Assessing Coastal Urban Sprawl and the "Linear City Model" in the Mediterranean – The Corinthian Bay Example

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Abstract. Urban sprawl and tourism urbanization, as prevailing trends in the Mediterranean coast, result in particular forms of 'linear' urban development, stretching with deployment of low-density urban fabric along extended areas near the shoreline. The evolving 'linear city model' accounts for: land and marine environmental degradation; higher vulnerability to climate change; and unsustainable future pathways of coastal urban constellations. Assessment of this model of urban development in coastal zones can reveal distinct spatial and functional irregularities and properly guide policy remediation action. This work elaborates on the exploration and identification of the "linear city" concept in the Mediterranean by use of a methodological approach that integrates: high-resolution multi-temporal data for built-up areas and their GIS-enabled elaboration; spatial metrics for quantifying morphological as well as spatial peculiarities and qualities of this linear city type; Principal Component and Cluster Analysis, unveiling built environment typologies; and correlation analysis, illuminating functionality weaknesses by linking these typologies with urban variables, e.g. population density, accessibility to transport and urban facilities. Implementation of this approach on a Greek example – Corinthian Bay, Northern Peloponnese – witnesses the discrete spatial typologies and highlights the fragmented and rather unsustainable, in spatial and functional terms, linear urban pattern of this coastal urban area.

Keywords: Coastal urban sprawl · Linear city model · Spatial metrics · Spatial planning and policy · Mediterranean coast

1 Introduction

The Mediterranean Region is perceived as a distinct part of the world, mainly due to its exceptional natural peculiarities, among which fall the extraordinary coastal and insular ecosystems and complexes as well as the 46,000 km of coastline, endowed with fabulous land and seascapes [1–4]. Concurrently, this Region is characterized by its distinguishable cultural diversity and wealth, being the result of its location at the crossroad of three continents; and the intense, back to ancient world, cultural and commercial interaction of eastern and western civilizations through the Mediterranean Sea routes [1, 2].

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At the heart of the Mediterranean historical trajectory lays its *coast*. Thus Mediterranean coastal regions are, through centuries, grasped as the most flourishing, prosperous, and preponderant places; and an appealing home to large population shares [1]. This, in turn, is reflected in the escalating population trends witnessed in Mediterranean regions [5]. In fact population in the Mediterranean Region has increased from approximately 419 million inhabitants in 2000 to 475 million in 2010 (+13,4%) and 529 million in 2020 (+11.4%) [6, 7]; while is predicted to reach the 572 million inhabitants by 2030 (https://www.medqsr.org/population-and-development). Additionally, a certain population concentration in the Mediterranean coastal part and especially coastal cities is noticeable [8, 9], since almost one third of the population of the states surrounding the Mediterranean Sea resides in the coastal zone and more than 70% of it in coastal cities [8].

Currently, coastal areas in the Mediterranean are highly rated, extremely attractive and globally acknowledged *tourism destinations* due to their mild climate, remarkable natural/cultural assets and the warm hospitality/spirit of the Mediterranean people. In fact, Mediterranean coastal regions host almost one third of the international tourism (32%), rising from 58 million of international tourist arrivals in 1970 to 314 million in 2014, a number that is expected to reach the 500 million tourists in 2030 (an increase of 59%, compared to 2014). The overarching coastal mass tourism model in the Mediterranean shoreline, however, coupled with the steadily increasing pressure from the intense habitation and economic activity pattern, leads to an immense demand for urban land in coastal zones, largely affecting the land- and sea-scape state [9, 10]; and severely endangering sustainability performance of relevant coastal territories. The growing urbanization due to habitation and economic activity (tourism included) [9], coupled with the repercussions of Climate Change (CC) in coastal areas, create an explosive mixture that renders coastal urban areas quite *vulnerable and fragile*. In fact, Mediterranean region as a whole is currently perceived as a *hotspot* in many respects [2] – all touching one way or another future developments of coastal urban constellations – namely a CC hotspot [11, 12]; a biodiversity hotspot [13]; an urbanization hotspot [2]; a sea transportation hotspot [11]; and a tourism hotspot [14], to name but a few.

Within such a decision environment, the study of urban development and/or sprawl patterns in Mediterranean coastal zones calls for articulating proactive and evidence-based *policy responses* to diverse risks, e.g. overpopulation, overtourism, biodiversity loss of land and marine environment, CC. That said, the *aim* of this research is to explore and illuminate aspects of the form/structure of the *linear city model* in Mediterranean coastal areas as the output of, among others, coastal intense urbanization processes. Therefore, a *geospatial methodology* is developed for quantifying density, dispersion, connectivity and accessibility of coastal urban contexts that bear attributes of a distinct 'linear city' model. The proposed methodology is implemented in Corinthian Bay in Greece, an area that is marked by a tough coastal urban sprawl pattern, displays a coastal-hinterland urban divide and is categorized as a typical "linear city" model. Urban sprawl patterns in the Corinthian coastal zone are analyzed at a disaggregated level, using high-resolution Global Human Settlement Layer data for 2017–2018 (GHS-BUILT-S2); and spatial metrics are applied to identify urban pattern typologies.

The *structure* of the paper has as follows: in Sect. 2 the emergence of the 'linear city' model as the prevailing urban form in the Mediterranean coast is shortly discussed;

Sect. 3 summarizes the proposed methodological approach, data sets, spatial metrics and methods used in order for the coastal urban form/development to be explored; Sect. 4 implements this approach in the specific case study of Corinthian Bay and comments on results obtained; while in Sect. 5 some key conclusions are drawn.

2 Evolving Linear City Patterns in the Mediterranean Coast

Apart from the physical characteristics as well as the social, environmental and economic processes, the *urban form* constitutes a key determinant in pursuing sustainability objectives in respective areas [15]. This is not only related to the repercussions of the urban form on mobility patterns [16], but also to the fact that shape, size, density and settlements' configuration as well as land use patterns have direct environmental, economic and social repercussions [17]. In urban planning theory, specific prototypes of the urban form – e.g. *compact, polycentric, linear and sprawl urban forms* – have been assessed and studied so far [15], with the urban sprawl model being generally regarded as an unsustainable one.

As a means to restrain urban sprawl, the *compact city model* has been proposed by various researchers. This model is delineated by higher built-up and population densities, land use diversity and sustainable mobility that favors public transport, walking and cycling [18]. 'Compactness' is also defined as high-density or monocentric development [19]; while Anderson et al. [20] suggest that both monocentric and polycentric forms can be grasped as compact ones. Compact cities are currently perceived as sustainable urban forms, as opposed to the urban sprawl model. This is due to their potential to contain soil sealing and loss of surrounding natural and agricultural land as well as reduce the amount of travel, car dependency, energy consumption and related air pollution [15]. However, to their detriment fall the high population densities that can lead to traffic congestion, poor environmental quality and lack of adequate open space.

Among the urban form typologies, the *linear city model* constitutes a particular and interesting case. From Soria y Mata's conceptualization of the linear city in the 19th century [21] to Gauthier's long mega-structures [22], linear cities have often been regarded as an 'ideal' type of urbanization, providing direct access to natural landscape and favoring a transit-based human settlement around major transport infrastructures. Linear urban development patterns are largely observed in coastal urban areas, taking the form of ribbon sprawl along *major roads/transit infrastructure* [23] such as the case of *coastal tourism destinations* [10, 24]. This form, however, usually defined as *coastalization* [25], mostly ascribes a linear and largely unsustainable urban development type, encroaching along the coastline. It is generally associated with uncoordinated forms of low-density sprawl, consuming agricultural and natural land; while is the source of severe environmental degradation. It is mostly driven by increasing population density in coastal zones; suburbanization; mass-tourism installations' investments, coupled with the spreading of vacation houses; and deployment of transport infrastructure in coastal zones.

In the Mediterranean Region, *coastalization* is identified as an increasingly alerting phenomenon that is heavily affecting its vulnerable land and marine ecosystems [25]. Historically, the dense concentration of urban settlements along the coastal zone is a

prevalent feature of the Region's landscape, taking the form of port towns as hubs of socio-economic activity; and serving intense economic/commercial transactions through the well-established ancient Mediterranean Sea routes. Recently, however, urban growth in coastal zones is no longer restricted around the main coastal cities. Additionally, the lack of a consistent and regulatory spatial planning framework, coupled with the massive urbanization investments of the past few decades, have led to extensive urban sprawl in the Mediterranean coastal zone [10, 26]. This, in turn, poses severe threats to coastal and marine ecosystems, consumes resources in a rather unsustainable way and increases vulnerability to CC [27, 28].

Coastalization in the Mediterranean Region is, among others, the outcome of the quite notable large-scale *mass tourism development*, calling for the deployment of tourist accommodation, leisure facilities and transport infrastructure, to name a few. Such a tourism-related developmental trajectory is further stressed by the increase of second homes/vacation houses [24, 29]; the new suburban style, observed in compact Mediterranean cities since late '80s [30]; and the so-called residential tourism phenomenon, i.e. mass movement of Northern Europe retirees, migrating to the sunny and hospitable European south [31]. The largely unplanned or poorly regulated character of settlements' expansion, accompanied by the large-scale infrastructure deployment in coastal and periurban areas [32] have so far been the key drivers of the linear urban expansion and growth of the Mediterranean economies [30]. Quite exemplar cases of this trend constitute the highly rated tourism destinations in the Mediterranean, e.g. in Spain, Italy, Greece and Turkey. Distinct examples are the *linear city model* along the Spanish coast [33]; the *Italian Adriatic Coast*, described as the longest – more than 1470 km – urban stretch in southern Europe [34]; the *Crete linear pattern* of urban development as the prevailing one in the northern, heavily based on tourism, coastline of the island [10]; to name but a few. In the subsequent sections, a methodology is articulated in order for the (linear) urban sprawl patterns at a disaggregated level to be quantified and assessed for properly guiding planning and policy action.

3 Data and Methods

The steps of the proposed methodological approach for assessing urban sprawl patterns and built environment typologies in coastal regions are shown in Fig. 1.

More specifically, urban sprawl patterns in the coastal zone are studied by use of high-resolution data (10 m resolution), based on Sentinel-2 images for the period 2017–2018 (GHS-BUILT-S2). Thus, the structural and morphological attributes of urban spatial patterns can be assessed. GHS built-up grid (GHS-BUILT-S2 R2020A) corresponds to a global map of built-up areas, expressed in terms of a probability grid at 10 m spatial resolution. Built-up probability values are rescaled in the range 0–100 (0 for probability $= 0$ and 100 for probability $= 1$). Dataset is delivered as tiff raster files, while each tile inherits the projection of the UTM grid zone to which it belongs to. A binary version of the raster is constructed by setting a 0.2 threshold point to binarize the probabilistic output (built-up probability values). A cell is defined as "built-up" if raster value > 20, while otherwise is defined as "non built-up".

Density, dispersion, connectivity and accessibility of urban compartments are quantified and evaluated at a disaggregated/local level by use of *spatial metrics*. The latter are

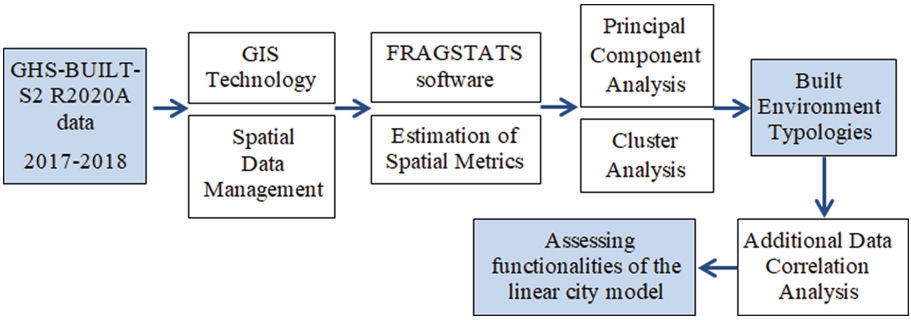

Fig. 1. Steps of the proposed geospatial methodological approach.

estimated at the urban patches level, i.e. discrete areas that are homogenous as to land use, habitat type, etc.; and are identified based on a binary raster grid, using a developed/non-developed land dichotomy approach. GHS-BUILT data are processed in the ArcGIS environment, reclassified and exported as GeoTIFF grids in FRAGSTATS software. Area/density/edge, shape, proximity, contagion/diversity and connectivity metrics are estimated by use of FRAGSTATS. Uniform tiles, with a side-length of 1 km, are used to calculate spatial metrics at a disaggregated/local level. Using the above steps, areas mostly affected by urban sprawl (low density, disconnected development etc.), can be identified; and the morphological and spatial peculiarities of this linear urban sprawl type can be assessed.

Following the estimation of the aforementioned spatial metrics, Principal Component Analysis (PCA) is used as a means to end up with a set of *explanatory factors*; and is followed by a Cluster analysis for assessing different built environment typologies. At a final step, the previously ascertained spatial patterns and typologies are linked to data regarding urban facilities, accessibility to transportation networks and major urban towns/settlements, population density and geomorphology. Additional data sources are used, including *Open Street Map*, the Greek official *geodata portal* (geodata.gov.gr) and data from the European Environmental Agency; while *correlation analysis* is applied for grasping functionality aspects of the linear city model.

The application of the above described methodological steps in the Corinthia coastal zone is presented in the following.

4 The Corinthian Case Study

4.1 The Study Region

The study region – coastal front of Corinthia Regional Unit (RU) (Fig. 2) – is located in the north-eastern part of Peloponnese, at a distance of 80 km from the Athens metropolitan area. In 2011, the RU of Corinthia counts for 145,082 habitants, while covers a surface of 2,297 km^2. Corinthus is the administrative center and a major urban area, located along the national road axis that connects Athens to Patras. Corinthia's coastal front is surrounded by two significant gulfs – Corinthian and Saronic – connected through the Isthmus canal.

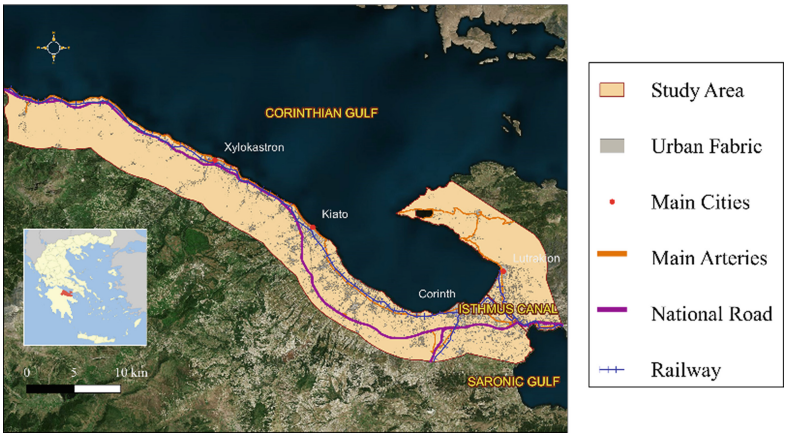

Fig. 2. The study area – a 5 km coastal zone in Corinthia RU.

The region's geomorphology demonstrates a great variety, ranging from a rough terrain, endowed by distinct mountainous ecosystems in the western part; to a smoother one along the eastern part of the Isthmus canal area. Cultural resources in the study area are abundant; same holds for natural ones, featured by four protected NATURA 2000 areas – both in land and sea – among which falls the Corinthian Gulf as a whole [35]. The proximity of the study area to the national road and railway networks – part of them unfolds across its coastal zone – is critical for the RU's geography. Tourism infrastructure includes hotels and Airbnb rooms/apartments, spreading along the coastal zone. The coastal front is marked as an Airbnb hotspot due to the extended offer of relevant accommodations [36]. Internal tourist flows prevail, with the tourism sector playing a significant role in the local economy and employment. Heavy industry facilities (Seveso areas) are also located in the eastern part of the Isthmus Canal.

In the study region, the concept of the *'linear city model'* is explored by elaborating on a 5 km zone adjacent to the shoreline (Fig. 2). This decision is justified by the fact that in the gradient of built-up density along distance from coast the curve is practically flattening beyond this distance [37].

4.2 Built Environment Typologies and 'Linear City' Pattern in Corinthian Bay

The previously presented methodological approach is applied in the Corinthian Bay case study. Towards this end and based on the GHS-BUILT-S2 R2020A data for 2017–2018 [38], a set of spatial metrics is firstly estimated, in order for built-up areas along the Corinthian Bay to be analyzed. The *spatial metrics* used are as follows:

- COV (Coverage): the sum of the areas (in ha) of all patches expressed as percentage (%) of total landscape area.
- PD (Patch Density): the number of patches divided by the total landscape area.
- ED (Edge Density): The total length (m) of patch edges, divided by total landscape area.

- MPS (Mean Patch Size): The mean area of patches.
- LPI (Largest Patch Index): The area of the largest patch, divided by the total landscape area.
- LSI (Landscape Shape Index): The sum of the landscape boundary and all edge segments (m) of patches within the landscape boundary, divided by the square root of the total landscape area (m^2), adjusted by a constant for square standard (raster).
- GYRATE (Gyration): The mean distance (m) between each cell in the patch and the patch centroid. This metric is estimated as "mean" value for all parches (mn) and "area-weighted" (am), based on the area of each patch.
- ENN (Euclidean Nearest neighbor, mn): The mean Euclidean distance to the nearest neighboring patch, calculated as the shortest edge-to-edge distance.
- CONNECT (Connectance): A measure of connection between patches, divided by the total number of possible connections among them. In this study, threshold distance is set to 200 m.
- PROX (Proximity): The sum of patch area, divided by the nearest edge-to-edge squared distance between the patch and the focal patch of all patches within a threshold distance (in this study set to 1000 m) of the focal patch. PROX is area-weighted (am) in this study, so that larger patches in proximity to be accounted for.

Uniform tiles of 1 × 1 km grid are applied; tiles mainly covered by sea (over 75%) are excluded. Overall, *408 valid tiles* are processed and summary statistics for spatial metrics are reported in Table 1.

Table 1. Summary statistics for spatial metrics based on tile analysis (1 × 1 km grid)

Spatial metric	Mean	Std. deviation	Minimum	Maximum
COV	7.04	10.73	0.01	78.3
PD	45.05	35.56	1.0	157.0
ED	87.88	93.74	0.40	441.4
LSI	7.24	3.96	1.0	17.1
LPI	3.45	9.19	0.01	76.9
MPS	0.17	0.55	0.01	8.7
GYRATE (mn)	11.06	5.51	5.0	69.9
GYRATE (am)	45.04	58.08	5.0	367.3
ENN (mn)	55.05	71.56	0.0	1052.6
CONNECT	28.11	21.95	0.0	100.0
PROX (am)	11.84	24.89	0.0	242.0

Results obtained demonstrate considerable variations in the spatial distribution of built-up areas along the coastal zone of Corinthia Bay. COV and ED high values are concentrated in the proximity of Corinthus town (from Isthmus to Kiato area – Fig. 2) and are spanning along a thin strip in the coastline zone; while high PD values spread towards the hinterland. In areas further inside from the coast, COV is less than 15, indicating development of very low-density (Fig. 3). LPI is maximized in the central zone of Corinthus and Kiato towns and is relatively low (<10) in all other tiles. A different pattern is observed in the distribution of GYRATE (mn) values, namely high values are spread in a larger inland zone and in proximity to major transportation infrastructure, where large elongated clusters tend to form. GYRATE metric is generally estimated higher for large irregular/elongated patches.

PCA analysis is used to reduce a number of variables to a minimum set of factors and obtain synthetic indicators, taking into account the variables assessed by spatial metrics. Towards this end, Varimax rotation with Kaiser Normalization is used in this work, while the KMO (Kaiser–Meyer–Olkin) and communalities indexes are also estimated. The indexes used for the evaluation of the PCA analysis show a good performance. KMO was estimated equal to 0.773, while communalities passed the test of 0.5. Bartlett's test of sphericity presents a small value of significance level (less than 0.01), therefore the hypothesis that correlation matrix is an identity matrix is rejected.

A total of three factors – Factor 1 (F1), Factor 2 (F2) and Factor 3 (F3) – are obtained (Table 2), with eigenvalues >1, accounting for 85.2% of the total variance of the initial variables. In F1, the COV, MPS, LPI, GYRATE (am) and GYRATE (mn) metrics are loaded on the positive axis; therefore, F1 is related to *high levels of patch aggregation, high density/coverage and complex/elongated patch shapes*. In F2, the PD, ED, LSI, PROX (am) are loaded on the positive axis; and CONNECT on the negative axis. Therefore, F2 is related to *high patch density with complex edge formation, high proximity and low connectivity*. In F3, ENN is loaded on the negative axis; therefore, F3 is related to *low levels of patch dispersion.*

To explore the "linear city" model and further analyze built-up typologies in the case study area, *Cluster Analysis* is performed using the three factors identified by the PCA (F1, F2 and F3). Hierarchical cluster, using Wards' method and squared Euclidean distance, is applied. A range of options regarding the number of clusters (5 to 7) is examined; and 7 clusters are selected as the optimal choice. Summary statistics for the spatial metrics per cluster are tabulated in Table 3.

Mean Factor values (F1, F2 and F3) per cluster group are displayed in Table 4. Inspection of results show that *Clusters 1* and *3* are the most important typologies identified, counting for 202 and 142 tiles respectively. *Cluster 1* is characterized by small (negative) average F1 values, therefore these tiles present low coverage, low patch aggregation and relatively simple patch shapes; while F3 is negative, a fact related to relatively high distances between built-up patches. *Cluster 3* is characterized by very high (positive) average F2 values (Table 4), therefore these tiles present high patch and edge complexity and low connectivity as well as patch aggregation and coverage close to the mean; while F3 is positive, a fact related to short nearest-neighbor distances between built-up patches.

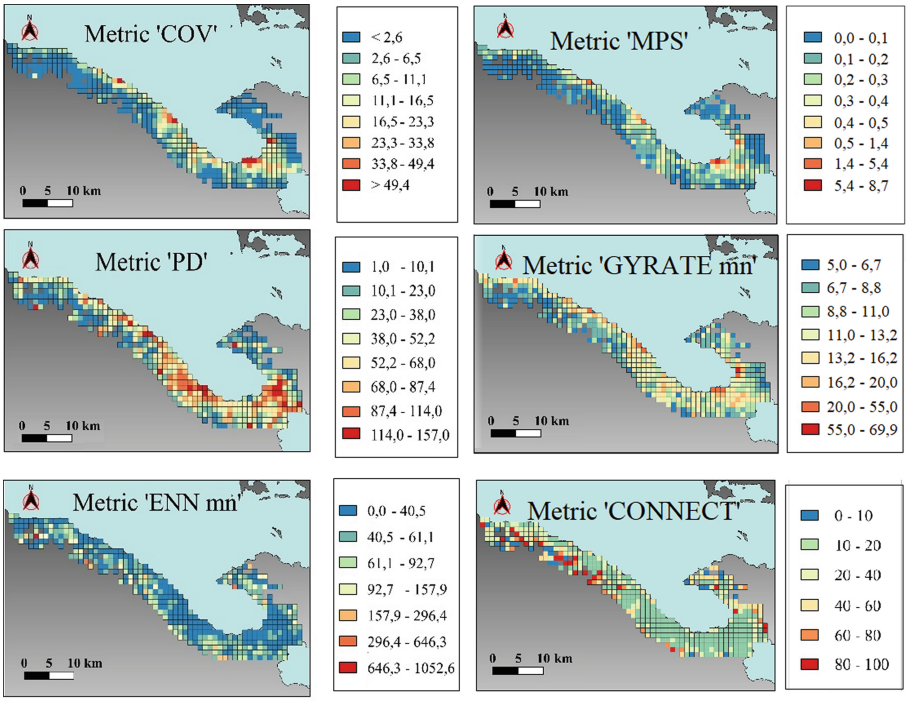

Fig. 3. Maps of COV, PD and ENN (mn) metrics and distribution of respective values along the 1 × 1 km tiles

Table 2. PCA results (rotated component matrix)

	F1	F2	F3		F1	F2	F3
LPI	0.961			LSI		0.898	
COV	0.908	0.366		ED	0.669	0.683	
MPS	0.885			CONNECT		−0.655	0.433
GYRATE (am)	0.880	0.308		PROX (am)	0.479	0.518	
GYRATE (mn)	0.856			ENN (mn)			−0.893
PD		0.904					

The next three important typologies are *Cluster 2* (26 tiles), *Cluster 6* (20 tiles), and *Cluster 4* (10 tiles). *Cluster 2* is characterized by negative F1 and F2 values, presenting low coverage, patch density and mean patch size; and very high (positive) F3 values. *Cluster 6* scores high on F1 and very high on F2 values, therefore patch and edge density in these areas is high, combined with high coverage and patch aggregation. In *Cluster 4*, all Factor values are negative, with F3 scoring very low on the average, a fact related to very high nearest-neighbor distances between built-up patches. *Cluster 7*

Table 3. Summary statistics for spatial metrics per cluster

Cluster		COV	PD	ED	MPS	LPI	LSI	GYRATE (mn)	GYRATE (am)	ENN	PROX	CONNECT
1 N = 202	Mean	1.70	24.61	28.73	0.07	0.61	4.89	9.0	20.6	57.2	27.91	1.83
	S.D.	1.75	16.70	22.66	0.07	1.07	2.18	3.1	21.2	33.0	16.66	2.44
	Min	0.01	1.00	0.40	0.01	0.01	1.00	5.0	5.0	0.0	0.00	0.00
	Max	10.24	65.00	112.40	0.42	9.02	9.37	23.1	188.4	189.4	100.00	15.35
2 N = 26	Mean	0.31	6.31	6.10	0.04	0.15	2.39	7.8	11.2	41.0	93.03	0.90
	S.D.	0.37	4.36	5.73	0.03	0.17	0.87	2.4	6.0	14.6	11.73	1.20
	Min	0.03	2.00	1.00	0.01	0.02	1.25	5.0	5.0	20.0	61.54	0.04
	Max	1.40	15.71	23.21	0.10	0.58	4.38	14.2	29.0	73.3	100.00	4.51
3 N = 142	Mean	10.49	81.49	150.38	0.14	3.17	11.02	12.8	54.7	34.7	18.20	17.43
	S.D.	4.94	26.65	54.17	0.07	2.41	2.11	2.6	28.3	5.2	4.82	15.66
	Min	2.99	36.39	72.60	0.03	0.14	7.07	6.9	9.6	21.9	12.11	1.27
	Max	26.73	157	304.60	0.47	10.93	17.11	19.6	144.2	49.1	34.19	76.42
4 N = 10	Mean	0.19	4.76	4.29	0.05	0.12	2.00	8.7	11.3	303.0	15.33	0.12
	S.D.	0.12	2.90	2.36	0.04	0.09	0.42	4.2	6.5	134.9	13.90	0.31
	Min	0.04	2.25	1.40	0.01	0.02	1.50	5.0	5.0	214.0	0.00	0.00
	Max	0.36	12.23	9.17	0.16	0.30	2.60	19.1	25.6	646.3	33.33	1.01
5 N = 1	Mean	0.02	2.0	0.80	0.01	0.01	1.33	5.0	5.0	1052.6	0.0	0.0
	S.D.	–	–	–	–	–	–	–	–	–	–	–
6 N = 20	Mean	29.20	72.58	285.53	0.45	19.86	12.35	16.5	195.7	31.6	19.45	86.76
	S.D.	7.59	21.99	68.01	0.18	9.37	2.61	3.1	54.3	7.2	7.14	60.26
	Min	19.00	25.63	102.91	0.21	6.84	5.70	13.3	79.2	23.8	13.57	2.37
	Max	48.00	104.0	398.81	0.76	41.41	15.79	25.7	299.7	54.6	46.44	242.03
7 N = 7	Mean	63.39	24.34	397.72	3.47	61.56	9.85	37.3	304.7	26.2	40.38	32.57
	S.D.	9.11	9.55	26.90	2.66	9.99	1.66	17.9	38.6	4.4	20.12	21.17
	Min	49.44	9.00	366.71	1.45	45.69	6.28	23.6	251.5	22.2	20.31	1.96
	Max	78.34	34.11	441.37	8.70	76.88	10.94	69.9	367.3	34.7	83.33	64.03
Total N = 408	Mean	7.04	45.05	87.88	0.17	3.45	7.24	11.1	45.0	55.1	28.11	11.84
	S.D.	10.73	35.56	93.74	0.55	9.19	3.96	5.5	58.1	71.6	21.95	24.89
	Min	0.01	1.00	0.40	0.01	0.01	1.00	5.0	5.0	0.0	0.0	0.0
	Max	78.34	157.0	441.37	8.70	76.88	17.11	69.9	367.3	1052.6	100.0	242.03

(7 tiles) displays the highest mean F1 values and negative F2 values, corresponding to very compact urban areas. *Cluster 5* contains only 1 tile (a mine site), therefore is not considered as a typology, but rather as a unique case.

Clusters along the 5 km coastal zone of Corinthian Bay are mapped in Fig. 4. In this figure, *Cluster 3* is identified as *'urban sprawl pattern'* forming a continuum along the coast and incorporating some pre-existing settlements. These areas are characterized by similar built-up patterns, with low-density development (mean COV 10.49%), very high PD and ED, low ENN and relatively high connectivity (CONNECT) at the 100 m threshold. High GYRATE values are related to geometrically complex built-up patches,

Table 4. Mean Factor values per cluster group

	Mean Factor values		
	F1	F2	F3
Cluster 1	−0.33	−0.48	−0.11
Cluster 2	−0.17	−1.83	1.42
Cluster 3	−0.03	0.93	0.22
Cluster 4	−0.16	−0.66	−3.39
Cluster 5	0.27	−0.18	−12.55
Cluster 6	1.71	1.33	0.03
Cluster 7	6.03	−1.22	0.04

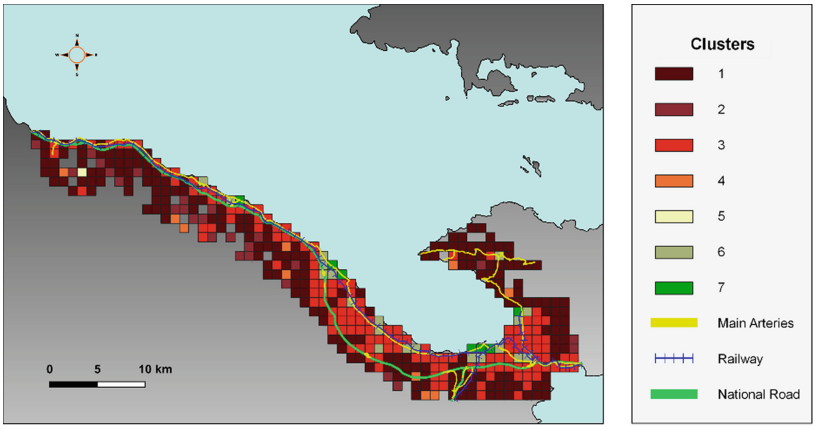

Fig. 4. Pattern of clusters/typologies along the Corinthian Bay.

usually with elongated shapes along the coast and/or the main road network. Taking into consideration the aforementioned results, Cluster 3 tiles are perceived as those shaping the *'linear city'* along Corinthian Bay.

Cluster 1 tiles are mostly identified in hinterland areas and semi-mountainous zones, characterized by low PD, LSI, ED values and Coverage between 1–10%. In most cases these refer to old rural settlements not affected by coastalization processes or isolated structures. *Cluster 2* tiles are similar to *Cluster 1*, with very low coverage areas, located far from the coast and next to the southern part of the national transportation network, presenting mostly isolated structures. *Cluster 6* tiles are suburban areas along the coast with a mean coverage of 29.20%; high PD, ED, MPS, LPI values; very high connectivity (CONNECT); and low ENN. *Cluster 7* tiles are compactly built-up areas with a mean coverage of 63.39%. Typical tiles of the above typologies, overlaid on satellite base map, are depicted in Fig. 5.

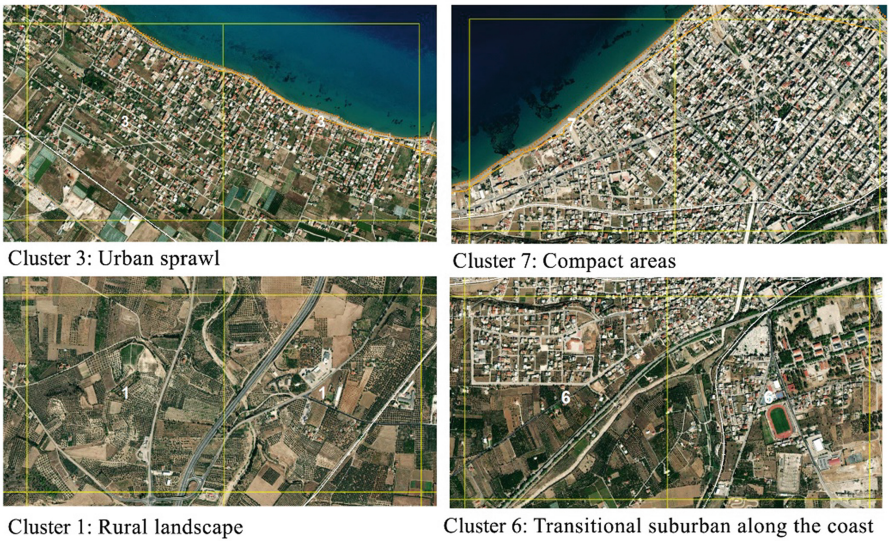

Fig. 5. Typical tiles of main cluster typologies.

4.3 Functionality Aspects of Built Environment Typologies in Corinthia 'Linear City'

Urban facilities of the study area and their relation to the transportation networks are shown in Fig. 6. Commercial uses are concentrated in the major settlements, in close connectivity with the main road arteries. Most cultural facilities are in close proximity to Corinthus town, while recreational facilities are dispersed along the coast. Educational infrastructure and public buildings are more evenly distributed in the settlement network, located in coastal and inland towns and villages. Inspection of the study area leads to the conclusion that this, although spatially connected, seems to be *functionally disconnected*. Indeed, urban facilities are mainly concentrated around major settlements; while the largest part of sprawling patterns is almost solely equipped by recreational and tourism facilities, and is marked by the lack of public space, a clear neighborhood structure and a complete urban facilities' network. Highway and railway networks act more like boundaries, separating the coastline part from inland zones.

In this linear city model, the *spatial relationship* between built-up typologies on the one hand and urban facilities – e.g. commerce, recreation, education – as well as transportation networks on the other, is examined by means of correlation analysis at the tile level. Towards this end, the following *additional variables* are defined:

- *UrbFacil:* The number of urban facilities, including commerce, education, public buildings, culture and other services, located within each tile.
- *Dis_Highway:* The mean distance from the nearest highway transportation node.
- *Dis_RoadNet:* The mean distance from the nearest point of the main road network (major roads connecting settlements).
- *Dis_RailNet:* The mean distance from the nearest railway transportation node.

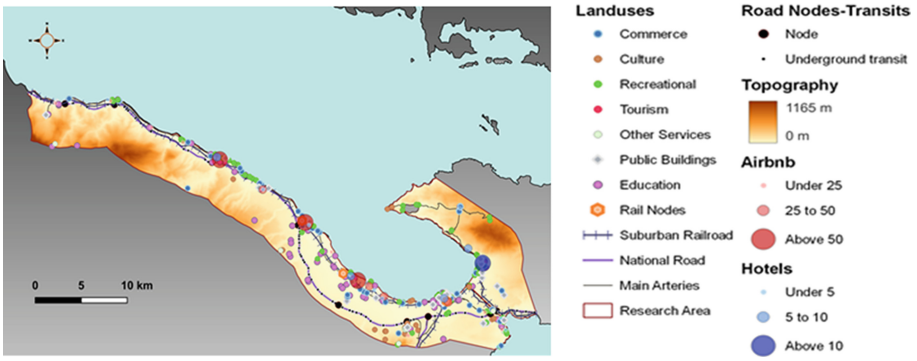

Fig. 6. Attributes of the Corinthian study region - urban facilities and networks

- *Dis_Settl:* The mean distance from the nearest major settlement.
- *Pop_den:* The mean population density, as estimated at the 250 m level by GHSL 2015 population grid (https://ghsl.jrc.ec.europa.eu/ghs_pop.php).
- *Elev:* The mean elevation of each tile (as estimated by the EU-*DEM* v1.1).

Results obtained from correlation analysis (Pearson correlation) at the tile level, incorporating F1, F2, F3 factors and the additional variables, are tabulated in Table 5. Among the additional variables, *Pop_den* is highly correlated to the distribution of urban facilities (*UrbFacil)*; and negatively correlated to distance from transport infrastructure and major settlements, since population is only partly concentrated around major towns and settlements. *UrbFacil* is also negatively correlated to distance from transport infrastructure (*Dis_RoadNet, Dis_RailNe* and *Dis_Highway)* and elevation (Elev), but with very low Pearson's r values (close to 0.1).

F1 is positively and highly correlated to density of urban facilities (*UrbFacil*) and population density (*Pop_Den*); and negatively correlated to elevation (*Elev*) and distance from transportation infrastructure (mainly *Dis_RoadNet* and *Dis_RailNet*). F2 is negatively correlated (r values < 0.5, yet statistically significant at the 0.05 level) to all variables, apart from population density. This shows that while urban sprawl areas (Cluster 3, high F2) are in close proximity to the transportation network, they lack of positive relationship with urban facilities. Additionally, urban sprawl areas are generally areas with low elevation, as they are closer to the coast. This fact explains the negative correlation of *Elev* variable with F2. On the contrary, in rural/agricultural areas (Cluster 1), where both F1 and F2 are low, urban facilities are scarce and both accessibility and population density are lower. The distribution of F3 values (related to dispersion of built-up patches) is not correlated to any of the variables used in this analysis.

Finally, distance from highway seems to affect to a lesser degree the formation of urban sprawl typology (Cluster 3), as Pearson's r between F2 and *Dis_Highway* is significantly lower than the corresponding value for *Dis_RailNet*. This can be explained by the fact that the national road network acts more like a physical boundary, splitting up the area into two different compartments; it is only recently constructed; and in the eastern part of the study area is relatively far from the coast. Settlement areas are mostly

Table 5. Pearson correlation and statistical significance levels among main variables.

		F1	F2	F3	UrbFacil	Dis_Highway	Dis_RoadNet	Dis_RailNet	Dis_Settl	Pop_den	Elev
F1	r	**1**	**0.0**	**0.00**	**0.712**	**−0.100**	**−0.272**	**−0.198**	**−0.198**	**0.796**	**−0.249**
	Sig.		1.00	1.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00
F2	r		**1**	**0.00**	**−0.116**	**−0.274**	**−0.427**	**−0.369**	**−0.317**	**0.320**	**−0.474**
	Sig.			1.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00
F3	r			**1**	**−0.009**	**−0.069**	**−0.058**	**−0.030**	**−0.041**	**0.035**	**−0.047**
	Sig.				0.80	0.16	0.25	0.54	0.406	0.48	0.34
UrbFacil	r				**1**	**−0.026**	**−0.116**	**−0.101**	**−0.100**	**0.625**	**−0.104**
	Sig.					0.60	0.02	0.04	0.04	0.00	0.04
Dis_Highway	r					**1**	**0.034**	**0.029**	**−0.083**	**−0.164**	**0.325**
	Sig.						0.49	0.57	0.092	0.00	0.00
Dis_RoadNet	r						**1**	**0.195**	0.238	**−0.317**	**0.575**
	Sig.							0.00	0.00	0.00	0.00
Dis_RailNet	r							**1**	0.905	**−0.310**	**0.48**
	Sig.								0.00	0.00	0.00
Dis_Settl	r								**1**	**−0.254**	**−0.100**
	Sig.									0.00	0.043
Pop_den	r									**1**	**−0.31**
	Sig.										0.00
Elev	r										**1**
	Sig.										

connected by the local road network that spans close to coastline and links residential areas to the sea.

5 Discussion and Conclusions

In the current millennium, escalating urbanization trends within a complex and uncertain, rapidly changing decision environment constitute a huge challenge for planners and policy makers. This holds even truer in case of *coastal areas*, taking into consideration the vulnerability of such areas to contemporary challenges, e.g. climate change, rising sea level, overtourism; the concern as to the integrated coastal zone management for ensuring environmental health and qualities of both land and marine ecosystems; but also the attractiveness of such areas for both habitation and economic activity.

In the Mediterranean Region in particular, *coastal urbanization* constitutes a historically witnessed trend that comes from the distant past; and continues to attract the interest of, among others, the residential, coastal tourism, maritime commerce and transport sectors, perceived as key drivers of change in coastal urban environments. However, the rapidly rising pattern of this trend is today grasped as an alarming, mostly beyond the carrying capacity of land and marine ecosystems, phenomenon that needs to be assessed and properly handled or restrained. Moreover, in many Mediterranean cases, coastal urban development displays a linear pattern, resulting in a city form that is marked by extremely thin low-density ribbon features along the coast; and is lacking the functional dimensions and qualities of typical cities and neighbourhoods of inland urban contexts. Additionally, such a linear urban form seems to hamper sustainability and resilience objectives and expose respective areas and their population to various (un)predictable risks.

Planning and policy formulation for restraining coastal urban sprawl and expanded linear forms of urban development as well as handling potential risks from such urban models presupposes a deep insight into each specific urban pattern and the distinct attributes of its various zones. This implies a data-intensive approach and extraction of knowledge out of it that is capable of guiding more informed *policy decisions*, e.g. zone regulation and protection, building rules and restrictions, design of adequate public space as well as provision of efficient services and infrastructures, to name but a few. The geospatial methodological approach proposed in this work can support these requests by indulging into novel and contemporary spatial data with regard to the built environment. Proper handling of these data by means of GIS technology; use of carefully selected and meaningful spatial metrics for assessing the nature and intensity of built environment in the various coastal city's compartments; and utilization of mature statistical methods (PCA and Cluster Analysis) for shifting data outcomes to planning-related spatial information, can support efforts of planners and policy makers towards identifying bottlenecks in that kind of coastal cities and designing specific zone-related policy remediation measures.

The implementation of this approach in the case of Corinthian Bay proves its value to explore and pinpoint morphological and structural attributes of the 'linear' urban development pattern; and classify zones that are mostly affected by urban sprawl. Additionally, this knowledge and its correlation to current city structural elements – e.g.

type and distribution of services, transport networks – unveils the inadequacies of this linearly-expanded coastal urban model as a functional space that are mainly due to the unplanned and incohesive urban sprawl pattern. Actually, overall evaluation of results can generally classify Corinthian region as a typical example of unsustainable linear coastal development that is featured by uncoordinated urban sprawl, a heavily burdened coastal part and severe deficiencies in terms of functionality aspects.

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