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Research Article

Warm Season Temperature-Mortality Relationships in Chisinau (Moldova)

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Results of the epidemiological study of relationships between air temperature and daily mortality in Chisinau (Moldova) are presented. The research's main task included description of mortality dependence on different temperature variables and identification of thermal optimum (minimal mortality temperature, MMT). Total daily deaths were used to characterize the mortality of urban and rural populations in April–September of 2000–2008, excluding the extremely warm season of 2007. The simple moving average procedure and 2nd-order polynomials were used for daily mean (T_{mean}), maximum (T_{max}), and minimum (T_{min}) temperatures and mortality approximation. Thermal optimum for mortality in Chisinau (15.2 deaths) was observed at T_{mean}, T_{max}, and T_{min} about 22°C, 27-28°C, and 17-18°C, respectively. Considering these values as certain cut-points, the correlations between temperature and mortality were estimated below and above MMTs. With air temperatures below its optimal value, each additional 1°C increase of T_{mean} (T_{max}, T_{min}) was accompanied by 1.40% (1.35%, 1.52%) decrease in daily mortality. The increase of T_{mean} and T_{max} above optimal values was associated with ~2.8% and 3.5% increase of mortality; results for T_{min} were not statistically significant. The dependency of mortality on apparent temperature was somewhat weaker below MMT; a significant relationship above MMT was not identified.

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 [1–11]. That summer many western European countries experienced dramatic death tolls, and temperatures were considered as "a shape of things to come" [12].

However, while an analysis of isolated heat waves provides a useful insight into the short-term response of populations to these events, the time-series epidemiological analysis of temperature-mortality association over a long time period enables the investigation and quantification of not only general temperature-related mortality dependencies, but also additional meteorological, environmental and social confounding risk factors (e.g., [1, 13–16]). In such studies, a J- or U-shaped relationship between temperature and mortality is often identified [4, 6].

Air temperature is usually expressed in terms of its mean (T_{mean}), maximum (T_{max}), or minimum (T_{min}) values as well as the composite indices such as apparent temperature (AT) that takes into account humidity; in particular, it was shown that heat-related mortality is generally better identified when effects of high humidity are taken into account [17]. A greater response of mortality to daily T_{max} was shown by Kyselý and Kříž [18] and Michelozzi et al. [19]; Gosling et al. [4] noted that very little attention is paid to the explicit role of a diurnal temperature range.

Table 1: Mean air temperature and aggregated daily deaths in April–September in Chisinau.

	Years								
	2000	2001	2002	2003	2004	2005	2006	2007	2008
Air temperature	18.5	18.1	18.5	18.4	17.3	18.2	18.0	19.9	18.2
Mortality counts	2802	2748	2966	2939	2880	3115	2978	3108	3117

This paper presents a part of the comprehensive analysis of impacts on human health carried out in the framework of climatological and epidemiological justification of the development of Heat Health Warning System (HHWS) for Moldova. The research was motivated by observations of a general warming of Moldova's climate, including the record heat waves of 2007 [20], and a complete lack of national biometeorological research in the country in recent times, especially concerning the impact of elevated summer temperatures. Therefore, the main goal of this paper was to present the first modern study of the regional relationships between population mortality and a warm period temperature regime in the capital city of Chisinau.

2. Materials and Methods

2.1. Initial Data. The air temperature exposure was examined during the warm seasons (April 1 to September 30) over the nine-year study period (2000–2008).

Daily mortality data comprised total daily counts of deaths from all causes in the resident population of Chisinau. This information was retrieved from the death certificates archived at the National Center of Management in Health. The data represented 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 encompassed about a quarter of Moldova's population at that time, including about half of the urban one.

Daily meteorological data were provided by the State Hydrometeorological Service. The daily values were calculated as the average of eight 3h measurements. The chosen period is long enough for statistical processing and does not include a significant long-term trend in air temperature (Table 1). Since the goal of research was to find the shape of relationships between ambient temperature and mortality for "typical" years, the year 2007, when the extremely intensive heat waves were recorded, was excluded.

In addition, apparent temperature (AT), as a measure of perceived exposure, was derived according to Steadman [21]:

$$\mathrm{AT} = -2.653 + \left(0.994 * T_a\right) + \left(0.0153 * T_d^2\right), \tag{1}$$

where T_a is air temperature and T_d is dew point temperature. Because apparent temperature was one of the main exposure measures, humidity was not modeled separately.

2.2. Temperature-Mortality Relationships Identification. This research involves explaining mortality as a health outcome based upon ambient air temperature, considered as a predictor, and potentially confounding variables, for example, month (season). To identify temperature-mortality relationships, both dependent (death) and independent (daily temperature) variables were averaged over the entire sample period: 2000–2008 years without the year 2007 (hereafter, for the sake of simplicity, in all descriptions of this period it is implied that 2007 is omitted). Such averaging smoothed the possible long-term trends and year-to-year variability in data and improved "signal-to-noise" ratio.

Because mortality has its inherent seasonal cycle that is not directly related to immediate atmospheric conditions, some forms of smoothing are usually used to account for seasonal patterns [2, 13, 22, 23]. In our study, a simple moving average procedure was used to choose the optimal degree of smoothing. To identify the statistically significant differences among monthly averaged deaths, or the presence of seasonality in daily mortality, the one-way analysis of variance (ANOVA) statistical tool [24] was applied.

The different forms of regression analysis, which utilized temperature variables as independent variables and mortality as a dependent variable, serve as a reliable research tool for the adequate description of temperature-mortality relationships. Given that the temperature-mortality relationship tends to be U-shaped, and the left and right slopes of the U-like curve represent respectively the cold- and heat-related impacts of temperature, these two segments of impacts need to be accounted for separately [13, 25, 26].

To calculate these slopes separately, it is important to find the breakpoint where, while temperature increases, mortality no longer decreases, thus reaching its *minimum value*, and increases thereafter. This *thermal optimum* [8] corresponds to the average temperature with the lowest mean mortality. Some research, for example, Vigotti et al. [26], uses for this point the term "minimum mortality temperature" (MMT). As far back as in the 1990s, the Europe-wide Euro summer project [27] revealed the existence of a relatively narrow temperature band in which mortality is the lowest. This band varies substantially within Europe, the USA and other countries (e.g., [28]). Different methods are used to identify MMT. For instance, Donaldson et al. [28] calculated the temperature at which daily mortality was the lowest by computing the mean daily mortality over a range of 3°C at successive 0.1°C intervals. The upper margin of this band was taken as the temperature of heat-related mortality onset. They also found that using narrower bands gives data with excessive random variability. The same approach was used by Laaidi et al. [8] to study temperature-related mortality in France. To smooth the high variability in daily mortality, sometimes evident at higher temperatures, the 2°C class interval was used by Gosling et al. [6].

In our research, the narrow-band approach has proved itself to be a good identifier of thermal optima as well as excess death thresholds in the heat-event study [29]. We grouped daily deaths into 2°C temperature class intervals with 0.01°C increments; such increments allow preserving all

Table 2: Descriptive statistic of monthly averages of total daily mortality in Chisinau, 2000–2008.

Month	T_{mean} °C	Death counts								
		Sum	Average	Sd	CV, %	Min	Max	Range	Ssk	Sku
April	10.8	536	17.9 ± 0.28	1.69	9.4	14.5	20.5	6.0	−0.08	−1.11
May	16.8	517	16.7 ± 0.27	1.76	10.5	13.1	20.5	7.4	−0.09	−0.43
June	19.8	480	16.0 ± 0.28	1.64	10.2	12.8	18.8	6.0	−0.95	−0.60
July	22.6	462	14.9 ± 0.27	1.15	7.7	11.6	16.5	4.9	−1.71	0.63
August	22.4	475	15.3 ± 0.27	1.40	9.2	12.2	18.2	6.0	−0.66	−0.71
September	16.2	475	15.8 ± 0.28	1.44	9.1	13.1	19.4	6.3	1.10	0.23
Period	*16.1*	*2946*	*16.1 ± 0.26*	*1.79*	*11.1*	*11.6*	*20.5*	*8.9*	*1.53*	*−0.35*

Sd: standard deviation; CV: coefficient of variation; Ssk: standardized skewness; Sku: standardized kurtosis.

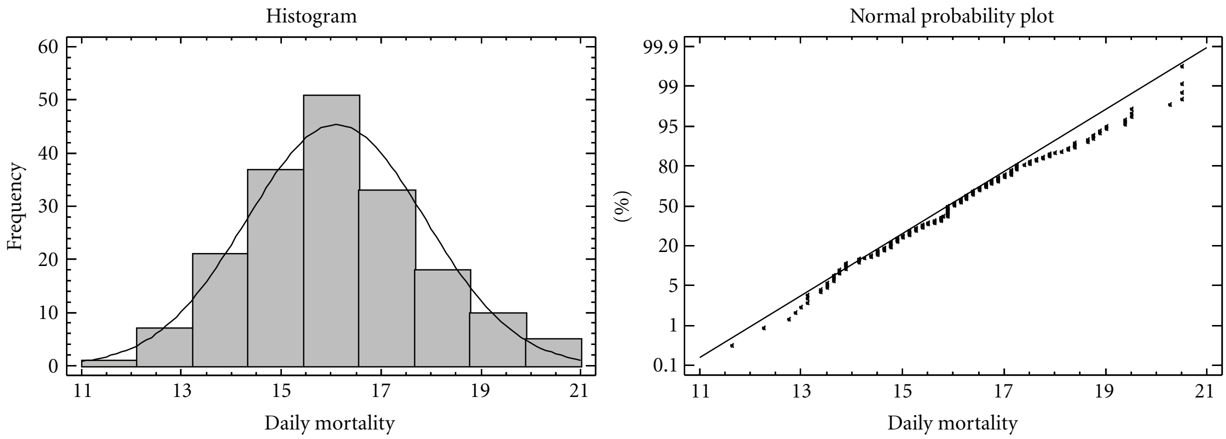


Figure 1: Normal distribution fitting of daily mortality in Chisinau in warm period, 2000–2008.

initial information given that air temperature is registered with 0.1°C resolution.

Statistical computations were performed, using the *StatGraphics Centurion Data Analysis and Statistical Software* [24].

3. Results and Discussion

3.1. Summary Statistics of Mortality. The average minimum mortality (about 15 deaths a day) was observed in July, the warmest month in Chisinau, and the maximum (about 18 deaths a day) in April (Table 2). Thus, the range of monthly averages is only 3 deaths; the range of their year-to-year variation is nearly double, at 6-7 deaths. Coefficient of correlation (CV), derived as the percentage ratio of standard deviation (Sd) to the average value, is 9-10%. Standardized skewness and kurtosis values within the range of −2 to +2 suggest that monthly deaths are close to being normally distributed. Across the warm season as a whole, daily death totals also follow a normal distribution (Figure 1).

Figure 2 demonstrates two outputs of ANOVA. In our case, mean mortality in April is statistically different from all other months; May is different from all months except June, and July is different from all months except August. All other combinations of monthly deaths show no significant differences between them. Both plots demonstrate clearly a seasonal course in mortality.

3.2. Comparison of the Information Content of Different Temperature Parameters. Undoubtedly, the quantification of temperature-mortality relationships requires the selection of an optimal metric. We found [30] that all daily temperature variables (T_{mean}, T_{max}, and T_{min}) and corresponding apparent temperatures (AT_{mean}, AT_{max}, AT_{min}) are highly ($r > .95$) and statistically significantly ($P < .001$) correlated. Slightly weaker correlations, though still generally statistically significant, are observed between daily ranges of air and apparent temperature. However, the correlations between observed temperature values and daily ranges are weak ($r < 0.3$-0.4).

Principal component analysis [24] yields similar results (Table 3). From eight components, only the first two with eigenvalues >1.0 can be used; together they account for 98.2% of the variability in the original data set. Weights of components show that the first one, accounting for 76.6% of general variability, is formed by direct characteristics of air temperature and apparent temperature, the second component with weight 21.6% by their diurnal ranges. The practically equal information adequacy of direct temperature variables, demonstrated by component weights, assumes *a priori* their adequacy in mortality description. This assumption is further supported by our research and is in full accord with the conclusion of Barnett et al. [31].

3.3. Identification of Mean Mortality Temperature. Figure 3(a) demonstrates the scatterplot of daily mortality

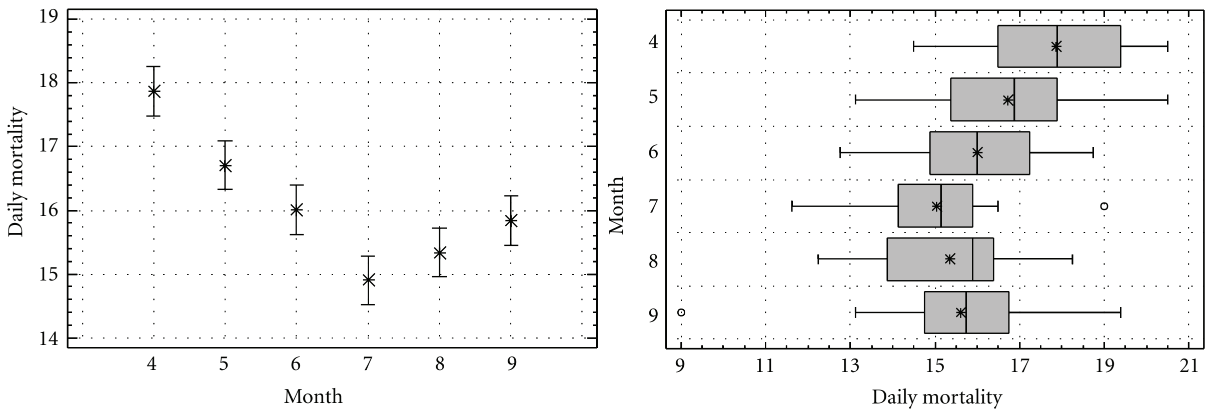
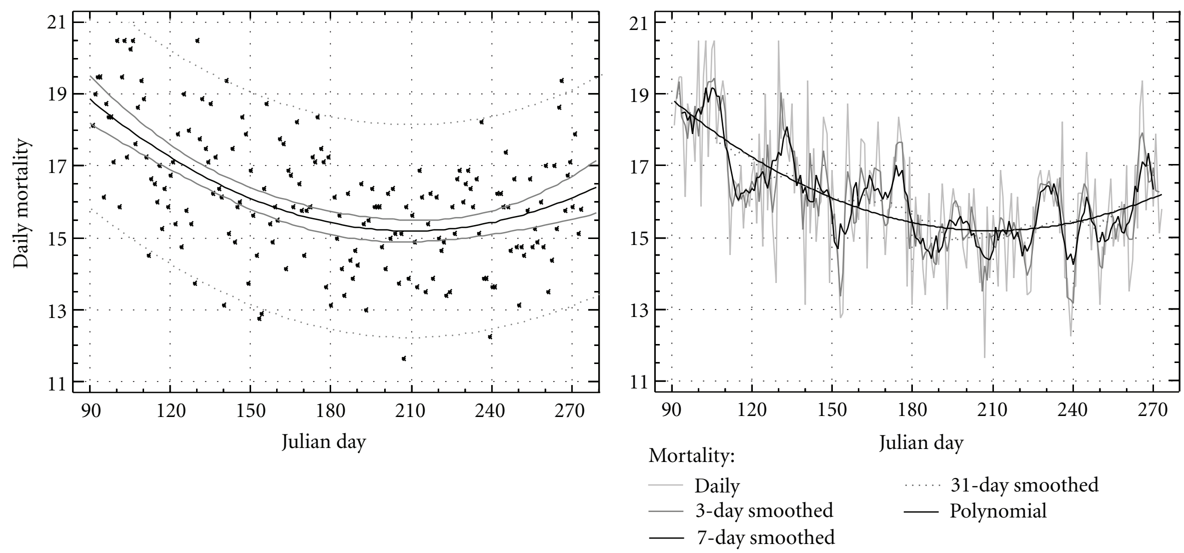


Figure 2: Mean (left) and Box-and-Whisker (right) Plots of daily deaths in warm period in Chisinau. (*Means plot* shows monthly death averages and Fisher's Least Significance Differences intervals. The overlapping of intervals signifies that two means are the same with 95% confidence.) (*The Box-and-Whisker Plot* divides data into four equal areas of frequency. The central boxes cover the middle 50% of the mortality, the box's sides are lower and upper 25% quartiles, the vertical line—the median, and the whiskers—the range. The means and outliers are marked as a single point (∗ and ∘, resp.)).



(a) (b)

Figure 3: Scatter plot of warm period daily mortality in Chisinau (2000–2008), approximated by 2nd-order polynomial (a) and simple moving averages of different length (b).

Table 3: Principal components analysis of the set of temperature characteristics: description of components (left) and components weights (right).

Component number	Eigenvalue	Percentage		Parameter	Component weight	
		Of variance	Cumulative		Component 1	Component 2
1	6.130	76.62	76.62	T_{mean}	0.402	−0.060
2	1.725	21.56	**98.18**	T_{max}	0.403	0.020
3	0.130	1.632	98.81	T_{min}	0.392	−0.172
4	0.012	0.149	99.96	AT_{mean}	0.401	−0.091
5	0.002	0.029	99.99	AT_{max}	0.403	−0.026
6	0.001	0.009	100.0	AT_{min}	0.388	−0.205
7	0.000	0.000	100.0	T_{range}	0.165	0.668
8	0.000	0.000	100.0	AT_{range}	0.146	0.685

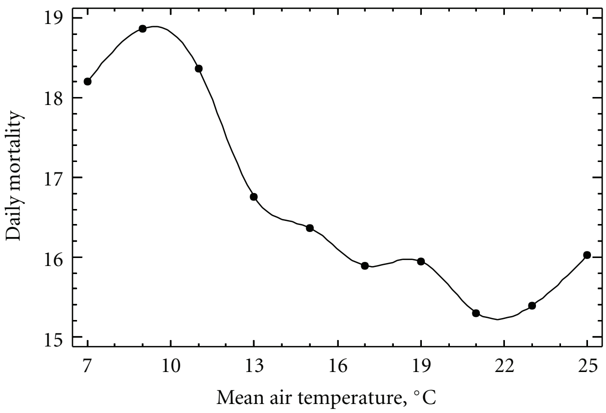


Figure 4: The third-order spline of daily mortality grouped by 2°C class intervals of mean daily temperature.

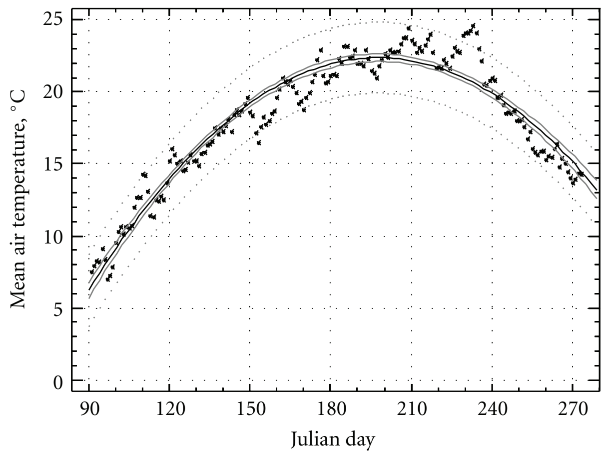


Figure 5: Plot of the dependence of mean air temperature on Julian day in Chisinau.

averaged for the whole period. The seasonality in data is evident and well approximated by the 2nd-order polynomial described by the equation:

$$\mathrm{Md} = 26.47 - 0.108 * \mathrm{Day} + 0.00026 * \mathrm{Day}^2, \quad R^2 = .3072, \quad P \le .001, \tag{2}$$

where Md is daily total deaths and Day is day of the beginning of year (Julian day).

The polynomial curve can be considered as a hypothetical seasonal course of daily mortality with an unlimited extension of the period of observations as well as with a reasonable extension of the period of smoothing. This assumption is well demonstrated in Figure 3(b) where daily mortality is smoothed by simple moving averages of different length. As the window in which the data are averaged increases from one to 31 days, the corresponding plots approach the polynomial approximation.

We can also note that in the warm period, starting from April 1, each subsequent day the total mortality is decreasing up to a certain moment (around 210 Julian Day, Figure 3), which could be treated as a thermal optimum or MMT, that is, the day (period) with temperature at which mortality is at a minimum. Thus, in Chisinau, using the polynomial approximation (Figure 3), the mean daily mortality (about 15.2 deaths) is observed in the late July–early August period when mean temperature reaches about 22°C. An alternative approach—the 3rd-order spline of death counts in 2°C temperature intervals (Figure 4)—shows a MMT of 21.8°C, with a mean mortality of 15.2 deaths as well.

3.4. Dependence of Daily Mortality on Mean Temperature. Over the summer, the mean air temperature is also very well approximated by a parabolic curve (Figure 5) that can be described by the equation:

$$T_{\mathrm{mean}} = 32.06 + 0.55 * \mathrm{Day} - 0.0014 * \mathrm{Day}^2, \quad R^2 = .9204, \quad P \le .001, \tag{3}$$

where T_{mean} is daily mean temperature and Day is Julian Day.

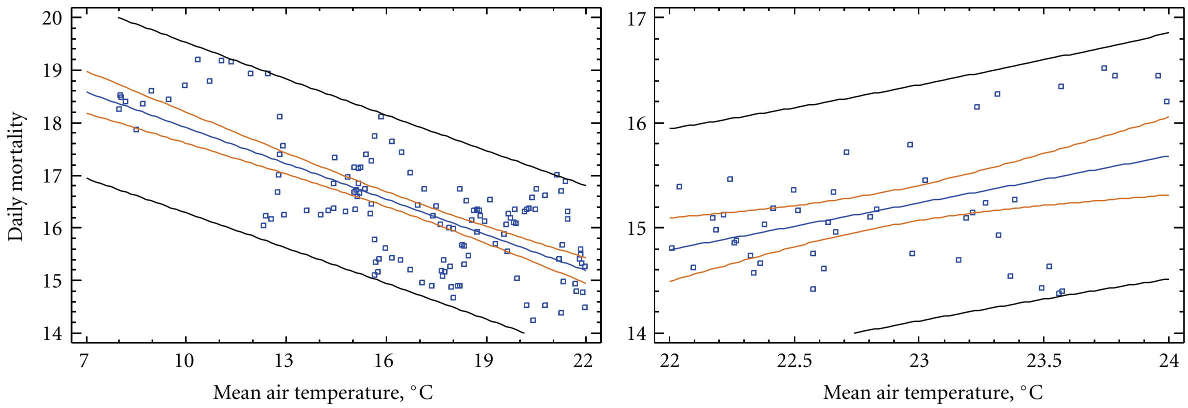
The comparison of two curves (Figures 3(a) and 5) presupposes the complex, mainly inverse relationship between mortality and temperature. We can also presuppose unacceptability of estimating this relationship as uniform for the entire temperature range because such an approach ignores the differences in mortality responses to temperature increase at two slopes of the dependency curve: below and above the thermal optimum (Figure 4). A linear regression analysis of daily mortality on T_{mean} (Figure 6) shows that *cold* (descending) and *heat* (ascending) parts of the mortality curve need to be analyzed separately.

Table 4 demonstrates results of the regression analysis of relationships between daily mortality and T_{mean} below the thermal optimum. All regression models, regardless of the level of smoothing, demonstrate very similar regression parameters, showing that prognostic power of the models is low sensitive to the length of moving average. At the same time, the 7-day smoothing was selected as optimal in comparison with three other alternatives as it is associated with high correlation and small errors yet still includes the entire weekly cycle of mortality. The 31-day averaging should be rejected as an evident "oversmoothing".

Thus, in Chisinau the dependency of daily mortality (Md) on warm period's temperatures below MMT ($\mathrm{Md}_{<\mathrm{MMT}}$) is well described by the following equation (notations as in Table 4):

$$\mathrm{Md}_{<\mathrm{MMT}} = 20.17 - 0.226 * T_{\mathrm{mean}}, \quad r = .719, \quad P \le 0.001, \quad \mathrm{SE} = 0.80, \quad \mathrm{MA} = 0.66. \tag{4}$$

The regression models estimate *per se* the mean response of mortality to ambient temperature change. In particular, the regression coefficients express human sensitivity to temperature exposure. So, proceeding from the regression coefficient (−0.226) in (4), we can state at the 99% confidence level that in spring–early summer period the increase of ambient temperature up to its optimal value, for example by 4°C,



(a) (b)

Figure 6: Dependencies of daily mortality (*death cases*) on air temperatures below (a) and above (b) thermal optimum. Both variables are smoothed by 7-day moving averages.

Table 4: Summary of simple regression analyses of daily mortality on mean air temperature below the thermal optimum for different lengths of smoothing.

Period of smoothing, days	Parameters of regressions						
	Constant	Regression coefficients	r	r^2, %	P	Standard error, SE	Mean abs error, MA
0	20.29	−0.237	−0.742	55.00	>0.001	0.80	0.65
3	20.30	−0.237	−0.740	54.71	>0.001	0.80	0.65
7	20.17	−0.226	−0.719	51.63	>0.001	0.80	0.66
31	19.70	−0.200	−0.600	36.05	>0.001	0.79	0.67

Table 5: Simple linear regression models of 7-day moving averages of daily mortality on analogously smoothed daily air temperatures.

Air temperature range	Parameters of regressions						
	Constant	Regression coefficient	r	r^2, %	P	Standard error	Mean abs error
Mean temperature							
<MMT	20.17	−0.226	−0.719	51.63	>0.001	0.80	0.66
≥MMT	4.987	0.446	0.419	17.54	0.004	0.55	0.43
Maximum temperature							
<MMT	21.18	−0.218	−0.725	52.7	>0.001	0.80	0.65
≥MMT	−1.05	0.568	0.466	21.7	0.028	0.57	0.46
Minimum temperature							
<MMT	19.34	−0.244	−0.717	51.5	>0.001	0.81	0.67
≥MMT	11.80	0.189	0.174	3.04	0.216	0.57	0.45

Table 6: Simple linear regression models of 7-day moving averages of daily mortality on analogously smoothed daily apparent temperatures.

Air temperature range	Parameters of regressions						
	Constant	Regression coefficient	r	r^2, %	P	Standard error	Mean abs error
Mean apparent temperature							
<MMT	19.36	−0.195	−0.699	48.91	>0.001	0.83	0.68
≥MMT	14.96	0.010	0.014	0.020	0.920	0.58	0.44
Maximum apparent temperature							
<MMT	20.25	−0.191	−0.713	50.96	>0.001	0.82	0.67
≥MMT	10.99	0.150	0.198	3.92	0.187	0.59	0.46
Minimum apparent temperature							
<MMT	18.50	−0.206	−0.690	47.58	>0.001	0.84	0.70
≥MMT	15.66	−0.027	−0.041	0.17	0.768	0.56	0.44

causes a decrease in daily mortality by one death. This also means that for average daily mortality in the observed period (16.1 deaths) a 1°C change in mean daily temperature causes 1.4% decrease in total death cases.

A somewhat different picture takes place on the ascending slope of temperature–mortality relationship after air temperatures have crossed MMT. Here, the analogous regression of daily mortality on mean temperature ($Md_{\geq MMT}$) is well described by the equation:

$$Md_{\geq MMT} = 4.99 + 0.446 * T_{mean}, \quad r = .419, \quad P \leq .01, \quad SE = 0.55, \quad MA = 0.43. \tag{5}$$

In other words, a mean temperature increase above thermal optimum leads to the corresponding increase of daily mortality (about 0.5 deaths per 1°C) that is practically twice more than its initial decrease caused by seasonal warming. Transformation of this value in relative daily mortality shows that high mean temperatures (those above MMT) cause on the average about 2.8% increase of daily mortality. This figure is in the range of European estimations—between 0.7% and 3.6% [32]. In Chisinau's "normal warm season" the range of these temperatures, smoothed in weekly windows (Figure 6), is only two degrees (from 22°C to 24°C). Because of the lower range of temperatures and smaller sample size, there is less certainty in the slope of the ascending limb of the regression line in comparison with that for the descending one ((5) versus (4)).

The effects of higher temperatures, describable as heat days, are considered in a special paper [29].

3.5. Maximum and Minimum Temperature as Predictors of Mortality. The splines of daily mortality, grouped by 2°C class intervals of maximum and minimum temperatures, showed their optimal values around 28°C and 18°C, respectively. These values, received as corresponding temperatures on the day of minimum mortality, were similar, 27.6°C and 17.4°C.

The parameters of regression models of daily mortality on increasing T_{max} and T_{min} are shown in Table 5 where, for easy comparison, the regressions' parameters for T_{mean} are repeated. Obviously, both variables are good predictors of a temperature-conditioned change in daily mortality for temperatures below MMT. Again, based on the warm season average daily deaths in Chisinau and regression coefficients, it can be stated that each 1°C increase of T_{max} and T_{min} up to the thermal optima causes respectively 1.3-1.4% and ~1.5% decreases in daily mortality. Thus, in the observed temperature range, mortality is slightly more sensitive to minimal night temperatures, while the sensitivity to mean and maximum daily temperatures is practically the same.

The increase of maximum temperatures above their optimum value causes an expected heightened mortality. Under such weather conditions, each additional 1°C of T_{max} yields a 2.9% increase of daily deaths—again about twice more that the positive effect of tolerable heat. The effect of minimum temperatures is not statistically significant.

3.6. Apparent Temperature versus Air Temperature in an Analysis of Mortality Sensitivity. The values of AT_{mean}, AT_{max}, and AT_{min} corresponding to minimal mortality, identified concurrently through a narrow-bands and long-term apparent temperature-mortality relationships, were respectively 21.5°C (21.9°C), 27.8°C (26.8°C), and 15.6°C (16.6°C). Given the strong correlation between air temperature and apparent temperature, their relationships with mortality below MMTs are rather similar, with slightly weaker correlation for the latter (Table 6). For all AT above MMT, no statistically significant relationships between their increase and daily mortality were found.

A somewhat weaker relationship between mortality and apparent temperature, in part explained by the relatively low humidity of the Moldavian warm season, emphasizes the necessity of direct accounting for humidity in assessing the weather-health relationships.

4. Conclusions

The statistical analysis of temperature-mortality relationships in Chisinau (Moldova) in the warm period suggests the following principal conclusions.

(1) An initial increase of ambient temperature from spring to summer months occurs with a decrease in human mortality, with its minimal mean values observed in July (14.9 ± 0.27 deaths per day). A transition from daily mortality decrease to its increase as the season progresses is observed in late July–early August. The second-order polynomial is a good describer both of the seasonal course of mortality and of its minimal value.

(2) The linear regression analysis is a good "estimator" of daily mortality dependence on air temperature in the warm season, but these dependencies must be estimated independently for descending and ascending parts of the mortality-temperature curve. A narrow-band approach, based on the distribution of daily mortality in 2°C temperature intervals is a good identifier of the minimum mortality temperature.

(3) In a warm period, due to high multicolinearity, the prognostic power of mean, maximum, and minimum temperatures is adequate. Inclusion of air humidity in the analysis (through an apparent temperature) has not resulted in the strengthening of regression models and in this case performed worse than temperature variables alone.

(4) The analysis of historical dependence of daily mortality on air temperature is a reliable tool for epidemiological studies and develops a good baseline for heat impacts early warning. At the same time, such analysis is insufficient to solve this task in full because it "hides" individual heat events, and an additional heat-episode analysis is needed.

(5) Also, the identified relationships between ambient temperatures and human mortality may not be stationary in time, being only relevant to the time

period studied (2000–2008). There are good reasons to expect that the equations derived in this work may change over time, both as a function of societal/technological changes as well as of climate change. Undoubtedly, with further accumulation of reliable daily meteorological and medical information, such research should be continued.

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