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Spatial variability in threshold temperatures of heat wave mortality: impact assessment on prevention plans

R. Carmona[a], C. Linares[a], C. Ortiz[a], I. J. Mirón[b], M. Y. Luna[c] and J. Díaz[a]

[a]National School of Public Health, Carlos III Institute of Health, Madrid, Spain; [b]Torrijos Public Health District, Castile-La Mancha Regional Health Authority (Consejería de Sanidad y Asuntos Sociales de Castilla-La Mancha), Torrijos (Toledo), Spain; [c]State Meteorological Agency (Agencia Estatal de Meteorología/AEMET), Madrid, Spain

ABSTRACT
Spain's current heat wave prevention plans are activated according to administrative areas. This study analyses the determination of threshold temperatures for triggering prevention-plan activation by reference to isoclimatic areas, and describes the public health benefits. We subdivided the study area – the Madrid Autonomous Region (MAR) – into three, distinct, isoclimatic areas: 'North', 'Central' and 'South', and grouped daily natural-cause mortality (ICD-10: A00-R99) in towns of over 10,000 inhabitants (2000–2009 period) accordingly. Using these three areas rather than the MAR as a whole would have resulted in a possible decrease in mortality of 73 persons (38–108) in the North area, and in aborting unnecessary activation of the plan 153 times in the Central area and 417 times in the South area. Our results indicate that extrapolating this methodology would bring benefits associated with a reduction in attributable mortality and improved effectiveness of public health interventions.

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Introduction

Since the first heat wave prevention plans were implemented in Europe in 2004 (Matthies et al. 2008; WHO 2009a, 2009b, 2011), these have been the subject of different evaluations and improvements aimed at minimising the impact of high temperatures on health (Fouillet et al. 2008; Lowe et al. 2011; Kovats and Bickler 2012; Culqui et al. 2014; Bittner et al. 2014; Linares, Sánchez, et al. 2015).

Knowledge of the health impact of heat waves has evolved: on the one hand, towards the use of an independent variable which would take meteorological factors other than air temperature into account, ranging from different temperature indices, such as apparent temperature (Steadman 1984; Baccini et al. 2008) and equivalent temperature (Nastos and Matzarakis 2012), to the inclusion of humidity (Epstein and Moran 2006) and/or wind speed (Sipple 1958); and on the other hand, towards the use of dependent variables, other than all-cause mortality, as a health indicator, which would pinpoint specific causes of mortality, such as circulatory- and respiratory-cause mortality (Díaz et al. 2002; Kyselý and Kríz 2008; Ha and Kim 2013; Mirón et al. 2015), or even mortality in more specific diseases, such as neurodegenerative diseases (Linares et al. 2016). Heat waves have also been studied in depth through stratification by age group (Díaz et al. 2015a), and even the effect of high temperatures on pregnant

CONTACT J. Díaz j.diaz@isciii.es

women has been analysed (Schifano et al. 2013; Carolan-Olah and Frankowska 2014; Arroyo et al. 2016). In addition, the impact of heat on health has been examined via other health indicators, such as hospital admissions (Mastrangelo et al. 2006; Linares and Díaz 2008; Hanzlíková et al. 2015), visits to primary care centres, and even emergency home care (Ng et al. 2014; Kataoka et al. 2015; Calkins et al. 2016).

A similar evolution has been seen in determination of mortality thresholds and prevention-plan activation temperatures. In some places, a merely climatological criterion is used, generally defined as the point at which a given percentile of the climatological series of maximum or mean daily temperatures is exceeded, usually the 95th percentile (Díaz et al. 2002; Montero et al. 2010; Tobías et al. 2012) or, in some cases, the 99th percentile of such series (Tobías et al. 2014). Elsewhere, this value has been calculated by basing it on studies in which this temperature is determined by reference to a robust causal relationship (Ebi et al. 2006), e.g. where daily heat-related mortality begins to rise in a statistically significant manner. This approach has become known as the 'epidemiological' method (Montero et al. 2010, 2013; Díaz et al. 2015b). As compared to the climatological method (Tobías et al. 2014), the use of this method amounts to an improvement in terms of geographical homogenisation of heat-related risks (Díaz et al. 2015b).

It is evident that climatology plays an important role in the determination of these mortality threshold or trigger temperatures, since people are accustomed to living within a range of temperatures (Curriero et al. 2002), and it is the effect of exceeding or failing to reach these that causes mortality to increase (Basu 2009). Apart from climatology, however, it is equally clear that other socio-economic and demographic variables have an influence, affecting these threshold temperatures and causing them to change and/or evolve in climatologically homogeneous areas (Davis et al. 2003; Montero et al. 2013).

Furthermore, determination of temperatures using the 'epidemiological' method requires daily mortality to be grouped geographically and a meteorological observatory designated to represent the geographical area in question (Roldán et al. 2011). This type of grouping tends to be merely administrative (Blazejczyk et al. 2015; Díaz et al. 2015b).

The aim of this study was to combine the above two aspects in order to achieve a more efficient determination of threshold temperatures, i.e. calculating this temperature on the basis of the distribution of daily mortality, yet grouping such mortality by reference to areas having the same climatic pattern, as opposed to administrative criteria such as provincial divisions. In addition, it assessed the improvement in prevention plans which exemplify the use of this novel method of grouping by climatologically homogeneous area in preference to the administrative grouping used until now. The case chosen for study purposes was the Madrid Autonomous Region of Spain, one that has a high demographic density and has been extensively studied from the standpoint of extreme thermal events (Alberdi et al. 1998; Díaz et al. 2002; Linares et al. 2016).

Material and methods

Study variables and scope

Our analysis focused on the Madrid Autonomous Region (MAR), which is situated in the centre of the Iberian Peninsula, with its capital, Madrid, also being the capital of Spain. The regional population of 6,436,996 (INE 2015) is mainly concentrated in the Madrid metropolitan area. The MAR has a surface area of 8,030 km^2. Climatologically speaking, it can be subdivided into three climatically homogeneous areas defined by the State Meteorological Agency (*Agencia Estatal de Meteorología/AEMET*) (AEMET 2016), namely, '*Sierra de Madrid*' (North), '*Metropolitana y Henares*' (Central) and '*Sur Vegas y Oeste*' (South). *These are areas with homogenous meteorology. Their definition is not administrative. They are used by AEMET in the National Plan for Prediction and Monitoring of Adverse Meteorology (METEOALERTA)* (AEMET 2016). *These areas have been chosen with the aim of matching the AEMET weather alerts with the alerts of the High Temperature Prevention Plan of the Ministry of*

Health, Social Services and Equality (MSSSI 2016). *So, the objective is that the geographical regions that use both institutions are the same.*

Figure 1 depicts the above three isoclimatic areas and the towns that comprise them.

As the health variable, we used daily mortality due to natural causes (all-cause mortality excluding deaths from external causes) (International Classification of Diseases 10th Revision (ICD-10): A00-R99) in each MAR town of over 10,000 inhabitants, across the period 1 January 2000 to 31 December 2009. The population left out of the study corresponds to 369,480 inhabitants, this figure represents to 5.78 % of the total population in MAR (INE 2015).

The daily mortality data for each town were allocated to the corresponding area, such that the distribution in Figure 1 shows 11 towns grouped in the *North area*, 25 in the *Central area* and 11 in the *South area*.

The daily mortality data were obtained from microfiches containing death data broken down by cause of death and supplied under a data loan agreement by the National Statistics Institute to the Carlos III Institute of Health (Ministry of Economic Affairs & Competitiveness/*Ministerio de Economía y Competitividad*), for the purpose of undertaking a 'Study of influenza-related mortality in Spain'.

The following meteorological observatories were designated to represent the respective isoclimatic areas (AEMET 2016): the Navacerrada observatory for the *North*; the Madrid-Retiro observatory for the Central; and the Aranjuez observatory for the *South*. The situation of each observatory is depicted in Figure 1. Maximum and minimum daily temperature data for all three observatories were furnished by AEMET.

Methodology of analysis

- Determination of daily mortality threshold temperatures (Tthreshold):

To determine the threshold temperatures (Tthreshold) in each isoclimatic area, we applied the methodology employed for determining the threshold temperatures previously used to define heat waves in Spain (Montero et al. 2010; Mirón et al. 2012; Roldán et al. 2014; Díaz et al. 2015a, 2015b; Linares,

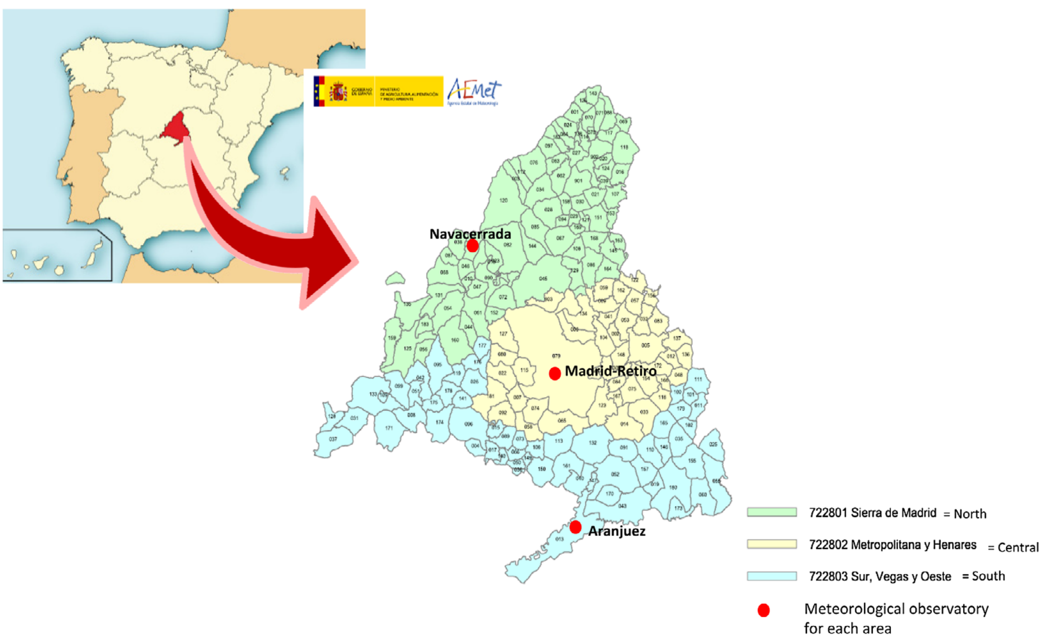


Figure 1. Isoclimatic areas in Madrid Autonomous Region and meteorological observatory for each area. Source: Author.

Díaz, et al. 2015; Carmona,Díaz, Mirón, et al. 2016). We first fitted a univariate autoregressive integrated moving average (ARIMA) model (Box et al. 1994) for daily mortality in each of the three mortality series corresponding to the respective isoclimatic areas, which enabled us to obtain the residuals of the mortality series. From the ARIMA models, we obtained the fit and the corresponding confidence intervals (upper and lower). Mortality residuals are the difference between raw mortality and the fit. We then proceeded to plot the following on a scatter-plot diagram: the mean value of the mortality series residuals on the same day (vertical axis); the maximum daily temperatures at 2°C intervals (horizontal axis), and their corresponding 95 % confidence intervals (CIs) (upper and lower limits of the CI: UL and LL, respectively); and the 95 % CIs of the mean of the residuals for the entire study period (shown by parallel dashed lines). When these mortality residuals are shown on a scatter-plot diagram along with the maximum temperature data, the deviations detected correspond to genuine mortality anomalies. The threshold temperature point is that when all residuals in a 2 °C bin are outside the confidence interval for the overall mean of the residuals.

The advantage of working with residuals rather than daily mortality is that, after modelling, residuals display neither trends nor periodicities (both of which are inherent in daily mortality), with the result that any associations found, we will obtain an unconfounded association mortality-temperature relationship from a statistical standpoint ($p < 0.05$), and associations between temperature and mortality will not be confounded by longer-term time trends and seasonal patterns.

The determination of threshold temperature using the described methodology (maximum daily temperature was calculated when mortality begins to increase statistically), presents the advantage, over the choice of a fixed climactic percentile, that in this way is taken into account socioeconomic and demographic factors of each place, that are not considered when using a threshold temperature based on purely climatic criteria.

- Determination of heat-related relative risks (RRs) and attributable risks (ARs) for each isoclimatic area.

Based on the Tthreshold value for each area, we calculated the variable, Theat, defined as follows (Díaz et al. 2006):

$$\text{Theat} = 0 \quad \text{if Tmax} < \text{Tthreshold}$$

$$\text{Theat} = \text{Tmax} - \text{Tthreshold} \quad \text{if Tmax} \geq \text{Tthreshold}$$

From the standpoint of its impact on mortality, a heat wave was defined as any day on which the designated threshold was exceeded in any town analysed (Díaz et al. 2002).

Given that the effect of a heat wave on mortality may not be immediate, the following lagged variables were calculated: Theat (lag 1), which takes into account the effect of the temperature on day 'd' on mortality, one day later, 'd + 1'; Theat (lag 2), which takes into account the effect of the temperature on day 'd' on mortality, two days later, 'd + 2'; and so on successively. The number of lags were selected on the basis of the literature, which establishes that the effect of heat is short-term (Theat: lags 0–4) (Alberdi et al. 1998).

We controlled: firstly, for seasonalities of an annual, six-monthly and quarterly nature, using the sine and cosine functions with these same periodicities; and secondly, for trend and the possible autoregressive nature of the series. To control the trend a variable called n1 has been introduced. This variable was defined as n1 = 1 for June 1st 2000, n1 = 122 for September 30th 2000, n1 = 365 + 1 for June 1st 2001, n1 = 365 + 122 for September 30th 2001 and so on.

The impact of temperature on mortality was quantified using generalised linear model (GLM) methodology, with the Poisson regression link. This methodology allows for calculation of the Relatives Risk (RRs) associated with increases in the environmental variable, in this case temperature.

Significant variables (Theat and its corresponding lags, and the control variables) were determined using the Stepwise with backward elimination, beginning with the model that included all the explanatory variables, and gradually eliminating those which individually displayed least statistical significance, with the process being reiterated until all the variables included were significant at $p < 0.05$. Modelling was performed for the summer months (June to September).

Based on the RR, we then calculated the Atributable Risks (ARs) associated with this increase via the following equation (Coste and Spira 1991):

$$AR = [(RR - 1)/RR] \times 100$$

The observed increases in RRs and ARs correspond to increases for each degree that the maximum daily temperature exceeded the threshold temperature.

To calculate the number of daily deaths attributed to extreme temperatures for each region we conducted the same methodology performed in Carmona, Díaz, Ortiz, et al. (2016). We first calculated the number of degrees whereby the temperature exceeded (excess °C) the threshold temperature for each region by means of the following expression:

$$\text{Excess °C} = \sum \text{Tmax} - \text{Tthreshold}$$

Σ extends to all days on which the maximum daily temperature exceeded the threshold temperature. On ascertaining the percentage increase in mortality for each °C via the AR, the total percentage mortality for the overall excess °C across the period 2000–2009 would be: percentage attributable to heat = AR × excess °C.

Accordingly, to go from percentages to daily mortality, it suffices for the mean mortality in any region to be taken into account as follows:

- Mortality attributable to heat = (percentage mortality attributable to heat × mean mortality)/100.

All analyses were performed using the IBM SPSS Statistics v22 and STATA v11.2statistical software programmes.

Results

Table 1 shows the descriptive statistics of the daily natural mortality and maximum and minimum daily temperatures recorded for each of the MAR's three isoclimatic areas. In terms of daily mortality, there were 372,826 deaths across the study period; of this total, 3.2 % corresponded to the North, 94.1 % to the Central and 2.7 % to the South. As can be observed from this table, maximum mortality

Table 1. Descriptive statistics of daily natural-cause mortality (ICD-10 A00-R99) and the meteorological variables considered, according to different isoclimatic areas of the Madrid Autonomous Region, across the period 2000–2009.

Isoclimatic area	Variables	N	Minimum	Maximum	Mean	Standard deviation
North	Organic-cause mortality	3653	0	10	3.09	1.91
10.10 % > 65 years	Tmax (ºC)	3653	– 10.9	31.3	11.3	8.8
Personal income (€) = 28,745	Tmin (ºC)	3653	– 17.5	20	3.2	6.5
Central	Organic-cause mortality	3653	52	174	96.17	15.49
15.27 % > 65 years	Tmax (ºC)	3653	1	38.6	20.2	8.7
Personal income (€) = 29,387	Tmin (ºC)	3653	−6.1	25	10.4	6.5
South	Organic-cause mortality	3653	0	11	2.80	1.90
8.17 % > 65 years	Tmax (ºC)	3653	– .7	41.6	22.3	9.0
Personal income (€) = 23,974	Tmin (ºC)	3653	– 12	23.7	7.8	7.0

occurred in the Central, with a far higher total number of deaths than those of the North and South. This unequal distribution of mortality is a consequence of the distribution of the population by town. According to data drawn from the National Statistics Institute (INE 2016), 4.1 % of the population live in the North, 89.2 % in the Central and 6.7 % in the South. In Central area, there is 15.27 % of people aged > 65 years, so the mortality is higher in this area in relation to the others.

Table 2 shows average, Percentile 90 % and percentile 95 % of daily maximum temperature and daily natural mortality in summer period (June-September) recorded for each of the MAR's three isoclimatic areas

Another noteworthy finding was the clearly differentiated pattern between the daily temperatures of the different areas considered, South in particular, with a maximum daily temperature in the study period of 41.6 °C, 3 °C above the maximum recorded in the Central area and 10.3 °C above the mean maximum daily temperature in the North area.

Figures 2(a)–(c) show the scatter-plot diagrams pertaining to determination of the heat wave threshold temperatures for the different isoclimatic areas considered. As will be seen, the respective threshold temperatures were 26 °C for the North area (Figure 2(a)), 36 °C for the Central area(Figure 2(b)) and 38 °C for the South area (Figure 2(c)), with values below these temperatures not being statistically significant.

In the case of North, the maximum daily temperature of 26 °C corresponded to the 87th percentile of the maximum daily temperatures series for the summer months (June–September) across the period 2000–2009; in the other two cases, the maximum daily temperature of 36 °C Central corresponded to the 95th percentile and that of 38 °C South corresponded to the 92nd percentile of this same series.

The GLM Poisson regression models equations for the baseline model (M0) for each isoclimatic area, and the models with the temperature variables added (M1) are the following showed below, in which:

$\hat{\mu}$: Daily Natural Mortality

$\hat{\mu}1$: Autoregressive order 1 of $\hat{\mu}$.

$$\begin{aligned}\text{Ln}\,(\hat{\mu}) = {} & \beta_0 + \beta_1\text{Trend} + \beta_2\sin 365 + \beta_3\cos 365 + \beta_4\sin 180 \\ & + \beta_5\cos 180 + \beta_6\sin 120 + \beta_7\cos 120 + \beta_8\sin 90 + \beta_9\cos 90 \\ & + \beta_{10}\mu 1 + \left[\beta_{11}\text{Tcal} + \beta_{12}\text{Tcal}_1 + \beta_{13}\text{Tcal}_2 + \beta_{14}\text{Tcal}_3 + \beta_{15}\text{Tcal}_4\right]\end{aligned}$$

North area

$$\text{M0: Ln}\,(\hat{\mu}) = 0.80 + 0.0001(\text{Trend}) - 0.0735(\sin 120) + 0.0160(\mu 1)$$

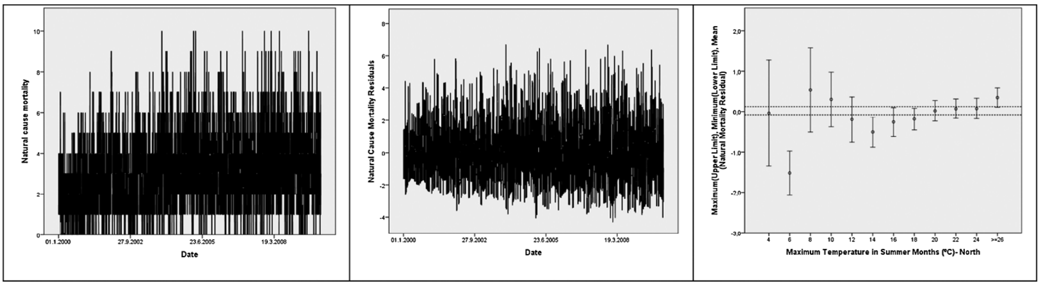
$$\text{M1: Ln}(\hat{\mu}) = 0.78 + 0.0001(\text{Trend}) - 0.0493(\sin 120) + 0.0135(\mu 1) + \left[0.0507(\text{Tcal}) + 0.0456(\text{Tcal}_4)\right]$$

Central area

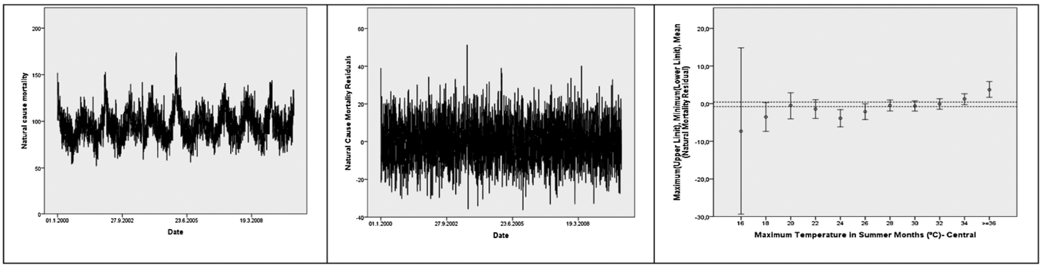
$$\begin{aligned}\text{M0: Ln}\,(\hat{\mu}) = {} & 4.21 + 0.0003(\text{Trend}) + 0.0352(\sin 365) + 0.0067(\sin 120) \\ & - 0.0322(\cos 120) + 0.0028(\mu 1)\end{aligned}$$

Table 2. Descriptive statistics of daily natural-cause mortality (ICD-10 A00-R99) and daily maximum temperature (Tmax), according to different isoclimatic areas of the Madrid Autonomous Region, across the summer (June-September) period 2000–2009.

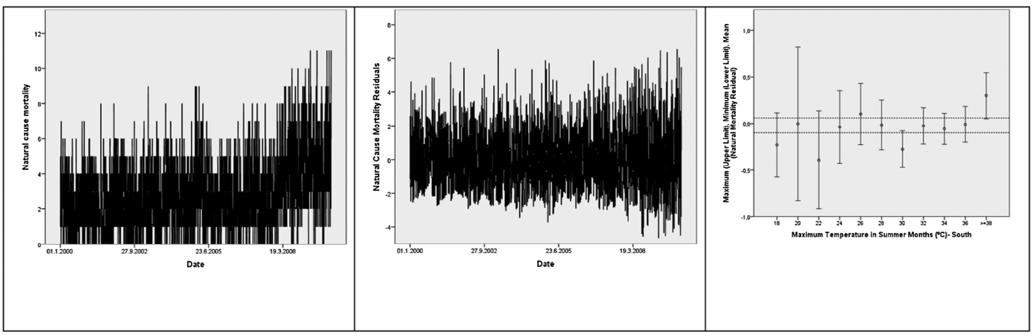
Isoclimatic area	Variables	*N*	Mean	SD	Percentile 90 %	Percentile 95 %
North	Tmax (ºC)	1220	20.7	4.9	26.5	27.6
	Natural-cause Mortality	1220	3.0	1.8	6	6
Central	Tmax (ºC)	1220	29.9	4.3	35.1	36
	Natural-cause Mortality	1220	86.3	11.8	102	107
South	Tmax (ºC)	1220	32.3	4.4	37.5	38.5
	Natural-cause Mortality	1220	2.61	1.9	5	6



a. North area.



b. Central area.



c. South area.

Figure 2. Graphics corresponding to natural cause mortality time series, residuals and scatter plot diagrams in North (a), Central (b) and South (c) area of MAR (2000–2009).

$$\begin{aligned} \mathrm{M1: Ln}(\hat{\mu}) \; &= 4.25 + 0.0003(\mathrm{Trend}) + 0.035(\sin 365) + 0.0015(\sin 120) - 0.033(\cos 120) \\ &+ 0.0022(\mu 1) + [0.0532(\mathrm{Tcal}) + 0.0449(\mathrm{Tcal}_2) + 0.0479(\mathrm{Tcal}_3)] \end{aligned}$$

South area

$$\mathrm{M0: Ln}(\hat{\mu}) = 0.42 + 0.0007(\mathrm{Trend}) - 0.1918(\cos 120) - 0.1014(\cos 90) + 0.0349(\mu 1)$$

$$\mathrm{M1: Ln}(\hat{\mu}) = 0.39 + 0.0007(\mathrm{Trend}) - 0.1814(\cos 120) - 0.0864(\cos 90) + 0.331(\mu 1) + [0.1583(\mathrm{Tcal}_3)]$$

Table 3 shows the increases in RRs and ARs for each degree that the maximum daily temperature exceeded the Threshold temperature of the respective isoclimatic areas. As will be seen, the ARs of the Centra*l* and South areas were higher than those of the North, though these differences were not statistically significant. With respect to the lags at which the association between temperature and the increase in mortality occurred, these were very short term (lag 0) solely in the North and Central areas, whereas a short- to medium-term effect (lags 3–4) was in evidence for all three areas.

Table 3. Results of Poisson modelling showing the daily mortality threshold temperature for each isoclimatic area of the Madrid Autonomous Region, the percentile to which this corresponded, and the increases in Relative Risk (RR) and Attributable Risk (AR) for each degree that the daily Tmaximum exceeded the threshold temperature.

		Threshold temperature (percentile summer months)	LAGS Theat	RR (95 % CI)	AR (%) (95 % CI)
Organic-cause mortality	Isoclimatic area *North*	26 °C (87th percentile)	0 and 4	1.09 (1.04 1.15)	8.8 (4.5 12.9)
	Isoclimatic area *Central*	36 °C (95th percentile)	0, 2 and 3	1.16 (1.13 1.19)	13.6(11.3 15.9)
	Isoclimatic area *South*	38 °C (92nd percentile)	3	1.17 (1.08 1.28)	14.9 (7.2 21.9)

Table 4. Differential effects on attributable mortality and number of days on which the current threshold temperature for prevention-plan activation was exceeded for the whole Madrid Autonomous Region (34 °C) and for isoclimatic areas (with specific thresholds).

Isoclimatic area	Heat wave threshold (percentile)	*Nº* days on which heat wave threshold was exceeded: 2000–2009	*Nº* days on which heat wave threshold of 34 °C was exceeded: 2000–2009	Difference (days)	Attributable mortality (95 % CI): 2000–2009
North	26 °C (87th p)*	150	0	–	73 (38–108)
Central	36 °C (95th p)	58	211	153	–
South	38 °C (92nd p)	87	504	417	–

*p: percentile.

Table 4 shows the benefits in terms of daily heat-related mortality on days of activation of the prevention plan (assuming the preventive plan is effective), using temperatures that take into account the three isoclimatic areas rather than a single threshold temperature for the entire MAR, set at a maximum daily temperature of 34 °C. In the period considered for this isoclimatic area, 2000–2009, the threshold temperature of 26 °C was exceeded on 150 days, whereas that of 34 °C was not exceeded once. This means that the plan ought to have been activated on 150 occasions, something that was not done because the threshold temperature was taken to be 34 °C. By activating the plan at 26 °C, the number of avoidable deaths in the North area would be 73 (38–108). For the other two areas, the benefit would lie in the reduction in the number of days on which the plan would have to be activated, a figure of 153 days in the Central area and 417 days in the South area.

Table 5 shows the Pearson correlations coefficients for summer months between the daily maximum temperature, percentile 90 and percentile 95 in each MAR area during the study period. This table shows that the coefficients are high and statistically significant for the daily maximum temperature.

Table 5. Pearson correlation coefficients corresponding to: Daily maximum temperature, percentile 90 and percentile 95 in summer months in each MAR area.

Pearson correlation			
Summer months	Tmax North	Tmax Central	Tmax South
Tmax North	1	0.934**	0.921**
Tmax Central		1	0.964**
Tmax South			1
	Tmax North p90	Tmax Central p90	Tmax South p90
Tmax North p90	1	0.199	0.346**
Tmax Central p90		1	0.481**
Tmax South p90			1
	Tmax North p95	Tmax Central p95	Tmax South p95
Tmax North p95	1	0.171	0.261
Tmax Central p95		1	0.280
Tmax South p95			1

**P-value < 0.01.

However, for the daily maximum temperature corresponding to high data (percentile 90 and 95) the coefficients are low or not significant.

Discussion

Determination of threshold temperatures in each isoclimatic area of MAR has the objective of triggering the prevention-plan activation to improve the public health benefits. Using the threshold calculated for three isoclimatic areas would have resulted in a possible decrease in mortality, estimated on 73 persons (38–108) in the North area, and in aborting unnecessary activation of the plan 153 times in the Central area and 417 times in the South area. Our results indicate that extrapolating this isoclimatic area-based methodology to currently prevailing prevention plans would bring benefits associated and improved effectiveness of public health interventions in this field. A detailed discussion of the results obtained is described in the paragraphs below.

Explanation about the different threshold temperatures and the percentiles obtained

From a climatological point of view, the values of the maximum and minimum daily temperatures display a clearly differentiated pattern among the three areas considered. If the threshold temperature values obtained for each of the MAR's isoclimatic areas are compared to that obtained for the MAR as a whole, i.e. 34 °C (Díaz et al. 2015a, 2015b), it will be seen that the North had a threshold temperature of 26 °C, which is appreciably lower than the 34 °C set for the MAR. This indicates that there were days on which the prevention plan should have been activated (those on which the temperature of 26 °C was exceeded) but was not implemented, since the plan is activated as from 34 °C.

This differential pattern is particularly noteworthy in the case of maximum temperatures, since it is these that show the closest association with heat wave mortality (Montero et al. 2013; Kent et al. 2014; Díaz et al. 2015b; Gasparrini et al. 2015). Differences in the mortality threshold temperatures are the direct consequence of a population's adaptation to the temperatures to which it is exposed (Keatinge et al. 2000; Curriero et al. 2002; Kovats and Kristie 2006). In relation to the percentiles shown in Table 2, there are multiple factors – demographic, socio-economic, and even health and cultural – which cause these to vary from one place to another (Nakai et al. 1999; Naughton et al. 2002; Vandentorren et al. 2006; Montero et al. 2013).

The results obtained in Table 3 differ from those reported by Montero's 2013 study (Montero et al. 2013), according to which the percentage of persons aged over 65 years (Table 1) was inversely related to the threshold-temperature percentile, such that the higher the proportion of over 65-year-olds, the lower the threshold temperature.

If one were to take into account each area's economic level (Table 1) based on its inhabitants' declared mean personal income (FEDEA 2016), the South area had the lowest income, with a figure of €23,974. Moreover, if the sole indicator related to the threshold-temperature percentile was this economic indicator, then the places having the highest income ought to correspond to those having the highest percentiles. This was indeed so for Central area, which had the highest income and highest percentile of threshold temperature, but not for the other two areas.

It should be noted that our study has focused on general population, and the level of income in the statically analysis has not been considered. Therefore, the data presented in Table 1, referring to the percentage of over 65s, and the incomes by isoclimatic areas refer only to data that have been used to explain the differential pattern found between the different regions.

It is thus clear that no single factor (population pyramid or income level) is in itself capable of accounting for the variations observed in the percentiles to which the mortality threshold temperatures correspond. This means that it must inevitably be a combination of both factors (Nakai et al. 1999; Naughton et al. 2002), including others that are not indicated, such as the number of older adults who live alone or the degree of health care, which will determine the percentile of this threshold temperature (Vandentorren et al. 2006).

Discussion about the RR and AR obtained and attributed mortality

If the RRs and ARs of each of the isoclimatic areas are compared (Table 3), it will be seen that these were very similar in the case of the Central and South areas, with ARs of 13.6 % (11.3 15.9) and 14.9 % (7.2 21.9), respectively. In contrast, the AR of the North area was appreciably lower, standing at 8.8 % (4.5 12.9), though this difference was not statistically significant. These findings are in line with those yielded by the analysis performed for Spain as a whole, which, as a general rule for heat (Díaz et al. 2015b) and cold alike (Carmona,Díaz, Mirón, et al. 2016), showed that low percentiles were associated with low RRs and ARs, while higher percentiles were associated with higher RRs and ARs (Díaz et al. 2015b).

Bearing in mind that the AR represents the percentage increase in daily mortality for each degree that the maximum daily temperature exceeds the threshold temperature, this enables one to calculate the related mortality which would have occurred on these 150 days, using the methodology proposed by Carmona, Díaz, Ortiz, et al. (2016). The heat-related mortality on the 150 days on which the threshold of 26 °C was exceeded amounts to a total of 73 deaths for the ten years considered. Furthermore, as can be seen from Table 4, activation of the prevention plan at 34 °C rather than at 36 °C for the Central area or 38 °C for the South, would entail unnecessary activation of the plan on 153 and 417 occasions, respectively over the 10-year period covered.

Limitations of the analysis conducted

Apart from the above study limitation, mention should be made of those inherent in the longitudinal ecological method used, which prevents inferences being made at an individual level. In addition, there are the limitations linked to the non-use of other environmental variables of interest, such as air pressure and relative humidity, which were not included in the analysis owing to their negligible relevance in the temperature-mortality relationship (Barnett et al. 2010; Montero et al. 2013). Insofar as air pollution is concerned, the lack of data in some of the areas rendered their use inadvisable. In this sense, the RR obtained for the impact of heat does not change substantially if in the GLM models we introduce data corresponding to air pollutants concentrations (Díaz et al. 2015a).

Implications in public health and communication strategy for the prevention plan

The results obtained in Table 5 shows the Pearson correlations coefficients, these results indicate that when in the Central and South areas there is an event of high maximum temperature, this fact does not occur in the North area and *vice versa*. So, the existence of different thresholds for the different isoclimatic areas is justified in case of extreme events of heat waves. From a point of view of public health this latter is important to protect population from this exposure with high impact on mortality.

Although the economic benefits of prevention systems can outweigh the cost of their implementation by as much as 10 times (Rogers and Tsirkunov 2011), it is clear that generalisation of alerts might entail a loss of efficacy, on the population becoming accustomed to these (Grasso et al. 2007), so that it is advisable to optimise the number of alerts issued, a goal that would be achieved by implementing the above-described methodology for setting thresholds by isoclimatic area.

One drawback of using these three threshold temperatures in the MAR instead of a single temperature might arise from attribution of the population's exposure, i.e. if a person resides in one place and works in another, there is the problem of deciding to which temperature is he/she exposed and which threshold temperature is applicable. Although this is evidently a limitation of the proposed method, one must nevertheless bear in mind that over 65-year-olds constitute a special risk group (Díaz et al. 2015a) which has a lower degree of mobility than the rest of the population. Moreover, the use of 3 isoclimatic areas in a region of 8,000 km^2 is in no way excessive, if this is compared to prevention plans implemented in some regions of Spain, such as the Valencian Autonomous Region, where there are as many as 30 such areas for a surface area of 23,000 km^2 (Generalitat Valenciana 2016).

Although the Spanish Ministry of Health updated its heat wave prevention plan in June 2015, going from a plan based on activation thresholds set by reference to climatological criteria to another based on threshold temperatures calculated by reference to 'epidemiological' criteria (MSSSI 2016), the benefits described in this study render it advisable to extrapolate this methodology and use the results to further improve and enhance the prevention plan.

The communication strategy for the activation of the plan, below our point of view, should rely on that only one official organisation in the country (this fact does not occur nowadays) could emit the heat wave alert. These prevention actions should be based on the thresholds calculated by isoclimatic areas extended to the whole country, in a similar way to those detected in our analysis. Furthermore, we are of the opinion that the methodology here described would be applicable to any prevention plan currently in force, regardless of its geographical situation, with expected benefits similar to those described in this paper.

Disclaimer

This paper presents independent results. The views expressed are those of the authors and not necessarily those of the Instituto de Salud Carlos III.

Disclosure statement

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ORCID

J. Díaz http://orcid.org/0000-0003-4282-4959

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