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Heat-related mortality in Moldova: the summer of 2007

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ABSTRACT: Heat waves of 2007 in Chisinau (Moldova) were used to study the relationship between elevated temperatures and excess mortality caused by these events. As reference information, daily temperature and mortality data for an 8-year reference period (2000–2008 without 2007) were used. Mean (T_{mean}), maximum (T_{max}) and minimum (T_{min}) daily air temperatures, and corresponding apparent temperatures (ATs) in the warm season (April to September) were correlated with excess total mortality in 2007, taken as the difference of daily death counts or their 7-d moving averages with those of the reference period. Observed excess mortality was totalled about 190–200 deaths or 6.5–6.9% of the reference mortality. The average daily excess deaths above the threshold temperatures (TTs), in terms of a used 'estimator' (a temperature variable), were in the range of 2.0–4.4% per 1 °C. TTs were identified as the lowest 2 °C class intervals above which the excess mortality rates began a sharp increase from their zero reference value. For T_{mean}, T_{max} and T_{min} they were estimated as ∼25, 31 and 19 °C; TTs for ATs were somewhat lower. The heat waves were defined as a continuous period satisfying three conditions for daily T_{max}: (1) it is above the 99th percentile of its reference distribution (2000–2008) for at least three consecutive days, (2) its average value is equal to at least this percentile for the entire period and (3) all daily values are above 90th percentile for the entire period. On the whole, eight heat events caused 146 excess deaths or about 73–77% of their total number in the warm period of 2007. Temperature–excess mortality relationships become stronger with an increasing time lag; maximal effects were revealed on the second–third days for T_{mean} and T_{max}, and on the first–second days for T_{min}. The total effect of mortality displacement was estimated as about 17–25% of 'positive' excess deaths.

KEY WORDS heat wave; excess death; threshold temperature; mortality displacement; lag effect

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1. Introduction

Mortality rates are ambient temperature dependent and have long been associated with the effects of both heat and cold. Research by epidemiologists and climatologists has grown rapidly following the European heat waves in 2003 (Schär *et al.*, 2004; Carson *et al.*, 2006; Laaidi *et al.*, 2006; Confalonieri *et al.*, 2007; Gosling *et al.*, 2007, 2009a, 2009b; Matthies *et al.*, 2008; Basu, 2009; Jendritzky and de Dear, 2009; Menne and Matthies, 2009; Tobías *et al.*, 2010). That summer many western European countries experienced dramatic death tolls, and temperatures were considered as 'a shape of things to come' (Beniston, 2004). The analysis of isolated extreme events in addition to the mean climate is supported by empirical evidence that impacts of high temperatures are different from those associated with variability in the mean climate: they tend to be greater within a shorter time frame (Hanson *et al.*, 2007). Moreover, such analysis provides an useful insight into the short-term response of populations to these events at the regional level.

Although the extremely hot summer of 2003 in Western Europe is well-known and well-studied (Parry *et al.*, 2007; Euroheat, 2009; D'Ippoliti *et al.*, 2010), another hot summer, in 2007, concentrated more significantly in southeastern Europe, has not received as much attention. This year was one of the warmest in the history of instrumental observations in Greece (Founda and Giannakopoulos, 2009), Romania (Busuioc *et al.*, 2007) and Moldova; in the latter, practically all temperature records were broken in winter, spring and especially in summer, including the all-time record maximum temperature of 41.5°C, reported on 21st July (Bugaeva and Mironova, 2007). Similar to the perception of 2003 in western and central Europe (Beniston, 2004), the year 2007 also appears unusual given Moldova's historical climate (Corobov *et al.*, 2010). This fact, along with general drying of Moldova's climate and a nearly complete lack of national biometeorological studies in recent times, has triggered this research.

Several basic aspects shaped its content. The first issue for debate is how heat waves should be defined. In the absence of an adequate definition, it is impossible to

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assess either their change in the past or their possible consequences for the future. In the scientific literature, heat waves have various and in some cases overlapping definitions. According to the most recent (IPCC, 2012, p. 560) a heat wave is 'A period of abnormally hot weather'. Reasoning by analogy, a heat day could be defined as 'A day of abnormally hot weather'. Heat waves occur typically on synoptic scales, being often associated with the development of large stationary or quasi-stationary high pressure systems (Kyselý, 2007, 2010; Koffi and Koffi, 2008), and are usually characterized by a very large positive anomaly of air temperature of several days duration. Because heat waves differ spatially in their duration, intensity and time intervals between individual events, their studies are generally based on combinations of these three dimensions. In turn, heat intensity can either be based on the probability of occurrence of given percentiles or on temperature threshold exceedance with respect to a given reference period and given time frame (days, month and season). The choice of an appropriate reference period is tied to the task to be addressed.

Different probability-based (*relative*) and threshold-based (*absolute*) definitions of heat waves, which were used for their identification, can be found in numerous articles (Huynen *et al.*, 2001; Vescovi *et al.*, 2005; Beniston *et al.*, 2007; Della-Marta *et al.*, 2007; Medina-Ramón and Schwartz, 2007; Koffi and Koffi, 2008; Kyselý and Kříž, 2008; EuroHEAT, 2009; Kyselý and Kim, 2009; Menne and Matthies, 2009; Orlowsky and Seneviratne, 2012). At the same time, both these approaches have their advantages and limitations in their relations to impacts, which are summarized in the IPCC Special Report (IPCC, 2012) as follows:

- Single absolute thresholds, which measure heat events of a *fixed intensity*, are space- and time-depended, being specific for every locations and time periods as well as to local population sensitivity to health.
- Relative thresholds, which measure heat events of a *fixed rarity* from the extreme tails of probability distributions is not necessarily extreme in terms of impacts. Moreover, as Ballester *et al.* (2009) noted, the choice of percentiles can be a 'trickier problem'.

These limitations hinder the formulation of a 'standard' heat wave definition and explain why it does not currently exist. From the view of this research, though heat waves are meteorological events, as the most suitable definitions appear those, which refer to human health impacts. One of such definition was proposed by Robinson (2001): '. . . an extended period of unusually high atmosphere related heat stress, which causes temporary modifications in lifestyle, and which may have adverse health consequences for the affected population'. Under such an approach, a critical moment in heat wave identification is to define a threshold above which it is believed that ambient temperatures may be hazardous to human well-being. The threshold value cannot be an arbitrarily chosen number; it has to be based on comprehensive studies that assess in terms of excess deaths the limits of human tolerance to hot temperatures.

The objective of this study was thus to estimate the effect of hot temperatures on mortality of Moldavian population, using the record drought and heat waves the country experienced in 2007 as a case study.

2. Materials and methods

We examined temperature exposure during the warm season, rather than limiting the research only to extremely high temperature periods or individual heat waves. The study period included 6 months (1 April to 30 September) for each of 9 years (2000–2008).

Daily mean (T_{mean}), maximum (T_{max}) and minimum (T_{min}) temperatures, as pertinent indicators of the observed and potential mortality impacts, were provided by the State Hydrometeorological Service of Moldova. In addition, apparent temperature (AT), as a measure of perceived exposure, was derived according to Steadman (1984):

$$\mathrm{AT} = -2.653 + (0.994 \times T_{\mathrm{a}}) + \left(0.0153 \times T_{\mathrm{d}}^{2}\right)$$

where T_{a} is air temperature and T_{d} is dew point temperature. Because AT was one of the main exposure measures, humidity was not modelled separately.

Daily mortality data comprised all-cause deaths in the resident population of Chisinau. A total of 26 651 deaths were recorded in the city during the summer months of the 2000–2008 period, including 3106 who died in 2007. This information was retrieved from the death certificates archived at the National Center of Management in Health and represents both urban and rural population. As of 1 January 2009, of the 785 400 residents of Chisinau, 716 920 (91.3%) resided in the city itself, with the remainder in the suburban area. On the whole, the study encompasses about a quarter of Moldova's population, including about half of the urban one. To remove an inherent seasonality in daily mortality records, a common 'observed−expected' method (Dessai, 2002; Gosling *et al.*, 2007) was used. An expected or reference mortality baseline was calculated as average death counts for each day of the study period where the warm period of 2007 was excluded. For greater reliability, both the expected and observed mortalities were taken as fixed daily death counts and their 7-d moving averages. Seven-day smoothing was selected as optimal in comparison with other alternatives (e.g. 3 or 31 d) because it is associated with small errors, yet still includes the entire weekly cycle of mortality. Subtraction of the reference mortality from daily mortality observed in 2007 resulted in mortality anomalies, or excess deaths.

The aggregate dose–response relationship between elevated temperatures and mortality was examined by grouping the daily excess death counts into non-overlapping 2 °C class intervals of temperature variables; the 0.01 °C increment of grouping ensured no loss of excess deaths. Because sample sizes (days) were small for

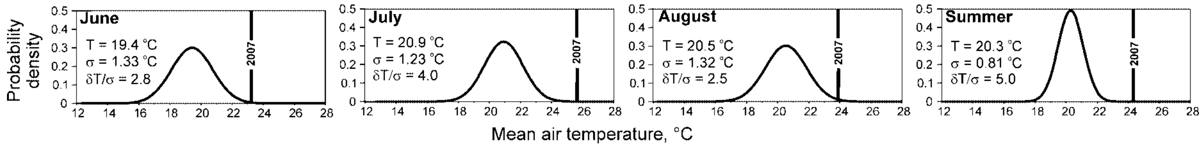

Figure 1. Mean monthly and summer air temperature in Chisinau in 2007 (vertical lines) relative to the temperatures of baseline 30 years (1961–1990), approximated by a normal distribution curve. T, observed temperatures; σ, standard deviation of the baseline period; $\delta T/\sigma$, normalized anomalies from baseline norms.

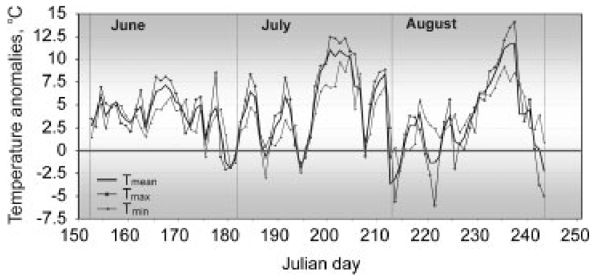

Figure 2. Deviations of Chisinau daily air temperatures in summer 2007 from their baseline values (horizontal zero line).

very high temperatures, only the intervals with samples including at least 5 d were considered. Poisson regression analysis was used to assess excess mortality sensitivity to heat above threshold temperature (TT).

From different approaches to heat-wave identification we decided to use the one based on the combination of relative TT with their durations. A two-level criterion, similar to Meehl and Tebaldi (2004), was selected. According to this criterion, a heat wave is the longest continuous period satisfying the following three conditions:

(i) The daily maximum temperature must be above T1 for at least three consecutive days.
(ii) The average daily maximum temperature must be at least T1 for the entire period.
(iii) The daily maximum temperature must be above T2 for every day of the entire period.

T1 and T2 were identified as those percentiles of temperatures distribution in the current climate that best match the identified TTs.

Some details on the methods are described in the corresponding subsections of the article. All statistical analyses were performed with the StatGraphics Centurion Data Analysis and Statistical Software (Statgraphics Centurion XVI User Manual, 2009)

3. Results and discussion

3.1. Air temperature and mortality of 2007 compared with reference values

The entire warm period of 2007 was unusual by its temperatures, but the summer months were extremely hot. Some illustrations of their extreme character are given in Figures 1 and 2 as well as in Table 1 that show the summary statistics for each of the variable selected for the research. The climatological analysis was carried out for three subsamples: the baseline period (1961–1990), the reference period (2000–2008 without 2007) as well as 2007 itself.

Figure 1 compares mean monthly and mean summer air temperatures in Chisinau with their distributions in the baseline period. The monthly temperatures in 2007 exceeded the baseline climate by 2.5–4.0σ, and the summer temperature by 5σ. Moreover, all three mean temperature variables for June through August 2007 exceeded the 95th percentile of the baseline climate (Table 2), exceeding the baseline normal by up to 12 °C. Such anomalies of monthly temperatures resulted from extremely hot days over the summer (Figure 2).

In the warm period of 2007, the average total daily mortality was higher than in the reference period by one death per day (Table 1). The connection between anomalous mortality and daily temperature is shown in Figure 3. The monthly analysis, carried out with a different approach, is shown in Table 3. Similar results are observed when using fixed daily mortality values or 7-d smoothed values.

In sum, in the warm season of 2007 the excess mortality in Chisinau, depending on the procedure of its calculation, reached between 190 and 200 deaths, or 6.5–6.9% of this period's reference mortality. Given the negative excess mortality in September, we can presuppose a certain mortality displacement that will be discussed below.

3.2. Temperature–mortality relationships above the 'thresholds'

General temperature–mortality relationships in reference or 'normal' warm seasons are valid to certain 'threshold' temperatures, above which these relationships change. The TTs were identified as the centres of the lowest 2 °C class intervals of temperature variables, approximated by cubic splines, above which excess mortality rates began a sharp increase from their zero reference value (Figure 4). A comparison of the temperature variables' thresholds with their corresponding summer averages for the reference period (Table 4) shows that for T_{mean} and T_{max} they exceed reference 'norms' by 3–4 °C, and for T_{min} by 1–2 °C. This difference suggests a greater sensitivity of excess mortality to an increase in warm night temperatures.

The nonlinear Poisson regression analyses, performed on the data above TTs, produced suitable approximations of high temperature–excess mortality relationships

Table 1. Descriptive statistics of the warm period (April to September) air temperature (°C) and daily mortality (deaths counts) in Chisinau for different periods of averaging.

Variable	Period	Statistics				
		Average	SD (σ)	Min	Max	Range
	1961–1990	17.3	3.9	8.1	22.3	14.2
T_{mean}	2000–2008	18.1	4.4	7.0	24.6	17.6
	2007	19.9	6.2	5.7	32.5	26.8
	1961–1990	22.8	3.9	13.7	28.4	14.7
T_{max}	2000–2008	23.5	4.6	11.2	30.3	19.1
	2007	25.5	7.0	6.7	39.4	32.7
T_{min}	1961–1990	12.3	3.7	4.0	17.2	13.2
	2000–2008	13.5	4.2	2.7	19.8	17.1
	2007	14.8	5.6	2.0	26.6	24.6
Mortality, case/day	2000–2008	16.1	1.8	9.0	20.5	11.5
	2007	17.1	4.9	8.0	34.0	26.0

Table 2. Summer 2007 temperatures (°C) in Chisinau in comparison with 90 and 95% quantiles of their distribution in the baseline climate.

Month	Monthly air temperature								
	Mean			Maximum			Minimum		
	2007	1961–1990		2007	1961–1990		2007	1961–1990	
		90%	95%		90%	95%		90%	95%
June	23.2	20.7	21.0	28.9	26.3	26.7	17.7	15.6	15.9
July	25.8	21.8	22.0	32.3	27.4	27.7	19.7	16.7	16.9
August	23.9	22.0	22.4	29.3	27.8	28.2	19.1	16.8	17.2
Summer	24.3	21.7	22.2	30.2	27.4	27.9	18.8	16.7	17.1

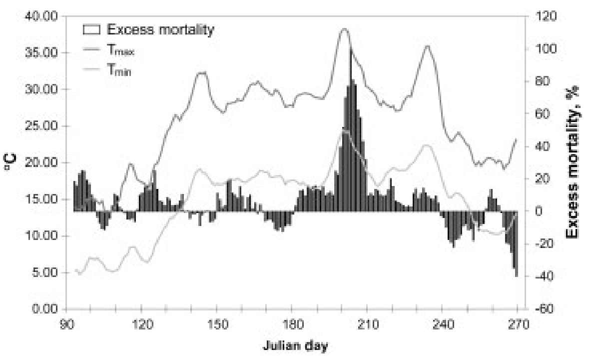

Figure 3. Dynamic of the excess mortality (columns) and temperatures in Chisinau in 2007.

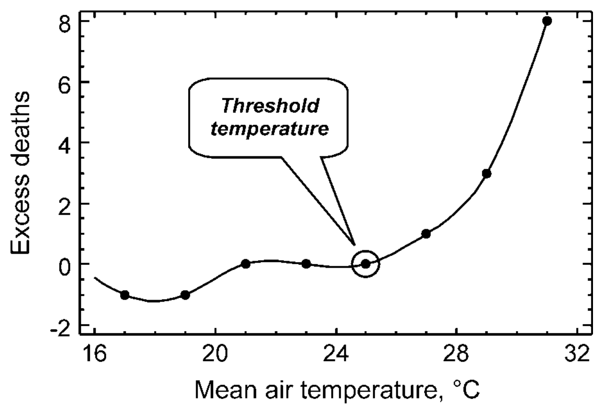

Figure 4. An example of the cubic spline of excess daily mortality grouped by 2 °C class intervals around the threshold value (mean air temperature).

(Table 4). Statistical significance and high levels of the explained variance (R^2) of excess mortality allow estimating the possible excess deaths at air and ATs above their specific 'tolerable-heat' threshold values (Table 5). Here, the higher ends of heat exposure are close to the maximum temperatures observed in Chisinau in summer 2007. With mean daily summer mortality in the reference period equal to 16.0 deaths, mean excess mortality increases from 2.0 to 4.4% per 1 °C increase in temperature, depending on temperature variable chosen. These results are close to other European estimates (Kyselý and Huth, 2004; Kyselý and Kříž, 2008; Menne and Matthies, 2009).

3.3. Heat-episode analysis

3.3.1. *Threshold temperatures versus percentiles*

Relative thresholds, determined by percentiles of the selected variable's distribution, are usually used to determine potential thresholds for heat–health watch–warning systems. In Table 6, the absolute thresholds are compared with four percentiles of baseline and reference summer (June to August) climate. The 90th percentile is the indicator of an extreme event according to IPCC definition

Table 3. Warm period excess mortality (death cases) in Chisinau in 2007, calculated using observed and 7-d smoothed data.

Variants of comparison	Month						Warm period
	April	May	June	July	August	September	
Observed mortality in 2007	565	538	491	608	507	397	3106
Reference mortality	536	518	481	462	475	444	2916
Excess mortality	29	20	10	146	32	−47	190
7-d smoothed mortality in 2007	504	540	487	609	508	359	3007
7-d smoothed reference mortality	480	516	482	464	475	393	2810
Excess mortality	24	24	5	145	33	−34	197
Fixed mortality of 2007[a] *versus* 7-d smoothed reference mortality	28	22	9	144	32	−34	201

[a]In this comparison, to have equal lengths of records, there were excluded three first (last) days of April (September) reference mortalities.

Table 4. Poisson regression of excess mortality (EM) on temperatures above their thresholds' integer values.

Variable	Statistics								The fitted model equation
	RT (°C)	TT (°C)	R^2	*P*-value		Error			
				Model	Residual	MSE	MAE	ME	
T_{mean}	21.6	25	.954	0.003	0.734	0.67	0.33	−0.13	$EM = \exp(-15.89 + 0.581 \times T_{mean})$
T_{max}	27.1	31	.886	0.007	0.625	0.38	0.29	0.04	$EM = \exp(-19.50 + 0.569 \times T_{max})$
T_{min}	16.8	19	.946	0.000	0.682	1.39	0.53	0.23	$EM = \exp(-20.19 + 0.835 \times T_{min})$
AT_{mean}	21.4	24	.914	0.001	0.909	0.28	0.39	−0.16	$EM = \exp(-13.93 + 0.497 \times AT_{mean})$
AT_{max}	26.3	30	.947	0.000	0.869	0.10	0.17	−0.09	$EM = \exp(-19.54 + 0.577 \times AT_{max})$
AT_{min}	16.1	17	.940	0.005	0.918	0.07	0.22	−0.10	$EM = \exp(-18.89 + 0.802 \times AT_{min})$

P-value for the model <0.05 indicates a statistically significant relationship between the variables at the 95.0% confidence level; *P*-value >0.05 for the residuals indicate that the model is not significantly worse than the best possible model for this data at the 95.0% or higher confidence level.
RT, summer daily temperature of the reference period; TT, threshold temperature; MSE, mean standard; MAE, mean absolute; ME, mean errors.

(IPCC, 2007), the 95th percentile is the delimiter of extreme events of low and high intensity in the EuroHeat classification (EuroHEAT, 2009), the 99th percentile characterizes the event of special rarity and severity (Schwartz (2005)), and the 97.5th percentile was selected as some interim percentile. As evidence of a warming climate, the thresholds identified for Chisinau were above the 99th percentile in the historical climate record. Assessing more recent years, the T_{mean}, T_{max} and T_{min} thresholds are close, respectively, to the 95–97.5th, 97.5th and 90th percentiles of their daily distribution in the reference period of 2000–2008 (excluding 2007). Thresholds for the ATs are somewhat lower.

3.3.2. *Heat episodes of 2007 and related excess mortality*

We identified T1 and T2 in the heat wave two-level criterion (Section 2) in such a way as to cover the 90–99th percentile tails of T_{max} distribution in the more recent (2000–2008) climate. On the one hand, T1 (the 99th percentile, ~32 °C), being slightly above the T_{max} threshold (Table 6), identifies heat days of exceptional intensity. On the other hand, T2 (the 90th percentile of T_{max}, 29.7 °C), though being somewhat below the threshold value, allows the inclusion of days with temperatures that might be nevertheless associated with excess mortality. Heat days represent individual days that exceeded these thresholds, but for which the duration criteria for a heat wave was not met.

The heat waves during summer 2007 in Chisinau, identified by these criteria, are shown in Figure 5 and their characteristics in Table 7. On the whole, in May to September six heat waves and two individual heat days, with a total duration of 47 d, were observed. The longest and most intense heat wave, which lasted over the second-half of July, resulted in 116 excess deaths. This evidence supports the statement of the EuroHEAT Technical summary (Menne and Matthies, 2009) that heat waves with a long duration and high intensity have the highest impact on mortality.

On the whole, enumerated heat events caused 146 excess deaths or about 77% of the total number in the warm period of 2007. This percent is higher than the EuroHEAT results – from 7.6 to 33.6% (Menne and Matthies, 2009; D'Ippoliti *et al.*, 2010) and differs from suggestions that mortality attributable directly to heat events is relatively small, and the majority of deaths occur at times other than during identified heat wave periods (WHO, 2006). We explain our results by the greater number, intensity and total duration of heat events in the Chisinau study of one very extreme summer of 2007, whereas EuroHEAT project included nine European cities; that project also showed a high heterogeneity of the effect between cities and populations.

Table 5. Excess mortality change with 1 °C temperature increase above threshold values. In bold there are shown excess deaths at temperature thresholds.

T scale	Excess death counts					
	Temperature			Apparent temperature		
	Mean	Max	Min	Mean	Max	Min
18	–	–	–	–	–	**0.01**
19	–	–	**0.01**	–	–	0.03
20	–	–	0.03	–	–	0.06
21	–	–	0.07	–	–	0.13
22	–	–	0.16	–	–	0.29
23	–	–	0.37	–	–	0.64
24	–	–	0.86	–	–	1.43
25	**0.26**	–	1.98	**0.22**	–	3.19
26	0.46	–	4.57	0.36	–	7.11
27	0.82	–	10.5	0.6	–	15.9
28	1.46	–	–	0.99	–	–
29	2.61	–	–	1.62	–	–
30	4.66	–	–	2.66	**0.11**	–
31	8.34	**0.16**	–	4.38	0.19	–
32	14.9	0.27	–	7.2	0.34	–
33	26.7	0.49	–	11.83	0.61	–
34	–	0.86	–	–	1.08	–
35	–	1.51	–	–	1.93	–
36	–	2.68	–	–	3.43	–
37	–	4.73	–	–	6.1	–
38	–	8.35	–	–	10.9	–
39	–	14.8	–	–	19.4	–
40	–	26.2	–	–	–	–
Average related excess mortality (%)						
–	4.2	3.8	2	3.3	4.4	2.9

Table 6. Threshold daily summer temperatures against different percentiles of their baseline (1961–1990) and reference (2000–2008) distributions.

Percentile	Period	Air temperature (°C)			Apparent temperature (°C)		
		Mean	Max	Min	Mean	Max	Min
90.0	1961–1990	21.7	27.4	16.7	–	–	–
	2000–2008	23.9	29.7	19.0	24.3	29.4	19.0
95.0	1961–1990	22.2	27.9	17.1	–	–	–
	2000–2008	24.5	30.4	19.6	25.1	30.3	19.9
97.5	1961–1990	22.5	28.3	17.4	–	–	–
	2000–2008	25.1	31.1	20.2	25.9	31.0	20.6
99.0	1961–1990	22.9	28.7	17.8	–	–	–
	2000–2008	25.7	31.8	20.8	26.7	31.9	21.5
Threshold temperatures		24.8	30.9	18.5	24.0	30.4	17.0

3.3.3. *Sensitivity analysis: lag effects and mortality displacement*

Different approaches are used to examine possible lag effects. Basu *et al.* (2008) examined several lag times through an exploratory analysis and found that a single-day effect of same-day AT exposure (lag 0) had the best model fit in comparison with moving averages over the same day and previous 3 d (lag 0–3) or the previous 3 d (lag 1–3). Gasparrini *et al.* (2010) also showed a very strong and immediate effect of heat, but suggested a more delayed effect for extremely hot temperatures. Gosling *et al.* (2007) studied the possible influence of lag effects, calculating excess deaths per day for up to 12 d afterwards. Taking into account the continuity of the heat waves observed in 2007 in Chisinau, we decided to test a likely lag effect through a cross-correlation analysis where in a simple linear analysis the excess mortality and temperature were, correspondingly, the dependent and independent variables. The best fitted lag was estimated and the results are presented in expanded form in Table 8. In our results, the same-day correlation between temperature and mortality is not statistically significant. Rather, these relationships become stronger as time lag increases. Maximal effects are revealed on the second and third days (except in April) for T_{mean} and T_{max}, but on the first and second day for T_{min}. This result

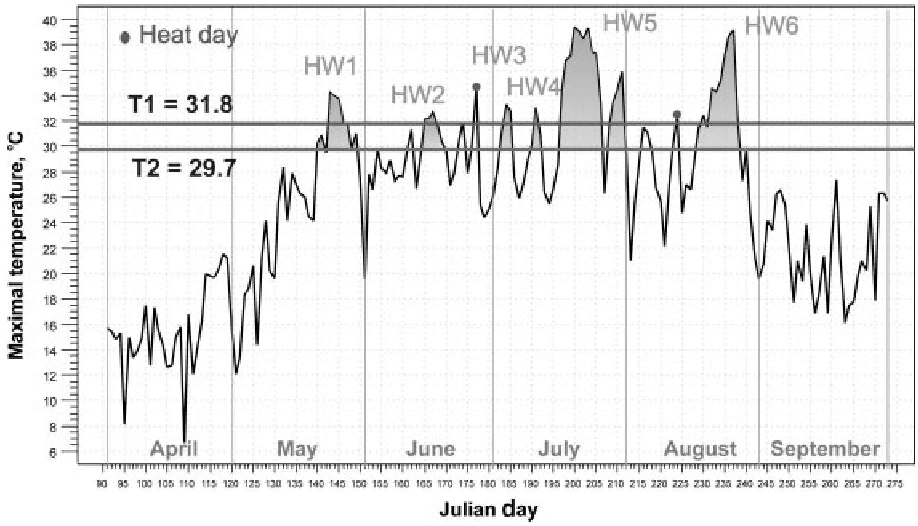

Figure 5. Heat-wave sequence in Chisinau in 2007.

Table 7. Heat wave (HW) and heat day (HD) characteristics.

HW, HD	Duration (d)	Period	Abs T_{max} (°C)	Excess deaths
HW1	8	22.05–29.05	34.2	2
HW2	5	14.06–18.06	32.7	3
HD1	1	26.06	34.7	−6
HW3	3	02.07–04.07	33.3	5
HW4	3	09.07–11.07	33.1	11
HW5	16	16.07–31.07	39.4	116
HD2	1	12.08	32.5	1
HW6	10	17.08–26.08	39.2	14
Total	47	–	–	146

is a further evidence of the greater sensitivity of mortality to night temperatures.

Heat waves create additional impacts on the human population, beyond those of the general temperature–mortality relationship (Hajat *et al.*, 2006). In the first part of Chisinau's 'normal' warm season an inverse relationship between temperature and daily mortality is observed, lasting usually up to its optimal value in late July (Corobov and Opopol, 2010). In 2007, this relationship is also evident from the negative sign of *r* in April to June that is manifested with different lags. In other words, when temperature is below its optimal value one cannot speak about 'excess death' because of so-called added positive effects of higher temperatures on negative temperature–mortality dependencies. These results differ from other studies that have shown an increased impact of early-season heat waves (Sheridan and Kalkstein, 2010); but in this case it may be due to the lack of substantial heat events early in the 2007 warm season. Further research on the seasonal trends in heat impacts on a longer data set is warranted. The combination of two effects – the seasonal rise in temperature, which accompanies a decrease in mortality rates, and the occurrence of heat waves that cause an increase in mortality – makes the temperature–mortality relationship difficult to quantify. However, in July we observe a sharp ubiquitous transition to high positive correlations between temperature and excess mortality.

While the heat wave analysis provides a useful insight into the short-term human response to a heat event, it can overestimate the temperature effect due to mortality displacement, or 'harvesting'. O'Neill and Ebi (2009) describe this phenomenon as an idea that some deaths associated with exposure to extreme temperature are those already expected among a frail subset of the population who would have died shortly thereafter anyway, regardless of the weather. Such deaths are only advanced by a few days, and hence do not represent a substantial shortening of a person's life. But although mortality displacement is often observed during heat waves, the real estimates of its contribution are not as common in the literature. At the same time, this concept is critically important for estimating the overall population-burden associated with exposure to extreme temperatures; the explicit evaluations whether the temperature effects represent 'harvesting' are also valuable for predicting the future impacts.

Mortality displacement is usually calculated as the relative percentage comparison of the mortality deficit (a number of 'negative excess deaths' after a heat wave, i.e. their quantity below the expected values) with that during heat waves (Le Tertre *et al.*, 2006; Gosling *et al.*, 2007; Kyselý and Kříž, 2008). Sometimes, such estimates are made for defined periods that include 'before', 'during' and 'after' the heat wave terms typically lasting less than 2 months (Gosling *et al.*, 2009a). However, any simple algorithms are good only when dealing with an isolated heat wave. When we have a high-frequency series of heat events, as in Figure 5, the interference of their effects complicates this task. Here, the excess mortality was observed each month of the May to August period. Therefore, as a total 'harvesting' effect we decided to consider the 'negative excess mortality' in September (about 35–45 deaths) that, based on different methods

Table 8. Lag effect in the dependency of excess deaths on air temperature in 2007.

Month	Lag (d)									
	0		1		2		3		4	
	r	*p*	*r*	*p*	*r*	*p*	*r*	*p*	*r*	*p*
Mean temperature										
April	−0.227	0.229	**−0.333**	0.078	−0.172	0.381	–	–	–	–
May	−0.231	0.210	−0.224	0.223	**−0.319**	0.080	−0.290	0.113	–	–
June	0.024	0.901	−0.006	0.973	−0.310	0.096	**−0.499**	0.005	−0.077	0.686
July	0.296	0.106	0.628	0.000	0.653	0.000	**0.686**	0.000	0.525	0.002
August	0.270	0.142	0.112	0.550	**0.345**	0.058	0.253	0.170	–	–
September	−0.137	0.467	0.067	0.738	**0.185**	0.330	0.172	0.347	–	–
Maximum temperature										
April	−0.126	0.508	−0.180	0.351	**−0.183**	0.351	−0.098	0.627	–	–
May	−0.108	0.564	−0.227	0.218	−0.302	0.099	**−0.338**	0.063	−0.199	0.284
June	−0.130	0.494	0.136	0.473	−0.300	0.107	**−0.593**	0.001	0.167	0.379
July	0.300	0.101	0.651	0.000	**0.703**	0.000	0.637	0.000	0.531	0.002
August	−0.089	0.638	0.199	0.284	**0.269**	0.143	0.211	0.255	–	–
September	−0.174	0.358	0.115	0.543	0.137	0.470	**0.281**	0.132	0.019	0.920
Minimum temperature										
April	−0.342	0.064	**−0.294**	0.121	−0.092	0.642	–	–	–	–
May	−0.243	0.188	−0.255	0.167	**−0.312**	0.088	−0.231	0.212	–	–
June	0.140	0.460	−0.221	0.241	**−0.254**	0.156	−0.254	0.175	–	–
July	0.374	0.038	**0.663**	0.000	0.606	0.000	0.642	0.000	–	–
August	0.297	0.104	0.184	0.322	**0.372**	0.039	−0.012	0.950	–	–
September	−0.039	0.838	−0.053	0.779	**0.154**	0.416	−0.102	0.591	–	–

Bold values indicate the best fit of models.
r, Pearson correlation coefficient; *p*, statistical significance of correlation.

of estimations (Table 2), amounts to about 17–25% of the total 'positive' excess deaths. For comparison, in the Czech Republic this effect was found to account on average for as much as 90% of the excess mortality during heat waves (Kyselý and Huth, 2004), though in one French study it varied from 1 to 30% (Le Tertre *et al.*, 2006).

4. Conclusion

Although the human impacts of excessive heat has been well established in the literature, this study contributes to our knowledge by assessing a region – the northern Black Sea region – and an event – the summer of 2007 – that has been relatively understudied. In Moldova, we uncovered a significant correlation between excess human mortality and temperature variables, with similar results appearing across several temperature and AT variables. In 2007 at least, a shift in the temperature–mortality relationship was observed in mid-summer, coinciding with the onset of the most severe heat waves. Our results support the use of lagged data in heat-episode studies, as a lag in heat wave mortality effect depends on the peculiarity of the selected temperature variable, being minimal (1–2 d) for increases in minimum temperatures and more delayed (2–3 d) for increases in mean and maximum temperatures. This specificity, as well as the lower temperature threshold for minimum temperature, supports a higher sensitivity of excess human mortality to night temperatures.

Given the warming of Moldova's climate, it was shown that, defining the TTs for heat wave identification, one should take into account the observed trends and changes in regional climate, as the extreme temperature percentiles have increased. Otherwise, the parameters of possible heat waves can be underestimated. Further, such a city-specific analysis is important because of evident regional differences in the human acclimatization to heat and imperative for the proper development of a heat health watch warning system. Under the projected future increases in heat wave frequency, severity and duration, today's population tolerance to heat may become insufficient to cope with heat wave consequences for human health.

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