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Mortality during Heatwaves and Tropical Nights in Vienna between 1998 and 2022

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Abstract: Rising summer temperatures lead to heat waves and tropical nights, which can result in health problems among the population. This work examined if mortality among Viennese people has increased under such weather conditions or whether the population was able to adapt to those periods of extreme heat. Therefore, the daily climatic data of the Austrian Weather Service and the number of daily deaths in Vienna from 1998 to 2022 have been put into relation. After calculating the mean values from those data sets, we analyzed the total number of daily deaths but also the death rate per 100,000 inhabitants for the total Viennese population, for men and women. The impact of age structure on possible trends was analyzed and ruled out. The analysis showed that the mortality on days with heat events was still higher, but the mean values of daily deaths decreased over time, despite a doubling of heatwaves and tropical nights, which speaks for an adaptation to heat events by the Viennese population.

Keywords: heat wave; Vienna; mortality; tropical night; mortality trend

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1. Introduction

In Austria, there has been an average temperature increase of almost 2 °C since 1880. Half of the rise in temperature took place in the last 40 years. A global increase of 3–5 °C by the end of the century is expected if extensive measures are not taken (APCC, 2014).

According to the Austrian Panel on Climate Change (APCC) [1,2], the most realistic climate projections expect an increase in the average global temperature of 2.2 °C by 2080, even based on the assumption that the greenhouse gas concentration might decrease by 2080. Climate model simulations show for the realistic scenario an average of 10.3 more hot spell days whereas for the business-as-usual scenarios, 23.3 more heat episode days are expected. One heat episode (or hot spell) consists of at least three consecutive days with a daily minimum temperature above 18 °C and a daily maximum temperature of at least 30 °C.

The summer of 2003 was a potential foretaste of things to come because heat records were broken from July to August in many European regions and cities. In Central Europe, the values were sometimes 3–5 °C above the long-term average and it was probably the hottest summer in at least 500 years. Throughout Europe, approximately 35,000 deaths were related to heat [3].

Fouillet et al. [4] came to corresponding results for the record summer, only concerning France. During the heat wave in August 2003, 15,000 more deaths than average were observed. The excess mortality started from the age of 35 and steadily increased. Most deaths (11,731) were in people aged 75. Overall, 9378 women were more affected than men (5351). However, the proportion of women in the population who were 75 years old, was about 3 million almost twice as high as that of men with 1.7 million.

About 20% of the deaths were directly related to heat dehydration, hyperthermia, or heat stroke. The next leading cause of death was related to cardiovascular problems, followed by respiratory diseases. In early 2008, Fouillet et al. [5] compared mortality during the 2006 hot spell with summer 2003. Contrary to expectations, excess mortality was lower in July 2006. About 6452 deaths were assumed, but the evaluation revealed approximately 2065.

Recent studies also showed an overall decrease in vulnerability to heat [6,7], especially among the older population [8–10]; for instance, a statistically significant decrease in mortality related to heat at almost all 272 locations (in Australia, Canada, Japan, South Korea, Spain, the United Kingdom, and the United States) that were analyzed was found. Similar results were obtained for France [5], Italy [11], Chicago, Illinois [12], the Netherlands [13] and Sweden [14]. However, a stable vulnerability was obtained for Australia, Ireland, and the United Kingdom [15]. Some studies [5,12] see the reason for the decrease in heat-related mortality in concrete measures and in the behavior of the population and decision-makers who have recognized the danger of heat episodes.

In the present work, we concentrate on the mortality trends in Vienna. For Vienna, the first study on the effect of heat waves on mortality was conducted by Hutter et al. [16]. They examined the mortality during heat waves in Vienna between 1998 and 2004. Mortality risk on hot days was up to 13% higher than the other days (days where no connection to hot spell periods is given). In all age groups, an increase in mortality could be noticed but significantly more in persons aged 65 and over; 80% of deaths were ascertained in this age group. During the pan-European heatwave in the summer of 2003, the excess mortality was around 180 persons per day in Vienna. It is estimated that 180 deaths could have been avoided if medical help had been provided quickly or if this population group had been better informed. Four years later, Matzarakis et al. [17] analyzed the correlation between heat stress and mortality in Vienna (Austria) for the period between 1970 and 2007. Long-term trends of mortality data and short-term adaptation to heat stress were considered by using a human biometeorological parameter, the thermal equivalent temperature, and by applying corrections in order to remove the influence of the age structure of the population and the influence of population growth. The evaluation was based on the physiologically equivalent temperature which is a thermal heat index, designed to estimate the perceived temperature and thermal comfort. A significant impact of heat stress on human health was found. The impact was significantly higher for women compared to men. Some decreases in the sensitivity indicate a possible long-term adaptation to heat stress due to climate change.

Weitensfelder and Mooshammer [18] examined human adaptability to the heat in Vienna and for the time period between 1970 and 2018. The optimal temperature was determined by looking at the lowest daily death rates as a function of temperature. The optimal temperature showed an increase per decade between 1.3 and 2.5 °C (absolute values of optimal temperature increased from −1 °C to 3 °C). It turned out that the "optimal temperature" increased faster than the average temperature (0.09 vs. 0.04 °C per year). The number of hospitalizations in Vienna was analyzed as a function of weather conditions [19]. It was shown that at temperatures above 30 °C the hospitalizations in Vienna increased by 1.3%. For temperatures above 34 °C the number of hospitalization increased by 2%. Above 36 °C, the rise in the number of hospitalizations shrunk again (possibly because of the too-small number of days).

Most of the performed studies showed a clear increase in mortality during heat waves. Further studies showed some kind of adaptation of the population to heat waves which was reflected in a decrease in the heat-related increase in mortality. Considering that climate change progresses, future questions that arise are whether Earth's inhabitants will be able to adapt to future climate conditions or whether there will be a new increase in heat-related mortality.

Regarding the city of Vienna, since 2007 the year for which the last mortality data were analyzed, the number of hot days (maximum temperature over 30) has increased steadily. Before 2007, only 2 years with 20 hot days or more were observed. Since 2012, every second year 20 hot days or more are measured. Because climate change is rapidly progressing, there is a need to continuously investigate the influence of warming on extreme physiological effects on humans such as mortality.

Since the last studies concerning excess heat-related mortality [16,17] were conducted with mortality data until 2007, there is a need for further studies using mortality data up to the present. The present study focuses therefore on excess mortality and a possible adaptation of the population to heat, by using the approach of [16] based on Kyselý heat waves (see definition in Section 2.1) and using the mortality data up to 2022.

2. Materials and Methods

2.1. Meteorological Data

The daily climatic data of the main measuring station Hohe Warte came from the Austrian Weather Service GeoSphere Austria. The period chosen for the analysis was from 1998 to 2022.

Since there is a clear maximum in mortality in Wintertime, we mainly focus on the months of June, July, and August. May and September served principally to have more data to calculate the basis mortality on "normal days". Our assumption is that an epidemic in the summer would not only affect the months of May and September but all summer months.

We included in our analysis, first, hot period days which are days which are included in a hot spell period. The definition of a heat wave is taken from [20].

According to this definition, "the heat wave is a continuous period during which (i) TMAX (daily maximum air temperature) is higher than 30 °C on at least 3 days; (ii) mean TMAX over the whole period is higher than 30 °C; and (iii) TMAX does not drop below 25 °C" [20]. This definition of a heat wave allows two periods of tropical days separated by a slight drop in temperature to make up one heat wave, but, on the other hand, two periods of tropical days separated by a pronounced temperature drop below 25 °C are treated as separate heat waves. These heat waves are also called Kyselý heat waves in the present manuscript.

Second, we included days with tropical nights. A tropical night is a night where the minimum air temperature does not fall below 20 °C. A limitation of the number of deaths that occurred between 6 p.m. and 6 a.m. (measurement period of a tropical night according to the German Weather Service (personal communication)) was not possible since the exact time of the death was not provided in the mortality data set. Since tropical nights may have an influence on the mortality of the same days and of the preceding day, weather conditions are linked to mortality data of the same day and of the preceding day. The average of the mortality data of two days during tropical night events was therefore used.

In the following sections, we use the term "hot days" for days that are either heat period days or days with tropical nights.

"Normal days" sometimes also referred to as "the other days" are the other kind of days of the period beginning of May until the end of September which do not belong to the group of hot days or days with tropical nights. We exclude the period from October to the end of April because mortality is usually higher in Wintertime due to Winter epidemics [18].

2.2. Mortality Data

Data concerning the number of daily deaths in Vienna were obtained from Statistics Austria. Data are classified by sex but not by age of the deceased. In the following sections, we use sometimes the term mortality (which is not a mortality rate) to describe the daily number of deaths.

We analyzed increasing or decreasing trends in death numbers and death rates during heat waves (hot spell period) and tropical nights. Three other factors have also an influence on mortality data: the variations in population, the age structure of the population, and the life expectancy [17].

Since the older population is more at risk and some studies also showed a difference in death rate as a function of gender, a first look at the demographic data of the city of Vienna seems opportune. Because the age of the deceased was not available in the data, we need to make a possible error estimation using the data of the age structure in Vienna.

From 1998 to 2022 the total population of Vienna increased from 1,542,252 inhabitants to 1,982,097 inhabitants (Figure 1). The female population grew from roughly 811,000 to over 1 million. The proportion of women however slightly decreased from 52.6 to 51%, whereas the percentage of the Viennese population aged 60+ only changed from 21.89% to 22.24% with an intermediate maximum at 22.45% in 2010. The number of 60+ inhabitants grew from roughly 337,700 to 440,870. In the first step, we analyzed the absolute number of deaths during hot and normal days. In the second step, these data were related to the number of inhabitants by calculating a death rate (number of daily deceased per 100,000 inhabitants). It is well known that the older population is more vulnerable to heat stress than the younger persons, an initial assessment of a possible influence of the age structure on mortality trends was therefore performed by analyzing the yearly changes in the proportion of the Viennese population older than 60 years using a Mann–Kendall test. The numbers obtained showed no significant trend (p value 0.62) which leads us to the conclusion that fluctuations in the proportion of older people might lead to some yearly fluctuations but not to any trends in mortality. Further analysis was however also performed (see Section 3).

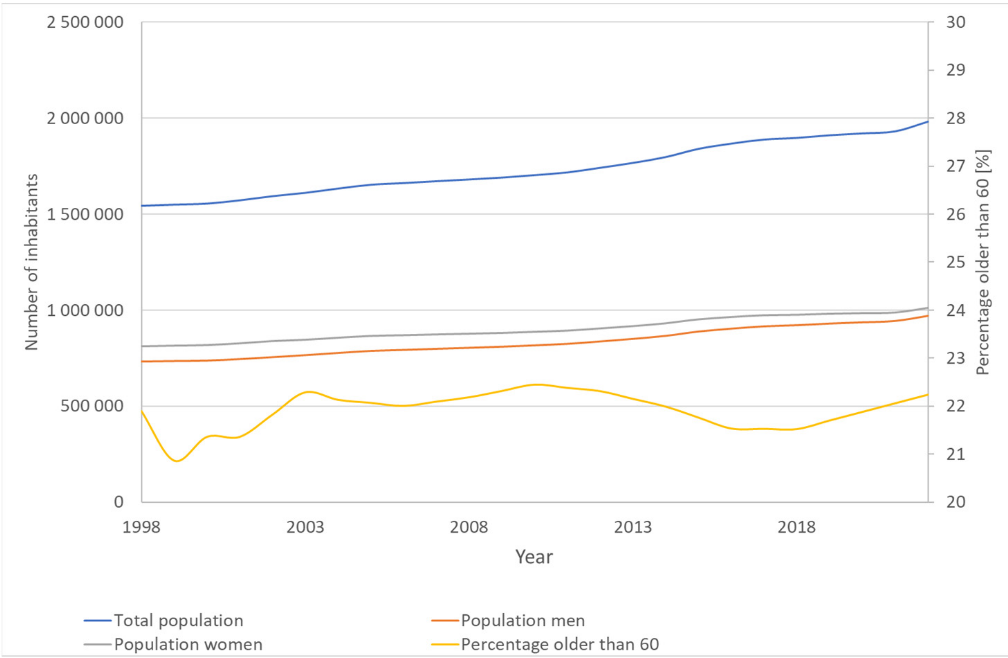

Figure 1. Population of the city of Vienna. The total number and the number of female and male residents as well as residents older than 60 years are displayed. The percentage of the population older than 60 years is also shown (right y scale).

2.3. Method of Analysis

Figure 2 shows the number of deceased as a function of the duration of the heat period. Only heat waves with a duration of 10 days or more are shown. The huge fluctuation of all the data including the average does not show any trend and indicates that an average of the daily deceased over the whole heat period may be used as an indicator for further analysis.

We, therefore, calculated the average daily mortality for normal days and hot days as well as the total sum of excess deaths during hot days. The analysis was also performed for the women's and men's populations. In the second step, a trend analysis was performed by taking into account the number of inhabitants. In order to analyze any adaptation of the population to heat waves the trend uncertainty due to a changing age structure was estimated.

The analysis of the statistical difference as a function of meteorological conditions was performed using a Wilcoxon test since data are non-normally distributed. Trend analysis was performed using the Mann–Kendall test. A significance level of 95% was used for all the statistical tests.

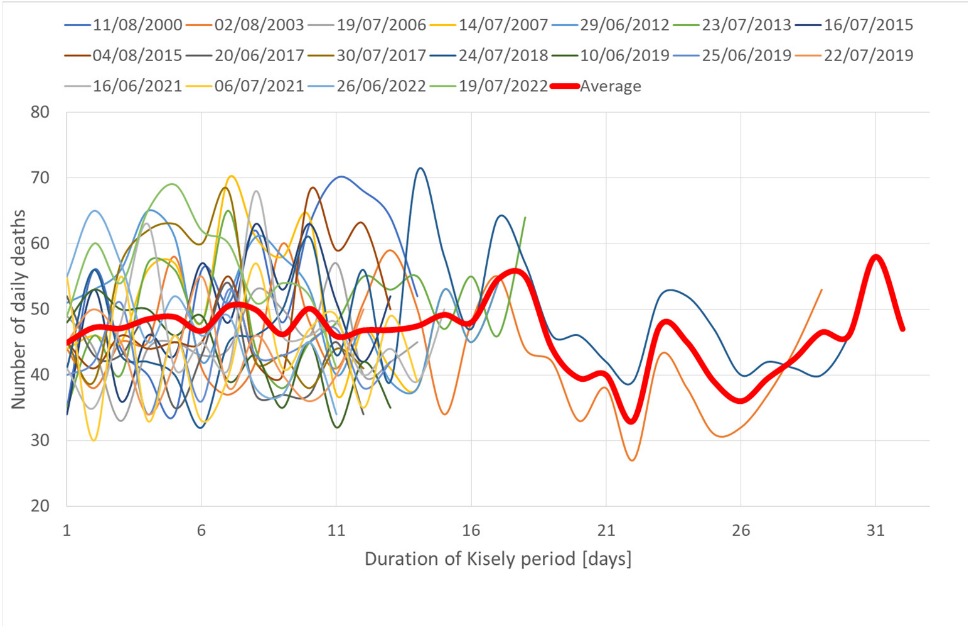

Figure 2. Daily number of deceased as a function of the duration of the heat wave. Mortality data of 18 heat waves with a duration longer than 10 days were used. The day of the beginning of the heat waves is indicated in the legend.

3. Results

3.1. Analysis of Climatological Trends

Figure 3 shows a sharp increase in hot spell days and tropical nights over the time period of 1998 to 2022. The number of hot spell days has more than doubled from the time interval 1998 to 2004 to the time interval 2015 to 2022. The number of tropical nights has also doubled during that time. The year 2003 stands out and does not fit with the trend.

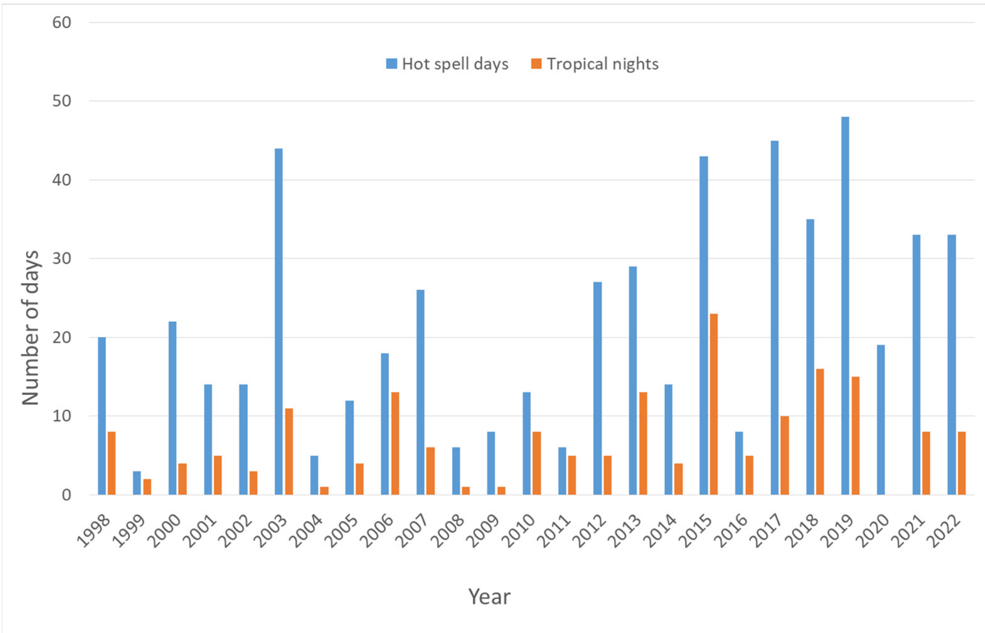

Figure 3. Number of hot spell days and tropical nights per year for the period of 1998 to 2022.

Figure 4 shows the average of all the mean daily maximum temperatures of the months of May to September over the time span of 1998 until 2022. The data are based on measurement data from the main meteorological station Hohe Warte in Vienna. A Mann–Kendall test shows a statistically significant increasing trend (p-Value 0.01) with a slope of 0.07 °C per year. The average maximum daily temperature has therefore increased by more than 1.4 °C within a period longer than 20 years. Finally, it was found (not shown here) that May and September within these 25 years did not play a crucial role with respect to heat waves and tropical nights. Heat events only occurred occasionally during these two months. This situation, however, could change due to the progressive change in temperature. May and September might in the future become more relevant for such evaluations.

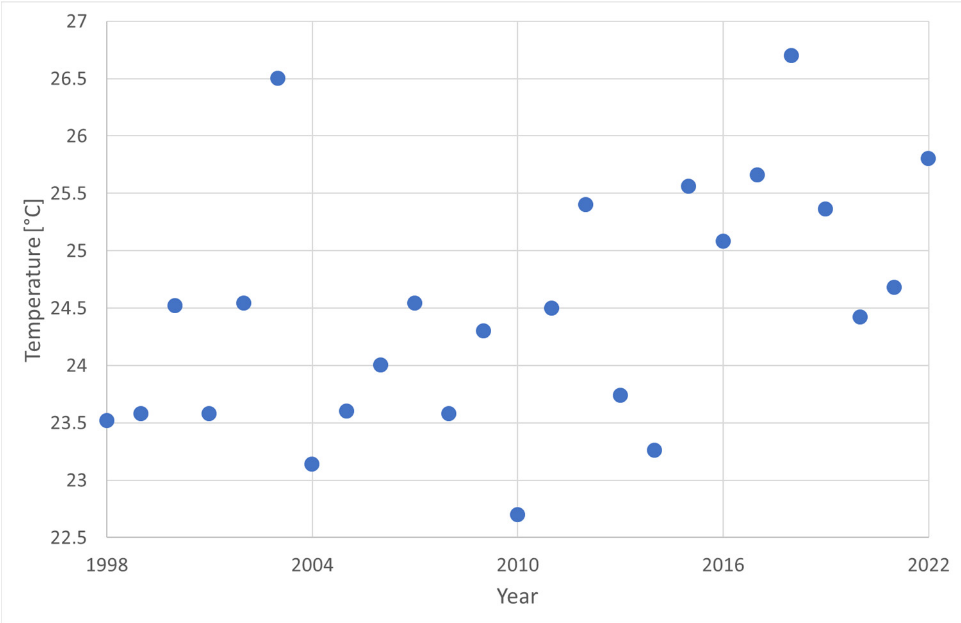

Figure 4. Average of all the daily maximum temperatures of the period May to September for the period of 1998 to 2022.

3.2. Analysis of Mortality Data

In addition to the calculation of the hot spell days, of the days with tropical nights, and their respective average mortality, we additionally determined the number of deceased for women and men separately (Table 1). In addition, the death rate (number of deceased per 100,000 inhabitants) as well as the total sum of excess deaths during hot days was calculated. The number of excess deaths is the sum of the difference between the average number of deaths during hot days minus the average number of deaths during normal days multiplied by the number of hot days. This number was determined for each year. The last column of Table 1 shows the percentage proportion of female deaths compared to the total number of deaths on normal days and hot days.

These numbers were then analyzed in more detail:

Figure 5 shows the average of daily deaths for the months of May to September for each year of the period 1998 to 2022. The number of deaths is almost for all the years lower on normal days. Statistical significance using the Wilcoxon test showed that the number of deaths during hot days (average 47.4; p-value 2.92×10^{-7}), hot spell days (average 45.41; p-value 3.86×10^{-5}), and days with tropical night conditions (46.61, p-value 0.0036) were significantly higher than on normal days (average 41.92). The highest mortality was observed at the beginning of this 24-year period (1998–2004).

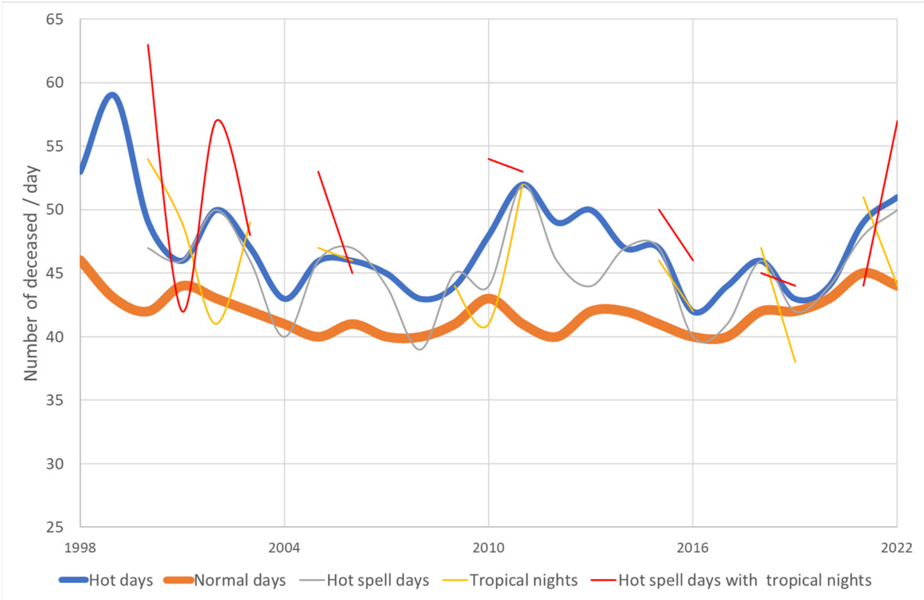

Figure 5. Distribution of the average of daily deaths for the months of May to September of each year. Average daily deaths are shown for hot days (blue line) which are hot spell days + days with tropical nights, normal days (all the days between 1 May and 30 September which are "not hot days"), days with tropical nights, and days which are at the same time hot spell days and days with tropical nights. The absolute numbers of death events are shown without taking into account the growth of the Viennese population.

Table 1. Comparison of the meteorological conditions and mortality data for the respective years (N = number; Mort = mortality; Perc = percentage).

Year	N Hot Spell Periods	N Hot Spell Days	N Tropical Nights	N Deaths/ Day Normal Days	N Deaths/ Day Hot Days	Mort Rate Normal Days	Mort Rate Hot Days	N Excess Deaths Hot Days	Perc Deaths Women Norm/Hot
1998	3	20	8	46	53	2.98	3.44	140	0.57/0.57
1999	1	3	2	43	59	2.78	3.81	48	0.56/0.54
2000	3	22	4	42	49	2.7	3.15	154	0.57/0.57
2001	3	14	5	44	46	2.8	2.93	28	0.54/0.59
2002	2	14	3	43	50	2.7	3.14	98	0.56/0.58
2003	3	44	11	42	47	2.61	2.92	220	0.56/0.55
2004	1	5	1	41	43	2.51	2.63	10	0.54/0.53
2005	2	12	4	40	46	2.42	2.78	72	0.55/0.59
2006	2	18	13	41	46	2.47	2.77	90	0.56/0.56
2007	3	26	6	40	45	2.39	2.69	130	0.55/0.58
2008	1	6	1	40	43	2.38	2.56	18	0.55/0.56
2009	2	8	1	41	44	2.43	2.60	24	0.54/0.57
2010	2	13	8	43	48	2.53	2.82	65	0.53/0.58
2011	1	6	5	41	52	2.39	3.03	66	0.54/0.56
2012	3	27	5	40	49	2.30	2.81	243	0.55/0.55
2013	3	29	13	42	50	2.38	2.83	232	0.55/0.54
2014	3	14	4	42	47	2.34	2.61	75	0.55/0.51
2015	5	43	23	41	47	2.23	2.55	258	0.51/0.53
2016	2	8	5	40	42	2.14	2.25	16	0.53/0.52

Table 1. *Cont.*

Year	N Hot Spell Periods	N Hot Spell Days	N Tropical Nights	N Deaths/ Day Normal Days	N Deaths/ Day Hot Days	Mort Rate Normal Days	Mort Rate Hot Days	N Excess Deaths Hot Days	Perc Deaths Women Norm/Hot
2017	5	45	10	40	44	2.12	2.33	180	0.53/0.52
2018	2	35	16	42	46	2.21	2.42	140	0.55/0.52
2019	5	48	15	42	43	2.20	2.25	48	0.52/0.51
2020	3	19	0	43	44	2.24	2.29	19	0.51/0.55
2021	3	33	8	45	49	2.33	2.54	132	0.51/0.51
2022	4	33	8	44	51	2.22	2.57	231	0.52/0.51

The average daily number of deceased on normal days shows some decrease until 2005, then remains at the same level until 2017 and shows a slight increase between 2017 and 2022. Since a steady growth of the Viennese population between 1998 and 2022 occurred, the number of deaths will be referred to the number of inhabitants (see next sections).

Basically, it can be seen that the highest daily number of deaths under all conditions occurred in the period of 1998 to 2004. One can also see that the largest ranges of annual values took place in this period. The daily mortality values on "hot days" ranged between 43 and 59 deaths per day. The average number of deaths was almost 50, as was the case with tropical nights (49/d). Here, the daily mortality values are between 41 and 54/d. On average, 46 Viennese people died on hot spell days per day, with minimum and maximum values of 40 and 50, respectively. Most deaths occurred when the heat period day and tropical night coincided, and the value reached 53/d. This range was the largest with minimum and maximum yearly average daily deaths of 42 and 63, respectively. Days without heat referred to as "normal days" came to an average of 43/d. Here was the smallest range with minimum values of 41 and maximum values of 46.

During the period 2005 to 2010, the daily number of deaths decreased for all the heat conditions. The range has also been significantly reduced. For hot days, the average mortality was reduced to 45 with values within a range of 43 to 48/d. The mortality during tropical nights was also reduced by 4 to 45. The minimum and maximum number of daily deaths was between 41 and 47. The average daily mortality for "normal days" (days which do not belong to the group of hot days) is—with the daily deaths number—just below 41 also reduced. On hot spell days, the average number of deceased was 45. When hot spell days and tropical nights coincided, the highest number of deceased was reached and, with 52 daily deaths, was slightly below the average of 57 for the period (1998 to 2004) (for similar weather conditions). The difference between the number of deceased on the "normal days" compared to the number of deceased during tropical night events and hot period days is lower than in period 1. A second maximum of average daily heat-related deaths was observed in 2011 with a mean value of 52 deaths per day. Since the meteorological conditions (Figures 3 and 4) regarding the number of hot days, the number of tropical nights, and the mean maximum temperature do not indicate extreme heat conditions, we can more likely conclude that it is an outlier or it may have other causes.

In the time period of 2011 to 2016, a decrease in daily deaths on both, hot days and normal days is shown. After 2016 a slight increase in both categories may be observed, which may be related to the increase in Vienna's population.

The maximum value of daily deceased approached that of the period 1998 to 2004 and reached 45. On hot spell days, the average number of deceased remained the same, with a range between 40 and 50 daily deaths. Under the tropical night conditions, minimum and maximum values were 38 and 51 deceased per day, respectively. The maximum yearly average of the number of deceased per day was 57 (for hot spell days with tropical night conditions) and therefore higher than that of the years between 2005 and 2016 for the same conditions. Overall, however, the number of deceased per day for the respective weather conditions was closer together. Statistical analysis was performed taking the total number of inhabitants into consideration and are shown in the next sections.

As briefly mentioned above, the mean values used so far were absolute values and were not related to the number of inhabitants of Vienna.

Figure 6 shows the sum of excess daily deaths per year. In some years almost no excess heat-related deaths may be observed (e.g., 2004: 10 deaths, 2008: 18, 2009: 24, 2016: 16, 2020: 19). On very hot years the sum of heat-related deaths amount to 220 (the year 2003), 243 (the year 2012), 232 (2013) and 231 (2022). Statistical analysis concerning a possible trend using the Mann–Kendall test was negative, with a *p*-value of 0.55. The explanation lies probably in the fact that on one side the population is adapting to heat stress by changing its behavior, but on the other side, there is a steady increase in the number of hot days.

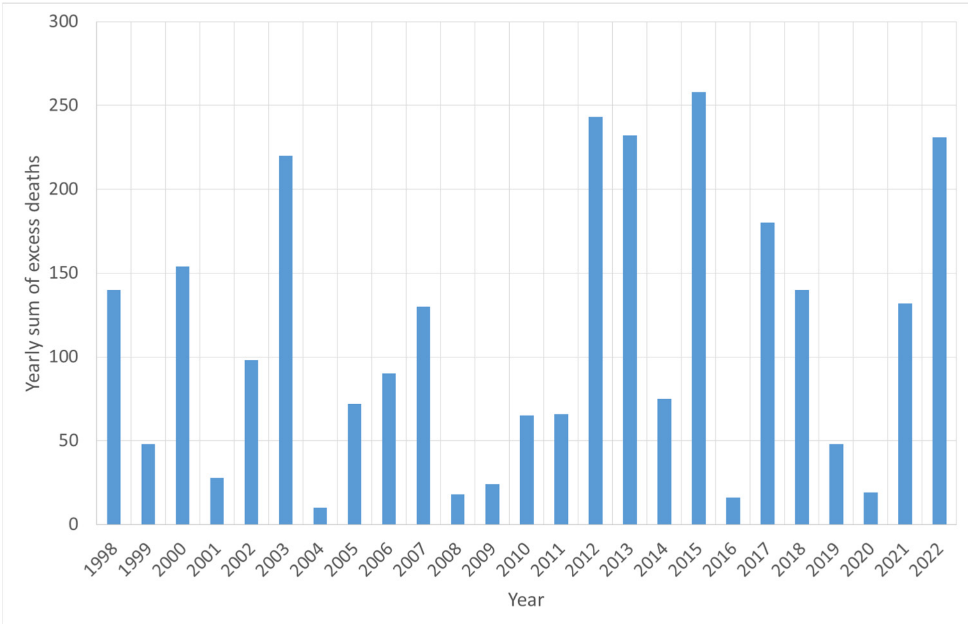

Figure 6. Yearly sum of excess deaths. The number of excess deaths is the sum of the difference between the average number of deaths during hot days minus the yearly average number of deaths during normal days, multiplied by the number of hot days.

In 25 years, the city of Vienna has grown by almost 440,000 inhabitants and now amounts to 1,982,393 inhabitants. The mortality data were therefore related to the number of inhabitants. The number of deceased per day, per 100,000 inhabitants was therefore calculated and is shown in Figure 7.

A steady decrease in mortality per 100,000 inhabitants on normal days is shown. The Mann–Kendall test also indicates a statistically significant decreasing linear trend (p value 1.37×10^{-7}, $R^2 = 0.89$) with a slope of -0.026. The mortality on hot days shows also a statistically significant decreasing trend (p value = 1.12×10^{-5}, $R^2 = 0.72$) with a slope of -0.037.

It is also, in general, in accordance with the observed decrease in mortality that was already reported by [17,18].

As can also be seen in Table 1, the results obtained for 1998 and 1999 showed rather high death numbers. This applied to hot days and normal days as well. The mortality rate continued to decrease until the end of the first period and then remained relatively constant for several more years. After 2010 there was a slight increase, which, however, stopped a year later and was reduced again. In 2019 and 2020, the death rates on hot and normal days were almost similar with a difference in daily deaths of 0.05 per 100,000 inhabitants. In the years after 2020, the difference in mortality between hot and normal days increased again. A connection with the COVID-19 (SARS-CoV-2) pandemic was not analyzed in this work.

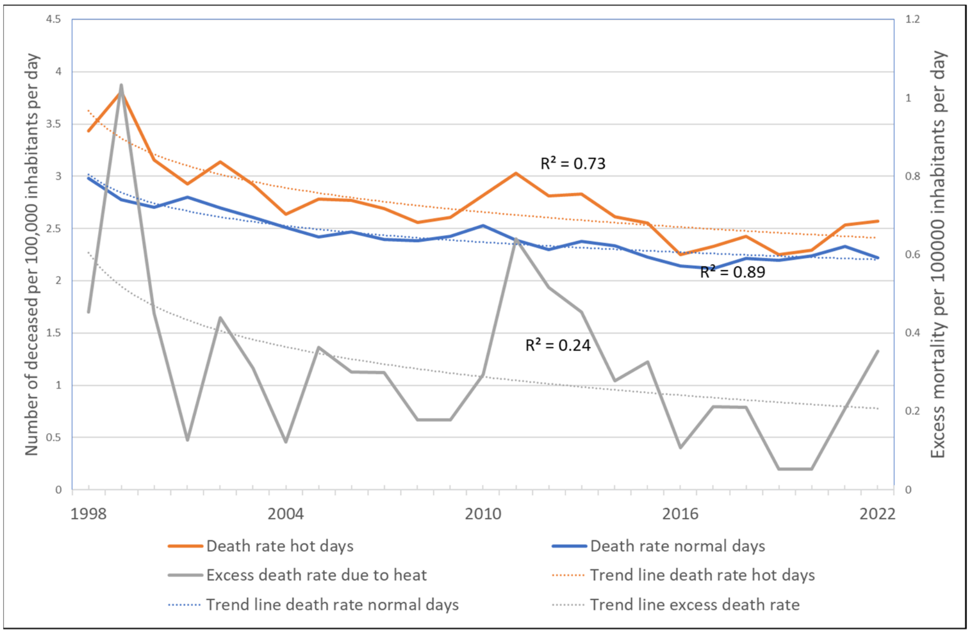

Figure 7. Annual comparison of death rates (number of deceased per 100,000 inhabitants per day) on normal and hot days. The excess (heat-related) death rate which is the difference between death rate on hot days minus death rate on normal days is also shown (right Y axis).

Altogether, the difference between mortality under hot and normal days decreased. According to the trend lines the distance between the trend lines decreased from 0.6 deceased per day and 100,000 inhabitants to approximately 0.2 deceased per day and 100,000 inhabitants. This was also tested for statistical significance and Mann–Kendall p values of 0.018 with a slope of -0.011 were obtained, which leads to the conclusion that the decrease in the difference between heat-related mortality and mortality on normal days is statistically significantly decreasing. In order to make further conclusions (e.g., as to a possible adaptation of the population regarding heat), the impact of the changing age structure needs to be excluded.

It is well known that the older population is more vulnerable to heat stress and heat- related deaths (e.g., [4]). The assumption that the difference in heat-related deaths compared to normal death rates may only be in relation to a change in the age structure of the Viennese population was tested using a worst-case scenario.

We assumed that all the heat-related deaths affect the population older than 60. We therefore calculated a fictive mortality per 100,000 members of the +60 population, assuming that all the deceased were aged 60 or older (Figure 8). A possible trend in the excess heat-related deaths was subjected to the Mann–Kendall test. A statistical significance showing a negative trend was obtained (p-value of 0.029, with a slope of -0.047). Since the death rate fluctuation within the older population is larger (also due to a smaller population), the uncertainty of the trend slope still remains very high.

In Section 2 no significant trend in the proportion of older people in the Viennese population was found, we then calculated an excess heat-related mortality per 100,000 people older than 60 and also found a statistically negative trend. The conclusion may therefore be drawn that the age structure (more older people) does not explain the adaptation of the population to heat and the resulting decrease in heat-related mortality.

Next, we investigated mortality per 100,000 female or male inhabitants. Figure 9 shows the yearly average of daily mortality of women per 100,000 female inhabitants. The same characteristic features as for the total Viennese population may be seen. A statistically significant decrease in average daily deceased on normal days is shown (p-value 3.52×10^{-8}, $R^2 = 0.83$, slope = -0.032). On hot days, a significantly decreasing trend in daily mortality is also obtained (p-value 3.32×10^{-6}, $R^2 = 0.73$) with a slope of -0.051. The excess mortality (heat-related mortality) also shows a larger fluctuation and a lower correlation coefficient of $R^2 = 0.2056$. The Mann–Kendall test indicates a statistically significant decreasing trend (p-value 0.0035 with a slope of -0.015).

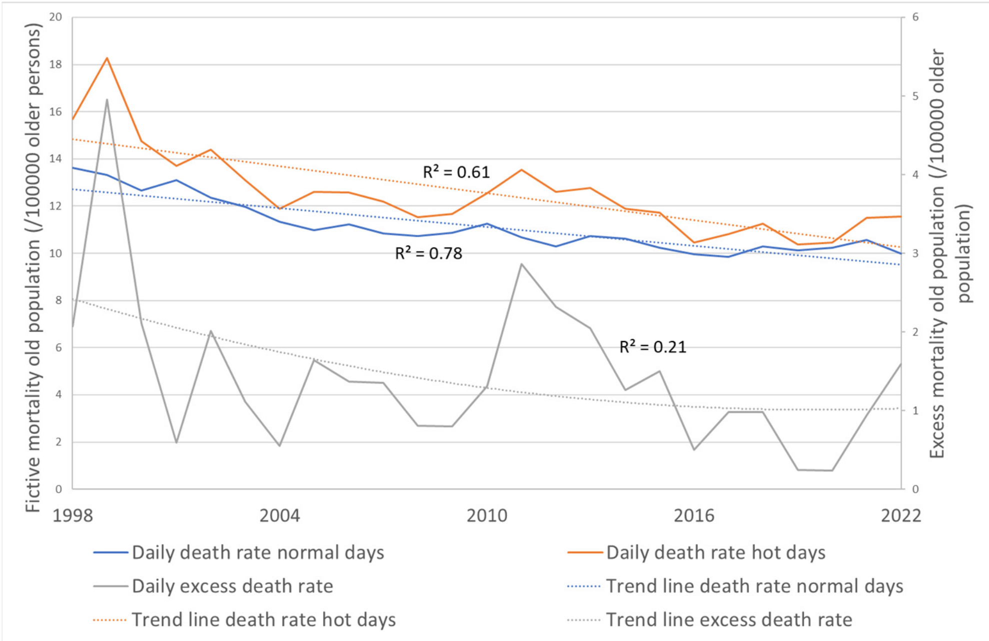

Figure 8. Fictive daily mortality per 100,000 older +60 inhabitants carried out to analyse a possible impact of the age structure of the Viennese population on mortality trends.

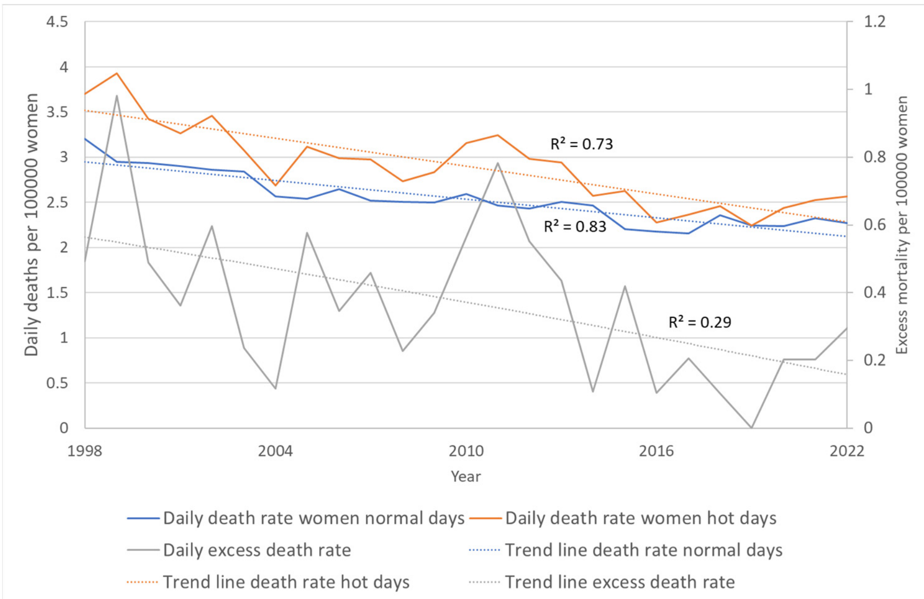

Figure 9. Daily average mortality of the Viennese women population per 100,000 female inhabitants. The daily heat-related excess death rate, which is the difference between both lines is shown in grey and is related to the right Y scale.

Figure 10 shows the yearly average of daily mortality of men per 100,000 male inhabitants. The characteristic features shown for the mortality of the total Viennese population and of the Viennese female populations are less pronounced. A statistically significant decrease in average daily deceased on normal days is shown (p-value 1.09×10^{-5}, $R^2 = 0.64$, slope = -0.02). On hot days a significantly decreasing trend in daily mortality is also obtained (*p*-value 0.0067 R^2 = 0.37) with a slope of – 0.024. The excess heat related death rate shows compared to the death rate of the total population and of the female population a much larger fluctuation and with R^2 = 0.04 no correlation. The Mann-Kendall test of the excess heat related death rate indicates with a p value of 0.28 no statistically significant trend.

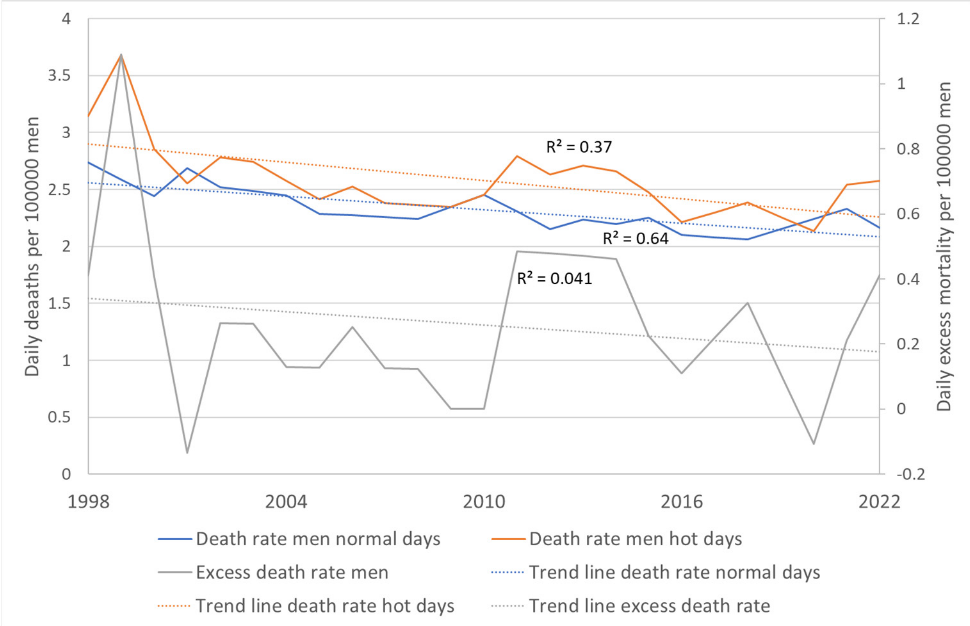

Figure 10. Daily average mortality of the Viennese male population per 100,000 male inhabitants. The daily heat-related excess death rate is shown in grey and is related to the right Y scale.

4. Discussion and Conclusions

This work examined the effects of heat waves and tropical nights on the mortality of the Viennese population. Basically, the mortality on hot days was compared to mortality on normal days. The 5-year average of daily deaths on hot days fell over time from almost 50 to 46 deaths per day, despite the fact that population growth of the Viennese population of approx. 440,000 people occurred.

Mortality on hot days was clearly statistically significantly higher than on normal days.

The results confirmed previous results which showed increased daily mortality during heat waves and tropical nights. The highest number of deceased was found on hot spell days with tropical night conditions. During the analyzed 25-year period, the average of the number of daily deceased (during tropical nights) fell, as did that of the hot period days.

Despite the fact that the number of hot days has more than doubled, especially during the last time period, and that, in addition, there was population growth of almost half a million, the difference in mortality between hot and normal days decreased. The total yearly sum of heat-related excess deaths shows larger fluctuations but does not show any statistically significant trend. Two factors lead to opposite trends. First, the decrease in daily heat-related death rate of the population, and, second, the growth of the Viennese population which leads to an increase in absolute daily death numbers.

After including the population (rate per 100,000), there was also a clear reduction in the difference between the death rate on hot days and the death rate on normal days. Daily mortality per 100,000 inhabitants decreased from 0.7 to approximately 0.2. The daily excess death rate showed a statistically significant negative trend with a slope of −0.01 daily death per 100,000 inhabitants. The change in the age structure (proportion of inhabitants older than 60 years) showed some fluctuations within +−1% of the total Viennese population but did not show any significant trend during the 25-year period. In addition, a worst-case scenario assuming that all the heat-related deaths affected people older than 60 years showed also that the older residents were able to adapt to heat. The analysis of the mortality data also showed that the difference in women's death rate between hot and normal days is larger than for men. The men's death rate on hot days is sometimes lower than the normal day death rate. The male population also did not show a statistically significant decrease in excess deaths due to heat, whereas a clear adaptation to heat of the female population could be seen. Since 2001 the proportion of women who belong to the Viennese 60+ population did not change by more than -0.3%. We may draw the conclusion that the male population is more likely to die due to other problems than heat (e.g., cardiovascular problems, etc.). Men are also likely to work more outside and may have already a heat protection strategy.

Possible explanations for the observed trends may be a general trend in increasing life expectancy over the period due to better general health of the population and medical care or adaptation mechanisms either of a physiological, behavioral adaptation (clothing, food, etc.) or structural adjustments and use of technology such as air conditioners. But it could also be a kind of selection within the population since vulnerable individuals are more likely to pass away during the first heat waves and this would lead to a reduction of weak people especially at risk during the following hot spell periods [18].

Future work could make more reference to the age of the deceased by differentiating different age classes among the +60 population. It could also examine mortality as a function of the environment. Research related to the questions of whether building and population density and the proportion of green areas could have positive or negative effects would add some new information.

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