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Development of an urban resilience indicator for Athens in the context of climate change

POLYDOROS A.[1,*], MAVRAKOU T.[1] and CARTALIS C.[1]

1National and Kapodistrian University of Athens, Zografou Campus Building PHYS-V, 15784 Athens Greece

*corresponding author:
e-mail: apoly@phys.uoa.gr

Abstract Urbanization interacts with climate change through the way cities are organized and built (land cover/ land use, urban morphology). Increased energy consumption and consequently CO2 emissions, combined with emissions from city functions (urban metabolism, anthropogenic heat sources) intensify urban climate change. The effects from more frequent extreme weather events and natural disasters etc. are already observed in cities in multiple spatial and temporal scales. Especially for the Athens basin, there has been an urban expansion of 28% from 1987 to 2010, a burden on human thermal comfort and a deterioration of the thermal environment in the suburban areas leading to social and economic inequalities within the urban complex of Athens.

The above highlight the necessity to develop an Urban Resilience Indicator (URI) as well as its spatial and temporal mapping over the Athens Basin. The indicator is based on the use of Earth Observation and census data and it allows the identification of urban units that exhibit limited resilience to climate change and the related factors. Moreover, the URI mapping will allow the identification of specific interventions that enhance resilience to climate change and the drafting of comprehensive plans for adapting and mitigating urban climate change.

Keywords: climate change, urban resilience, GIS, remote sensing

1. Introduction

Today, around 360 million people - 72% of Europe's total population - live in cities. The percentage of the urban population in Europe continues to grow, and is likely to exceed 80% by 2050 (United Nations, 2019). In the context of climate change cities are frequently exposed to climate-related risks such as heatwaves, floods and droughts indicating the necessity of strengthening urban resilience (Mal et al., 2018).

The concept of resilience has gained increasing attention the last decade (Meerow et al., 2016). Schaefer et al. (2020) defined the resilient city as follows "a climate resilient city has the ability to adapt proactively to changing environmental conditions and recover quickly from the negative consequences of external shocks triggered by extreme weather events". Therefore, resilience indicators need to be developed in order to characterize the elements of an urban system, to raise community awareness, as well as to monitor progress and prioritize the system needs (Cutter, 2016; Feldmeyer et al., 2019).

Urban characteristics associated with climate change such as urban population, urban extent and structure, surface urban heat island and many others can be estimated and monitored from earth observation data (Milesi and Churkina, 2020). Remote sensing offers long term observations in fine scales from a variety of sensors providing directly measured parameters or proxies in various spatial and temporal resolutions. (Cartalis et al., 2015). Especially for the Athens basin the human thermal discomfort during heatwaves (Polydoros and Cartalis, 2014) was assessed and the thermal hot spots were identified (Mavrakou et al., 2018) using remote sensing data.

In this study, an Urban Resilience Indicator (URI) is developed for the Athens Basin based on Earth observation and census data leading to the identification of urban areas that exhibit limited resilience to climate change.

2. Methods

2.1. Study area

The Athens basin is located in the center of Attica and is delimited from east by Mount Hymettos, from north by Mount Parnitha and Penteli and from west by Mount Aegale (Mavrakou et al., 2012). It occupies an area of approximately 534 km^2 and includes the urban core of metropolitan Athens which is the most densely populated area in Greece (Figure 1). It mainly consists of urban residential areas, commercial and industrial areas, suburban areas and the associated road network. The Athens basin urban areas are characterized by a high degree of mixed land-use, limited green and open public spaces, and limited ventilation routes that do not allow the influx of airflow from the surrounding countryside leading to a burdened urban environment vulnerable to climate change associated risks such as heatwaves, floods and drought.

Figure 1. The study area (red polygon).

2.2. Methodology and data

The adopted methodology for the estimation of URI is mainly based on satellite remote sensing data and products. The resilience of the urban system is divided and studied in three subsystems following the framework of previous studies (Cutter, 2016; Feldmeyer et al., 2019), namely the environmental, the societal and the infrastructural (Table 1). Actually more subsystems exist and can be included in resilience studies (e.g. institutional adaptiveness) but they do not fall under the scope of this study since it is difficult to capture in a quantitative manner.

Table 1. Final indicator set for quantifying climate resilience in Athens Basin

Subsystem	**Indicator**
Environment	NDVI
	LST
	Imperviousness degree
	Building height
	Slope
	Land use
Socio-economic	Proportion of elderly +70 years
	Proportion of unemployed population
	Population Density
Infrastructure	Proximity to hospitals
	Accessibility of fire brigade

To properly assess the resilience of cities, the use of consistent high resolution data is essential. Freely available Earth observation and secondary data that is routinely refreshed and published by space and statistical agencies is important for cities to compare their resilience over time. In order to quantify the climate resilience of the three subsystems ten indicators were determined (Table 1).

Various data (Table 2) differing in spatial and temporal scales, as well as in their format (raster, vector, spreadsheets) were employed in order to calculate the indicators used for describing each dimension. An effort was made to collect the most recent data available but this was not always possible especially for statistical socio-economic data.

Regarding the environmental subsystem Sentinel 2 (10m spatial resolution) and Landsat 8 (30m spatial resolution) remote sensing data were used to calculate the Normalized Difference Vegetation Index (NDVI) and Land Surface Temperature (LST) respectively. Both indicators are highly correlated with natural infiltration in case of heavy rainfalls and potential heat stress respectively. Data products from the Copernicus Land Monitoring Service (CLMS) were used to assess the urban characteristics of the city such as imperviousness degree and buildings height in 20m spatial resolution. Digital Elevation model (DEM) data form ASTER satellite provided useful insight about the slope (30m spatial resolution) of each area of the city so as to assess the terrain characteristics in case of heavy rainfall events.

Table 2. Description of data used

Source	**Description**
Raster	Sentinel 2, Landsat 8, Copernicus Land Service, Global Human Settlement Layer (GHSL)
Vector	Points of Interest, Land Use
Census	Hellenic Statistical Authority

Concerning the socio-economic subsystem the proportion of the elderly +70 per municipality was calculated, using data from the Hellenic Statistical Authority database, as it is a sensitive population group that is vulnerable to extreme weather events and sometimes unable to reach safety. Additionally, population density data were used, from Global Human Settlement Layer in 9arcsec spatial resolution, in order to define the areas with high population densities that may be exposed to urban heat island effects and flash floods events. Also the proportion of unemployed population per municipality was calculated as this group may have less financial resources for adapting in climate related risks (Schaefer et al., 2020).

Regarding the infrastructure subsystem, GIS-based data in vector format were used to defined the points of interest, such as hospitals and fire stations in order to assess the proximity of the population to critical health services and the accessibility of fire services in case of emergency.

All data were processed in the freely available QGIS software in order to reprojected them in a common geographic coordinate system and were resampled to 100m spatial resolution which is an appropriate resolution to depict the urban characteristics and it is a practical scale to plan adaptation and mitigation actions. Each numerical indicator of the environment subsystem was normalized and the study area was classified in five categories using the K-Prototypes clustering algorithm which is a hybrid clustering algorithm that can process Categorical Data and Numerical Data (Huang, 1998). The resulting five categories were then analyzed and characterized using linguistic variables (i.e “more resilient”, “moderate resilient”, etc.). The same procedure was applied for the socio-economic and infrastructure subsystems. Finally the categories of the three subsystems were combined and further grouped into nine categories of urban resilience which were also characterized using linguistic variables (i.e “more resilient”, “moderate resilient”, etc.).

3. Results and Discussion

Resilience maps representing each urban subsystem (environment, socio-economic and infrastructure) are depicted in Figure 2, highlighting the interdisciplinarity as well as the diverging aspects of urban resilience. From the environmental point of view, the southwest part of the Athens basin exhibits less resilience (red and orange colors) due to the lack of natural vegetation, higher percentage of non-impervious surfaces and higher LST’s compared with the northeastern part. The high spatial resolution of the remote sensing data leads to the identification of specific areas that are less resilient and where mitigation and adaptation measures should be prioritized.

Concerning the socio-economic resilience which is based on low spatial resolution census data it is clearly observed that the core urban area of the city, that is the municipality of Athens, is less resilient due to the high population density and high unemployment rates found in the city center.

Regarding the infrastructure dimension of resilience the results revealed that the majority of the Athens basin is adequately resilient since a large number of hospitals and fire stations exist in the Athens basin.

The combined analysis of the three subsystems led to the creation of the urban resilience presented in Figure 2(d). The majority of the study area demonstrates moderate and rather less resilience levels (yellow and orange colors) but a tendency of high resilient levels (green and blue colors) in the periphery of the urban core is clearly observed. The least resilient areas are concentrated in the city center where the environmental and socio-economic indicators highlight the burdened urban climate conditions and indicate the areas where mitigation and adaptation actions should be prioritized.

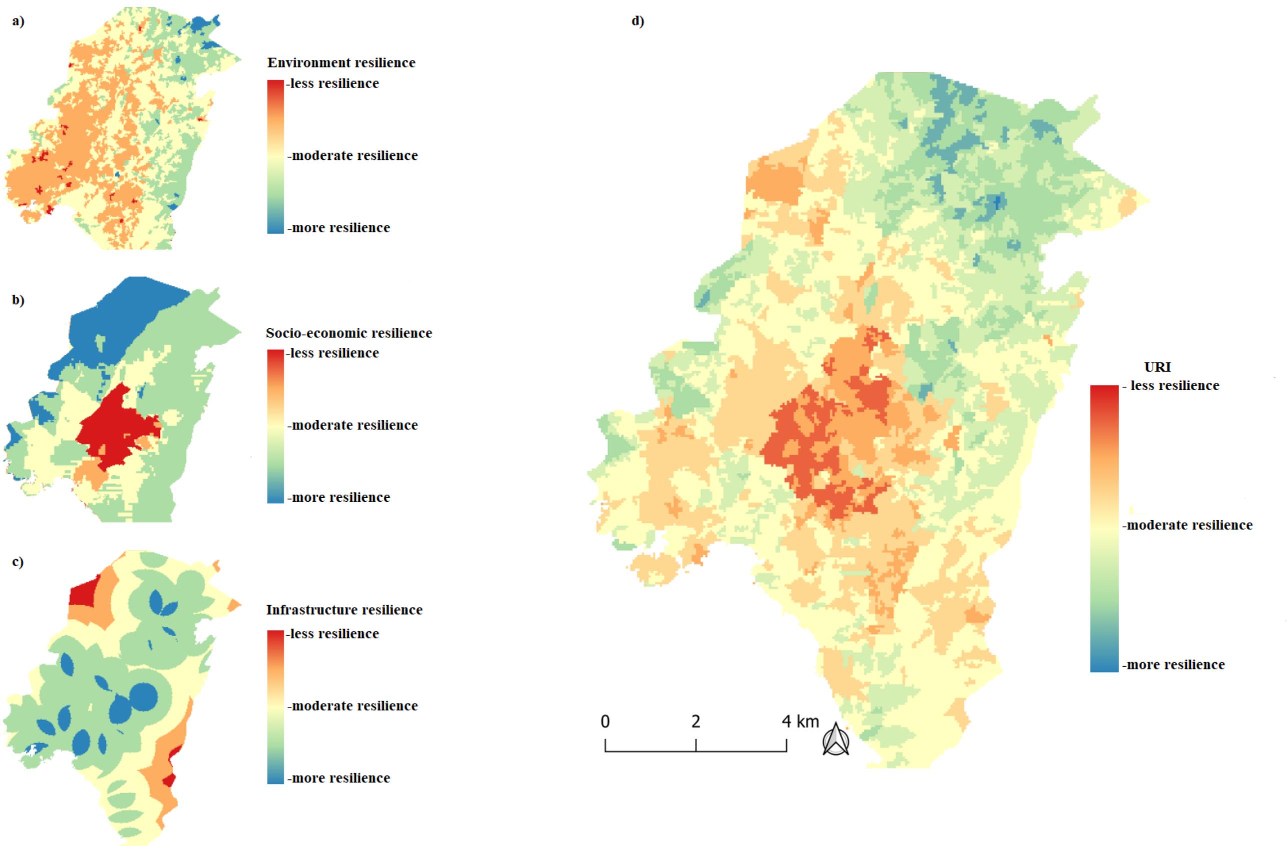

Figure 1. Resilience results for the three urban subsystems: a) environment, b)socio-economic, c) infrastructure and d) the urban resilience index for the Athens basin.

4. Conclusions

The purpose of this study is to present a multidimensional analysis of the urban resilience of the Athens basin based on remote sensing data and products and census data. It provides a robust proof of concept for the integration of socio-economic census data and Earth observation data for urban resilience studies.

The mapping of urban climate resilience using high spatial resolution data and GIS techniques reveals the spatial distribution of the urban resilience and leads to the identification of specific low resilient areas within the city where mitigation and adaptation actions should be prioritized. The least resilient areas are concentrated in the city center where the environmental and socio-economic indicators highlight the burdened urban climate conditions.

Further improvement of the URI is possible by increasing the number of indicators or by using more detailed census data when available, keeping in mind that the publicly availability of data is a key aspect of analysis. The methodology can be easily reapplied in the future for the same study area or replicated in another major European city where data availability is guaranteed.

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