The impact of heat waves on daily mortality in districts in Madrid: The effect of sociodemographic factors.

López-Bueno, J. A., Díaz, J., Sánchez-Guevara, C., Sánchez-Martínez, G., Franco, M., Gullón, P., Núñez Peiró, M., Valero, I., & Linares, C. (2020). The impact of heat waves on daily mortality in districts in Madrid: The effect of sociodemographic factors. *Environmental research*, *190*, 109993.

https://doi.org/10.1016/j.envres.2020.109993

The Impact of Heat Waves on Daily Mortality in Districts in Madrid: The Effect of Sociodemographic Factors.

López- Bueno JA[1], Díaz J[1] , Sánchez-Guevara C[2], Sánchez-Martínez G[3], Franco M[4,5], Gullón P[4], Núñez Peiró, M[2] , Valero I[2], Linares C[1]

[1]Escuela Nacional de Sanidad, Instituto de Salud Carlos III

[2] Escuela Técnica Superior de Arquitectura. Universidad Politécnica de Madrid

[3.] The UNEP DTU Partnership. Copenhagen, Denmark.

[4.] Public Health and Epidemiology Research Group, School of Medicine and Health Sciences, Universidad de Alcala, Alcala de Henares, Madrid, Spain.

[5.] Department of Epidemiology, Johns Hopkins Bloomberg School of Public Health, Baltimore, MD, USA.

Corresponding Author:
Dr. Julio Díaz Jiménez
Escuela Nacional de Sanidad. Carlos III Institute of Health.
Avda Monforte de Lemos 5.
280209 Madrid

Abstract

Although there is significant scientific evidence on the impact of heat waves, there are few studies that analyze the effects of sociodemographic factors on the impact of heat waves below the municipal level. The objective of this study was to analyze the role of income level, percent of the population over age 65, existence of air conditioning units and hectares (Ha) of green zones in districts in Madrid, in the impact of heat on daily mortality between January 1, 2010 and December 31, 2013. Seventeen districts were analyzed, and Generalized Linear (GLM) Poisson Regression Models were used to calculate relative risks (RR) and attributable risks (RA) for the impact of heat waves on mortality due to natural causes (CIEX:A00-R99). The pattern of risks obtained was analyzed using GLM univariates and multivariates of the binomial family (link logit), introducing the socioeconomic and demographic variables mentioned above. The results indicate that heat wave had an impact in only three of the districts analyzed. In the univariate models, all of the variables were statistically significant, but Ha of green zones lost significance in the multivariate model. Income level, existence of air conditioning units, and percent of the population over age 65 in the district remained as variables that modulate the impact of heat wave on daily mortality in the municipality of Madrid. Income level was the key variable that explained this behavior.

The results obtained in this study show that there are factors at levels below the municipal level (district level) that should be considered as focus areas for health policy in order to decrease the impact of heat and promote the process of adaptation to heat in the context of climate change.

Key words: Heat waves, income level, green zones, air conditioning, seniors 65 and over, adaptation.

1. Introduction

According to forecasts of the IPCC (IPCC, 2013), heat waves will become more frequent and intense, with increasing average temperatures already above 1ºC at the global level compared to the preindustrial era (WMO, 2019). In the case of Spain, it is expected that in an Representative Concentration Pathway (RCP) 8.5 scenario for the 2021-2050 period, average maximum daily temperatures will reach 30.3ºC in the summer, and 33.6ºC later on in 2051-2100. There will be increases of 1.6ºC and 4.9 ºC respectively, compared to the reference period of 2000-2010 (Díaz et al., 2019). This horizon supposes an important increase in mortality attributable to heat if there are no processes of adaptation to heat, in addition to a significant increase in healthcare expenditure (Díaz et al., 2019). Adaptation to this rate of temperature increase is a challenge for health systems and requires knowledge about which variables most influence adaptive processes (Sheridan et al., 2018; Martínez et al., 2019; Linares et al 2020). On its own, biological adaptation to increasingly high temperatures is insufficient in the face of the temperature increases mentioned (Follos et al, 2020).

However, what is clear is that there is a process of population adaptation to higher temperatures that is taking place , as shown by the decrease in the effect of heat on mortality (Díaz et al., 2018; Barreca et al.2016; Wang et al. 2016). Also, it seems to be greater in the countries of southern Europe compared to their northern neighbors (Ward et al., 2016). In addition, the increase in minimum mortality temperatures that has been found in some places seems to point in the same direction (Mirón et al., 2008; Astrom et al., 2016 & 2018; Chung et al., 2017; Follos et al., 2020).

One of the principal factors that is known to influence the greater or lesser impact of heat on mortality is the number of people over age 65 (Montero et al., 2012; Díaz et al., 2015a; Gronlund et al., 2016), due to the aggravation of prior circulatory and respiratory (Díaz et al., 2002) as well as renal conditions (Gasparrini et al., 2015). Recent research also finds an increase in mortality due to heat in terms of the aggravation of neurodegenerative diseases and mental health (Linares et al., 2016; Trombley et al., 2017).

In addition to what has been mentioned above, there are different processes that could explain this gradual adaptation to heat (Sheridan et al., 2018; Martínez et al., 2019; Follos et al., 2020). Some are social in nature, such as the so called “culture of heat” (Bobb et al., 2014). This term refers to the preventive measures carried to prevent the effects of extreme high temperatures. These measures consist on the extensive heat–health warning systems and public health response programs have been implemented in several U.S. cities. These programs often contain specific measures targeted toward the elderly population, which could be one reason why heat-related mortality declined most rapidly for the oldest age group, others are related to the health system as in the existence of prevention plans (Linares et a., 2015; Ebi & Rocklov 2014) or improvements in health services (Mirón et al., 2015), and some seem to be related to architectural and urban factors (Fisk, 2015). Thus, some studies show how the age of buildings can explain the distribution and intensity of the risks associated with temperature (López-Bueno et al., 2019; Loughnan et al., 2015). In this sense, variables such as proper insulation in housing or energy efficiency of buildings are important (Willand et al. 2016), as well as the existence of air conditioning units (Martínez et al., 2019; Díaz et al., 2018). Furthermore, urban planning factors such as the presence of green zones and reduce the heat island effect (Bowler et al., 2010; Burkart et al., 2016; Norton et al., 2015; Lee et al., 2016).

Also related to these factors are issues such as income per household (Laverdière et al., 2016; Mushore et al., 2018; Phung et al., 2016), because it conditions the use of air conditioning systems, which play a central role in mitigating the impact of heat waves on health (Barreca et al. 2016; Fisk, 2015; Guirguis et al., 2018; Laurent et al., 2018; Loughnan et al., 2015; Zhang et al., 2017). Also, households with low income levels have difficulties in repairing and improving living spaces, and income can also determine the levels of health and healthcare services of those who are vulnerable.

Although there are many studies that delve into these areas with respect to the impact of heat on a city (Díaz et al., 2015b; López-Bueno et al., 2019), on a country (Barreca et al., 2016) or on multiple countries (Guo et al., 2018), there are few that approach the problem at a level below the municipal level and that focus on possible heterogeneity that can exist at the level of different districts (or neighborhoods) within a city. Neighborhoods can be characterized by large differences at the socioeconomic and demographic levels as well as in terms of urban planning and infrastructure. Knowledge of how these variables can modulate and determine the impact of high temperatures is crucial in order to guide the development of policies that aim to mitigate the consequences of heat on the health of the population.

The objective of this study is to analyze the impact of heat waves on different districts in Madrid during the 2010-2013 period and to study whether variables such as income, the percentage of the population over age 65, access to cooling systems and the hectares of green zones in each zone explain the different behavior of the impact of heat on daily mortality.

2. Materials and methods

The analysis strategy has followed two phases. In a first stage, an ecological, longitudinal retrospective time series analysis was carried out to analyse the impact of heat waves on daily mortality in different districts of the city of Madrid, by calculating relative risks (RR) and associated attributable risks (AR) between January 1, 2010 and December 31, 2013.

In the second stage, Binomial models were conducted to investigate if the variables of social context influence the relation in the pattern of risks found. Therefore, the results of both phases are examined together in order to analyse whether the previous results found at the district level using RR and RA could be explained by variables related to the social, demographic and urban context, such as income level, the percentage of the population over age 65, the access to cooling systems, and hectares of green zones in each district. Univariate models were constructed first and supported later multivariate models to determine those models with the final, statistically significant variables.

2.1 Calculation of relative risks and attributable risks associated with heat waves

Generalized Linear Models (GLM) of the Poisson family were used to determine the existence of risks associated with extreme heat events as follows:

2.1.1 Variables

The dependent variables used were annual aggregated data on daily mortality due to natural causes (CIE X: A00 – R99) by district. This data were provided for "Instituto de Estadística de la Comunidad de Madrid" and agreggated by "Madrid Salud" (Council of Madrid City).

The districts of Madrid are pictured in Figure 1. Of them, districts 14, 18, 19 and 21, which correspond to Mortalaz, Villa de Vallecas, Vicalvaro and Barajas, respectively, were discarded for having more than 10 percent missing data.

The independent variable considered was heat waves, or Theat, quantified based on data for maximum daily temperatures measured in the observatory of reference in Madrid-Retiro from the State Meteorological Agency (AEMET).

The variable Theat is defined in the following way:

Theat = Tmax – 36 when Tmax > 36ºC

Theat = 0 when Tmax ≤ 36ºC

The maximum daily temperature of 36 ºC, is the daily threshold temperature, at which mortality due to heat begins to increase in the municipality of Madrid, according to prior studies (Carmona et al.,2017). As the effect of heat manifests in the short term, lag variables were introduced for the variables Theat of up to for days (Díaz et al., 2015b). Also included were the values of average relative daily humidity. Other control variables included in the models were series trend and seasonal components and the autoregressive nature of the series. Only an autoregressive of order one was used to control the autoregressive nature of the daily mortality series in the Poisson models. The reason for including only the autoregressive of order 1 focus on previous studies conducted (Alberdi et al., 1997).

2.1.2 Calculation of relative risks and attributable risks

The modeling of the Poisson regression allowed us to obtain the relative risks (RR) associated with the variable Theat and the lags that were statistically significant in relation to daily mortality in each district analyzed. Based on the values of RR, population attributable risks (PAR) were calculated using the equation: RA = (RR-1/RR)* 100 % (Coste and Spira, 1991). This process was repeated for each district. The models were adjusted using a backward stepwise modeling process, eliminating the variables that did not reach statistical significance with p-value ≤ 0.05. The following equation represents the models analyzed:

$$Ln(y_i) = b + \beta_j T_{ij} + \omega_k C_{ik} + \varepsilon_z E_{iz}$$

Where i represents each observation; y_i, the morbi-mortality data used; *b,* the intercept; β_j, represents the coefficient calculated for wave T_{ij} and its lags *j*; ω_k, represents the coefficient calculated for each of the *k* control variables (C_{ik}); and ε_z represents the coefficient calculated for each of the *z* environmental variables (E_{iz}) considered in the model. A model was designed for each cause, age group and administrative level analyzed.

2.2 Analysis of the pattern of risks

The pattern of risks calculated during heat waves was analyzed using univariate and multivariate GLM models of the binomial family that use the logit function as link.

Detection of risk, defined Rheat, was used for the dependent variable, a dummy variable that adopts a dichotomous value for each observation, described as follows:

If RA > 0 then Rheat = 1

If RA = 0 then Rheat = 0

The contextual explanatory variables were the aggregated income per hosehols, the population over age 65, the percentage of household without cooling systems and hectares of green zone, included in the following way:

- Net income per hosehols by district: Expressed as thousands of euros per year and taken from Sanz Fernández et al. 2016 with available data between the years 2011 and 2013 from the National Statistics Institute (Instituto Nacional de Estadística, 2015).
- Age groups: Based on the percentage of the population over age 65 by district – available in the open access database of the Statistics Institute of the Community of Madrid (Instituto de Estadística de la Comunidad de Madrid, 2020)– the following levels were considered: group 1 - if the percent of the population over 65 years old

was less than 25 percent (17.12%), group 2 if the same value was found between percentiles 25 and 75 (21.92%), and group 3 if the percent was above the 75th.

- Non-air-conditioned homes (%): percentage of homes without cooling systems by district in the year 2001, based on Sanz Fernández et al. 2016 and indicators collected by INE (Instituto Nacional de Estadística, 2001).
- Green zones per district (Ha): Calculated as the aggregated area of green zones, gardens, and historic and forest parks. Data available in the open data portal of Madrid, 2020.

These models were made with days that meet with the condition Theat > 0. The explanatory variables included were contrasted one by one and adjusted in the GLM models of the multivariate binomial family. The variables that did not reach statistical significance with a p-value ≤ 0.05 were withdrawn from the final model presented in the results. The equations that are presented here refer to the univariate and multivariate models analyzed, respectively:

$$\log\left(\frac{p}{p-1}\right) = b + b_i Ctxt_{ij}$$

$$\log\left(\frac{p}{p-1}\right) = b + \beta_1 R_J + \beta_{2z} GE_z + \beta_3 V_j + \beta NR_j$$

Where p represents the probability of detecting impact; *b,* the intercept of the model; *β* represents the coefficient calculated for the context variable (*Ctxt*) *i* in the district *j*. These context variables were income (*R*), age group z (*GE*), green zone(V) and homes without access to cooling systems (*NR*).

The free R software was employed for the construction and cleaning of the data, and STATA software version 14.2 was used to calculate the models.

3. Results

Table 1 shows basic descriptive statistics related to mortality in different districts in Madrid. It shows that mortality is similar in all of the districts with an average mortality that is double that of districts with lower mortality.

The descriptive statistics of the context variables used are shown in Table 2. It highlights the fact that in none of the districts in Madrid do cooling systems reach less than 50 percent of households. In contrast, there is a quite unequal distribution of green zones among districts, which drives a higher dispersion.

Figure 2 represents the geographical distribution of the districts in Madrid where the study was carried out. It shows that risks were detected in three of the analyzed districts: Tetuan, Carabanchel, and Puente de Vallecas. The values of these risks are shown in Table 3. In Tetuan and Puente de Vallecas there is an immediate impact of heat (lag 0), but in Carabanchel there is also a short-term effect (lag 2), although there are no statistically significant differences in terms of the values of these risks.

Table 4 shows the results of the regression models in terms of the response variable and the explanatory variables, considered one by one. Statistically significant differences can be observed for all of them except for age. Finally, Table 5 shows the results of the adjusted multivariate model.

The statistical association with income per household and access to air conditioning was maintained in the adjusted model. As income level increases, the probability of detecting a heat wave impact decreases in a statistically significant way. In the same way, as the percentage of homes without access to cooling increases in a given district, this probability increases.

As shown in Figure 3, income level per household tends to increase with the percentage of those over age 65 in the districts. This could explain why there are no statistically significant differences by age group in the univariate model. However, there is an association in the adjusted model. In the districts found in group 2—with intermediate percentages of vulnerable population— the probability of finding risk increases with respect to the reference group: those districts with less population at risk. The contrast between districts in group 3 and group 1 could not be carried out, because there was no risk detected in any of the districts with more vulnerable populations.

Finally, after analyzing the relationship between the pattern of risk and the Ha of green zones found in each district, we observed that as green zones increase the probability of detecting heat impacts decreases in a statistically significant way. However, this effect disappears in the adjusted model.

4. Discussion

The first notable result of this study is that heat impacted daily mortality in only three of the districts analyzed. This result is supported by other studies carried out in the city of Madrid (Díaz et al., 2015a), in Spain (Díaz et al., 2018) and in other countries (Barecca et al., 2016) which show that the effect of heat on mortality is clearly decreasing in recent years.

The role played by the population over age 65 on the impact of heat seems to be limited, despite being the age group with a greater incidence of heat (Díaz et al., 2002; Díaz et al., 2015a; Gronlund et al., 2016). In fact, this analysis did not detect a heat impact in any of the districts with the greatest percentage of population over age 65, which correspond to group 3. This result seems to contradict what has been found in other studies that established a direct relationship between the percentage of people over age 65 and a greater impact of heat (Montero et al., 2012). Therefore, it seems that there must be other factors that modulate the effect of heat beyond those that are exclusively physiological. According to our results income level is a determinant factor in explaining this behavior, and this is shown in Tables 4 and 5, in which income is statistically significant both in the univariate model (Table 4) and the multivariate adjusted linear model (Table 5). The collinearity between the age group and the income level per household could explain this result. The results observed agree with prior studies that point to vulnerable populations bearing the burden of greater risks related to heat waves (Laverdière et al., 2016; Mushore et al., 2018; Phung et al., 2016).

Another factor that has been a source of controversy in recent studies is the role of air conditioning in the impact of heat on population health (Sheridan et al., 2018; Martínez et al., 2019). Some studies indicate that this is a determinant factor in modulating the impact of heat waves (Barreca et al. 2016; Fisk, 2015; Laurent et al., 2018). The results of our study confirm this hypothesis. It could be that this factor is directly related to income level, but the fact that in Table 5 both variables (income level and percentage with air conditioning) are significant could indicate that they explain different realities. Even when they have air conditioning units, low income people tend not to use them when they feel discomfort (Gao et al., 2020; Sánchez-Guevara et al., 2015; Núnez Peiró et al., 2017). The inability to cope with electricity consumption from air conditioning, even if the household has the equipment, is a little explored but potentially very relevant facet of energy poverty in the study of socio-economic factors of vulnerability to heat (Bouzarovski & Petrova, 2015; Lane et al., 2014). On the other hand, there are studies that show that living alone and with a low income (Sanz Fernández et al., 2016), is a factor that increases the risk of death during a heat wave (Lin et al., 2019; Zhang et al., 2017). Therefore, the level of income per household is a key social indicator of heat vulnerability that explains other related aspects such as loneliness and energy poverty. Also, it could be that families with lower incomes might lack the time and resources needed to guarantee sufficient levels of care to the population at risk. In contrast, families with greater incomes could access services that offer additional compensatory compensation for the most vulnerable, such as health services or private assistance (Sanz Fernández et al., 2016).

Another factor that is indirectly related to income level is the percentage of green zones. Green zones play an important role in mitigating the heat island effect, by which temperatures, especially at night, can be several degrees higher in the interior of cities than in the periphery (Alonso and Renard, 2020; Heaviside et al., 2017; Sánchez-Guevara et al., 2019;). On the other hand, green zones have the capacity to mitigate high temperatures, thanks to heat dissipation due to evapotranspiration of plants and the creation of shade (Burkart et al., 2016). This protective effect of green zones related to heat impact can be observed in Table 4 of this study, which corresponds to the univariate model. The table shows that the probability of risk related to extreme heat events decreases as hectares of green zones increase. However, in Table 5, which shows the adjusted multivariate model, this variable loses statistical significance. This result agrees with the findings of a study in the city of Berlin, which showed that facades, rooftops and urban green zones do not necessarily lead to a statistically significant reduction in interior air temperature (Buchin et al., 2016a). In this sense, some studies have determined that interior air temperature of buildings are more intimately correlated with the presence of climatization systems and construction characteristics than with exterior temperatures (Loughnan et al.,2015; Lundgren et al., 2019). In this way the risks associated with heat waves could be better explained by factors related to interior air temperatures than exterior temperatures in cities (Buchin, et al. 2016b; Walikewitz, et al. 2018). A previous paper reported a similar behavior between green zones and climatization systems (McDonald et al., 2020).

However, this does not imply that the role of green zones is not important or does not exist. Recently it has been shown that as homes install air conditioning systems, the association between green zones and heat mortality becomes weaker, and at the same time the association between green zones and energy savings during heat waves becomes stronger (MacDonald et al., 2020). Therefore, the protective effect of green zones is reflected indirectly in terms of the greater need for energy to reach a comfortable temperature in the home. In addition, the presence of green zones reduces the levels of air pollution in cities (Rafael et al., 2020), and contribute to improved physical condition and mental health (Andreucci et al., 2019; Marchegguiani et al., 2019). Both factors contribute to population response to heat.

Finally, the lack of risk found for any district in group 3—in which those over age 65 tend to live—could be explained by this population's income level. The average income per household in these districts (Figure 3) is above 50,000 net euros per year, which is well above average for the districts (38,770 net euros per year). Thus explained is the apparent contradiction between not finding risks in districts with a more vulnerable population thanks to the compensatory role of higher income per household, which allows for effectively protecting patients at risk of exposure to heat waves. In contrast, in the districts with lower income, this factor is important, for example, in not finding a heat wave effect in Villaverde or in the central district, despite having the lowest income levels, given that they simultaneously have lower populations over age 65.

This study has limitations, including those related to the nature of ecological studies. On one hand, the results of this type of study can only be applied at the population level and not at the individual level. Another possible limitation present in all of these studies is that meteorological variables are measured delocalized from the place in which exposure is produced, such that not necessarily all of the population analyzed is really exposed to the temperatures they've been assigned. Moreover, the possible temperature differences between the centre and the urban periphery caused by the heat island effect, given that this is a night-time phenomenon, should not be too far-reaching in this respect. Furthermore, it should be noted that the environment in which the measuring stations are located is very different from that of the urban fabric (Núñez Peiró, et al. 2019). However, these problems are common among this type of study (Samet et al., 2000), and they are minimized by including control variables in the generalized linear models carried out to calculate risks (Ingebrigtsen et al., 2015). The use of stepwise methods to specify the models are in danger of omitting explanatory variables that, although relevant, would not be statistically significant due to collinearity. If these were so, a specification error would occur, leading to biased estimators.

This study did not control for air pollution due to the lack of available data at this level of disaggregation. In this sense, it should be noted that the role of air pollution in relation to the impact of heat daily mortality is relatively small (Díaz et al., 2015b). Finally, there is the limitation of finding effect in only 3 of 17 analyzed districts, which would affect the statistical significance of the associations found in Tables 4 and 5. Finally, the data used for air conditioning were collected in 2001, nine years before the starting date of the time series of the mortality data. However, there are no more updated data.

In summary, the pattern of risks found in this study is explained primarily by income per household, such that in those districts with greater income levels people tend to have the means to compensate for or avoid heat waves, which does not happen in lower income districts, where risks are more likely. Evidently, an important factor that is conditioned by income level is the access to cooling systems, but it is not the only factor. Among the districts where income levels do not permit compensating for the exposure, we did find that the role of the population at risk is important, and that detecting an impact among the younger population is less probable. Finally, although green zones mitigate the impact of heat waves, their role is not more determinant than that of income level or air conditioning in homes. In general, we can confirm that the impact of climate change is more accentuated among marginalized social groups (Rossati, et al., 2017).

The socioeconomic factors together with the age of the population are the key factors to explain the different heat impact detected in the districts of Madrid City. Public policies that aim to urban regeneration to guarantee a minimum thermal habitability conditions in a passive way, as well as the development of urban green, together with others aimed at guaranteeing access to suitable air-conditioning systems, would make it possible to maintain comfortable temperatures by optimising energy consumption and achieving a significant reduction in the excess mortality attributable to the cold.

5. Acknowledgements

The authors are grateful for the contribution of Madrid Salud, for providing the mortality data that have served as a basis for the development of this paper.

In addition, his research was funded by the Municipal Consumption Institute of the Madrid City Council and the FEMENMAD project – "Feminización de la pobreza energética en Madrid. Exposición a extremos térmicos" – funded by the Madrid City Council under the call "Subvenciones 2018 para la realización de proyectos de investigación en materia de ciudadanía global y cooperación internacional para el Desarrollo".

6. Disclaimer

The researchers declare that they have no conflict of interest that would compromise the independence of this research work. The views expressed by the authors do not necessarily coincide with those of the institutions whose affiliation is indicated at the beginning.

7. References.

- Alberdi JC, Díaz J. Modelización de la mortalidad diaria en la Comunidad de Madrid de 1986 a 1991. Gaceta Sanitaria. 1997;11:9-15.

- Alonso L, Renard F. A (2020). Comparative Study of the Physiological and Socio-Economic Vulnerabilities to Heat Waves of the Population of the Metropolis of Lyon (France) in a Climate Change Context. Int J Environ Res Public Health.5:17(3)
- Andreucci, M. B., Russo, A., & Olszewska-Guizzo, A. (2019). Designing Urban Green Blue Infrastructure for Mental Health and Elderly Wellbeing. Sustainability, 11(22), 6425.
- Åström, D. O., Tornevi, A., Ebi, K. L., Rocklöv, J., & Forsberg, B. (2016). Evolution of minimum mortality temperature in Stockholm, Sweden, 1901–2009. Environ Health Perspect 124(6), 740-744.
- Åström, D. O., Ebi, K. L., Vicedo-Cabrera, A. M., & Gasparrini, A. (2018). Investigating changes in mortality attributable to heat and cold in Stockholm, Sweden. Int J Biometeorol 62(9), 1777-1780.
- Barreca, A., Clay, K., Deschenes, O., Greenstone, M., & Shapiro, J. S. (2016). Adapting to climate change: The remarkable decline in the US temperature-mortality relationship over the twentieth century. J Political Econ 124(1), 105-159.
- Bobb, J. F., Peng, R. D., Bell, M. L., & Dominici, F.(2014). Heat-related mortality} and adaptation to heat in the United States. Environ Health Perspect. 122(8), 811–816.
- Bouzarovski, S., & Petrova, S. (2015). A global perspective on domestic energy deprivation: Overcoming the energy poverty–fuel poverty binary. Energy Research & Social Science, 10, 31–40. https://doi.org/10.1016/J.ERSS.2015.06.007
- Bowler, D. E., Buyung-Ali, L., Knight, T. M., & Pullin, A. S. (2010). Urban greening to cool towns and cities: A systematic review of the empirical evidence. Lands Urb Plan 97(3), 147-155.
- Buchin, O., Hoelscher, M. T., Meier, F., Nehls, T., & Ziegler, F. (2016a). Evaluation of the health-risk reduction potential of countermeasures to urban heat islands. Ener Buildings, 114, 27-37.

- Buchin, O., Jänicke, B., Meier, F., Scherer, D., & Ziegler, F. (2016b). The role of building models in the evaluation of heat-related risks. Nat Haz & Earth Syst Sciences, 16(4).
- Burkart K, Meier F, Schneider A, Breitner S, Canário P, Alcoforado MJ, Scherer D, Endlicher W. (2016). Modification of heat-related mortality in an elderly urban population by vegetation (urban green) and proximity to water (urban blue): evidence from Lisbon, Portugal. Environ Health Perspect 124(7), 927-934.
- Carmona R, Linares C, Ortiz C, Mirón IJ, Luna MY, Díaz J. (2017). Spatial variability in threshold temperatures of heat wave mortality: impact assessment on prevention plans. Int J Environ Health Res. 27(6):463-475.
- Chung, Y., Noh, H., Honda, Y., Hashizume, M., Bell, M. L., Guo, Y. L. L., & Kim, H. (2017). Temporal changes in mortality related to extreme temperatures for 15 cities in Northeast Asia: adaptation to heat and maladaptation to cold. Am J Epidemiol, 185(10), 907-913.
- Coste J, Spira A (1991). Le proportion de cas attributable en Santé Publique: definition(s),estimation(s) et interpretation. Rev. Epidemiol. Sante Publique 51, 399–411.
- Díaz J, López C, Jordán A, Alberdi JC, García R, Hernández E, Otero A. (2002). Heat waves in Madrid, 1986-1997: effects on the health of the elderly. Int Arch Occup Environ Health.2002; 75:163-170.
- Díaz J, Carmona R, Mirón IJ, Ortiz C, Linares C. (2015a). Comparison of the effects of extreme temperatures on daily mortality in Madrid (Spain), by age group: The need for a cold wave prevention plan. Environ Res.Nov;143 (Pt A):186-91.
- Díaz J, Carmona R, Mirón IJ, Ortiz C, León I, Linares C (2015b). Geographical variation in relative risks associated with heat: Update of Spain's Heat Wave Prevention Plan. Environ Int. 85:273-83.

- Díaz J, Carmona R, Mirón IJ, Luna MY, Linares C (2018). Time trend in the impact of heat waves on daily mortality in Spain for a period of over thirty years (1983-2013). Environ Int 116:10-17.
- Díaz, J., Sáez, M., Carmona, R., Mirón, I. J., Barceló, M. A., Luna, M. Y., & Linares, C. (2019). Mortality attributable to high temperatures over the 2021–2050 and 2051–2100 time horizons in Spain: Adaptation and economic estimate. Environ Res 172, 475-485.
- Ebi KL, Rocklöv J. (2014). Climate change and health modeling: horses for courses. Glob Health Action 7:24154.
- Fisk, W. J. (2015). Review of some effects of climate change on indoor environmental quality and health and associated no-regrets mitigation measures. Build Environ 86, 70-80.
- Follos F, Linares C, Vellón JM, López-Bueno JA, Luna MY, Sánchez-Martínez G, Díaz J (2020). The Evolution of Minimum Mortality Temperatures as an Indicator of Heat Adaptation: The Cases of Madrid and Seville (Spain). Sci Tot Environ. In press.
- 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 ML10., Guo Y.L., Wu C.F., Kan H., Yi S.M., de Sousa M., Saldiva P.H., Honda Y., Kim H., Armstrong B. (2015). Mortality risk attributable to high and low ambient temperature: a multicountry observational study. The Lancet, 386(9991), 369-375.
- Gao, Y., Chan, E. Y., Lam, H. C., & Wang, A. (2020). Perception of Potential Health Risk of Climate Change and Utilization of Fans and Air Conditioners in a Representative Population of Hong Kong. International J Dis Risk Sc, 1-14.
- Guirguis, K., Basu, R., Al-Delaimy, W. K., Benmarhnia, T., Clemesha, R. E., Corcos, I., Guzman-Morales J.,Hailey B.,Small I., Tardy A., Vashishtha D., Zivin J.G. & Gershunov

A., (2018).Heat, Disparities, and Health Outcomes in San Diego County's Diverse Climate Zones. Geo Health, 2(7), 212-223.

- Guo Y., Gasparrini A., Li S., Sera F., Vicedo-Cabrera A.M., de Sousa M., Saldiva PHN, et al (2018). Quantifying excess deaths related to heatwaves under climate change scenarios: A multicountry time series modelling study. PLoS Med.15(7):e1002629.
- Gronlund, C. J., Zanobetti, A., Wellenius, G. A., Schwartz, J. D., & O'Neill, M. S. (2016). Vulnerability to renal, heat and respiratory hospitalizations during extreme heat among US elderly. Clim Change, 136(3-4), 631-645.
- Heaviside C, Macintyre H, Vardoulakis S (2017). The Urban Heat Island: Implications for Health in a Changing Environment. Curr Environ Health Rep.4: 296-305
- Instituto de Estadística de la Comunidad de Madrid (2020) Accessed at: http://www.madrid.org/iestadis/fijas/estructu/demograficas/padron/estructupcrd.htm
- Instituto Nacional de estadística, 2001. Censos de Población y Vivienda 2001. Resultados definitivos. Accessed at: https://www.ine.es/censo/es/inicio.jsp
- Instituto Nacional de Estadística, 2015. Urban Audit Complete Methodology Report. Accessed at: https://ec.europa.eu/eurostat/web/products-manuals-and-guidelines/-/KS-BD-04-002?inheritRedirect=true
- Ingebrigtsen, R., Steinsland, I., Cirera, L1., Saez, M (2015). Spatially misaligned data and the impact of monitoring network on health effect estimates (Doctoral thesis at NTNU).In: Ingebrigtsen, R. (Ed.), Bayesian Spatial Modelling of Non-stationary Processes and Misaligned Data Utilising Markov Properties for Computational Efficiency. Norwegian University of Science and Technology.
- IPCC, (2013): Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T. F., D. Qin, G. K. Plattner, M. Tignor, S. K. Allen, J. Boschung,

A. Nauels, Y. Xia, V. Bex and P. M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp. Accessed at: http://www.ipcc.ch/report/ar5/2.

- Lane, K., Wheeler, K., Charles-Guzman, K., Ahmed, M., Blum, M., Gregory, K., Graber, N; Clark, N; Matte, T. (2014). Extreme Heat Awareness and Protective Behaviors in New York City. Journal of Urban Health, 91(3), 403–414. Accessed at: https://doi.org/10.1007/s11524-013-9850-7
- Laurent, J. G. C., Williams, A., Oulhote, Y., Zanobetti, A., Allen, J. G., & Spengler, J. D. (2018). Reduced cognitive function during a heat wave among residents of non-air-conditioned buildings: An observational study of young adults in the summer of 2016. PLoS Med, 15(7), e1002605.
- Laverdière, É., Payette, H., Gaudreau, P., Morais, J. A., Shatenstein, B., & Généreux, M. (2016). Risk and protective factors for heat-related events among older adults of Southern Quebec (Canada): The NuAge study. Canad J Pub Health, 107(3), e258-e265.
- Lee, H., Mayer, H., & Chen, L. (2016). Contribution of trees and grasslands to the mitigation of human heat stress in a residential district of Freiburg, Southwest Germany. Lands Urb Plann 148, 37-50.
- Lin, Y. K., Maharani, A. T., Chang, F. T., & Wang, Y. C. (2019). Mortality and morbidity associated with ambient temperatures in Taiwan. Sci Tot Environ 651, 210-217.
- Linares, C., Sánchez, R., Mirón, I. J., & Díaz, J. (2015). Has there been a decrease in mortality due to heat waves in Spain? Findings from a multicity case study. J Integr Environ Sciences, 12(2), 153-163.
- Linares C, Martinez-Martin P, Rodríguez-Blázquez C, Forjaz MJ, Carmona R, Díaz J (2016). Effect of heat waves on morbidity and mortality due to Parkinson's disease in Madrid: A time-series analysis. Environ Int;89-90:1-6

- Linares C, Díaz J, Negev M, Sánchez-Martínez G, Debono R, Paz S (2020). Impacts of Climate Change on the Public Health of the Mediterranean Basin Population - Current Situation, Projections, Preparedness and Adaptation. Environ Res. 182 .109107.
- López-Bueno, J. A., Díaz, J., & Linares, C. (2019). Differences in the impact of heat waves according to urban and peri-urban factors in Madrid. Int J Biometeorol 63(3), 371-380.
- Loughnan, M., Carroll, M., & Tapper, N. J. (2015). The relationship between housing and heat wave resilience in older people. Int J Biometeorol, 59(9), 1291-1298.
- Lundgren Kownacki, K., Gao, C., Kuklane, K., & Wierzbicka, A. (2019). Heat stress in Indoor environments of Scandinavian urban areas: A literature review. Int J Environ Res Pub Health, 16(4), 560.
- Marcheggiani, S., Tinti, D., Puccinelli, C., & Mancini, L. (2019). Urban green space and healthy living: an exploratory study among Appia Antica parks users (Rome-Italy). Feb-Fresenius Environ Bull, 4984.
- Martínez GS, Linares C, Ayuso A, Kendrovski V, Boeckmann M, Díaz J. (2019). Heat-Health Action Plans in Europe: challenges ahead and how to tackle them. Environ Res 176:108548.
- McDonald, R. I., Kroeger, T., Zhang, P., & Hamel, P. (2020). The value of US urban tree cover for reducing heat-related health impacts and electricity consumption. Ecosystems, 23(1), 137-150.
- Miron IJ, Linares C, Montero JC, Criado-Alvarez JJ, Díaz J., (2015). Changes in cause-specific mortality during heat waves in central Spain, 1975-2008. Int J Biometeorol 59(9):1213-22.
- Miron, I. J., Criado-Alvarez, J. J., Diaz, J., Linares, C., Mayoral, S., & Montero, J. C. (2008). Time trends in minimum mortality temperatures in Castile-La Mancha (Central Spain): 1975–2003. Int J Biometeorol, 52(4), 291-299.

- Montero, J.C., Miron, I.J., Criado-Alvarez, J.J., Linares, C., Diaz, J., (2012). Influence of local factors in the relationship between mortality and heat waves: castile-La Mancha (1975-2003). Sci. Total Environ. 414, 73–80.
- Mushore, T. D., Mutanga, O., Odindi, J., & Dube, T. (2018). Determining extreme heat vulnerability of Harare Metropolitan City using multispectral remote sensing and socio-economic data. J Spat Sci 63(1), 173-191.
- Norton, B. A., Coutts, A. M., Livesley, S. J., Harris, R. J., Hunter, A. M., & Williams, N. S. (2015). Planning for cooler cities: A framework to prioritise green infrastructure to mitigate high temperatures in urban landscapes. Lands Urb Plann 134, 127-138.
- Núñez Peiró, M., Sánchez-Guevara Sánchez, C., & Neila González, F. J. (2017). Update of the urban heat island of Madrid and its influence on the building's energy simulation. Sustainable development and renovation in architecture, urbanism and engineering (pp. 339-350) doi:10.1007/978-3-319-51442-0_28
- Núñez Peiró, M., Sánchez-Guevara Sánchez, C., & Neila González, F. J. (2019). Source area definition for local climate zones studies. A systematic review. Building and Environment, 148, 258-285. doi:10.1016/j.buildenv.2018.10.050
- Portal de datos abiertos del Ayuntamiento de Madrid (2020). Accessed at: https://datos.madrid.es/portal/site/egob/menuitem.c05c1f754a33a9fbe4b2e4b284f1a5a0/?vgnextoid=559b401daf436610VgnVCM1000001d4a900aRCRD&vgnextchannel=374512b9ace9f310VgnVCM100000171f5a0aRCRD&vgnextfmt=default
- Phung, D., Guo, Y., Nguyen, H. T., Rutherford, S., Baum, S., & Chu, C. (2016). High temperature and risk of hospitalizations, and effect modifying potential of socio-economic conditions: A multi-province study in the tropical Mekong Delta Region. Environ Int, 92, 77-86.

- Rafael, S., Augusto, B., Ascenso, A., Borrego, C., & Miranda, A. I. (2020). Re-Naturing Cities: Evaluating the effects on future air quality in the city of Porto. Atm Environ, 222, 117123.
- Rossati, A. (2017). Global warming and its health impact. Int J Occup Environ Med, 8(1), 7.
- Sánchez-Guevara, C., Sanz Fernández, A., Hernández Aja, A., 2015. Income, energy expenditure and housing in Madrid: retrofitting policy implications. Build. Res. Inf. 43, 737–749. doi:10.1080/09613218.2014.984573
- Sánchez-Guevara, C., Núñez Peiró, M., Taylor, J., Mavrogianni, A., Neila González, F.J., 2019. Assessing population vulnerability towards summer energy poverty: Case studies of Madrid and London. Energy Build. 190, 132–143. doi:10.1016/j.enbuild.2019.02.024
- Samet, J., Dominici, F., Zeger, S., Schwartz, J., Dockery, D., 2000. The National Morbidity, Mortality and Air Pollution Study. Part I: Methods and Methodologic Issues. Health Effects Institute, Boston. Report No. 94.
- Sanz Fernández, A., Gómez Muñoz, G., Sánchez-Guevara, C., & Núñez Peiró, M. (2016). Estudio técnico sobre pobreza energética en la ciudad de Madrid.
- Sheridan, S.C., Allen, M.J., (2018). Temporal Trends in human vulnerability to excesssive heat. Environ Res Letters3.
- Trombley, J., Chalupka, S., & Anderko, L. (2017). Climate change and mental health. AJN Am J Nurs 117(4), 44-52.
- Walikewitz, N., Jänicke, B., Langner, M., & Endlicher, W. (2018). Assessment of indoor heat stress variability in summer and during heat warnings: a case study using the UTCI in Berlin, Germany. Int J Biometeorol 62(1), 29-42.
- Wang, Y., Bobb, J. F., Papi, B., Wang, Y., Kosheleva, A., Di, Q., Di Q., Schwartz JD., Dominici F. (2016). Heat stroke admissions during heat waves in 1,916 US counties for the period from 1999 to 2010 and their effect modifiers. Environ Health, 15(1), 1-9.

- Ward, K., Lauf, S., Kleinschmit, B., & Endlicher, W. (2016). Heat waves and urban heat islands in Europe: A review of relevant drivers. Sci Tot Environ, 569, 527-539.
- Willand, N., Ridley, I., & Pears, A. (2016). Relationship of thermal performance rating, summer indoor temperatures and cooling energy use in 107 homes in Melbourne, Australia. Ener Build, 113, 159-168.
- WMO (2019). World Meteorological Organization. The Global Climate in 2015–2019. Geneve. 2019
- Zhang, Y., Nitschke, M., Krackowizer, A., Dear, K., Pisaniello, D., Weinstein, P., Tucker G., Shakib S., Bi P. (2017). Risk factors for deaths during the 2009 heat wave in Adelaide, Australia: a matched case-control study. Int J Biometeorol 61(1), 35-47.