P. Rajagopalan, V. Soebarto and H. Akbari (Eds.), *6th International Conference on Countermeasures to Urban Heat Islands (IC2UHI)*, pp. 12-20. ©2023, RMIT University, Melbourne, Australia.

Impact of increased ambient temperatures due to climate change in human health: evidence from four European countries

Sofia Tsemekidi Tzeiranaki[1], *Theocharis Tsoutsos* [2]
[1,2,] *Engineering Technical University of Crete, Chania, Greece*

ABSTRACT

A rise in urban overheating due to the increased ambient temperatures has occurred during the last decades. Cooling Degree Days at the European Union level were increased by 173.9% from 1979 to 2021. Heatwaves, Urban Heat Islands and extreme weather conditions became significant risks for cities, especially for vulnerable citizens, as they lead to respiratory problems and increased mortality. This article studies the consequences of increased ambient temperatures on human health and living conditions in the context of climate change using statistical analysis, based on Eurostat data. It assesses the impact of overheating on mortality rates in the regions of four European countries (Italy, Spain, Greece, and France) from 2014 onwards and examines which of these regions were mostly affected through their correlation coefficients. By identifying the climatic and geospatial characteristics that make a region more vulnerable to overheating, policy planning could be more targeted and effective. Results showed strong correlations between mortality and overheating in many cases, and sometimes, the coefficient was higher than 80%. Regarding characteristics that enhance a region's vulnerability, there are the distance from the sea, the continental climate, the increased energy poverty levels, and the urbanization degree. Finally, it is important to note that deaths due to the exceptional event of COVID-19 taking place after 2020 significantly affected the result patterns. This analysis was essential to highlight the zones that could be less resilient in the future, so that the stakeholders can adopt the appropriate measures that will emphasize on them.
Keywords: climate change adaptation, urban overheating, vulnerability, urban health

Introduction

Overheating, extreme temperatures and Urban Heat Islands (UHI) significantly affect contemporary cities, probably enhanced by climate change and global warming. Public health, urban environment and lifestyle habits are highly impacted by climate change, and this is going to become more intense in the following years (Romanello et al. 2021). Increased urban temperatures, heatwaves and discomfort conditions are different aspects of overheating as a result of climate change in cities. Long-term and short-term goals have been set to address these risks. An example is the 2050 strategy (European Commission, 2019) for a sustainable Europe, setting a target to cut off greenhouse gas emissions in the context of fighting climate change. Although this could be an

[1] Corresonding Author [stsemekidi1@tuc.gr].
[2] [ttsoutsos@tuc.gr], [Theocharis.Tsoutsos@enveng.tuc.gr].

overall ambitious target, the development of regional and urban policies and measures considering the specific need of each city has to be established. In order to do so, an analysis of how overheating affects cities based on its area-specific characteristics is needed.

This research selects to study the impact of increased temperatures on human health and life, as one of the most direct and hazardous consequences of climate change (WHO, 2022, Ji, 2022). This is evident by the increased occurrence of heatwaves during the last decades (Machard et al., 2023), which can directly affect human health by creating heat-related respiratory problems (Rocque et al., 2021) and excess deaths. Furthermore, official data showed an increased need for cooling in buildings (Eurostat, 2022), affecting the built environment. Finally, projections showed (Seker and Gumus, 2022) that temperatures are going to continue to increase during the forthcoming years; consequently, immediate action is needed.

The effects of overheating, especially on public health, are selected to be studied as a major challenge for urban life. The recent experiences that urban environments faced due to the Covid-19 pandemics (Sheehan et al., 2021) and due to intense heatwaves that took place during the last decades, brought forward the need to study this aspect. In addition, the insufficiencies of health systems to manage these situations (Wondmagegn et al., 2021) brought the need to introduce innovative planning, funding and other tools to reorganize the facilities based on cities' and regions' characteristics and vulnerability.

Mortality and excess deaths are often used by recent studies as metrics for climate change consequences on health (Liu et al., 2023, Zhou et al., 2022). Heatwaves and increased temperatures can be associated with numerous diseases that could be of high risk to human life and vulnerable population. Mortality rates have increased significantly during past heatwave phenomena (Robine et al., 2008). In addition, data of good quality on mortality rates are publicly available and easy to access (Eurostat, 2022). These are some reasons for selecting mortality as a metric for public health in this study. Other metrics existing in recent literature are: the increase in hospital admissions (Wondmagegn et al., 2021) or the occurrence of cardiovascular disease (Gasparini et al., 2015).

Based on the above, the paper analyses two variables and the way that they are correlated. The variables are the Cooling Degree Days (CDDs) (reflecting changes in urban temperatures) and the mortality. By analyzing them, it aims to extract conclusions on the factors enhancing their correlation. The factors could be geographical and geospatial characteristics, economic and social conditions, buildings, and urban planning. The study aims to identify these factors to contribute to the planning of city-oriented specific climate change policies. More analytically, it tries to determine which geospatial characteristics contribute to the increased correlation between mortality and increased temperatures, in order to develop typologies of regions that could present an increased vulnerability level. For this reason, the geospatial characteristics of regions with the highest coefficients are identified. These could be the urbanization degree, the distance from the sea, the prevalent climate zone, or the morphology of the terrain.

The previously mentioned findings could be the basis for the development of city-typologies (Hurlimann et al., 2021). A special focus on Mediterranean countries and cities is given by this study. It was considered by recent literature as a highly-exposed to overheating area (Negev et al., 2022) due to its climate (Tsitoura et al., 2016) and socio-economic characteristics (Linares et al., 2020). Finally, the study gives evidence for city-focused policy planning based on special local and climate needs.

The novelty of the study can be summarized by the following points:

- It tries to quantify the already observed impact of climate change on health and mortality but also to give quantified evidence on the vulnerability degree of a city or region to overheating.
- It sets the base for city and region typologies based on their climate and geographic characteristics that could be applied on a worldwide scale to inform stakeholders about the future risks and hazards to which they could be exposed and about the potential barriers to be addressed.
- It focuses on the Mediterranean region, one of the most vulnerable areas due to the combination of various economic, social and climate factors.
- It considers an intermediate level of regions while similar studies focus on neighbourhood/city/town level or country level. Regions can be quite significant for policy-making.

Methodology

The relationship between death rates and the increased need for cooling due to overheating is studied by means of statistical analysis and, more specifically, by calculating the correlation degrees (R2) (Tsemekidi Tzeiranaki et al., 2019; Aboura, 2022). The study has been applied using the Pearson correlation coefficients measuring the strength of the linear relationship between two variables. In this context, R-squared values and p-values have also been calculated. The selected locations are the regions of four European countries around the Mediterranean Sea. These are Greece, Spain, France and Italy. The chosen timeframe corresponds to the last decade with available data (2011-2021). When data were incomplete in the former years, the analysis starts from the most recent year with complete availability.

Special emphasis has been given to the period before the Covid-19 outbreak (up to 2019) as more indicative of the whole situation. Indeed, in most of the cases, higher correlations appeared when the period after 2020 was excluded.

The next step was the development of maps classifying the regions by their correlation degrees. The reason was to observe a combination of strong correlation degrees with specific geomorphologic, climatic or urbanization characteristics. The following table shows the selected variables and the data sources:

CDDs have been used recently in literature (Salata et al.,2022). Data for CDD has been collected only for July and August, corresponding to the warmest months of a calendar year in Europe. Mortality rates have been calculated for the same periods and expressed as deaths per capita (D/cap). The analysis has been performed at the regional level (NUTS 2 regions).

Finally, for the consideration of energy poverty in the final results, the indicator FEC_{PC} has been developed. It represents the final residential energy (FEC) per capita (p) consumed for space cooling normalized by specific climate needs (c).

Table 1. Variables and data sources

Indicators	Variables	Source	Datatable	Geographic element
Mortality rates	Death	Eurostat	Deaths by week and NUTS 3 region (demo_r_mwk3_t)	NUTS 2 regions
	Population	Eurostat	Population on 1 January by age, sex and NUTS 2 region (demo_r_d2jan)	NUTS 2 regions
Need for cooling	Cooling Degree Days	Eurostat	Cooling and heating degree days by NUTS 3 regions - monthly data (nrg_chddr2_m)	NUTS 2 regions

Results

Italy

Significant correlations between mortality and overheating have been found in Italian regions and especially in the ones that are distant from the sea. Especially in Piemonte and Umbria, landlocked regions, surrounded by mountains, the correlations exceed 70%. South Italy seems less affected by overheating, maybe because other causes may have more substantial impacts. These could be the increased criminality phenomenon, the lower economic development, and the incapacities of local health systems.

Another case of a region that seems to be affected less by overheating in the period 2011-2021 is Veneto. The reason for this is the strong presence of Covid-19 cases in 2020, which affected importantly the patterns and caused numerous additional deaths. When we exclude the sub-period 2020-2021 from our analysis, the correlations in most of the regions turn higher. For example, in Piemonte, it arrives at 85%. The following figure shows the correlation in the Italian regions for the period 2011-2019.

Note that p-values have been calculated at lower than 0.05 levels for all the regions of Italy, meaning a statistically significant result. Moreover, they are also under 0.001 for the first 11 regions of the following graph when we exclude Covid-19 period, and for the first 13 regions if we include Covid-period, meaning a statistically high significance

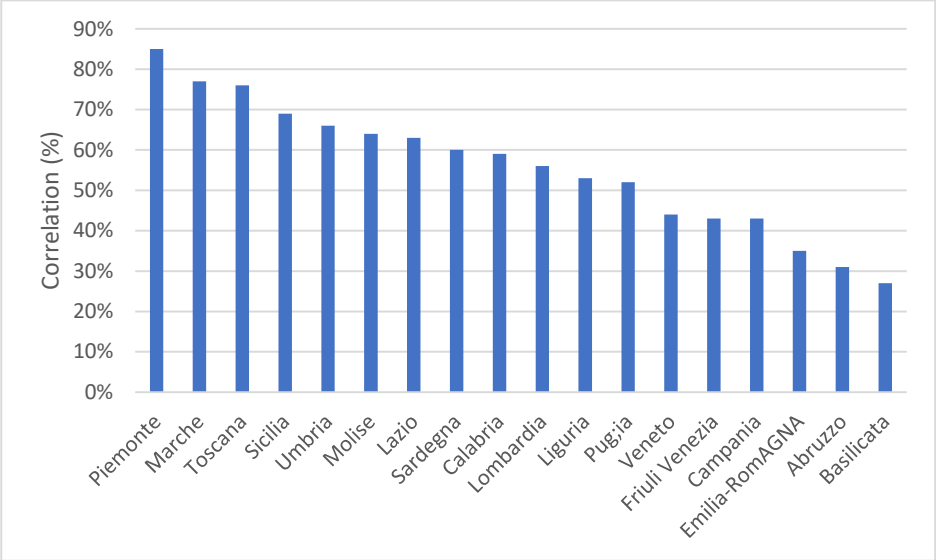


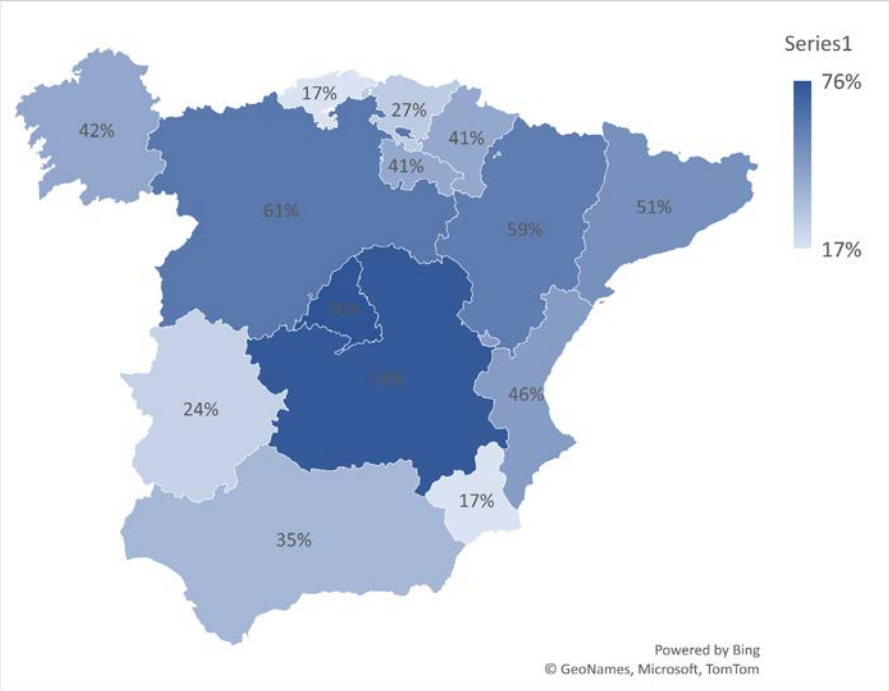
Figure 1. Correlations between mortality and overheating in Italian regions, 2011-2019, (Source: elaboration of Eurostat data)

Spain

Similar findings have been reported for Spain. More analytically, central, landlocked, and highly urbanized areas with continental climate showed elevated correlations. For example, the correlation for Comunidad de Madrid, when we exclude the post-Covid sub-period, arrives at 75%.

In addition, the calculated FEC_{PC} is the lowest one in Spain among the studied countries. This means that in Spanish cities, less energy is consumed for space cooling despite the fact that climate and population needs could be higher. This may be evidence of energy poverty challenges and highlights the importance of ensuring the ability to keep comfortable thermal conditions in buildings. The following map shows the correlations in the Spanish regions for the period 2011-2019.

Regarding the p-values, they have been calculated at lower than 0.05 levels for almost all the regions of Spain, meaning a statistically significant result. Exceptions are the regions of Murcia and Cantabria if we exclude Covid-19 period and the region of Pais Vasco if we include Covid-19 period. It seems that for these cases, we cannot extract a safe conclusion. On the other hand, there are also regions with p-values under 0.001, meaning a statistically high significance. These are Madrid, Castilla la Mancha, Castilla y Leon, Aragon and Catalunya with the exclusion of the period 2020-2021 and Madrid, Castilla la Mancha, Castilla y Leon if the aforementioned period is included.



Map 1. Correlations between mortality and overheating in Spanish regions, 2011-2019 (Source: elaboration of Eurostat data)

Greece

In Greece, the incompleteness of data makes the extraction of conclusions more difficult. The correlations in Greek cities are around 50%. The presence of increased migration phenomenon as well as the inadequacies of the health system may affect the overall situation. The highest correlations have been found in the region of Crete and Pelloponisos. The availability of data for Greece started in 2015. Based on the calculated p-values, results are highly statistically significant (less than 0.001) for the regions of Peloponisos and Crete, statistically significant (less than 0.05) for all the rest except for the cases of Thessalia, West Macedonia and North Aegean where no conclusions can be extracted (p-value>0.05).

France

In France, the inland regions, distant from the Atlantic Ocean and close to mountains, present correlations above 60%. This confirms the findings observed in Italy and Spain and raises the need for planning climate and health policies targeting the regions and cities with such characteristics. The highest correlation has been found in the region of Rhône-Alpes (73%) for the period 2013-2019. The following table summarizes the findings of all the studied countries.

P-values have shown high statistically significant results (p-values<0.001) for Rhône-Alpes and Alsace for the period 2013-2021 and for Rhône-Alpes, Provence-Alpes-Côte d'Azur and Alsace for the period 2013-2019. Statistically significant results (p-values<0.05) are calculated for the other 8 regions in the period 2013-2021 and for the other 10 regions in the period 2013-2019. Finally, we cannot extract results for 12 regions in the period 2013-2021 and for 9 regions in the period 2013-2019 (p-values>0.05).

Table 2. Correlations and regional typologies

Correlation degree	Geographic position	Climate	Geomorphology	Other characteristics
Above 70%	Inland/landlocked	Continental, low humidity	Valley, proximity to mountains	Urbanization
50-70%	Mostly close to the sea/water bodies	Various	Various	Urbanization, tourism activities
Below 50%	Mostly close to the sea/water bodies	Mediterranean, oceanic	Various	Lower GDP rates, criminality, migration

Discussion and conclusions

This paper analyzed the possible correlations between mortality or excessed deaths and increased ambient temperatures in the regions of 4 European countries close to the Mediterranean Sea. Afterwards, it tried to set the base for the development of city/region typologies according to their correlation degree and their climate, geographic and other characteristics. The aim was to assess which characteristics could make a city more vulnerable to climate change in order to focus on them during the policy-planning future process.

The findings showed that mortality rates had been affected by increased ambient temperatures (expressed in CDDs) in almost all the regions, but for some of them, the correlations were significantly elevated (even more than 80%). This could mean that overheating and increased temperatures could be one of the major causes of excess deaths in some cities. In general, when the Covid period was excluded from the result, the correlation became even higher.

Final energy consumption per capita in the residential sector for space cooling, normalized by climate conditions, was lower in Spain and Italy. At the same time, the regions of these two countries presented higher correlations compared to France and Greece. This fact highlights the need to ensure the ability of citizens to maintain comfort and healthy cooling and heating levels in buildings.

Regarding the city typologies that present higher correlation degrees between overheating and mortality and could be more vulnerable to climate change challenges, it has been found that they are mainly landlocked, surrounded by mountains, distant from the coastline, with a continental climate. On the other hand, cities and regions close to the sea, with oceanic climate, seem to be affected less. In some cases, other factors like migration, criminality levels, economic development, and activities, as well as the Covid-19 outbreak, might be more decisive factors influencing the results.

This analysis highlights the need to strengthen the policies addressing overheating, especially at regional and urban levels. These policies may have to target city and region typologies that are more vulnerable to such phenomena due to their specific characteristics. Exampled of such policies and measures could be funding for health systems, replanning urban spaces and renovating buildings, tools for real-time monitoring of climatic and weather conditions, raising awareness campaigns and education for the impact of climate change and overheating on health. Relevant

future studies could emphasize broadening and completing region and city typologies by considering more indicators, economic or social characteristics.

References

Aboura, S., The influence of climate factors and government interventions on the Covid-19 pandemic: Evidence from 134 countries, Environmental Research, Volume 208, 15 May 2022, 112484

Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions, The European Green Deal, COM/2019/640 final

European Commission—Eurostat. Eurostat Database on Energy Statistics. Available online: http://ec.europa.eu/eurostat/web/energy

Gasparrini A., Guo Y., Hashizume M., Lavigne, E., Zanobetti, A., Schwartz, J., Tobias, A., Tong, S., Rocklöv, J., Forsberg, B., Leone M., De Sario, M., Bell, M., Guo, Y.L., Wu, C., Kan, H., Yi, S.M., Zanotti, M., Saldiva, P., Honda, Y., Armstrong, B., Mortality risk attributable to high and low ambient temperature: a multicountry observational study, The Lancet, Volume 386, Issue 9991, 25–31 July 2015, Pages 369-375

Hurlimann, A.C., Moosavi, S., Browne, G.R., Climate change transformation: A definition and typology to guide decision making in urban environments, Sustainable Cities and Society, Volume 70, July 2021, 102890

Ji, J.S., Heatwave sears China: Need for actionable climate change adaptation to protect public health, Volume 25, 100568, August 01, 2022

Linares, C., Diaz, J., Negev., M., Sanchez Martinez, G., Debono, R., Paz, S., Impacts of climate change on the public health of the Mediterranean Basin population – Current situation, projections, preparedness and adaptation, Environmental Research, Volume 182, March 2020, 109107

Liu, C., Kershaw, T., Fosas, D., Ramallo-Gonzalez, A.P., Natarajan, S., Coley, D.A., High resolution mapping of overheating and mortality risk, Building and Environment, Volume 122, September 2017, Pages 1-14

Machard, A., Inard, C., Alessandrini, J.M., Devys-Peyre, F., Martinez, S., Riberon, J., Pele, C., Climate change influence on buildings dynamic thermal behavior during summer overheating periods: An in-depth sensitivity analysis, Energy and Buildings, 2023, Volume 284, 1 April 2023, 112758

Negev, M., Zohar, M., Paz, S., Multidimensional hazards, vulnerabilities, and perceived risks regarding climate change and Covid-19 at the city level: An empirical study from Haifa, Israel, Urban Climate, Volume 43, May 2022, 101146

Robine, J.M., Cheung, S.L., Le Roy, S., Van Oyen, H., Griffiths, C., Michel, J.P., Herrmann, F., Death toll exceeded 70,000 in Europe during the summer of 2003, C. R. Biologies 331 (2008) 171–178

Rocque, R.J., Beaudoin, C., Ndjaboue, R., Cameron, L., Poirier-Bergeron, L., Pouline-Rheault, R.A., Fallon, C., Tricco, A.C., Witterman, H.O., Health effects of climate change: an overview of systematic reviews, BMJ Open, 2021 (11) (2021), Article e046333

Romanello, M., McGushin, A., Napoli, C.D., Drummond, P., Hughes, N., Jamart, L., Kennard, H., Lampard, P., Rodriguez, B.S., Arnell, N., The 2021 report of the Lancet Countdown on health and climate change: code red for a healthy future, Lancet, 398 (2021), pp. 1619-1662, 10.1016/S0140-6736(21)01787-6

Salata, F., Falasca, S., Ciancio, V., Curci, G., Grignaffini, S., De Wilde, P., Estimating building cooling energy demand through the Cooling Degree Hours in a changing climate: A modeling study, Sustainable Cities and Society, Volume 76, January 2022, 103518

Seker, M., Gumus, V., Projection of temperature and precipitation in the Mediterranean region through multi-model ensemble from CMIP6, Atmospheric Research, 2022, Volume 280, 15 December 2022, 106440

Sheehan, M.C., Freire, M., Sanchez Martinez, G., Piloting a city health adaptation typology with data from climate-engaged cities: Toward identification of an urban health adaptation gap, Environmental Research, Volume 196, May 2021, 110435

Tsemekidi Tzeiranaki, S., Bertoldi, P., Diluiso, F., Castellazzi, L., Economidou, M., Labanca, N., Serrenho, T.R., Zangheri, P., Analysis of the EU Residential Energy Consumption: Trends and Determinants, Energies (2019), 12, 1065

Tsitoura, M., Michailidou, M., Tsoutsos, T., Achieving sustainability through the management of microclimate parameters in Mediterranean urban environments during summer, Sustainable Cities and Society, Volume 26, October 2016, Pages 48-64

Wondmagegn, B.Y., Xiang, J., Dear, K., Williams, S., Hansen, A., Pisaniello, D., Nitschke, M., Nairn, J., Scalley, B., Xiao, A., Jian, L., Tong, M., Bambrick, H., Karnon, J., Bi, P., Increasing impacts of temperature on hospital admissions, length of stay, and related healthcare costs in the context of climate change in Adelaide, South Australia, Sci Total Environ, 2021 Jun 15;773:145656

World Health Organisation Website, accessed on December 2022

Zhou, L., He C., Kim H., Honda Y., Lee, W., Hashizume, M., Chen, R., Kan, H., The burden of heat-related stroke mortality under climate change scenarios in 22 East Asian cities, Environment International, 2022, Volume 170, December 2022, 107602