Climate Change and Urban Open Spaces: A Spatial-Statistical Analysis of Adaptive Capacity in Naples

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Abstract. Extreme weather events are natural phenomena, occurring at considerable distances in time, and have always been part of human experience and people's historical memory. These events are characterized as rare at a particular place and time of year, with unusual characteristics in terms of magnitude, location, timing, or extent. Over the past 10 years, we have been witnessing these phenomena more conspicuously in terms of frequency and intensity, annually reporting at least one phenomenon that emerges on a global scale and connotes itself as "the phenomenon of the year," sometimes earning a familiar household name, such as Charon or Katrina. These epochal events, nevertheless, although surprising in terms of magnitude, do not come unexpectedly. Not surprisingly 2024 was the hottest year on record since the pre-industrial age, with the global average temperature reaching +1.54 °C, even exceeding the limit identified as an extreme not to be surpassed in the Paris Agreements. Urban open spaces, both green and built-up, play a key role in improving thermal comfort and soil permeability, contributing to reducing energy consumption. Differing from most of the studies focused on just one of the two main issues affecting urban areas (energy and climate change), this work considers the open space system as the driver to strengthen the adaptive capacity of cities. The work aims to classify the urban area according to the relationships among the climatic, physical, environmental, and social characteristics of the fabrics where open spaces are located and the inner features of these built environment elements. Spatial-statistical analysis based on a cell grid is developed and applied to the study area of Naples. This paper represents a first step in a larger PRIN-funded research project 'Definition of a handbook of guidelines for implementing climate neutrality by improving the effectiveness of ecosystem services in rural and urban areas', aimed at defining an energy-efficient decision support tool based on urban and open space characteristics.

Keywords: Climate Change Adaptation · Urban Open Spaces · Green Areas · GIS · UHI · Flooding · Energy saving

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1 Introduction

In recent years, the increasing complexity of contemporary urban phenomena, particularly with regard to climate change and growing energy demand, has stimulated the development of increasingly sophisticated analytical tools aimed at classifying and understanding the morphological, climatic and energy characteristics of cities [28]. Such tools are particularly effective in the field of urban planning, where the need to identify homogeneous urban typologies in terms of micro-climate and energy behaviour allows for more precise targeting of climate mitigation and adaptation strategies. In the scientific literature, the most widespread urban classification methodologies are based on data mining techniques, most notably cluster analysis, used to group spatial entities (neighbourhoods, blocks, urban areas) based on the similarity of a set of physical, functional, morphological, climatic, energy and socioeconomic variables. The objective is not only descriptive but operational: to identify urban fabric models on which to apply targeted intervention strategies and evaluate urban transformation scenarios. Among the most widely used techniques is the K-means method, appreciated for its computational efficiency and simplicity of implementation [1–3]. However, the need to define the number of clusters a priori, the sensitivity to outliers and the requirement to znormalize variables constitute non-negligible limitations. To overcome these critical issues, alternative approaches such as hierarchical clustering or hybrid techniques have been developed, including the two-step method, which is zcharacterized by its ability to automatically determine the optimal number of clusters. This approach allows the analysis of complex datasets comprising both continuous and categorical variables and is particularly suitable for use in urban settings [4, 5]. Applications of classification techniques are developed on different spatial scales, i.e. at the macro level, cities or regions are zanalyzed in terms of emissions, climate vulnerability and urban morphology [5, 6], while at the local level, the focus is on urban fabric characteristics, through physical (building density, building height), geomorphological (tree cover, permeable vegetation), microclimatic (surface temperature, thermal comfort) indicators, often supported by GIS technologies, remote sensing and microclimate simulations [3, 7, 8]. A crucial aspect in the methodological differentiation of this study from the previous ones is the set of the indicators as it is in line with the systemic approach of the governance of urban transformations. Indeed, some studies zemphasize the ecological component, assessing the capacity of green areas to mitigate the urban heat island effect [1, 9]. In contrast, others focus on the adaptive potential of urban open spaces, estimating the physical and functional capacity to accommodate adaptive solutions [3]. In still other cases, classifications focus on building forms, integrating bottom-up energy models to estimate thermal requirements in relation to urban form and local climatic conditions [10, 11, 29]. A recent methodological development concerns the integration of three-dimensional components, thanks to the use of high-resolution 3D maps obtained from LiDAR data, which allow volumetric variables to be included in classification models [4]. The flexibility offered by the variety of available approaches makes these techniques indispensable tools for integrating spatial analysis, climate adaptation and energy demand management. In particular, two-step clustering proves to be particularly suitable for complex urban contexts, thanks to the possibility of dealing with mixed variables, supporting the generation of urban typologies useful for subsequent microclimate simulation phases.

The present work consists of four main phases: (i) the variable selection and calculation, which consists in the identification of the most relevant physical, functional, microclimatic, geomorphologic and socioeconomic indicators for classification purposes, and the measurement of data through open source sources, integrating official databases, satellite data in GIS; (ii) the definition of minimum unit of reference for calculating the indicators; (iii) the cluster analysis with the application of the two-step method for the spatial classification of urban fabrics according to the detected characteristics. Finally, (iv) the interpretation of results, reading of the identified clusters and definition of urban typologies, focusing on the implications of climate adaptation, andenergy-saving potential.

Compared to the cluster analysis developed in the previous studies, this work includes a wide set of indicators that are all open data and easy available to collect, to guarantee the replicability of the analysis to different urban contexts. This feature allows to interpret the obtained outputs in a very detailed way, allowing to define the characteristics of the different parts of the city at a micro-level.

2 GIS-Based Methodology

2.1 The Minimum Reference Unit

In the preliminary phase of urban spatial analysis, the definition of the minimum reference unit plays a strategic role in constructing a robust and coherent methodological framework. This unit needs to have a level of detail that allows the detection of morphological and functional variations of the urban fabric while maintaining operational compatibility with the scale of the urban planning tools and databases available [7]. Among the main approaches are methods that divide the territory into sectors based on directions and quadrants [12, 13], and geometrical based ones, where the urban area is segmented into regular rings around the urban center to study spatial gradients linked to landscape fragmentation or urban growth [14, 15]. Another approach, instead, is based on the classification of urban areas based on the functional zoning defined by local authorities [16], or another prevalent methodology is the one that considers morphological, compositional and surface coverage parameters to define climatically homogeneous units [17–20]. Finally, subdivisions based on administrative units are particularly useful for interoperability with urban development plans and for analyses on an institutional scale [21, 22].

Despite the variety of approaches, the use of a regular grid has proven to be particularly effective, as it allows for an objective and replicable subdivision of the territory, useful for both spatial analysis and environmental modelling [23, 24].

2.2 The Indicators Selection and Measurement

The definition of the set of indicators to be used for urban fabric classification needs to be based on an in-depth systematic review of the scientific literature, with the aim of identifying the most relevant variables to analyze the relationships between morphological and functional characteristics of the urban environment and microclimatic phenomena,

territorial vulnerability and energy consumption. Numerous studies highlight the importance of adopting an integrated and multidimensional approach in defining indicators, which considers local dynamics and evolving climatic conditions [1, 2]. Therefore, the selected indicators aim to coveringa plurality of dimensions, including demographic, socioeconomic, infrastructural, environmental, climatic, morphological and functional, to provide a representation of the urban context as complete and articulated as possible. In selecting variables, it is appropriate to favor those theoretically solid indicators that have revealed relevance in urban evaluation models, but also accessible in open format or easily derived from geospatial proxies [4, 6].

The spatial granularity of the information is a further critical element: the indicators need to be consistent with the minimum reference unit and guarantee interoperability between heterogeneous datasets, avoiding misalignments in the units of measurement and reference systems. The calculation of the indicators occurs through spatial analysis techniques implemented in a GIS environment, which include intersection operations, element counting, aggregation, zonal analysis and raster statistics, depending on the nature of the data [7]. Once calculated, the indicators must be normalized on homogeneous scales, using formulas that allow their integration into subsequent multivariate models or spatial classifiers.

2.3 The Cluster Analysis Two Step

The most widely applied methodology for urban analysis and classification consists of the use of clustering algorithms, with the aim of identifying homogeneous groups of spatial units, based on the urban characteristics that emerge from the set of selected indicators. The cluster-based approach allows to overcome rigid classifications based on single parameters or arbitrary thresholds, returning instead a segmentation of the territory that reflects characteristics emerging from the data themselves. Scientific literature underlines the effectiveness of this approach for complex spatial analysis, as it allows for the coherent synthesizing of the interaction between morphological, climatic, functional, and socioeconomic dimensions [3, 5, 10]. Among the most widespread techniques for clustering urban spatial units are k-means, particularly suitable for large numerical datasets; hierarchical analysis, useful for preliminary explorations and dendrogrammatic representations; fuzzy clustering, which allows the probabilistic attribution of units to multiple clusters simultaneously; DBSCAN (Density-Based Spatial Clustering of Applications with Noise), suitable for data with irregular distributions and presence of noise; and finally, two-step clustering, a more recent but very effective technique for the simultaneous management of continuous and categorical variables [10]. In the two-step multivariate cluster analysis, the process is divided into two main phases. In the first, the units are preliminarily grouped into small subgroups through a pre-clustering procedure, which reduces computational complexity even in the presence of large datasets. In the second phase, these subgroups are aggregated into final clusters through a hierarchical procedure, with the optimal number determined automatically based on the internal coherence of the groups and the penalization of the complexity of the model. This approach allows to obtain a robust, reproducible and statistically based classification. Once the classification has been performed, the results must be represented cartographically, returning the spatial distribution of the obtained clusters. Each cluster must be interpreted

based on the average values of the indicators that characterize it to attribute a synthetic name and build a typological profile that is easily understandable and operationally useful.

3 Application to the City of Naples

The proposed methodology is applicated to the City of Naples, Italy (Fig. 1). The city is selected as a case study for its morphological complexity, the variety of microclimatic and socioeconomic conditions, as well as for the availability of detailed geospatial data, deriving from both institutional sources and open databases. Furthermore, the application of the urban classification methodology to the city of Naples allows to compare the obtained results with the main classification of the current spatial planning tools and interpret them according to the available information sources and the technical tools accessible for the analysis.

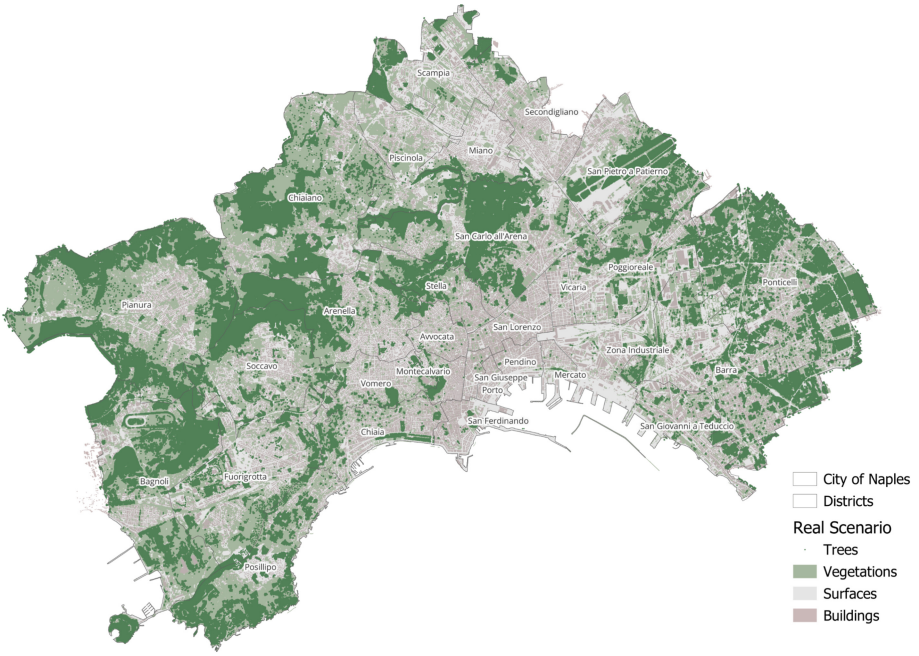

Fig. 1. The built and unbuilt surfaces distributed in the different districts of Naples.

For the case study of Naples, the minimum reference unit adopted is a regular grid with square cells of 250 × 250 meters. This choice is based on several reasons, including the need to have a unit consistent with the grids already adopted in official documents such as the PAESC (Sustainable Energy Action Plan) and the PRG (General Regulatory Plan) [25], allowing for direct integration between environmental analysis and urban planning tools. The grid is georeferenced based on the union frameworks prepared by the Campania Region, covering the entire municipal territory. Each grid cell

represents a homogeneous portion of urban fabric on which a set of physical, functional, socioeconomic, geomorphological, and microclimatic indicators have been calculated. This methodological approach allows the integration of data from different sources and scales, ensuring the detailed analysis of urban phenomena and supporting the definition of climate mitigation and adaptation strategies on a local basis.

In the case study of the city of Naples, the indicator selection process follows a literature review aimed at identifying the most recurrent variables in urban classification models oriented towards climate adaptation and energy efficiency, in addition to these indicators, additional data were added that were necessary to further deepen the spatial analysis, that are: acclivity from the calculations on contour lines and slope, typology of inner courtyards continuity of urban fabric from Copernicus Data, for example Urban Atlas and Corine Land Cover [27], Runoff coefficient from PRG, cooling effect area [26, 31] and Real Estate Market Observatory zones from Agenzia delle Entrate. Subsequently, the indicators are adapted to the local context, considering the data's availability and quality.

Finally, 35 indicators are selected (Table 1), discarding those not available at the municipal level, the specific ones of a microclimatic nature, and the redundant socio-demographic ones, such as the average age, replaced by an indicator that is more explanatory of the incidence of vulnerable groups (<15 and >65 years).

Table 1. The system of indicators.

Characteristics		Variables	Indicators	ID
Open SpaceSystem	Vegetation and Greenery	Trees	Tree-lined areas	OS1.1
		Urban Forest	Forest areas	OS1.2
		Urban Greenery	General Vegetation	OS1.3
	Surface Area	Squares	Public Green areas	OS2.1
			Impermeable open spaces	OS2.2
		Parking	Parking areas	OS2.3
		Street orientation and geometry	Road surfaces	OS2.4
			Acclivity	OS2.5
		Courtyards in urban areas	Inner courtyards	OS2.6
			Green inner courtyards	OS2.7
Urban Context	Land Use	Functional urban areas	Industrial area	UC1.1
			Historical areas	UC1.2

(*continued*)

Table 1. (*continued*)

Characteristics		Variables	Indicators	ID
			Residential area	UC1.3
		Natural and Agricultural areas	Forest areas	UC1.4
			Agricultural land	UC2.1
	Building Density	Building coverage ratio	Built-up area Naples	UC2.2
		Mobility infrastructure	Local Public Transport stops	UC2.3
		Building material	Density of building in reinforced concrete	UC2.4
			Density of building in brickwork	UC2.5
			Density of building in steel, wood, etc.	UC2.6
		Neighborhood compactness and layout	Continuous urban fabric SL more 80%	UC2.7
			Discontinuous medium density urban fabric SL 30%–50%	UC2.8
			Low urban density and SL less 30%	UC1.1
Microclimatic and Geomorphology	Solar Radiation	Radiant temperature	Mean Radiant Temperature (MRT)	MG1.1
	Energy	Energy use consumption	Density of residential energy consumption	MG1.2
	Flooding	Flooding and Precipitation Tendency	Runoff coefficient	MG2,1
			Flooding Tendence	MG2.2

(*continued*)

Table 1. (*continued*)

Characteristics		Variables	Indicators	ID
	Temperature	Thermal indexes	Universal Thermal Climate Index (UTCI)	MG3,1
			Cooling Effect Area	MG3.6
			Land Surface Temperature (LST)	MG3.2
	Geomorphological features	Distance to coasts	Cartographic marine coastline	MG4.1
Socioeconomic and Demographic Indicators	Socioeconomic data	Total population	Density of total population	SED1.1
		Education	Density of the population with a specific education	SED2.1
		Income	Income per capita	SED2.2
		Real estate value	Real Estate Market Observatory zones	SED2.3
		Vulnerable Population	Density of vulnerable population	SED2.5
		Worker population	Density of general workers	SED2.6

The main data sources include the PAESC and the PRG of the Municipality of Naples, the Territorial Information System (SIT) of the Metropolitan City, national open data databases, the Copernicus Land Monitoring Service (Urban Atlas, HRL), OpenStreetMap (for buildings, roads and public green areas) and the Corine Land Cover. The indicators were calculated on the regular 250 × 250 m grid already defined, using zonal statistics functions for raster data (such as those from Copernicus) and vector operations for discrete spatial data.

In this work, the classification of spatial units of the city of Naples is carried out through multivariate cluster analysis using the two-step algorithm implemented in the SPSS software. This methodological choice is driven by the dataset's mixed nature, which included numerical variables (e.g. building density, percentage of impervious soil, runoff index) and categorical variables (e.g. land use class, type of land cover). The

two-step algorithm stands out for its ability to simultaneously process data of different types, automatically estimating the optimal number of clusters. This feature makes it particularly suitable for complex urban contexts, where the variety of information sources and the multidimensionality of phenomena require a flexible and scalable approach [5].

The application of the algorithm produces eight distinct clusters, each characterized by a specific combination of mean values of the indicators, which defines its functional and morphological profile (Table 2). The analysis allows the outline a functional map of the Neapolitan urban territory, highlighting critical issues, opportunities and local specificities in an integrated and quantitative way. The interpretation of the clusters occurred through the analysis of the centroids and the distribution of the values of the variables for each group. Each cluster has then named on the basis of the prevalent characteristics, with the aim of facilitating the operational understanding of the results. The classification obtained represents a solid basis for defining climate adaptation strategies, orientation of urban solutions and interventions, and support for integrated territorial planning [30]. Figure 2, below displays the map resulting from the classification, highlighting the spatial distribution of the clusters throughout the territory of Naples.

3.1 Results

Cluster 1 – Green Lungs

The areas included in this cluster are mainly located in the north-western part of the city and represent the main green lungs of Naples. Their distinctive feature is the strong presence of vegetation, which translates into particularly high values compared to the other clusters for the "vegetation and greenery" category. Here the building density is extremely low, and the impermeable surfaces are reduced to a minimum (Table 2). The PRG confirms that many of these areas are classified as "Zone F - Areas intended for parks and public greenery". Temperatures are on average lower than in the rest of the city, thanks to the mitigating effect of the vegetation. The population living in these areas has an average income higher than the city average. From an urban planning point of view, it is crucial to preserve and enhance these areas to guarantee their contribution to the reduction of the heat island effect, such as the ecological function.

Cluster 2 – Residential Areas in Green Areas

This cluster is located mainly in the immediate vicinity of Cluster 1, in adjacent areas in the north-western strip, with some scattered portions in the city's eastern part. These are areas where vegetation is present, although to a lesser extent than in the previous cluster, and where land use is strongly oriented towards agricultural activities. The PRG classifies these areas as "Zone E - Agricultural areas", "Zone F - Sub-zone Fb - residential areas in the park" and, in some cases, as "Zone D - New production settlement areas". The building density is low, and the presence of natural surfaces is significant, even if a certain fragmentation of the urban fabric is observed. Temperatures are slightly higher than in Cluster 1, partly due to the lower tree cover (Table 2).

From a socioeconomic point of view, these areas have a low population density and an average income slightly higher than the city average. These parts need to be preserved according to their agricultural and naturalistic vocation and prevent the uncontrolled expansion of built-up areas.

Table 2. Cluster analysis output matrix showing the average values of indicators for each cluster.

N	159	396	201	386	133	220	445	166	2106
%	7.5%	18.8%	9.5%	18.3%	6.3%	10.4%	21.1%	7.9%	100.0%
Cluster	1	2	3	4	5	6	7	8	TOT
OS1.1	0.224	0.037	0.016	0.009	0.025	0.006	0.011	0.003	0.032
OS1.2	0.563	0.056	0.018	0.006	0.009	0.008	0.003	0.001	0.058
OS1.3	0.711	0.456	0.135	0.155	0.186	0.043	0.167	0.067	0.238
OS2.1	0.005	0.002	0.014	0.026	0.112	0.001	0.005	0.009	0.016
OS2.2	0.000	0.0002	0.006	0.003	0.075	0.001	0.001	0.022	0.008
OS2.3	0.003	0.002	0.005	0.010	0.110	0.015	0.017	0.013	0,016
OS2.4	0.034	0.081	0.154	0.183	0.179	0.022	0.126	0.218	0.123
OS2.5	0.340	0.209	0.251	0.081	0.072	0.088	0.039	0.086	0.133
OS2.6	0.002	0.002	0.018	0.025	0.034	0.002	0.011	0.249	0.031
OS2.7	0.000	0.001	0.003	0.008	0.009	0.002	0.004	0.105	0.012
UC1.1	0.000	0.006	0.000	0.009	0.074	0.001	0.144	0.030	0.040
UC1.2	0.014	0.014	0.357	0.099	0.174	0.074	0.019	0.825	0.144
UC1.3	0.012	0.062	0.385	0.619	0.245	0.031	0.141	0.097	0.219
UC1.4	0.089	0.367	0.041	0.063	0.018	0.023	0.057	0.014	0.108
UC2.1	0.003	0.010	0.056	0.049	0.039	0.005	0.017	0.218	0.040
UC2.2	0.009	0.014	0.099	0.031	0.167	0.012	0.023	0.096	0.043
UC2.3	0.103	0.145	0.107	0.102	0.036	0.010	0.041	0.096	0.083
UC2.4	0.092	0.118	0.080	0.090	0.094	0.023	0.138	0.072	0.096
UC2.5	0.072	0.176	0.186	0.143	0.051	0.019	0.085	0.037	0.109
UC2.6	0.001	0.002	0.043	0.046	0.067	0.004	0.012	0.063	0.025
UC2.7	0.017	0.087	0.155	0.084	0.009	0.008	0.010	0.008	0.052
UC2.8	0.055	0.061	0.003	0.001	0.002	0.000	0.000	0.000	0.016
MG1.2	0.051	0.049	0.201	0.154	0.070	0.012	0.029	0.200	0.088
MG2.1	0.197	0.312	0.626	0.664	0.661	0.427	0.602	0.850	0.535
MG2.2	0.330	0.471	0.606	0.718	0.744	0.192	0.713	0.877	0.590
MG1.1	0.202	0.582	0.480	0.571	0.619	0.562	0.796	0.632	0.591
MG3.1	0.806	0.833	0.730	0.736	0.776	0.194	0.815	0.527	0.705
MG3.2	0.689	0.802	0.785	0.782	0.826	0.701	0.846	0.769	0.786
MG4.1	0.002	0.001	0.019	0.000	0.036	0.217	0.002	0.005	0.028
SED1.1	0.042	0.068	0.293	0.179	0.065	0.010	0.050	0.154	0.105

(*continued*)

Table 2. (*continued*)

N	159	396	201	386	133	220	445	166	2106
%	7.5%	18.8%	9.5%	18.3%	6.3%	10.4%	21.1%	7.9%	100.0%
Cluster	1	2	3	4	5	6	7	8	TOT
SED2.1	0.021	0.028	0.311	0.067	0.037	0.005	0.020	0.072	0.062
SED2.2	0.451	0.407	0.745	0.370	0.438	0.109	0.331	0.397	0.390
SED2.3	0.381	0.386	0.813	0.398	0.459	0.082	0.286	0.529	0.392
SED2.5	0.041	0.063	0.305	0.175	0.067	0.009	0.047	0.145	0.103
SED2.6	0.004	0.004	0.008	0.004	0.064	0.003	0.010	0.009	0.010

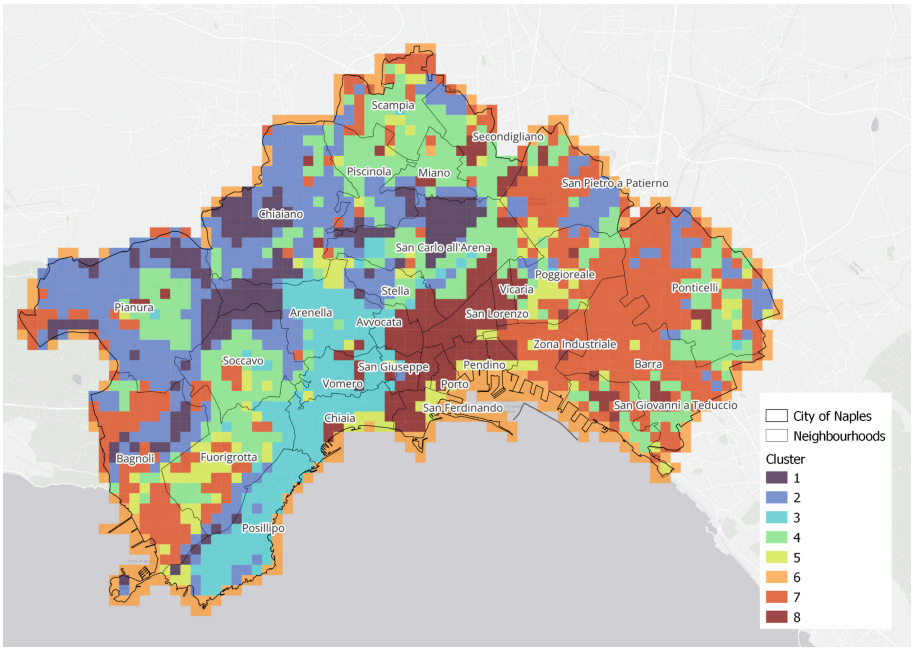

Fig. 2. Cluster Analysis map for the case study of the city of Naples.

Cluster 3 – Hillside Residential Areas

These areas include the coastal strip of Posillipo and Chiaia, extending to Vomero. They are characterized by a low presence of vegetation, compensated by a high environmental quality and a strong residential attractiveness. The PRG classifies these areas mainly as "Zone A - Settlements of historical interest" and "Zone B - Areas of urban completion". Land use is predominantly residential and characterized by a less dense built fabric than other city central areas. The population living in these areas has the highest income among all the clusters, with property values well above average (Table 2). From a climatic point

of view, temperatures remain in line with the city average, while the risk of flooding is high. In these areas urban planning should focus on mitigating the effects of climate change by increasing soil permeability to reduce hydrogeological risk.

Cluster 4 – Vulnerable Areas
This cluster includes the northern areas of the city, such as Scampia and Secondigliano, and extends eastwards towards neighborhoods such as Barra and Ponticelli, as well as including some portions of Soccavo, Pianura and Fuorigrotta. These are areas characterized by a lack of greenery and a high building density (Table 2). Most of the buildings are social housing, and the urban fabric is the result of expansions that are often carried out in a disorganized way. The PRG classifies these areas as "Zone B - Recent Expansion" and "Zone C - Areas of low-cost and social housing". The socioeconomic indicators highlight a population with low incomes and high social vulnerability. The microclimatic conditions are, on average, worse than other areas of the city, with temperatures and levels of solar radiation above average. To improve the quality of life in these neighborhoods, it would be necessary to implement urban regeneration strategies, increasing the provision of green spaces and improving existing infrastructure.

Cluster 5 – Open Space Areas
These areas are distributed in a fragmented manner throughout the city and are characterized by the presence of large open surfaces, including parking lots and public spaces. The building density is low and the soil permeabilization is particularly high. The PRG classifies many of these areas as "Zone F - Areas for parking and public infrastructure". From a climatic point of view, temperatures above average and high solar radiation are recorded, due to the lack of vegetation cover (Table 2). These areas need to be redeveloped through urban forestation interventions and the creation of multifunctional areas capable of reducing urban overheating.

Cluster 6 – Border Areas
The areas that comprise this cluster are located on the edges of the consolidated urban fabric and represent a transition area between the built-up area and the more open areas and between the municipal border and the neighboring municipalities. The PRG classifies them mainly as " Zones B - Urban completion areas". The building density is medium-low, and the urban fabric is rather fragmented (Table 2). Socioeconomic indicators show that a population with incomes is generally lower than the city average. From an urban planning point of view, these areas could benefit from targeted interventions to improve urban cohesion and encourage the presence of services and public spaces connecting the different municipalities.

Cluster 7 – Productive and Abandoned Areas
These areas are mainly concentrated in the eastern part of the city, including neighborhoods such as Poggioreale, Barra and Ponticelli, as well as portions of Fuorigrotta and Bagnoli. These are areas with a productive vocation, often characterized by the presence of abandoned industrial infrastructures. The PRG classifies them as "Zone D - Productive Areas". The building density is relatively low, but the soil permeability is very high. The hydrogeological risk is significant, and temperatures are on average higher than the

city average (Table 2). An adequate urban redevelopment strategy could transform these areas into new centers of sustainable economic development.

Cluster 8 – Consolidated Historic Areas
This cluster includes the historic center and surrounding areas, characterized by a high building density and a very low presence of vegetation. The PRG classifies these areas as "Zone A - Settlements of historical interest". The heat island effect is particularly pronounced, with high temperatures and strong soil sealing (Table 2). Urban planning strategies should focus on increasing urban green spaces and on solutions to mitigate summer overheating.

4 Conclusions

In conclusion, the application of the urban classification methodology to the case study of the city of Naples highlights the effectiveness and flexibility of the adopted approach, both from a methodological and operational point of view.

The choice of using a regular grid of 250 × 250 m as the minimum unit of analysis allows a homogeneous and detailed reading of the urban fabric, facilitating the integration of heterogeneous indicators from institutional sources and open data. This approach guarantees the possibility of developing solutions at a local scale, making the analysis directly readable in a holistic perspective. Furthermore, this methodological coherence facilitates direct comparison with indicators already adopted in official documents such as the PRG, strengthening the validity and operational utility of the results.

The definition and measurement of 35 indicators, considering the availability, quality and significance of the data for the City of Naples urban context, has allowed us to provide a complex and multidimensional picture of the territory. The use of Two-Step Cluster Analysis represents a methodological choice consistent with the mixed nature of the dataset, allowing the identification of eight functionally and morphologically distinct clusters, capable of exhaustively describing the urban complexity of the city. The results of the analysis highlight a marked territorial heterogeneity, returning a multifaceted image of the city of Naples, divided into eight functionally and morphologically distinct clusters. We move from areas with a prevalent environmental vocation, such as Cluster 1, which represents the large green lungs of the city, fundamental for climate regulation and environmental quality, to heavily built-up areas with high social vulnerability, such as Cluster 4, which require urgent interventions for urban redevelopment and strengthening of social resilience. Cluster 2 includes agricultural and peri-urban areas, with low building density and a rural vocation, which pose interesting prospects in terms of urban agriculture and landscape protection. Cluster 3, composed of prestigious hillside neighborhoods, highlights high real estate values and an average high environmental quality, although it presents critical issues related to hydrogeological risk. Cluster 5 is made up of fragmented areas, dominated by impermeable surfaces and underused public spaces, which represent a strategic potential for interventions on open spaces. Cluster 6 occupies the transition zones along municipal edges, often characterized by discontinuous fabrics and low real estate value, where planning can play a crucial role in strengthening urban cohesion. Cluster 7 identifies disused industrial areas, with high impermeability and poor

environmental quality. Finally, Cluster 8 includes the densely built historic center, with high climatic criticalities due to the heat island effect and the lack of urban greenery. This segmentation not only highlights areas characterized by a high presence of green spaces or, on the contrary, by high building density and impermeable surface but also highlights socioeconomic and microclimatic criticalities, which are fundamental information for the identification of targeted interventions for climate adaptation.

Furthermore, this methodology proves solid and replicable and capable of providing an operational representation of the urban territory [33], useful for supporting strategic decisions aimed at adapting to climate change, UHI and flooading in particular [32], and energy saving. The analysis developed in the city of Naples provides a model that can be exported to other metropolitan contexts characterized by urban complexity, representing a useful tool for the governance of urban and territorial transformations.

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