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Projections of Heat-Related Mortality under the Impact of Climate Change in Thessaloniki, Greece †

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Abstract: The present study estimates the future impact of climate change on heat-related mortality in Thessaloniki, Greece. Mortality attributed to high temperatures will increase from 0.64% (95% eCI = −1.12, 2.48) to 3.32% (95% eCI: 0.52, 6.1), whereas cold-related mortality will be reduced from 0.7% (95% eCI = −2.24, 3.31) to 0.37% (95% eCI = −1.63, 2.2). Overall, the excess total mortality attributed to temperature will be increased by 2.33% in the future. Among the elderly, high temperatures will cause 5.14% of deaths, highlighting their increased vulnerability. These findings emphasize the urgent need for targeted public health planning, mitigation, and adaptation strategies to address the health effects of climate change.

Keywords: heat-related mortality; apparent temperature; health impact; climate change

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1. Introduction

The relationship between public health and weather conditions has been a major concern for the scientific community in recent decades. Elevated temperatures, usually detected above a certain percentile of the area-specific temperature distribution [1], have profound impact on human health, including increased risks of heat-related illnesses, infectious diseases, malnutrition, and mental health issues [2,3]. In addition, there is direct link between heat exposure and human mortality from respiratory, cardiovascular, and cerebrovascular causes [4–8]. Research suggests that individuals with reduced ability for thermo-regulation, such as the elderly and pregnant women, are the most vulnerable groups of the population to the effect of extreme high temperatures [9–11].

Meanwhile, climate change is one of the most imperative global health threats in the 21st century. Higher average global temperatures are expected to lead to more frequent, persistent, and intense heat waves in the future [12], which will undeniably rise climate-sensitive health risks. Central and southern parts of Europe are projected to experience a sharp surge in heat-related impacts on health [13], while the mortality associated with high temperatures could increase to 5% in these regions [14].

Urban areas will experience an enhanced impact of climate change under the influence of urban heat islands. Several studies underline the enlarged impact of heat waves in big cities around the globe [15,16]. For instance, Thessaloniki, Greece, is projected to exhibit a change of +0.2 °C UHI intensity in summer afternoons along the coastline between 2096 and 2100 [17].

Compared to other regions, the global warming effects in the Mediterranean are projected to be particularly intense, which is a cause for great concern. The authors in Ref. [18] indicate a rate of warming around 2–4 °C, while an additional month of summer days is expected for the period 2031–2060 under different climatic scenarios. Greece will experience a significant rise in the number of hot days with temperatures above 35 °C until 2100 [19]. Under RCP8.5, the annual near surface temperature is projected to increase on average by 4.3 °C, and precipitation is generally projected to decrease by −16% at the end of the century [20].

Although Thessaloniki is the second-largest city in Greece, it is currently under-represented in the literature. Recently, [21] demonstrated noteworthy impacts of heat above the temperature threshold of 33 °C and a respective increase of 4.4% and 5.9% in the risk of cardiovascular and respiratory mortality above this threshold. The authors in [22] report a 1.95% increase in all-cause mortality due to heat, whereas deaths attributed to heat were higher than deaths attributed to cold for 2006–2016. In [23], the highest relative risks of cardiovascular mortality are associated with extreme temperatures and the population in Thessaloniki is found to be more susceptible to low temperatures. With the influence of climate change, heat-related cardiorespiratory mortality in the city is projected to increase; the excess of annual heat-related deaths in 2080–2099 will range from 2.4 to 433.7 under different scenarios [24].

Predicting the health impacts linked to a particular environmental stressor is a difficult undertaking due to the intricate risk patterns and the inherent uncertainties that arise when considering future climate scenarios [25]. In addition, the relationship between temperature and mortality is widely recognized to be highly dependent on the climate features of a specific region [26]. Therefore, conducting environmental epidemiology studies that are specific to the local region is essential [27], especially when studying regions with additional well-established environmental problems such as poor air quality [28,29].

The contribution of the present study lies in its focus on the urban area of Thessaloniki, which is currently understudied in the existing literature on the relationship between environmental stressors and mortality. While previous studies have highlighted the impacts of heat on human health, this study aims to analyze the association between temperature and mortality in Thessaloniki under current (2006–2010) and future (2096–2100) climatic conditions, specifically considering the RCP8.5 scenario. By examining the impact on the elderly population (>65 years) of the city, the study provides valuable insights into the vulnerability of this specific demographic group in the face of climate change. By conducting this environmental epidemiology study that is specific to Thessaloniki, the researchers address the importance of considering local climate features and environmental problems in understanding the health risks associated with temperature changes. Ultimately, this study contributes to a better understanding of the potential health impacts and challenges that Thessaloniki may face in the future, allowing for informed decision-making and the development of targeted mitigation and adaptation strategies.

2. Materials and Methods

2.1. Study Area

This research focuses on the urban area of Thessaloniki, the second-largest city in Greece, situated in the northern part of the country with a population of about 1,000,000. The city lies on the northeastern coast of the Thermaikos Gulf and close to Hortiatis mountain (1200 m) on the eastern side. The city is greatly affected by the nearby sea, which contributes to its Mediterranean climate. The mean annual temperature of Thessaloniki is ~16 °C and the mean annual relative humidity is 62.4% [30].

2.2. Data Analysis

In this study, health impact projection under the RCP8.5 scenario is estimated, by demonstrating temperature-related mortality impacts in the urban area of Thessaloniki. The exposure variable is represented by the daily maximum value of Apparent Temperature (Tappmax), computed from daily temperature and dew-point observational data as follows:

$$\mathrm{Tapp} = -2.653 + 0.994 \times \mathrm{T_a} + 0.0153 \times \mathrm{T_d}^2$$

The observational dataset includes the daily number of cause-specific deaths stratified by age group in Thessaloniki between 2006 and 2016 [22]. The climate simulations were conducted through the regional WRF-ARW numerical weather prediction model for historical (2006–2010) and future (2096–2100) periods as presented in [17], providing results of high spatial resolution (2 km) and temporal resolution of 3 hours. All post-processing analysis of model data was conducted via package DLNM within the statistical environment R (R version 4.1.1; https://www.r-project.org/foundation/ (accessed on 14 April 2023)).

3. Results and Discussion

3.1. Extrapolation of Exposure–Response Relationship and Quantification of the Projected Impact

In this section, the main methodology and results concerning the extrapolation of an exposure–response relationship from observational data to historical and future modeled values are presented, along with the projected impact of future climatic conditions on human mortality.

There are several reasons why risk estimates obtained from historical periods may not apply to future scenarios, and therefore they cannot be automatically assumed to be accurate, e.g., different exposure–response associations in the future due to population adaptation or vulnerability. The future distribution of a particular environmental stressor (here, Tappmax) is expected to differ from the current one, even when assuming no changes in risk, and may extend beyond the region captured in the estimated exposure–response curve. For this, extrapolation of the exposure–response relationship is performed beyond the observed boundaries, as shown in Figure 1.

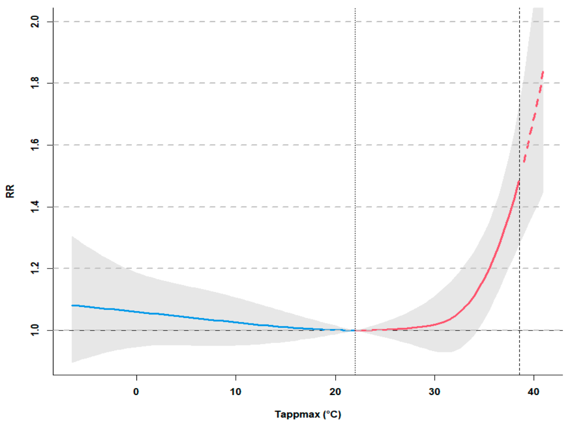

Figure 1. Exposure–response curve with 95% empirical confidence intervals (gray area). The dotted vertical line corresponds to Minimum Mortality Temperature (MMT, 22 °C), which defines the cold and heat (blue and red, respectively) portions of the curve. The dashed part of the curve represents the extrapolation beyond the Tappmax observed in 2006–2010 (dashed vertical line).

For the current climate conditions, relative risk (RR) increases up to 1.1 for Tappmax values below the Minimum Mortality Temperature (MMT). RR rises exponentially beyond 30 °C and reaches its maximum value of 1.5 at 38 °C. In the extrapolation area for the future climate, represented by the dashed vertical line above 38 °C, there is increase in relative risk up to 85% for temperatures around 43 °C.

Based on this study, Thessaloniki is expected to experience more intense thermal discomfort near the end of the century; more specifically, the average annual Tappmax of the city is expected to increase by ~3.5 °C by 2100.

The distribution of estimated attributable mortality for the historic and future period in Thessaloniki under the assumption of stable populations and no changes in vulnerability is shown in Figure 2. The mortality burden due to heat, corresponding to Tappmax values below MMT, is larger (6%) than that for Tappmax values above MMT (cold, 4%) in the current climate (2006–2010, grey). When assessing the future (2096–2100, blue), heat-attributable mortality by far exceeds cold, reaching 10% in contrast to nearly 1%. Comparing the estimates between the two periods, heat-attributable mortality will substantially increase in the future by 6%, whereas mortality due to cold will be reduced by 5%.

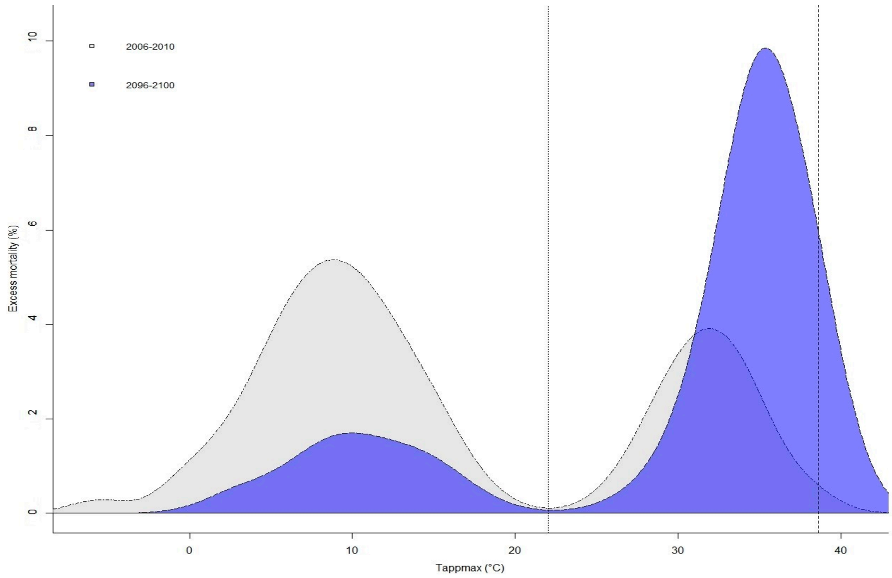

Figure 2. Distribution of excess mortality for the current and future climate under RCP8.5, expressed as the fraction of additional deaths (%) attributed to non-optimal Tappmax compared to MMT.

3.2. Assessing the Projected Impact on the Elderly Population

When assessing the temperature–mortality relationship explicitly for the elderly (>65 years), a consistently higher RR along the Tappmax range compared to all ages is observed, as shown in Figure 3. Indicative of the fact that the older population of Thessaloniki is more vulnerable to temperature than the general population, MMT decreases from 22 °C to 19 °C, showing lower acclimatization.

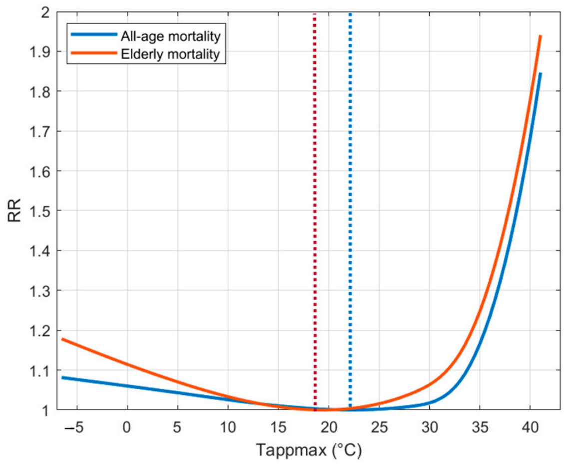

Figure 3. Exposure–response curves for all-age (blue) and elderly mortality (red), for the period 2096–2100. Dashed lines represent the MMTs.

In Table 1 the attributable fractions of all-age and elderly mortality are reported. Historically, the older fraction of citizens is more susceptible to temperature (2.87%) than the general population (1.35%), which is also evident in the future projection as well (5.67% and 3.68%, respectively). In terms of elderly mortality, heat accounts for more deaths than cold both in 2006−2010 (1.79% and 1.08%) and in 2096−2100 (5.14% and 0.53%). In the future, heat-attributable deaths will increase compared to the past while cold-related deaths will decrease substantially, both for all-age and elderly citizens.

Table 1. Attributable Fractions (%) of all-age and elderly mortality due to ranges of Tappmax for the historical and future periods.

		Historical			Future	
Mortalities	**Total**	**Heat**	**Cold**	**Total**	**Heat**	**Cold**
All-age	1.35	0.64	0.7	3.68	3.32	0.37
Elderly	2.87	1.79	1.08	5.67	5.14	0.53

4. Conclusions

The present study sheds light on the association between temperature and mortality in Thessaloniki, Greece, and provides crucial insights into the potential health impacts of climate change in the region. By specifically quantifying the mortality impact on elderly citizens near the end of the century, this work contributes to a better understanding of the potential risks and challenges that the city may face in the future. The present findings can inform evidence-based decision-making and facilitate the development of targeted strategies to mitigate and adapt to the health risks posed by climate change in Thessaloniki and similar regions.

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