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Spatial metrics for Greek cities using land cover information from the Urban Atlas

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Abstract

This paper discusses the Urban Atlas dataset that was recently released by the European Environment Agency for analyzing urban areas. The Urban Atlas provides information on land use for all cities in Europe which participate in the Urban Audit, that is cities with population of more than 100,000 inhabitants. After providing an overview of the differences between this dataset and the CORINE land cover dataset that has been available since 1990, it presents the estimation of various landscape metric indicators for several cities in Greece. These indicators can be used for comparing the structure and the form of the various cities.
Keywords: spatial metrics, land cover, urban atlas, CORINE, Greece.

1 Introduction

Lack of data on land use in urban agglomerations has severely hampered research in the area of comparing various cities as well as monitoring the way cities grow. The traditional methodology has been to produce such datasets from aerial imaging and/or satellite sensors. High spatial resolution satellite images nowadays available at a relatively low cost for most cities could provide information on land use after significant processing at a resolution of about 30 m (Landsat type), or higher (2.5 m for SPOT 5). However, these information were available only for some cities and most often were not produced using the same methodology.

The CORINE Land Cover database [3] first developed in 1990 and updated for 2000 and 2006 was until recently the most comprehensive land cover database for European cities. However, with the focus being on agricultural, forests and wetlands out of the 44 land cover classes there are information for only two classes related to the urban fabric areas.

Addressing the issue the European Space Agency (ESA) started in 2009 through the Global Monitoring for Environment and Security (GMES) program releasing the Urban Atlas, a dataset that contains polygons of land usage for all cities in Europe that take part in the Urban Audit (more or less cities with population of more than 100,000). Information on the dataset is available at http://www.eea.europa.eu/data-and-maps/data/urban-atlas [4]. The data have been produced from satellite images with spatial resolution of 2.5 meters and have a minimum mapping unit of 0.25 ha. There are a total of 20 distinct land use classes. Data for about 300 cities have been released. The dataset is produced with uniform standards for all cities thus permitting cross comparisons. Most important to maximize the use of the dataset ESA is making the dataset available for free for either private or business use. Users can download, without even registering, the dataset for any city they might be interested.

Using the Urban Atlas there are many different ways for analyzing the structure of a city. Providing simple percentages for different land use classes is one way for accomplishing this. However they hide information about the urban form. In the last fifteen years spatial metric techniques are used to define indicators for the landscape that could be used for comparing the structure and the form of the various cities. They provide a framework for examining unique spatial components of intra-and inter-city urban structure, as well as, the dynamics of change [1, 6, 7, 10].

In the following section there is a discussion about the Urban Atlas dataset and its differences and similarities with the CORINE land cover dataset. In the third section there is a discussion on the estimation of spatial metric indicators for the cities in Greece for which data are available on the Urban Atlas.

2 Urban Atlas in comparison with the Corine dataset

The Urban Atlas was developed by analyzing thousands of satellite images and provides detailed land cover/usage data for all European cities with population more than 100,000. As it has been already mentioned, the Urban Atlas dataset can be downloaded from the EEA Urban Atlas website.

Urban Atlas classification scheme identifies 20 different land use classes of which 17 van be considered built/artificial/ urban classes. The urban fabric (equivalent CORINE LC classes 1.1.1 and 1.1.2) are differentiated by their degree of imperviousness which is integrated from the Land Monitoring Core Service (LMCS) high resolution soil sealing layer. The production is based on a mix of photo-interpretation and classification with a 3-step validation involving a project internal quality assessment, independent experts and a technical review by the European Topic Centre Land Use and Spatial Information. The scale of CORINE LC is 1:100,000 and the minimum mapping unit is 25 hectares (ha) [2, 3]. The scale of Urban Atlas is 1:10,000 and the minimum mapping unit is 0.25 ha for the artificial surfaces and 1 ha for the other surfaces.

The complete Urban Atlas nomenclature scheme is shown in Table 1 [5]. In general terms it follows the CORINE land use classes. However, in the CORINE dataset there are two urban fabric classes; continuous (sealing degree >80%) and Discontinuous (sealing degree 30%-80%) [2]. In the Urban Atlas, the first category is retained, whereas the second one is broken into two (discontinuous dense and discontinuous medium density with 50% sealing degree being the cutoff point). Two additional categories discontinuous low density and discontinuous very low density urban fabric are added.

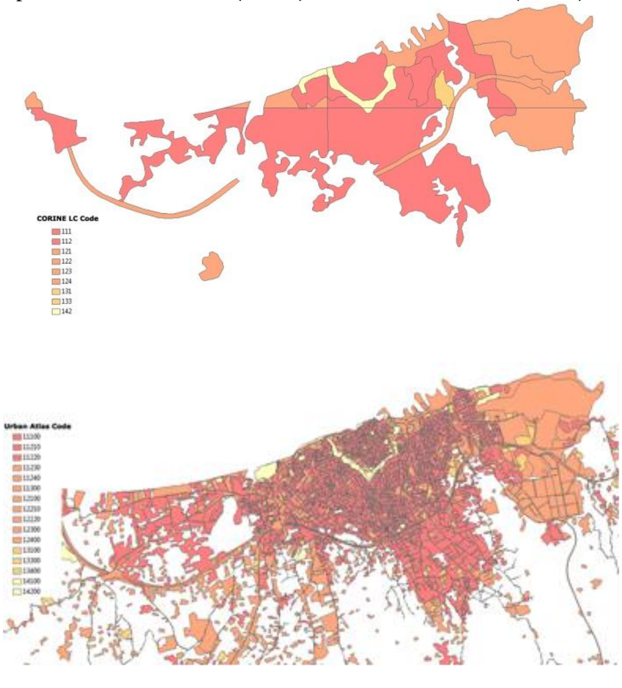
Table 1: Land use classes in CORINE LC and in Urban Atlas

Corine	Class code	Urban Atlas land use class
Continuous Urban Fabric	11100	Continuous Urban Fabric (Sealing Degree > 80%)
Discontinuous Urban Fabric	11210	Discontinuous Dense Urban Fabric (Sealing Degree 50% - 80%)
	11220	Discontinuous Medium Density Urban Fabric (S. D. 30% - 50%)
	11230	Discontinuous Low Density Urban Fabric (S. D. 10% - 30%)
	11240	Discontinuous Very Low Density Urban Fabric (S. D. < 10%)
	11300	Isolated Structures
Industrial, commercial	12100	Industrial, commercial, public, military and private units
Roads and Railroad	12210	Fast transit roads and associated land
	12220	Other roads and associated land
	12230	Railways and associated land
Ports	12300	Port areas
Airports	12400	Airports
Mineral extraction	13100	Mineral extraction and dump sites
Dump sites		
Construction sites	13300	Construction sites
	13400	Land without current use
Green urban areas	14100	Green urban areas
Sports and leisure facilities	14200	Sports and leisure facilities
	20000	Agricultural + Semi-natural areas + Wetlands
	30000	Forests
	50000	Water bodies

It must be pointed out that although there might be similarities in the naming of the various land use classes between Urban Atlas and CORINE LC they are not always compatible. The main reason for that is the different resolution and mapping unit. For example, in CORINE class 11200 (discontinuous urban fabric) can be distinguished when buildings and other artificially surfaced areas cover between 30% and 80% of the total surface area. According to this definition and using maps of scale 1:100.000, CORINE identifies areas corresponding to class 11200 and marks them out as polygons (Figure 1). However, the same polygons investigated at the scale of Urban Atlas are divided in smaller zones as shown in the same Figure. The area shown on the Figure is part of Heraklion. The Urban Atlas urban fabric classification is therefore more detailed (5 Levels).

Last but not least it should be noted that the land cover identified in CORINE corresponds to year 2000, whereas the land cover mapped by Urban Atlas is for 2008, hence differences between the two land covers might exist as a result of the changes that occurred between 2000 and 2008. An update of the 2000 CORINE was done for 2006 and probably the differences between the two datasets due to the urban change might be smaller.

Figure 1: The artificial surface for the city of Heraklion, as provided in CORINE (above) and the Urban Atlas (below).



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3 Spatial metrics

Spatial metrics have been introduced in the mid-80s in the literature of ecology to define landscapes, diversity of species etc. Starting in the late 90's [1, 6, 7] they were adopted in geography and landscape architecture for describing and comparing the structure and form of the various cities. Typical applications include estimation of metrics to describe an urban environment with particular emphasis on the urban vs non-urban dichotomy and computation of metrics for the same city or region for different time periods to assess the dynamics of change.

In this paper six landscape metrics are evaluated. Five of the indexes are estimated separately for each land use class, whereas for the estimation of one (the contagion index) all land use classes are used. The indicators were estimated for the 9 Greek cities for which the Urban Atlas contains data. Population and area of the various cities is shown in Table 2. Artificial area is the area that corresponds to classes 11100 through 14200.

With the objective being to identify the form of the built environment only the area covered by artificial surfaces was considered. Some of the land use classes were aggregated since for some of them the percentage coverage of the whole area was relatively small and it was also felt that their detailed treatment could not be used for any meaningful analysis of the form of the city. For a city like Athens the continuous urban fabric land class accounts for 33.53 % of all patches, 13.25% of the surface and 10.87% of the perimeter of all patches.

The following land use classes were considered:

- Main Class 1 (MC1): contains Urban Atlas class 11100 (Continuous Urban Fabric);
- Main Class 2 (MC2): contains Urban Atlas class 11210 (Discontinuous Dense Urban Fabric)
- Main Class 3 (MC3): contains Urban Atlas classes 11220 – 11300 (Discontinuous Medium/Low/Very Low Density Urban Fabric and Isolated Structures).
- Main Class 4 (MC4): contains Urban Atlas class 12100 (Industrial, commercial, public, military and private units).
- Main Class 5 (MC5): contains Urban Atlas classes 12210 (Fast Transit Roads and Associated Land), 12220 (Other Roads and Associated Land) 12230 (Railways and Associated Land), 12300 (Port Areas) and 12400 (Airports).
- Main Class 6 (MC6): contains Urban Atlas class 13100 (Mine, Dump), 13300 (Construction Sites) and 13400 (Land without current use).
- Main Class 7 (MC7): contains Urban Atlas class 14100 (Green areas) and 14200 (Sport facilities).

Table 2: Population, Area and Contagion index values for the various cities

Urban agglomeration	Population 2011	Total area (000) (Urban Atlas)	Artificial area (000) (Urban Atlas)	Contagion Index
Athens Metropolitan area	3,812,330	3,042,235	71,065	20.04
Thessaloniki Metropolitan area	781,806	1,425,817	15,565	23.04
Patras Metropolitan area	214,580	512,633	5,078	22.24
Heraklion Metropolitan area	189,849	604,442	4,475	30.99
Larissa	163,380	1,549,413	12,226	31.32
Volos Metropolitan area	144,420	304,257	3,518	26.77
Ioannina	111,740	1,325,266	8,213	28.81
Kavala	70,360	351,612	1,894	26.49
Kalamata	70,130	441,717	2,805	28.84

The FRAGSTATS software [9] was used to estimate the various indicators for each of the 7 Main Classes. The estimated values of Contagion Index for each of the Greek urban agglomerations analysed are shown in Table 2, whereas the values of the other landscape metrics are reported in Table 3.

Since it was felt that it is not meaningful to discuss in detail all spatial metric indicators, the discussion below focuses on some of the main issues. The discussion covers mainly the indicators for the 5 first land use classes since these are the dominant land uses in the cities examined. Availability of green areas is always of concern in urban areas, however, the total coverage is less than 4% in most cities.

3.1 Contagion index

The Contagion index (CONTAG) describes the heterogeneity of a landscape by estimating the probabilities that a pixel of land use class a is adjacent to a pixel of land use class b. It measures to what extent landscapes are aggregated or clumped. Landscapes consisting of patches of relatively large, contiguous landscape classes are described by a high contagion index. If a landscape is dominated by a relatively greater number of small or highly fragmented patches, the contagion index is low. The more heterogeneous the urbanized area becomes, e.g. resulting from higher fragmentation or more individual urban units, the lower the contagion index [8].

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Table 3: Spatial Metric indicators for the Greek cities

Main Class	PD	LPI	ED	FRAC_AM	ENN_MN	PD	LPI	ED	FRAC_AM	ENN_MN
			Athens					Volos		
MC1	0,9976	6,3964	23,4608	1,2775	385,1773	1,6338	13,0587	43,3552	1,3102	279,343
MC2	3,0564	0,8399	36,5495	1,1514	314,9302	5,7065	1,4266	48,7539	1,1396	178,744
MC3	4,5834	2,7275	55,054	1,1654	309,3732	13,2126	1,8647	75,4514	1,127	200,596
MC4	3,3229	1,1235	31,4441	1,1178	382,4871	10,4659	8,4887	68,8806	1,1392	272,351
MC5	9,9259	1,3387	63,7623	1,068	288,0983	38,809	0,9235	119,292	1,0693	158,228
MC6	1,0111	0,1895	6,8096	1,0503	654,7055	2,8888	1,9712	18,9428	1,0874	343,502
MC7	1,2164	0,3007	11,3257	1,0861	520,8393	2,0127	0,219	10,8211	1,0631	473,855
			Thessaloniki					Ioannina		
MC1	1,0956	5,8583	27,1444	1,2333	649,0041	1,5862	2,4564	15,7977	1,2096	514,97
MC2	4,2395	1,3079	48,8056	1,1161	300,556	5,9614	0,8942	60,9661	1,1531	260,26
MC3	5,4239	0,1481	32,3463	1,0442	367,2405	13,5835	0,2582	70,7332	1,0896	245,203
MC4	6,1396	2,9563	53,9779	1,1267	387,0388	23,5795	1,0166	106,6454	1,0793	226,603
MC5	9,693	2,749	58,395	1,0598	343,2006	57,666	1,485	153,006	1,0472	163,233
MC6	1,5596	0,3652	10,996	1,0564	701,5615	3,4172	1,9055	35,2894	1,1355	393,375
MC7	1,2881	0,153	9,3327	1,0473	636,375	1,1178	0,314	8,2502	1,0859	1043,02
			Patra					Kavala		
MC1	2,6564	5,4719	29,7839	1,2645	316,1629	1,8227	8,3011	34,948	1,2459	390,85
MC2	8,8242	0,5003	63,9527	1,1338	207,3259	4,2397	2,8232	51,0946	1,1612	231,064
MC3	16,2838	1,8285	111,1121	1,1441	202,1701	11,8474	1,6543	62,0109	1,1175	291,466
MC4	8,6605	0,7596	52,6905	1,0949	280,6626	7,2511	2,5557	53,2145	1,0936	270,494
MC5	42,5745	0,7551	146,1906	1,0939	151,4223	40,9708	5,2897	133,056	1,0644	162,468
MC6	3,3295	0,796	19,1585	1,0829	334,6809	2,3774	3,1798	20,9212	1,0655	631,13
MC7	5,3127	0,3593	26,7637	1,0774	240,3288	2,2585	0,6637	14,1852	1,0814	431,928
			Heraklion					Kalamata		
MC1	1,1619	4,3329	19,6232	1,2616	452,987	2,1614	3,2331	22,5144	1,1976	205,701
MC2	3,0177	3,5462	37,8424	1,171	428,8131	6,4841	0,6844	38,4726	1,1076	247,015
MC3	14,6851	4,2643	121,5476	1,1495	212,9886	21,5418	1,1437	135,6268	1,1255	170,155
MC4	7,4394	2,8604	53,0036	1,1029	284,8007	10,5548	2,0443	63,1484	1,1037	308,595
MC5	38,4556	2,8241	111,849	1,0609	169,1226	58,6816	8,6996	166,1203	1,0577	161,454
MC6	2,1947	0,8513	14,201	1,0582	457,4814	2,8458	0,3332	13,7968	1,058	606,541
MC7	0,8553	0,4478	7,0359	1,0905	1358,7562	2,0893	0,1531	11,2392	1,0573	577,927
			Larissa							
MC1	2,4876	2,3369	31,0602	1,2069	370,0551					
MC2	4,3812	0,8392	50,1216	1,168	186,3163					
MC3	10,9143	0,3099	49,6482	1,0839	327,9803					
MC4	7,9017	1,0738	58,2729	1,0981	309,0127					
MC5	86,9187	3,9014	237,3093	1,0647	173,1029					
MC6	2,2552	0,4734	15,855	1,0781	583,6188					
MC7	1,2395	0,4433	7,325	1,0932	824,8193					

As expected lower values of CONTAG are observed in larger and more compact cities. The values of this index range from 20 for Athens to 31 for Larissa. The lowest values are for Athens, Patras and Thessaloniki the three largest urban agglomerations in terms of population. It should be expected that in these areas there is mixed land use, hence the overall probabilities of adjacency of the various patches is the lowest. Among the other urban agglomerations Volos and Kavala have about the same CONTAG whereas Larissa and Heraklion have the highest. The results for the latter two cities also are reasonable because they tend to be more uniform with small interspersion of land use patches and also larger uniform patches.

3.2 Patch density

Patch density (PD) is defined as the ratio between the number of patches of a land use class and the total area of the city. It can be considered a measure of the fragmentation/ spatial distribution of the patches of a land use class. Low values imply that there are relatively fewer patches, whereas higher values imply more patches and therefore a higher spatial heterogeneity of a land use class. Values of this indicator are affected by the size of the pixel and also the minimum mapping unit since this is the determining factor for delineating individual patches. Smaller mapping units imply more patches and therefore higher values.

For all cities the PD indicator takes the lowest values for the continuous urban fabric class with the second lowest being for the discontinuous dense urban fabric. This appears reasonable since these two land uses areas are more compact than other land uses. For all cities, the highest values of the indicator are for MC5 (Transport infrastructure) which again is reasonable given the fact that this "land use class" provides connectivity in a city and therefore is dispersed. PD indicators in Athens and Thessaloniki, the two largest cities, are relatively the same for most land use classes. In Thessaloniki the indicator for industrial activity is higher than in Athens signifying a "relatively" wider dispersion of commercial activity. For Green/Sport facilities land use class the indicator takes values between 0.85 (Heraklion) and 5.3 (Patras) with most cities having a PD between 1.0 and 2.0.

3.3 Edge density

Edge density (ED) is defined as the ratio between the sum of the perimeters of all patches of a land use class and the total area of the city. In contrast to the PD metric discussed above it considers both the complexity of the shape of the patches and their spatial distribution. Low values imply that that there are relatively fewer and simpler patches of the land use under analysis, whereas large values imply that there are many patches with jagged/ complicated shapes. Similar to PD its value is affected by the pixel size and the minimum mapping unit since the smaller the mapping unit the delineation of the various patches will result in an increase of the edge length.

As expected the highest values for this indicator for all cities is for the transport infrastructure land use class. In all urban areas the ED indicator takes the lowest values for the continuous urban fabric, with higher values for the other two classes of discontinuous urban fabric. This implies that continuous urban fabric patches are simpler in shape and less spatially distributed. For Athens the ED metric for land use class 1, 2 and 3 take respectively the values 270, 370 and 435 meters per hectare. It is worth mentioning the relative similarity of the value of this index for industrial activity for all cities. This should be expected since the average area of a patch, as well as, the average perimeter are similar for this land use for all cities.

3.4 Largest patch index

This metric (LPI) is defined as a ratio; the area of the largest patch of a land use class divided by the total area of the urban agglomeration. It can be considered a measure of the separation of the urban landscape into smaller individual patches versus a dominant core. The values of the LPI indicator for continuous urban fabric are somehow similar for the three largest cities, implying that the size of the largest patch is equivalent in all three cities when considering also the size of the urban area. These are the cities with the lowest CONTAG. For Volos the value is significantly higher which means that there is a relatively large concentration of continuous urban fabric. To a lesser extent this is also true for Kavalla.

3.5 Euclidean Nearest-Neighbor

This metric (ENN_MN) is defined as the average distance of all patches of a land use class to the nearest neighboring patch of the same class, based on shortest edge-to-edge distance from cell center to cell center. This metric is a measure of the segregation/ spatial separation of the patches of a certain land use class. Low values imply that patches are relatively close to each other, whereas larger values imply spatial separation.

As expected for all cities the lowest values are estimated for the Transport Infrastructure class. For the three urban fabric land use classes in Athens the distance is between 300 and 400 meters, while for Thessaloniki the ENN_MN metric for the continuous urban fabric is double the one for the other two classes. This implies that continuous fabric areas are more segregated and this might be an indication of a defined multicenter city. In Volos, a city with a well defined street network the ENN_MN metric is lower than the other cities.

3.6 Area Weighted Mean Patch Fractal Dimension

The AWMPFD metric is estimated as the area weighted mean value of the fractal dimension values of all patches of the same class. This metric can take values between 1 and 2 and can be interpreted as a measure of the complexity of the shapes of the patches of a land use class. Its estimation is based on a function that considers the perimeter of the patches divided by the area of the patch. A value close to 1 implies simple shapes, whereas values of 2 denote highly convoluted shapes. For all land uses with the exception of continuous and discontinuous urban fabric this index takes values less than 1.1 thus making difficult any valid comparative interpretation. Continuous urban fabric for all cities has values of 1.2 and only for Volos it just exceeds 1.3. The low values for this index can be attributed to the minimum mapping unit of 0.25 ha and the image resolution of 2.5 m. since these might result in patches that are not jagged but have a relatively simple shape.

4 Conclusions

There is no doubt that the availability of Urban Atlas will have major impact on the analysis of urban areas. It will provide a dataset that can be immediately used for planning purposes and estimating various indicators particularly if combined with other datasets. Just by comparing percentages of land use classes planners will be able to develop a macro image of the form of the city.

For urban metrics the Urban Atlas dataset will permit a comparison of urban areas in different countries and different sizes both in terms of population and area. Research in the area of the definition of urban metrics might be stimulated since the metric indicators used today have been defined on the basis of datasets that contained fewer urban land use classes. New landscape indicators might be developed to describe the landscape using two or three land use classes at the same time.

In conclusion availability of such a massive dataset for almost all urban areas in Europe, developed with the same standards might revolutionize the field of urban studies and research and eventually lead to improved planning and therefore a more sustainable future.

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