to map availability in the different parts of the region, an on-screen digitization of pools was conducted uniformly from high-resolution Google Earth imagery dated 2001-2003 and 2011-2013 (with 2002 and 2012 taken as reference years) under the supervision of an operator with broad knowledge of the study area. Summer images (June-September) have been selected, a period in which all pools are presumably used by residents (Salvati, data unpubl.). Images from three years were considered to get a complete coverage of the entire area. Each pool was digitized to produce a final point shape map compatible with the ArcGIS software. To test the reliability of Google Earth images as an information source for swimming pools in the AMA, we performed a digitizing session independent of the orthophoto maps, taken during the same period (the most recent available at 1: 5,000 scale). A topographic map (1: 5,000) provided by the Hellenic Statistical Office (ESYE) which covers all urban settlements belonging to the AMA and the UA map (scaled 1:10,000 and dated 2010) were used to control the water surfaces different from swimming pools (e.g. urban ponds, ornamental fountains, etc.).

Pool distribution has been described on a local scale through the use of two static indicators (pools per 100 inhabitants (pool_pop_03) and pool density (per square km: pool_dens_03) in 2002) and two diachronic indicators (% change in pools per 100 inhabitants: pool_pop_chg, and 5 change in pool density between 2002 and 2012: pool_dens_chg) calculated for each prefecture and municipality of the AMA. Descriptive statistics and maps were prepared for all indicators considering each municipality as elementary unit of analysis. Local administrative boundaries have been widely used as the denominator for socio-demographic and land-use analysis (Tsai, 2005; Couch *et al.*, 2007; Vidal *et al.*, 2011; Serra *et al.*, 2013). The use of municipal boundaries as the spatial domain of analysis allows for reliable comparisons with external sources, such as statistical data (Salvati, 2013a). Municipalities (the NUTS-5 level of the statistical nomenclature for the administrative levels in Europe) are the minimum mapping unit of most statistical surveys and are easily interpreted as an homogenous administrative layer (Salvati et al., 2013b). Municipalities in Greece are the institution deciding for land destination and final use, land protection regime, building volume and settlement size, and so they embody a relevant role in urban planning (Chorianopoulos *et al.*, 2010).

A total of 40 independents variables describing sprawl patterns on a local scale and derived from the two high resolution pan-European maps described above (Urban Atlas and Soil Sealing maps, both released by European Environment Agency) were used to validate the pool indicators described above: (i) the percent area of the 20 UA land-use classes including specific sprawl classes (e.g. '11220', '11230' and '11240') and (ii) the percent area of 20 soil sealing intensity classes indicating imperviousness rate from 0% to 100% (see Appendix 1 for the complete list of variables). The relation between validation variables and the four indicators based on pool distribution (see above) was studied on a municipal scale by pair-wise non-parametric Spearman correlations testing at $p < 0.05$ after Bonferroni's correction for multiple comparisons. The spatial similarity among pool indicators and validation variables has been investigated through hierarchical clustering (Euclidean distance, Ward's agglomeration rule). The analysis explores the latent spatial organization of urban regions and identifies sprawl patterns in time and space (Frenkel *et al.*, 2013).

RESULTS & DISCUSSION

A total of 5,097 and 9,768 swimming pools were surveyed in the AMA respectively in 2002 and 2012 with an observed increase by 9.2% per year (Table 1). Although pool distribution on a regional scale is comparable over time, a considerable increase of pools was observed in specific areas (north-east and south-east of Athens) developed during the Olympics and in the most recent period (Fig. 1). In 2002, 64% and 33% of the total surveyed pools were concentrated respectively

Table 1. Indicators describing the spatial distribution of swimming pools in Athens' metropolitan area by prefecture and year

Prefecture	# pools	% pools	Pools/100 inhabitants	Pools/km^2
		2002		
Athens	1708	33.5	0.06	4.8
Pireaus	45	0.9	0.01	0.3
Eastern Attica	3239	63.6	0.80	2.1
Western Attica	105	2.1	0.07	0.1
The study area	*5097*	*100*	*0.14*	*1.7*
		2012		
Athens	3157	32.3	0.12	8.8
Pireaus	86	0.9	0.02	0.6
Eastern Attica	6317	64.7	1.26	4.2
Western Attica	208	2.1	0.13	0.2
The study area	*9768*	*100*	*0.26*	*3.2*
		2002-2012 (percent changes and absolute values for #pools and % pools)		
Athens	1449	-1.2	50.0	54.0
Pireaus	41	-0.1	50.0	53.5
Eastern Attica	3078	1.1	63.5	51.3
Western Attica	103	0.2	53.9	47.6
The study area	*4671*	-	*53.8*	*52.0*

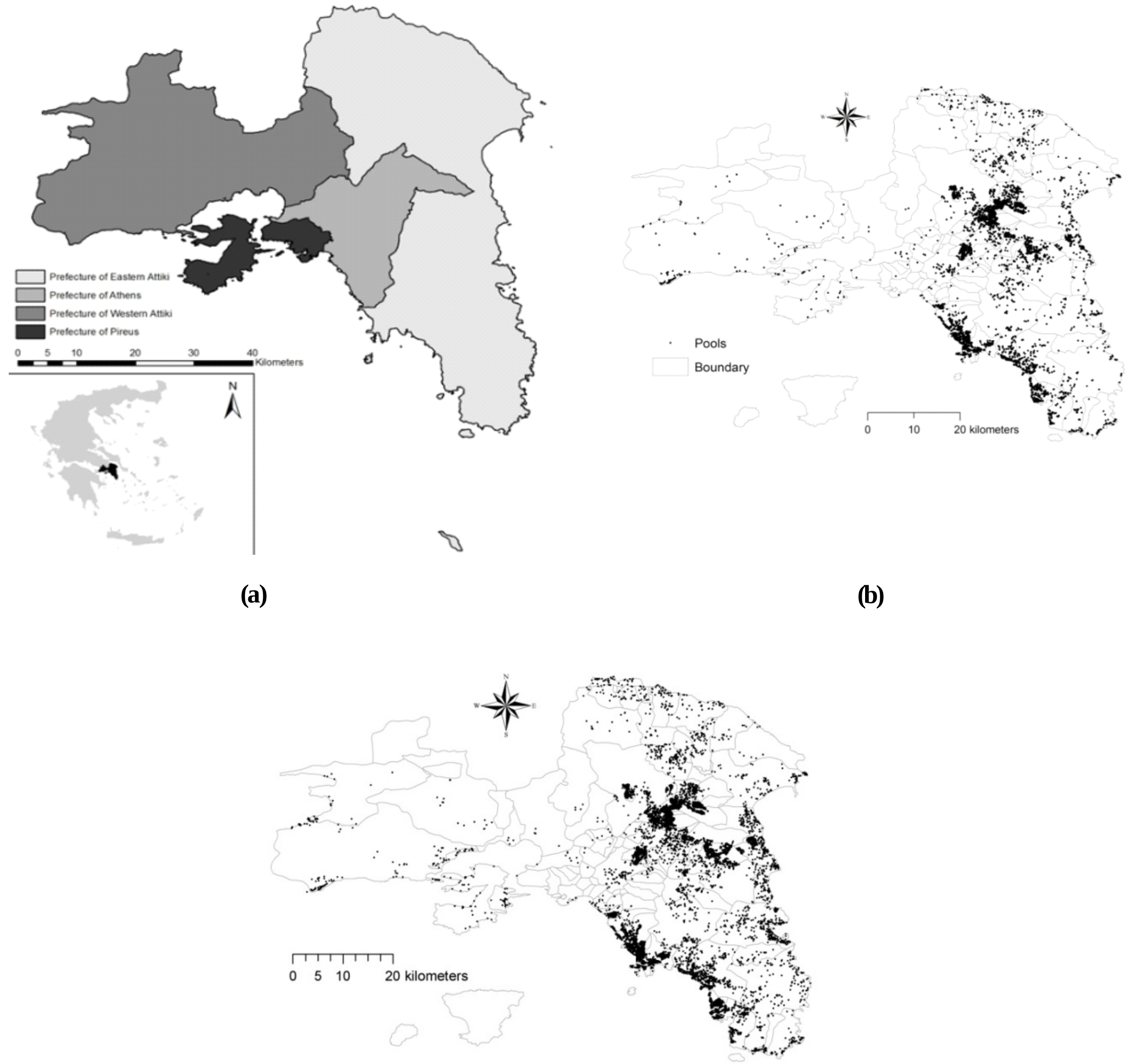

Fig. 1. Maps illustrating the study area with the administrative boundaries of prefectures (a) and the spatial distribution of swimming pools in 2002 (b) and 2012 (c)

in the prefectures of eastern Attica and Athens while the remaining 3% of pools was found in the prefectures of Piraeus and western Attica. These percentages remained quite unaltered in 2012 with eastern Attica concentrating 65% of the pools found in the AMA.

The number of pools per 100 inhabitants candidate eastern Attica as the area with the highest number of pools available to residents (0.8 pools per inhabitant in 2002 with the largest increase observed in the AMA: 6.4% per year). The remaining prefectures ranked low with Piraeus being the area with the lowest number of pools in the whole region. Pool density showed a quite different spatial pattern with Athens prefecture occupying the highest ranking in both 2002 and 2012 and eastern Attica ranking bottom, possibly due to the different settlement patterns observed in the two prefectures. The highest growth rate in pool density was observed in Athens prefecture (5.4% per year) preceding eastern Attica prefecture.Local-scale differences in 'pools per population' and 'pools per area' reveal contrasting spatial patterns and relations with validation variables, as clearly identified by correlation (Table 2) and multivariate analysis (Fig. 2). Non-parametric correlations between the two validation variables' sets (describing land-use composition and soil sealing intensity) and the four pool indicators (both static and

Table 2. Spearman rank correlation coefficients between (a) pools per 100 inhabitants or (b) pool density (per square km) and selected variables describing land-use composition and soil sealing intensity on a municipal scale (bold indicates significant correlations at p < 0.05 after Bonferroni's correction for multiple comparisons)

Land-use class	Pools per population		Pools per area		Soil sealing intensity	Pools per population		Pools per area	
	2002	2002-2012	2002	2002-2012		2002	2002-2012	2002	2002-2012
11100	**-0.76**	**-0.72**	**-0.45**	-0.31	1-5	**0.64**	**0.63**	**0.63**	**0.56**
11210	-0.30	-0.28	0.15	0.29	6-10	**0.62**	**0.63**	**0.71**	**0.69**
11220	**0.61**	**0.59**	**0.77**	**0.73**	11-15	**0.50**	**0.51**	**0.63**	**0.62**
11230	**0.82**	**0.78**	**0.76**	**0.63**	16-20	0.41	0.43	**0.64**	**0.64**
11240	**0.72**	**0.70**	**0.56**	0.45	21-25	0.33	0.35	**0.63**	**0.67**
11300	**0.55**	**0.55**	0.10	0.02	26-30	0.24	0.26	**0.55**	**0.62**
12100	**-0.52**	**-0.55**	-0.26	-0.23	31-35	0.09	0.08	0.48	**0.52**
12210	0.04	0.03	0.05	0.07	36-40	-0.07	-0.08	0.38	0.43
12220	**-0.56**	**-0.52**	-0.11	0.04	41-45	-0.16	-0.16	0.28	0.37
12230	-0.16	-0.14	-0.22	-0.18	46-50	-0.24	-0.24	0.24	0.31
12300	-0.16	-0.14	-0.22	-0.21	51-55	-0.35	-0.33	0.09	0.20
12400	0.12	0.11	0.07	0.06	56-60	-0.37	-0.37	0.11	0.20
13100	0.10	0.09	-0.18	-0.28	61-65	**-0.53**	**-0.52**	-0.09	0.03
13300	0.12	0.09	0.17	0.11	66-70	**-0.56**	**-0.55**	-0.11	0.03
13400	-0.15	-0.08	0.09	0.26	71-75	**-0.62**	**-0.60**	-0.21	-0.06
14100	-0.24	-0.26	0.23	0.26	76-80	**-0.68**	**-0.66**	-0.31	-0.19
14200	-0.27	-0.28	0.11	0.18	81-85	**-0.71**	**-0.67**	-0.35	-0.19
20000	**0.50**	**0.50**	0.02	-0.08	86-90	**-0.73**	**-0.71**	-0.41	-0.29
30000	0.23	0.27	-0.07	-0.08	91-95	**-0.74**	**-0.73**	-0.45	-0.34
50000	-0.05	0.02	0.10	0.08	96-99	**-0.73**	**-0.72**	-0.48	-0.39

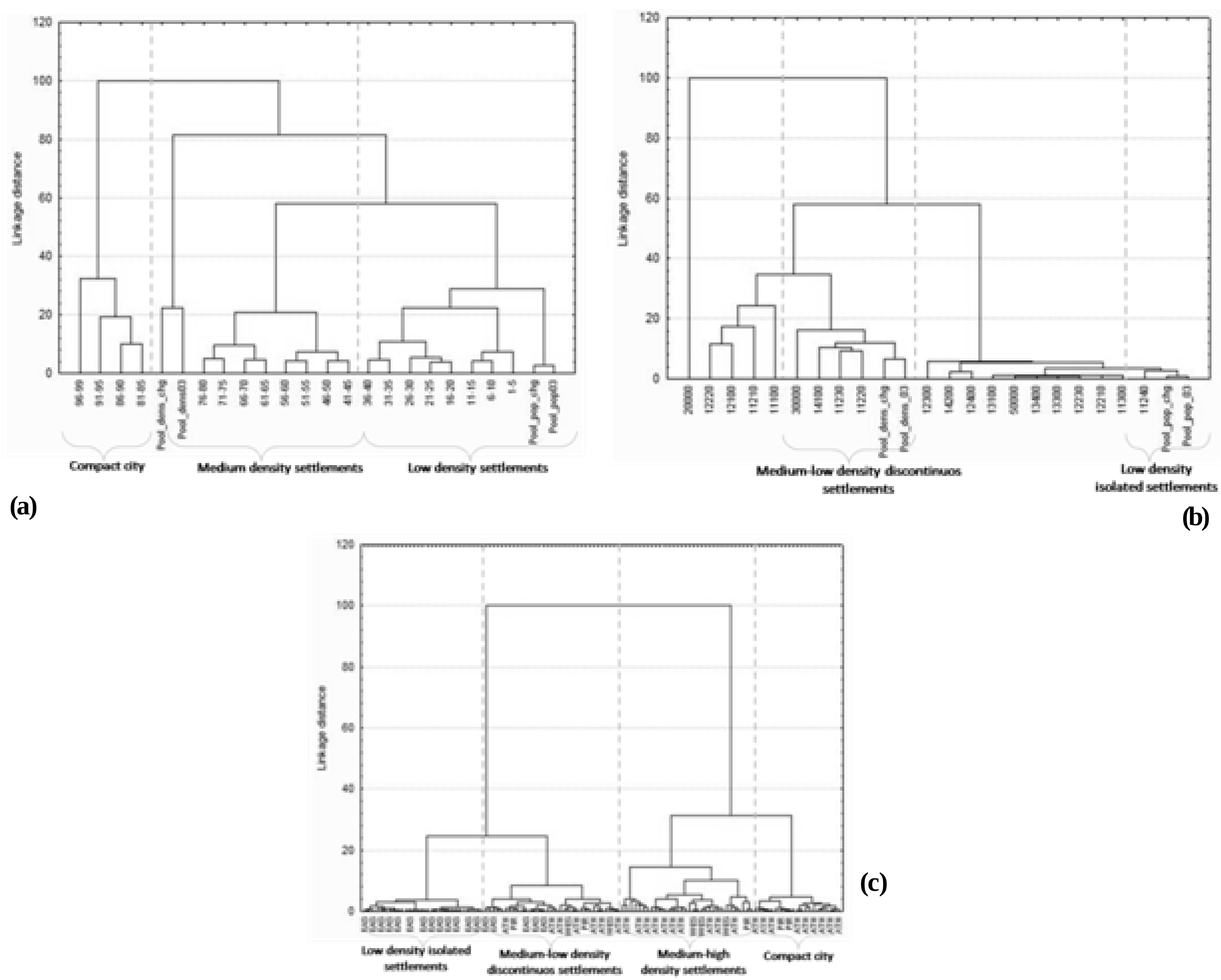

Fig. 2. Hierarchical clustering of the four pool indicators with soil sealing intensity variables (a) and land-use composition variables (b), and clusters of AMA municipalities (c) considering both datasets

diachronic) were reported in Table 2 and indicate a different correlation profile observed for pools per population and pool per area indicators.

As far as land-use composition is concerned, pools per 100 inhabitants in 2002 and the percent change between 2002 and 2012 correlated positively to all land-use classes associated to sprawled settlements ('11220', '11230', '11240' and '11300') and agricultural areas ('20000'), and correlated negatively with compact urban settlements ('11100'), industrial areas ('12100') and the infrastructural network ('12220'). The correlation profile with soil sealing intensity variables confirms the association of pools per population with low intensity classes (ranging from 1% to 15% imperviousness; indicating the prevalence of sprawled settlements in the landscape) and the diverging spatial pattern with high intensity classes (ranging from 61 to 99% imperviousness; indicating the prevalence of compact and dense settlements). Pool density in 2002 and its change over time correlated positively to three land-use classes representing sprawled settlements ('11220', '11230' and '11240'). The correlation profile with soil sealing intensity variables was more articulated and confirms the positive relation of pool density with medium-low intensity classes (ranging from 1% to 15% imperviousness) and the negative correlation with high intensity classes (ranging from 61% to 99% imperviousness).

Fig. 2 illustrates dendrograms classifying variables and municipalities according to their degree of spatial similarity. Static and diachronic indicators (for both 'pools per population' and 'pools per area') showed a coherent spatial distribution.

Pools per population indicators share a similar pattern (Fig. 2a) with medium-low intensity classes (from 1% to 40%). Pool density indicators clustered together with medium-intensity sealing classes (from 41% to 80%). Interestingly, high-intensity classes (from 81% to 99%) clustered together indicating no spatial relationship with any of the pool indicators considered. Pool per population indicators (Fig. 2b) were mainly associated to the proportion of very-low density sprawled settlements ('11240' class) in the landscape. On the contrary, pool density was primarily associated to the proportion of medium-low sprawled settlements ('11220' and '11230' classes) in the landscape together with the proportion of urban gardens ('14100' class) and forests ('30000'). This indicates a typical 'sprawl' landscape with predominant residential medium-low density settlements intermixed with green areas. Compact urban areas, industrial settlements and infrastructures showed a peculiar spatial distribution and agricultural areas clustered alone. Fig. 2c provides a dendrogram of AMA municipalities grouped by prefecture. The analysis identified four main clusters with a group (left in the figure) constituted by municipalities belonging to eastern Attica prefecture. This homogeneous cluster includes municipalities with a high rate of 'pools per inhabitant' and medium-high pool density. Another cluster (middle-left in the figure) includes municipalities from all prefectures with medium-low density settlements, intermediate rate of 'pool per population' and a high pool density. These clusters reflect the diverging spatial pattern observed for 'pools per population' and 'pools per area' indicators. The third cluster (middle-right) includes medium-high density municipalities with moderate pool concentration and, finally, the fourth cluster (right) includes few compact and hyper-dense urban municipalities with low pool density and very low rate of 'pools per population'.

CONCLUSIONS

The present study illustrates a simplified and low-cost approach based on static and diachronic pool indicators to identify areas with dispersed urbanization and to discriminate between different patterns of urban expansion. As argued by Frenkel and Ashkenazi (2008), sprawl is a multifaceted phenomenon that needs to be quantified with distinct measures and during an enough long period of time. Swimming pools proved to be a relevant landmark for peri-urban landscapes characterized by low- and medium-density settlements. Pool distribution in Athens highlights the polarization in scattered low-density and compact high-density settlements suggesting that the proposed indicators can be effectively used for identifying sprawl patterns. Results from correlation and multivariate analysis suggest that the indicators proposed in this study can be used as proxies for identifying very-low density, isolated settlements (pools per population) and medium-low, discontinuous urban settlements (pool per area). Based on the procedure illustrated in this article, pool indicators endorse positive characteristics as a low-cost and comprehensive tool for monitoring sprawl on both local and regional scales since they are easy to derive from freely available sources with global spatial coverage (Google Earth diachronic imagery) and comparable across countries. Analysis confirms their reliability and coherency over time and the ability to discriminate between different sprawl patterns.

The (negative) environmental consequences of urban sprawl require new strategies to mitigate the growing problem of land consumption in peri-urban areas. In this regard there is a urgent need for reliable, homogeneous and low-cost quantitative measurements (Jaeger & Schwick, 2014). Pool indicators are effective indicators of land consumption and can be easily disseminated to the interested stakeholders. Moreover, pool indicators can be used to assess sprawl impact on natural resources (e.g. water consumption), as pointed out by Vidal et al. (2011). Finally, pool indicators can be used as proxies for sprawl patterns also in emerging and economically-disadvantaged countries with less technological facilities and restricted availability of spatial data. Further studies should be dedicated to identify socio-economic and territorial profiles associated to varying pool densities. The analysis can be expanded creating diachronic maps on local, regional and country levels and integrating pool indicators with other information to monitoring urban regions.

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