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Developing a System for Integrated Environmental Information in Urban Areas: An Estimation of the Impact of Thermal Stress on Health †

Dimitrios Melas [1], Daphne Parliari [1,*], Theo Economou [2], Christos Giannaros [3], Natalia Liora [1], Sophia Papadogiannaki [1], Serafeim Kontos [1], Stavros Cheristanidis [1], Donatella Occhiuto [4], Maria Agostina Frezzini [4], Jonilda Kushta [2], Theodoros Christoudias [2], Chrysanthos Savvides [5], Ioannis Christofides [5], Giampietro Casasanta [6], Stefania Argentini [6], Athina Progiou [7], George Papastergios [8] and Apostolos Kelessis [8]

1 Laboratory of Atmospheric Physics, School of Physics, Aristotle University of Thessaloniki, 54124 Thessaloniki, Greece; melas@auth.gr (D.M.); lioranat@auth.gr (N.L.); spapadog@physics.auth.gr (S.P.); serkontos@gmail.com (S.K.); stavrcher@auth.gr (S.C.)
2 Climate and Atmosphere Research Center (CARE-C), The Cyprus Institute, 2121 Nicosia, Cyprus; t.economou@cyi.ac.cy (T.E.); j.kushta@cyi.ac.cy (J.K.); t.christoudias@cyi.ac.cy (T.C.)
3 Department of Physics, National and Kapodistrian University of Athens, 15784 Athens, Greece; cgiannaros@phys.uoa.gr
4 ARPA Lazio, Regional Environmental Protection Agency, 00187 Rome, Italy; donatella.occhiuto@arpalazio.it (D.O.); mariaagostina.frezzini@arpalazio.it (M.A.F.)
5 Department of Labour Inspection, Ministry of Labour and Social Insurance, 1080 Nicosia, Cyprus; csavvides@dli.mlsi.gov.cy (C.S.); ichristofides@dli.mlsi.gov.cy (I.C.)
6 Institute of Atmospheric Science and Climate, National Research Council, 00133 Rome, Italy; g.casasanta@isac.cnr.it (G.C.); s.argentini@isac.cnr.it (S.A.)
7 AXON ENVIRO-GROUP Ltd., 11257 Athens, Greece; ap@axonenviro.gr
8 Department of Operational Planning (Resilience Office), Municipality of Thessaloniki, 54636 Thessaloniki, Greece; g.papastergios@thessaloniki.gr (G.P.); kelesis@envdimosthes.gr (A.K.)
* Correspondence: dparliar@auth.gr
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Abstract: Poor air quality remains the largest environmental health risk in Europe, despite the EU policy efforts. Especially in cities, the synergistic interactions between the urban heat island and urban pollution result in premature mortality, associated with cardiovascular and respiratory diseases. Mediterranean urban areas are particularly susceptible under the consideration that the intensity, frequency, and duration of heat waves will increase due to climate change. The LIFE SIRIUS project designates that air quality management needs to go beyond traditional approaches in order to consider synergistic effects. This paper assesses the impact of temperature on daily mortality from 2004 to 2019 in the Republic of Cyprus with the use of a Generalized Additive Model (GAM). The association between mean daily temperature and mortality is nonlinear, implying that a prompt rise in deaths occurs when temperatures are high, while for colder temperatures, the effect is delayed. We report an inverted J-shaped relationship between mean temperature and mortality, with the most prominent effects on human health documented at low temperatures. The population under study appears to be acclimatized to local conditions, as mortality increases after 10 days of exposure to the environmental risk. The results of this study will assist in the definition of city-specific thresholds above which health warnings for the protection of the local population will be issued, in the framework of LIFE SIRIUS.

Keywords: air quality; thermal discomfort; urban heat island; human health; climate change

1. Introduction

The problem of poor air quality is becoming increasingly urgent, with cities around the world experiencing more frequent and severe episodes of high pollution levels [1], while the number of associated deaths is constantly increasing [2]. The detrimental effects of air pollution on human health are established, and there is a substantial body of evidence linking exposure to air pollution to increasing mortality especially from cardiovascular and respiratory causes [3–5], exacerbated chronic diseases [6], elevated mortality risk concerning frail inhabitants [7], and additional years of life lost [8].

Urban areas are particularly sensitive, because of the synergistic interactions between urban heat islands (UHIs) and urban pollution islands (UPIs). The UPI has been recently coined to describe the spatial and temporal variations in pollution concentrations that exist not only between urban and rural areas, but also within cities themselves [9]. This new term draws an analogy to UHI, which traditionally denotes the additional warmth in cities compared to their non-urbanized surroundings, as well as the thermal differences within urban areas [10]. The synergies between UHIs and UPIs become even more important when considering the increasing frequency, intensity, and duration of heat waves due to climate change [11]. Thus, air quality management in urban areas needs to go beyond the traditional approaches in order to consider the compound effects of UPIs, UHI, and heat waves.

Despite the implementation of EU policies for mitigating air pollution, numerous regions continue to exceed the recommended guidelines outlined in the European Council Directive 2008/50/EC. For instance, Thessaloniki, Greece, reported numerous exceedances in EU daily limits of PM_{10} for 2019 [12]. In the same year, Nicosia, Cyprus, documented violations not only for PM_{10}, but for O_3 thresholds as well [13], and Rome, Italy, surpassed the 2019 annual NO_2 average [14]. The inability of national authorities to adhere to the PM_{10} and NO_2 limits established by the EU in Thessaloniki and Rome, respectively, has resulted in the initiation of infringement proceedings by the European Commission against Italy (Case C-573/19 (https://curia.europa.eu/juris/document/document.jsf?text=&docid=217525&pageIndex=0&doclang=EN&mode=req&dir=&occ=first&part=1&cid=26708984 (accessed on 23 May 2023))) and in the recent conviction of Greece (Case C-70/21 (https://curia.europa.eu/juris/document/document.jsf?text=&docid=271781&pageIndex=0&doclang=EL&mode=req&dir=&occ=first&part=1&cid=5755193) (accessed on 23 May 2023)).

As a result, the European Court of Auditors proclaimed that EU countries are not protecting public health effectively, partly due to the inadequate performance of Air Quality Plans (AQPs) in ensuring compliance with European air quality standards [15].

In light of this, the project LIFE SIRIUS aims to enhance air quality planning in three EU urban metropolitan areas (Thessaloniki in Greece, Rome in Italy, and Nicosia in Cyprus) in order to

1. Assess and improve the cities' air quality plans, considering current (2019) and future (2030) climate conditions;
2. Identify UHI and UPI hotspots and forthcoming HWs, where short-term mitigation measures should be prioritized;
3. Provide health-related warnings considering the differential heat and air pollutants' effects through the examination of the air-pollution–mortality association at different temperature strata.

To set the scientific basis for the health-related warning systems of Nicosia, the assessment of premature mortality from short-term exposure to heat stress is realized. The present epidemiological study quantifies the impact of mean temperature on the human health of the population of Cyprus, and, secondly, it defines city-specific thresholds for issuing warnings for the protection of the population.

2. Materials and Methods

2.1. Study Area

This study focused on Cyprus, an island in the Eastern Mediterranean. Its climate is typical of the region, characterized by dry and warm summers (June–September) and variably "wet" winters (November–March). Autumn and spring are generally short-lived and transitions are sharp. During hot months, the temperature often reaches 36 °C. The specific study area (for which health data are available) is the area controlled by the Republic of Cyprus, an area inhabited by a population of about 1 million.

2.2. Data Analysis

We applied a distributed-lag non-linear model using the framework of Generalized Additive Models or GAMs ([16], ch. 7) in order to estimate the health impact of thermal stress by demonstrating temperature-related mortality effects in Cyprus.

The dataset, including the daily number of deaths and mean daily temperature (Tmean) between 2004 and 2019, was acquired from the Ministry of Health of the Republic of Cyprus. Specifically, the data comprise deaths from cardiovascular and respiratory causes (ICD10 codes I00–I99 and J00–J99). All post-processing analysis of model data was conducted via the mgcv package [17] within the statistical environment R [18].

3. Results and Discussion

Figure 1 displays the bi-dimensional exposure–lag-response surface of the estimated Relative Risk (RR) in a three-dimensional diagram for mean temperature and lag values. The risk values are relative to the overall (sample) mean mortality count during the period. The association between Tmean and mortality RR suggests an immediate increase in mortality for exposure to elevated temperatures, whereas for low ones, the effect is delayed, in agreement with the literature [19,20]. The impact on health is most prominent at very high values of the exposure variable at days 0–1, corresponding to an estimated increase in mortality of about 11%. The secondary peak of RR at low temperatures (5% mortality increase) indicates that the local population is vulnerable not only to heat but to cold as well.

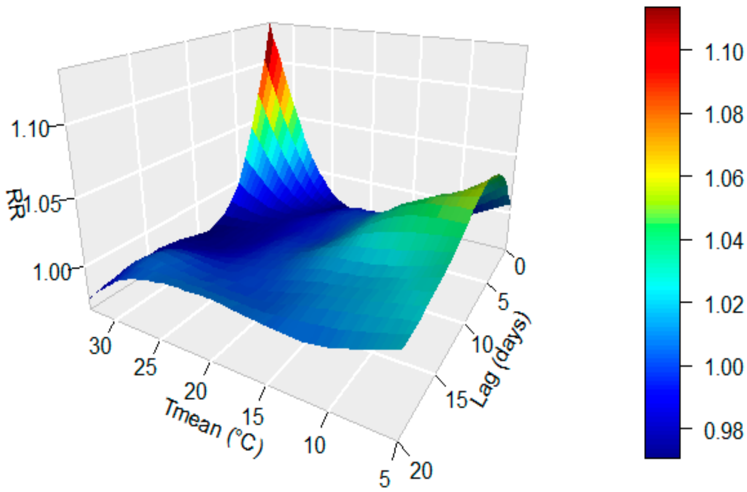

Figure 1. Exposure-lag-response risk surface demonstrating the nonlinear association between mean temperature and mortality.

To better understand this complex association, we extracted two-dimensional relationships: Figure 2 shows the overall cumulative exposure–response curve interpreted as the mean number of daily deaths cumulated over the entire lag period of 20 days, and Figure 3 illustrates the non-linear effects of Tmean on the mean number of daily deaths for each lag.

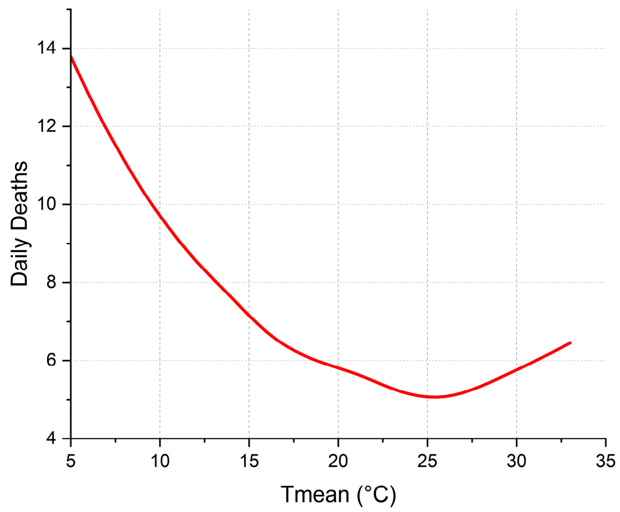

Figure 2. Cumulative exposure–response curve between daily Tmean and mortality over lag days 0–20.

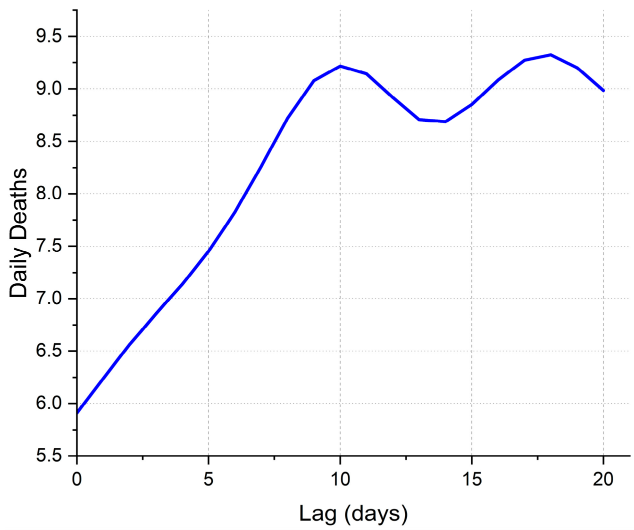

Figure 3. Non-linear effects of Tmean on daily mortality at lag 0–20.

The exposure–response curve (Figure 2) is inversely J-shaped with the largest increase in mortality occurring at cold temperatures. The lowest point of the curve (25 °C) corresponds to the optimum temperature for the local population. In general, U, J, or V-shaped relationships between temperature and mortality have been identified in many previous studies (e.g., [21]), while the exact shape of the curve varies by geographic location, climatic, and demographic characteristics [22].

The estimated lag–response relationship (Figure 3) denotes the acclimatization of the Cyprus population to meteorological conditions of the region as mortality risk starts from the lowest point at day 0 and peaks 10 days later. The subsequent decrease (days 10–15) before the second peak (day 18) may be attributed to mortality displacement, which describes a negative risk in mortality followed by an event of extreme temperatures [23].

4. Conclusions

This study analyzes the impact of mean daily temperature on all-cause mortality of the population of Cyprus over a lag period of 20 days. Our findings indicate a rapid rise in mortality risk due to exposure to high temperatures, whereas for lower temperatures, the impact persists longer. Although local citizens appear to be acclimatized, the majority of deaths occur under cold conditions. The present results highlight the importance of implementing location-specific protection measures and offer significant insights for national and regional authorities to create effective health and air quality strategies.

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Conflicts of Interest: The authors declare no conflict of interest.

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