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ORIGINAL PAPER

# Human mortality impacts of the 2015 summer heat spells in Slovakia

**Dalibor Výberči[1] · Lívia Labudová[2,1] · Milada Eštóková[3] · Pavol Faško[2] · Milan Trizna[1]**

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**Abstract** In 2015, Central Europe experienced an unusually warm summer season. For a great majority of climatic stations around Slovakia, it had been the warmest summer ever recorded over their entire instrumental observation period. In this study, we investigate the mortality effects of hot days' sequences during that particular summer on the Slovak population. In consideration of the range of available mortality data, the position of 2015 is analysed within the years 1996–2015. Over the given 20-year period, the summer heat spells of 2015 were by far the most severe from a meteorological point of view, and clearly the deadliest with the total of almost 540 excess deaths. In terms of impacts, an extraordinary 10-day August heat spell was especially remarkable. The massive lethal effects of heat would have likely been even more serious under normal circumstances, since the number of premature deaths appeared to be partially reduced due to a non-standard mortality pattern in the first quarter of the year. The heat spells of the extremely warm summer of 2015 in Slovakia are notable not just for their short-term response in mortality. It appears that in a combination with the preceding strong influenza season, they subsequently affected mortality conditions in the country in the following months up until the end of the year. The impacts described above were rather different for selected population subgroups (men and women, the elderly). Both separately and as a part of the annual mortality cycle, the 2015 summer heat spells may represent a particularly valuable source of information for public health.

## 1 Introduction

Along with the frequent occurrence of periods with extremely high air temperatures, excess mortality is one of the most discussed and documented direct impacts of the current warming climate on society (e.g. Gosling et al. 2009; Hajat and Barnard 2014; IPCC 2014). In the future, ongoing climate change is expected to result in even more intense, more frequent and longer lasting heat waves (e.g. Meehl and Tebaldi 2004; Amengual et al. 2014). Therefore, assessments of the severe heat event-human mortality relationship remain of high importance worldwide. On a national level, numerous recent Slovak studies unanimously affirm the ongoing warming trend, or an increase of atmospheric-related heat stress as well (e.g. Kolláriková et al. 2013; Labudová et al. 2015; Lapin et al. 2016; Švec et al.

✉ Dalibor Výberči
daliborvyberci@gmail.com

1 Faculty of Natural Sciences, Comenius University in Bratislava, Mlynská dolina, Ilkovičova 6, 842 15 Bratislava, Slovakia

2 Slovak Hydrometeorological Institute, Jeséniova 17, 833 15 Bratislava, Slovakia

3 Public Health Authority of the Slovak Republic, Trnavská cesta 52, 826 45 Bratislava, Slovakia

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2016), and Slovakia has also recorded its heat-induced deaths in these changing climatic conditions (Výberči et al. 2015). Despite the fact that heat-related diseases and deaths are largely preventable (Lowe et al. 2016), no complex public health protection mechanisms presently operate in Slovakia. Only general health alerts and meteorological warnings are issued during periods of high temperatures.

In the current era of climate change, Central Europe may still be expecting its 'mega heat wave' with a magnitude and impacts comparable to the 2003 Western Europe (e.g. Toulemon and Barbieri 2008; García-Herrera et al. 2010) and the 2010 European Russia events (e.g. Barriopedro et al. 2011; Shaposhnikov et al. 2015). However, it did experience a very hot summer in 2015. According to Russo et al. (2015), owing to the magnitude, Central European summer heat waves from that year were placed in sixth position in a European heat wave ranking, which has been conducted since 1950. The summer of 2015 was extraordinary, even unprecedented in terms of hot weather intensity in a narrow area of the central part of the continent (Crhová et al. 2016; Hoy et al. 2017; Wypych et al. 2017). At a vast majority of Slovak climatic stations, it was the hottest recorded summer in their operational history, with an exceptionally high number of days having a maximum air temperature at/above 35.0 °C and a characteristically high number of tropical nights (when the temperature does not drop below 20.0 °C) (Bochníček et al. 2015; Kajaba et al. 2015). Negative impacts of the summer of 2015 on mortality have been expertly documented as well, for instance, in Switzerland (Vicedo-Cabrera et al. 2016) and Italy (Michelozzi et al. 2016).

An event that particularly marked the 2015 summer season in Slovakia was a pronounced hot period in the first half of August, during which the highest maximum temperature of the year was recorded in the country (39.0 °C in Topoľčany). Although this extended period of extreme temperatures has not been expertly evaluated at a local level yet, it can be assumed with great certainty that it is among the most severe in the era of meteorological observations. In the neighbouring Czech Republic, this event has been classified among the three most intensive heat waves since 1961, being ranked first at several stations (Crhová et al. 2016). According to Hoy et al. (2017), it was certainly the most severe heat wave on record in Vienna (Austria; since 1855), Uzhhorod (Ukraine; since 1946) and at other stations as well. In Lublin, Poland, it was the longest heat wave on record since the 1950s (Krzyżewska et al. 2016).

This paper aims to evaluate the nationwide impacts of heat spells recorded in Slovakia during the summer of 2015 on the total mortality of the local population, as well as on selected subgroups. Particular attention is paid to the impacts of the most remarkable August heat episode. Our effort was to observe and discuss the potential effects of associated factors modifying the relationship between high air temperatures and mortality. The occurrence of heat spells, as well as their observed effects and impacts on mortality, are studied and compared over a time period of 20 years (1996–2015). Due to the extent of available mortality data, unfortunately, the comparison period does not include some exceptional heat situations, e.g. the prolonged heat episode of July/August 1994, which had a massive mortality impact in the neighbouring Czech Republic (Kyselý 2004). Even in the period investigated in this paper, however, several summers with remarkable heat events were recorded.

## 2 Material and methods

### 2.1 Meteorological data

The daily mean air temperature data from 23 climate stations (Fig. 1) were used for the period 1996–2015, acquired by the Slovak Hydrometeorological Institute. In the case of one station (Moravský Svätý Ján; the westernmost one), the data have been available only since 1997. Daily means are calculated from actual temperatures measured at 7, 14 and 21-h local mean time according to the formula $(T_7 + T_{14} + 2 \times T_{21}) / 4$.

The selected stations were given preference over others due to the quality of their time series. The stations represent the whole territory of Slovakia and its various climatic regions, as well as various altitudes except for mountain and high mountain ranges, where permanent settlements are not located or where there are a negligible number of inhabitants (Fig. 1). No station is located in the centre of a big city. Ultimately, the stations represent all of the most densely populated areas and at the same time respect the distribution of the Slovak population in terms of the absolute number of inhabitants in the studied time period.

### 2.2 Identification of heat events

There is no general consensus on the definition of heat events (e.g. Kuchcik 2006; Perkins and Alexander

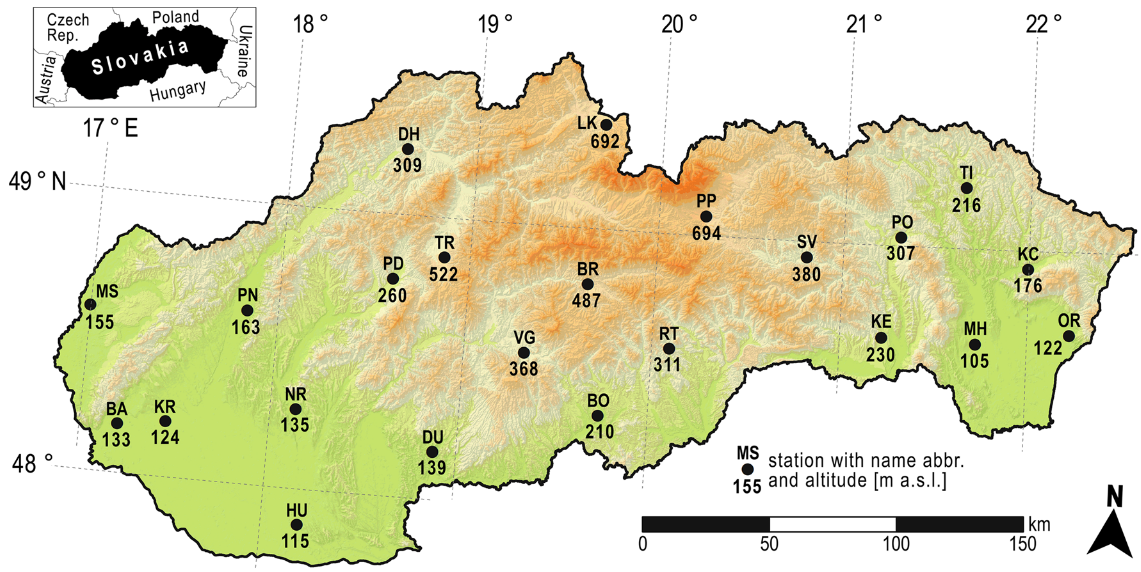


**Fig. 1** Location of climate stations within the hypsometry of Slovakia

2013). By applying the quantile approach (cf. Gosling et al. 2009), our analysis identifies and defines '*heat spells*' as periods with the duration of at least 2 days in which the daily mean air temperature anomaly from normal for individual days exceeds the value of the 90th percentile of its empirical distribution in the summer months (June, July, August) over the full period of interest (1996–2015). Multiple corresponding events (individual heat days or series of heat days) separated by only 1 day with a slight (up to 1 °C) drop of the temperature anomaly below the threshold were considered as a single heat spell. In order to highlight the occurrence of unusually high heat stress, the term '*strong*' heat spell(s) is used in some places to refer to similarly defined days in which the temperature anomaly exceeds the 95th percentile.

One advantage of using anomalies is that they effectively remove the mean temperature variation between stations (effects of various elevations, specific local climate, etc.). Daily anomalies are calculated for each station and, consequently, averaged to determine a value representing the entire territory of Slovakia. When calculating stations' temperature normals, the annual cycle is smoothed by 7-day centred moving averages. This type of smoothing was chosen from several alternatives as being optimal because it preserves the singularities in the annual cycle to a suitable degree and simultaneously smoothens its irregularities (large day-to-day variability).

For defining heat spells while utilising the appropriate terminology, the aim was to do so while taking into consideration general theoretical aspects in heat-induced mortality research (Robinson 2001; Kuchcik 2006; Gosling et al. 2009; Montero et al. 2013; Perkins and Alexander 2013; Gosling et al. 2014), as well as findings from our previously conducted research on this issue in Slovakia (Výberči et al. 2015). A recent contribution by Lapin et al. (2016) defines heat waves specifically in Slovak climatic conditions; the authors propose the duration of such an event to be at least 5 days. However, since it has been proven that even 2-day heat periods cause a statistically significant direct response in the country's mortality (Výberči et al. 2015), we do not consider the proposed definition to be suitable for the purposes of heat-induced mortality research in the Slovak population. Since there is no definition of heat events in the public health sector either, we present our own identification procedure of them in this study.

Numerous earlier publications (Hajat et al. 2006; Barnett et al. 2010; Kim et al. 2011; Vaneckova et al. 2011; Urban and Kyselý 2014; Davis et al. 2016) were taken into account when choosing a meteorological variable as the predictor of heat-induced mortality. Their authors recommend using daily mean air temperature over biometeorological indices or they accept it as an equal alternative to them.

### 2.3 Target population and mortality data

Mortality data for the period 1996–2015 were provided by the Public Health Authority of the Slovak Republic based on the micro-database of the Statistical Office of the Slovak Republic. Each death record contains the date of death which allows for the determination of the daily number of deaths for the whole period under study. Each record also includes information on sex and age of the deceased. The analysis is therefore concerned with total (all cause) mortality and also with mortality of three selected population subgroups: by sex—both males and females—and by age—people aged 65 years and older (post-productive elderly population according to European standards).

Nationwide mortality was evaluated; the whole country population is usually exposed to heat events which tend to be spatially extensive and thus easily impact the entire territory of Slovakia (~49,000 km$^2$). Between 1996 and 2015, the mid-year population as of 1 July remained fairly stable, fluctuating around the value of 5.4 million (Statistical Office of the Slovak Republic 2017). In the summer months of 1996–2015, the average daily total number of deaths was 137.2, of which 72.5 (52.9% of total mortality) were males, 64.7 (47.1%) females and 96.3 (70.2%) elderly people aged 65 and older. A more detailed picture of the corresponding mortality trends in Slovakia in the long term can be found in the studies by Káčerová and Nováková (2015) and Šprocha et al. (2015).

To evaluate mortality for all selected population groups, indirect standardisation was applied: a procedure of calculating deviations of death counts from the baseline (expected) mortality (cf. Gosling et al. 2009). Baseline daily mortality values were calculated employing a methodology that has been in use for a longer period of time and gradually developed and revised in biometeorological research in the Czech Republic (e.g. Kyselý 2004; Kyselý and Kříž 2008; Kyselý and Plavcová 2012; the latest exact procedure is described in detail, for example, in the study Hanzlíková et al. 2015).

Based on this methodology, daily baseline mortality $M_0(y,d)$ for day $d$ of year $y$ was calculated as follows:

$$M_0(y,d) = M_0(d) \times W(y,d) \times Y(y)$$

where $M_0(d)$ denotes the mean annual mortality cycle within the period of interest determined as the average number of deaths on a particular day of the year; $W(y,d)$ is a correction factor for the weekly mortality cycle for each day of the week defined as a ratio of mean mortality on a given day of the week to the overall mean daily mortality (the influence of public holidays was eliminated); $Y(y)$ is a correction factor for year-to-year changes in mortality defined as a ratio of the number of deaths in a particular year to the mean annual number of deaths in the whole period of interest.

The correction factors $W(y,d)$ and $Y(y)$ were calculated over the May–September period which is unaffected by the season of influenza, influenza-like illnesses and acute respiratory infections (hereafter also referred to as 'influenza season'), which could have a substantial impact on mortality. A modification in the selection of the time period used for the calculation of correction factors (using the May–September period instead of April–November) was our only adjustment made to the mortality data standardisation process described in the source publication (cf. Hanzlíková et al. 2015) due to the unavailability of necessary epidemiological data.

Deviations of the observed mortality from the baseline were computed for each day and summed up (absolute characteristics) or averaged (relative characteristics) over the relevant time periods of heat spells. A 95% confidence interval was selected to evaluate the statistical significance of the deviations. Confidence intervals were determined based on a procedure suggested by Morris and Gardner (1988) for a Poisson-distributed variable. This method is suitable for large sample approximations with more than 20 observed cases.

This complete approach of calculating baseline mortality and of subsequently establishing mortality deviations is appropriate when analysing longer time series. At the same time, such an approach takes into consideration both long-term (mainly reflecting overall socio-economic changes) and short-term changes in mortality (Gosling et al. 2009; Hanzlíková et al. 2015).

Lag effects of heat spells on mortality were taken into account. A preliminary analysis showed a 1-day lag as being the best performing, which is commonly found in the literature (e.g. Davis et al. 2003; Kyselý 2004; Gosling et al. 2009; Sheridan and Lin 2014). Therefore, the values of relevant mortality indicators are presented with this lag in the Section 3.

## 3 Results

### 3.1 Heat spells' characteristic

The total duration of heat spells in Slovakia in the summer of 2015 was exactly four calendar weeks, representing by far the longest annual duration in the 1996–2015 period (Table 1).

**Table 1** Annual characteristics of identified summer heat spells in Slovakia, 1996–2015

| Year | Number of heat spells | Total duration of heat spells (days) | Number of included strong heat days | Average heat spell duration (days) | Sum of daily mean temperature anomalies (°C) | Average of daily mean temperature anomalies (°C) |
|---|---|---|---|---|---|---|
| 1996 | 2 | 6 | 1 | 3.0 | 28.5 | 4.7 |
| 1997 | 1 | 2 | 1 | 2.0 | 11.3 | 5.7 |
| 1998 | 3 | 7 | 3 | 2.3 | 38.6 | 5.5 |
| 1999 | 1 | 2 | 1 | 2.0 | 10.2 | 5.1 |
| 2000 | 4 | 12 | 6 | 3.0 | 63.7 | 5.3 |
| 2001 | 1 | 3 | 1 | 3.0 | 14.3 | 4.8 |
| 2002 | 3 | 10 | 4 | 3.3 | 52.8 | 5.3 |
| 2003 | 3 | 6 | 2 | 2.0 | 29.4 | 4.9 |
| 2004 | Without heat spells | | | | | |
| 2005 | 1 | 3 | 3 | 3.0 | 17.6 | 5.9 |
| 2006 | 2 | 7 | 2 | 3.5 | 35.0 | 5.0 |
| 2007 | 2 | 10 | 7 | 5.0 | 60.4 | 6.0 |
| 2008 | 1 | 3 | 2 | 3.0 | 16.0 | 5.3 |
| 2009 | Without heat spells | | | | | |
| 2010 | 3 | 13 | 8 | 4.3 | 69.7 | 5.4 |
| 2011 | 4 | 11 | 4 | 2.8 | 58.3 | 5.3 |
| 2012 | 3 | 17 | 13 | *5.7* | 101.7 | 6.0 |
| 2013 | 3 | 15 | 11 | 5.0 | 91.7 | *6.1* |
| 2014 | 1 | 3 | 0 | 3.0 | 13.7 | 4.6 |
| 2015 | *6* | *28* | *18* | 4.7 | *164.3* | 5.9 |

The highest values are marked in italics

This summer was also marked by the highest number of included strong heat days and quite notably by the highest sum of daily mean temperature anomalies during heat spells, but the daily average of these anomalies reached high values as well. Year 2015 was also a year when the highest number of individual heat spells occurred, which was of fairly long average duration. An extraordinary heat spell in the first half of August 2015 was the longest recorded, and in terms of the sum of temperature anomalies, it was also the most massive one for the comparison period from 1996 (see Table 2 in the next subchapter). Another heat spell, a 4-day one which occurred at the very end of the summer, had the highest average of the daily mean temperature anomalies from normal out of all identified heat spells in the analysed 20-year period.

### 3.2 Impacts on mortality

The observed level of mortality throughout the 2015 summer season and corresponding heat spells in Slovakia is captured in Fig. 2 and Table 2.

The 2015 summer heat spells resulted in a considerable 14.0% increase (95% confidence interval [CI] 10.7 to 17.5%) in total mortality in Slovakia. In the absolute number, this percentage accounts for 539 excess deaths, thus representing by far the greatest absolute excess in 1996–2015; 314 extra deaths were registered during the summer heat spells with the second highest excess mortality (2013). An increase in mortality was more pronounced in males (15.5%; 95% CI 10.8 to 20.3%) compared to females (12.5%; 95% CI 7.7 to 17.4%), while the mortality of the elderly aged 65 years and older increased more markedly (17.6%; 95% CI 13.6 to 21.7%) above the baseline. Strong heat days within the heat spells had the following impact: total mortality rose by 15.9% (95% CI 11.7 to 20.3%), male mortality by 18.6% (95% CI 12.7 to 24.8%), female mortality by 13.0% (95% CI 7.1 to 19.2%) and elderly mortality by 19.4% (95% CI 14.4 to 24.6%). We would like to emphasise that all the values are presented for the considered lag of 1 day.

The first summer heat spell in Slovakia in 2015 recorded in mid-June was the least severe from a meteorological

**Table 2** Characteristics of selected summer heat spells in Slovakia, 1996–2015, and their response in human mortality with a lag of 1 day

| Date | Heat spell duration (days) | Number of included strong heat days | Average of daily mean temperature anomaly (°C) | Relative deviation of mortality from the baseline (95% confidence interval) (%) | | | |
|---|---|---|---|---|---|---|---|
| | | | | Total mortality | Male | Female | The elderly of 65 years and older |
| 12–14 June 2015 | 3 | 1 | 4.8 | 2.1 (−7.3 to 12.2) | 2.4 (−10.8 to 17.0) | 1.6 (−11.6 to 16.2) | −2.3 (−13.1 to 9.4) |
| 5–8 July 2015 | 4 | 2 | 6.0 | 20.0 (11.0 to 29.4) | 16.8 (4.6 to 30.1) | 23.1 (10.3 to 37.0) | 24.5 (13.9 to 35.8) |
| 17–19 July 2015 | 3 | 1 | 5.0 | −2.9 (−12.1 to 7.1) | 4.6 (−8.5 to 19.1) | −11.0 (−23.7 to 3.1) | 1.5 (−9.6 to 13.7) |
| 21–24 July 2015 | 4 | 2 | 5.6 | 28.1 (18.9 to 37.8) | 30.1 (17.2 to 44.0) | 26.0 (13.1 to 40.0) | 34.4 (23.3 to 46.2) |
| 6–15 August 2015 | 10 | 8 | 6.0 | 17.8 (12.1 to 23.8) | 18.6 (10.6 to 26.9) | 17.1 (9.0 to 25.7) | 20.8 (14.0 to 27.9) |
| 28–31 August 2015 | 4 | 4 | 7.1 | 5.9 (−2.6 to 15.1) | 9.8 (−2.2 to 22.9) | 1.8 (−10.1 to 14.9) | 12.2 (1.8 to 23.3) |
| 19–23 June 2002 | 5 | 2 | 5.4 | 5.4 (−2.1 to 13.3) | 6.4 (−3.8 to 17.4) | 4.2 (−6.8 to 16.0) | 5.9 (−3.1 to 15.5) |
| 15–22 July 2007 | 8 | 6 | 6.2 | 20.8 (14.5 to 27.3) | 18.2 (9.7 to 27.2) | 23.6 (14.5 to 33.3) | 22.7 (15.2 to 30.6) |
| 11–17 July 2010 | 7 | 5 | 5.6 | 20.6 (13.9 to 27.6) | 23.5 (14.1 to 33.5) | 17.5 (8.1 to 27.6) | 20.5 (12.6 to 28.8) |
| 23–27 August 2011 | 5 | 4 | 6.2 | 14.3 (6.3 to 22.8) | 9.4 (−1.4 to 21.1) | 19.6 (7.8 to 32.4) | 15.7 (6.0 to 25.9) |
| 17–21 June 2012 | 5 | 4 | 6.1 | 8.2 (0.6 to 16.2) | −1.4 (−11.3 to 9.3) | 18.7 (7.3 to 31.0) | 13.7 (4.5 to 23.5) |
| 30 June–3 July and 5–8 July 2012 | 8 | 8 | 6.5 | 16.7 (10.5 to 23.3) | 14.8 (6.2 to 23.9) | 18.9 (9.8 to 28.5) | 18.5 (11.0 to 26.3) |
| 17–22 June 2013 | 6 | 5 | 6.5 | 20.6 (13.2 to 28.4) | 21.0 (10.7 to 31.9) | 20.2 (9.7 to 31.5) | 24.6 (15.7 to 34.0) |
| 3–4 and 6–9 August 2013 | 6 | 4 | 5.9 | 11.0 (3.8 to 18.5) | 9.7 (−0.2 to 20.3) | 12.4 (2.1 to 23.5) | 16.2 (7.5 to 25.4) |
| All heat spells 1996–2015 | 158 | | 5.6 | 12.6 (11.2 to 14.0) | 11.3 (9.4 to 13.3) | 14.0 (11.9 to 16.1) | 14.8 (13.1 to 16.5) |
| Only strong heat days within all heat spells 1996–2015 | | 87 | 6.3 | 15.7 (13.8 to 17.6) | 14.2 (11.5 to 16.9) | 17.3 (14.5 to 20.1) | 18.4 (16.1 to 20.7) |

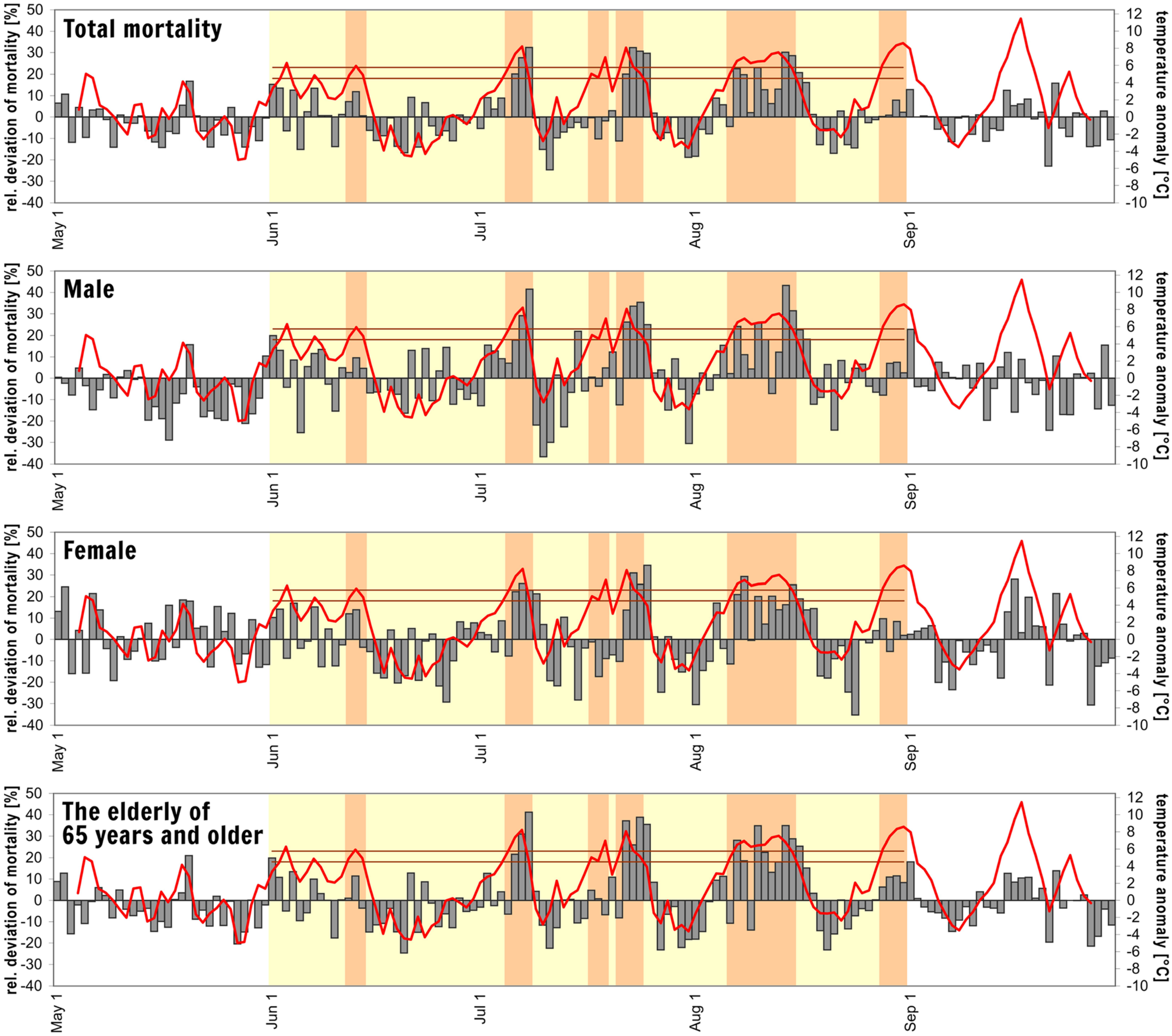


**Fig. 2** Temperature conditions (*lines*) and human mortality (*bars*) during May–September 2015 in Slovakia. Summer season is highlighted in *light yellow*, wherein dates of heat spells are highlighted in *tan*. The *red curve* shows daily mean temperature anomalies. *Horizontal lines* represent the threshold values of daily mean temperature anomaly for the classification of heat (4.02 °C) and strong heat summer days (5.28 °C)

point of view and did not have a major effect on the population mortality (Fig. 2 and Table 2). After the subsequent period of relatively colder weather, a 4-day heat spell with a pronounced temperature peak followed at the beginning of July causing a considerable excess mortality for the first time during the summer (Fig. 2 and Table 2). In little more than a week after its end, very hot weather returned in mid-July with two consecutive heat spells. The first of them with the onset on 17 July was less intensive and did not greatly affect mortality, whereas in the case of the next heat spell, which culminated on 22 July, the relative deviation of mortality from the baseline was the highest among all heat spells that summer for the whole population as well as for the selected subgroups (Fig. 2 and Table 2). With the exception of the female subgroup, the relative deviations were higher than for any other heat spell even within the 1996–2015 period. The next observed heat spell was a particularly extreme 10-day event in the first half of August which resulted in 242 excess deaths, thus becoming the deadliest summer heat episode in Slovakia since at least 1996. The last heat spell at the end of the summer, despite having the most prominent temperature conditions, was accompanied with only a moderate increase in mortality, and this was statistically significant only for the elderly (Fig. 2 and Table 2). Short-term drops in the number of deaths were well expressed following/between the heat spells (Fig. 2).

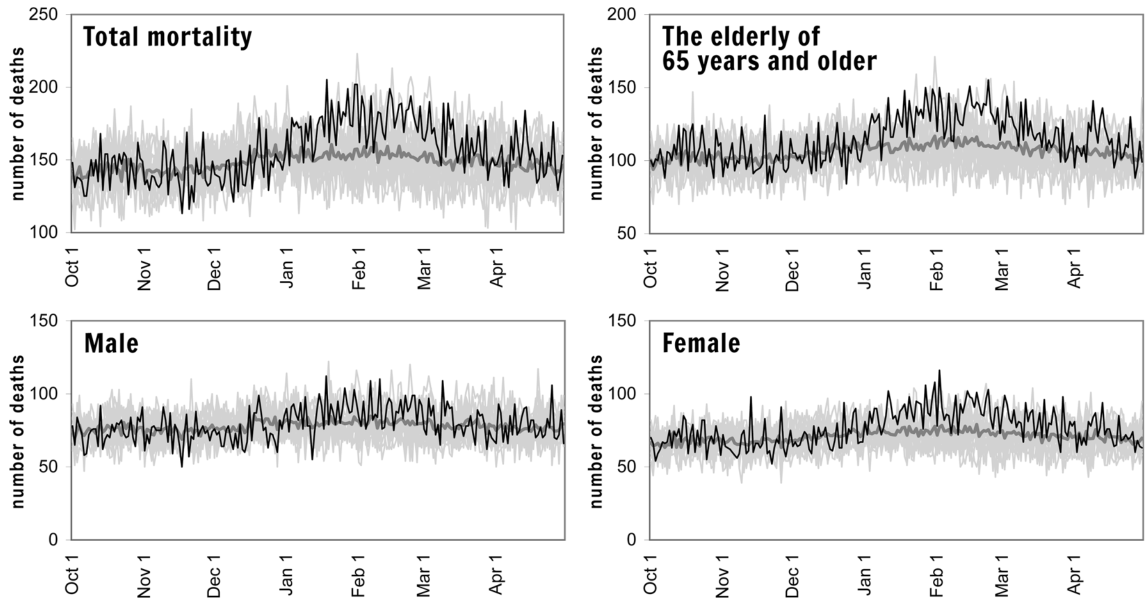


**Fig. 3** Human mortality during seasons of influenza, influenza-like illnesses and acute respiratory infections (October–April) in Slovakia. The *black curve* denotes the 2014/2015 season; the *light grey curves* denote the particular seasons from 1996/1997 to 2013/2014, and the *dark grey curve* denotes the 1996/1997–2013/2014 season average

## 4 Discussion

To the best of our knowledge, there is no large evidence of European studies to date, which describes the mortality impacts of the heat events during the extremely hot summer of 2015. Our analysis shows that these events caused a very significant increase in mortality in Slovakia. After considering the differences in the heat events' identification, it can be stated that the relative values of excess mortality were comparably high to those registered during the heat episodes in Switzerland (Vicedo-Cabrera et al. 2016).

In general (e.g. Oudin Åström et al. 2011; Yu et al. 2012; Hajat and Barnard 2014), but also in the local conditions of Slovakia (Table 2; see also Výberči et al. 2015), a greater mortality increase during heat events can be usually observed in the elderly as well as in females, when comparing genders. Nonetheless, relative excess mortality was more pronounced in males during the 2015 summer heat spells in Slovakia.

A substantial excess mortality was observed in European countries in the winter of 2014/2015, predominantly in coincidence with the considerable expansion of influenza viruses, particularly in elderly individuals (Mølbak et al. 2015). Slovakia also recorded a marked increase in deaths during the corresponding influenza season, mainly from January to March, but partially in April 2015 as well. The increase was slightly more noticeable in females than males, and appropriately, it was excess mortality with a predominance of deaths among the older population (Fig. 3). Thereafter, there was a considerable decrease in male mortality in May 2015, most likely owing to the well-known mortality displacement (harvesting) effect (for more information about this phenomenon, see Gosling et al. 2014; Saha et al. 2014, etc.) after the epidemic situation in the preceding period, while female mortality fluctuated around normal values in that month (see Fig. 2). A compensatory decrease in female deaths after substantial excess mortality at the beginning of the year was seemingly delayed until the summer months. In accordance with such a development, decreases in periods of reduced (displaced) mortality after the 2015 summer heat spells were generally more pronounced in females, despite the fact that the relative excess mortality induced by the heat spells was lower in their case. Therefore, it can be safely assumed to a fair degree of certainty that the higher relative increases in male mortality during the summer heat spells of 2015 were more or less a consequence of the previous mortality conditions occurring that year. In this example, the findings of an existing correlation between winter and summer mortality in the following seasons (Rocklöv et al. 2009; Stafoggia et al. 2009; Ha et al. 2011; Goldstein et al. 2012) can be confirmed in Slovakia as well.

As previously mentioned, Slovak male mortality in the summer of 2015 was affected less by the situation during the influenza season than female mortality. Also worth mentioning in this context is that in comparison to the other selected groups, male mortality did not show any substantial short-term death deficits following the heat spells in the second half of the summer, particularly after the extreme August heat spell. This indicates that these episodes claimed the lives of greater numbers of otherwise immune (healthy) men who would not have died shortly after the heat spell under normal circumstances. It is also supported by the daily death counts in the following period until the end of the year with mortality prevailing below average values, especially for males. This pattern was apparent as well in December 2015. To illustrate the situation, in the period of October–December 2015, the total number of deaths in Slovakia was 603 lower than the average for the same months in 1996–2014. Of the total deceased, men accounted for 473 deaths, women for 130 and the elderly for 286. It is known that in relation to anomalously hot weather, longer term mortality consequences are possible (Toulemon and Barbieri 2008; Shaposhnikov et al. 2015). At the same time, the entire annual mortality cycle is an example of a situation when the distribution of deaths satisfactorily indicates a seeming interaction between mortality rates in various parts of the year.

In accordance with general knowledge, relative mortality increases in the elderly during the heat spells of 2015 in Slovakia were larger than that of total mortality. It reached higher values, even in spite of the already discussed excess mortality at the beginning of the year that was particularly pronounced in the old age subgroup. This accentuates the existence of an increased physiological susceptibility of the elderly to premature death in very hot weather. In Switzerland as well, the summer heat had a greater impact on the elderly, although a strong influenza epidemic at the beginning of 2015 is also stated as one of the explanations for the relatively low excess mortality in very old people above 85 years (Vicedo-Cabrera et al. 2016). Another factor playing a role in the increased excess mortality of the elderly is the demographic process of population ageing (Gosling et al. 2009), which is an important current trend also within the Slovak population (e.g. Káčerová and Ondačková 2015). The percentage of Slovaks aged 65 and older in the total population (as of 1 July of the respective year) rose from 11.0% in 1996 to 14.2% in 2015 (Statistical Office of the Slovak Republic 2017).

In order to provide a thorough evaluation of heat-induced mortality in 2015 in Slovakia, it is necessary to take into account the added effect of heat as well (i.e. the increasing risk of premature death during extended periods of sustained, exceptionally high temperatures (Hajat et al. 2006)) which was most likely also reflected in the elevated mortality rate. Specifically, this was demonstrated in the case of the extraordinary extreme heat spell in the first half of August 2015. In this spell, the mortality reached high values despite that (1) it was the fifth heat spell of the summer, therefore supporting the hypothesis of within-season acclimatisation to high temperatures according to which negative impacts on mortality decrease in each subsequent hot period of a season due to several reasons (Gasparrini et al. 2016); (2) the previously discussed pre-summer mortality pattern, which was, to some extent, also supporting the following reduction in the pool of susceptible individuals. What is also noteworthy is that the greatest increases in total mortality within the prolonged 10-day August heat spell were registered in the latter days of this event, simultaneously with its main temperature peak. This suggests that among the people who died late in this heat spell, there might not only be displaced cases but also some extra, true heat-related deaths. Along with these impacts of this extraordinary heat spell, it is also worth mentioning the mortality associated with the next late, season's final heat spell at the very end of August 2015 (very hot weather for that time of year persisted in Slovakia even on 1 September). Despite achieving the highest average of temperature anomalies out of all the summer heat spells from 1996 to 2015, this 4-day heat event did not cause any notable impact on mortality. One further hot days' sequence of a similar duration, which was the last summer heat spell yet even warmer in relation to the time of year, occurred in the mid-September 2015. Its peak was on 17 September with the daily mean temperature being almost 11 °C above the normal, which is equivalent to the actual daily means within a summer heat spell. However, during this unusually warm period which lasted several days, only a moderate increase in total mortality was registered as well (see Fig. 2).

When assessing impacts of heat waves, night-time temperatures must be considered as well (Robinson 2001), since these have an effect on regeneration of the human body after daytime highs. The 2015 Central European summer heat was characterised by a slow cooling during the night (Russo et al. 2015), and as a consequence, record-breaking numbers of nights with a high minimum temperature were observed in that area (Crhová et al. 2016; Hoy et al. 2017), including Slovakia (Bochníček et al. 2015; Kajaba et al. 2015). Thus, there are assumptions indicating a possible contributive adverse effect of night-time temperatures on excess mortality in Slovakia in the summer of 2015; however, it is not our intention to assess the meteorological attributes of heat spells in detail. In any case, the presented presumption has been previously supported by the results of the Swiss study (Vicedo-Cabrera et al. 2016).

From the statistical point of view, it is most likely that humidity did not highly influence the heat-induced excess mortality in the summer of 2015 in Slovakia. For instance, the average values of water vapour pressure during the heat spells were at a lower level than in other notable years. The summer of 2015 was characterised by markedly dry conditions, with a dry spring season as a good predisposition. During the summer, the situation became considerably severe in virtually every part of the country. Some regions were affected by a long-lasting extreme drought episode. Extraordinary values of drought indices reached new long-term records: at several locations in Slovakia, such severe conditions had not occurred since at least 1961 (Labudová and Turňa 2015). However, the summer drought of 2015 was remarkable in a much broader geographical context (Orth et al. 2016; Van Lanen et al. 2016; Hoy et al. 2017; Ionita et al. 2017). Under such circumstances, along with prevailing airflow patterns, dry heat was clearly inclined to occur. Thus, humidity did not seem to substantially increase the temperature-induced burden on the population.

As a possible limitation of this study, we have to mention that despite being frequently used and recommended, air temperature alone can only mean a proxy as it is only one variable (though an important one) in the heat exchange between the human body and the atmosphere. Our investigation also does not address the possible effect of air pollution, which can play a significant role in the high temperature-mortality relationship (e.g. Analitis et al. 2014; Li et al. 2017).

## 5 Conclusions

In 2015, an extremely severe season of summer heat affected Slovakia with its population, which had already been impacted by the preceding very lethal influenza season (see Public Health Authority of the Slovak Republic 2015). In terms of overall meteorological extremity, heat spells from no other years within the period under study (1996–2015; for which the mortality data was available) cannot be remotely compared to those which hit Slovakia in 2015. Thus, being incomparable with the heat of other severe summers, the heat spells of 2015 can be considered in all respects extraordinary and exceptional for biometeorological research and public health in the country. With regards to the described mortality situation prior to the season of very hot weather, it can be concluded that the summer heat spells of 2015 were very deadly for the Slovak population, with the consequences being substantial both in their extent and duration. Since it has been proven that a high winter mortality can, to a certain extent, reduce the adverse mortality effects of the following summer season (Rocklöv et al. 2009; Stafoggia et al. 2009), the summer heat spells of 2015 might have had even more lethal impacts under normal circumstances. Nevertheless, the length of life of the Slovak population lost in heat events was apparently longer than usual in 2015. The evidence suggests that the massive August heat spell appeared to have an essential position in heat-induced excess mortality.

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