IDŐJÁRÁS

Quarterly Journal of the Hungarian Meteorological Service
Vol. 119, No. 2, April– June, 2015, pp. 143–158

Assessment of heat-related mortality in Budapest from 2000 to 2010 by different indicators

János Bobvos*, **Balázs Fazekas,** and **Anna Páldy**

National Institute of Environmental Health, Budapest, Hungary
Albert Flórián u. 2-6, H-1097 Budapest, Hungary
E-mails: bobvos.janos@oki.antsz.hu;
fazekasbalazshu@gmail.com; paldy.anna@oki.antsz.hu

**Corresponding author*

(Manuscript received in final form April 17, 2014)

Abstract―The increase of the temperature and frequency of extreme weather events are predicted as the most visible effects of expected climate change. The number of publications dealing with heat-related mortality has been increasing for the last 20 years. They concluded that no formal definition of a heat wave existed, so the definition of such events would be very important. A more consistent methodology for calculating excess mortality would enhance comparisons between studies.

It is a growing demand to elaborate and use indicators which can provide comparable information of the impact of heat on mortality in different geographic and climatic regions. Therefore, the World Health Organization developed a set of climate change related health indicators in the CEHAPIS (Climate, Environment and Health Action Plan Information System) project. The authors aimed to assess heat related excess mortality by using this methodology, in addition to indicators used in the Hungarian Heat Alert System, in order to provide a recommendation for a more precise detection of health effects in Budapest.

In this paper, the heat wave related daily excess mortality is analyzed for the summer periods of 2000–2010 in Budapest. Mortality is characterized by the daily total mortality and that of the age group 65 years and over. Meteorological variables of the Pestszentlőrinc station, regarded as an urban background meteorological station, were used. Daily temperature was characterized by four indicators: mean and maximum daily temperatures, and mean and maximum daily apparent temperatures. The impact on mortality was compared in relation to the different temperature indicators and threshold values. A method was developed to define the optimal threshold range where the excess mortality could be identified effectively.

The recommended method is capable to detect the changes of temperature and to assess the impact of heat waves on daily mortality. The results are in accordance with previous studies. Concerning the indicators, the application of daily mean temperature values seems to be optimal for Budapest. Further analyses are required to answer the question to what extent the Budapest findings can be used in other cities.

Key-words: heat indicators, heat-related mortality, heat-health warning system, climate change, health effects of climate change

1. Introduction

The number of publications dealing with heat related mortality has been increasing for the last 20 years. These studies have been reviewed from different points of view. In a review article, *Basu* (2009) analyzed the epidemiological studies dealing with the association of ambient temperature and mortality published in the period of 2001–2008. The majority of the studies used time series analysis or case-crossover methods and proved the impact of heat on mortality. Several studies identified cause- or age-specific vulnerable subgroups. In their critical review, *Hajat* and *Kosatsky* (2010) identified the comparable multicenter studies in order to explore the heterogeneity of the effects. Heat-related mortality could be detected in the majority of cities, the older age groups were more vulnerable, and the bigger heat effect was associated with higher population density. A higher threshold value was found in cities with higher summer temperatures.

The majority of studies call attention to the negative impacts of predicted climate change. According to the latest report of IPCC (Intergovernmental Panel on Climate Change, AR5 Fifth Assessment Report), the global mean surface temperature change for the period 2016–2035 relative to 1986–2005 will likely be in the range of 0.3 °C to 0.7 °C. The increase of global mean surface temperatures for 2081–2100 relative to 1986–2005 is projected to likely be in the ranges 0.3 °C to 4.8 °C (*IPCC,* 2013). A greater likelihood of injury, disease, and death due to more intense heat waves and fires is expected (*IPCC,* 2014). In his critical review, *Gosling et al.* (2009a) examined present temperature-mortality relationships and discussed climate change issues. He concluded that no formal definition of a heat wave existed, so the definition of such events would be very important. A more consistent methodology for calculating excess mortality would enhance comparisons between studies. There is evidence that climate change will affect temperature-related mortality heterogeneously, so there is a need for inter-regional comparisons that account for changes in the mean and variance of temperature.

Several studies analyzed the Budapest data as well. *Paldy et al.* (2005) investigated the effect of weather on daily mortality in Budapest, 1970–2000. *Hajat et al.* (2006) and *Gosling et al.* (2007) analyzed the same period by different methods. The data from the nineties were evaluated by *Ishigami et al.* (2008) and *Baccini et al.* (2008); a cause- and age-specific analysis was carried out by *D'Ippoliti et al.* (2010). Besides the Budapest data, a comparison of heat related mortality was carried out between the urban and rural populations in Hungary (*Bobvos* and *Paldy,* 2009). The excess mortality due to the strongest heat wave ever recorded in 2007 was analyzed at regional (*Paldy* and *Bobvos,* 2009) and small area levels (*Paldy et al.,* 2011). The predicted heat related excess mortality due to climate change was assessed by *Gosling et al.* (2009b), *Baccini et al.* (2011), and *Bobvos et al.* (2011) using a regional climate model.

Based on the studies, the proven impact of heat on mortality is a great burden on society. In order to decrease the negative effects, heat-health warning systems have been developed by public health services all around the world. These systems are based on meteorological forecasts and include different measures during warnings. *Kovats* and *Ebi* (2006) reviewed the public health aspects of heat waves and evaluated the relative effectiveness of public health responses. *Kovats* and *Hajat* (2008) emphasize the important differences in vulnerability existing between populations, depending on climate, culture, infrastructure (housing), and other factors. Based on the forecasts of the Hungarian Meteorological Service, the Hungarian Heat Alert System was introduced in Hungary in 2005. The system has three levels: a 1st warning, a 2nd alert, and a 3rd alarm level. The threshold temperature of the alert is 25 °C daily mean temperature. A heat wave is defined as three or more consecutive days with temperatures above this threshold. During the heat waves, the health care services and the local authorities launch previously prepared measures.

The above cited studies used a great variety of heat-related indices. It is a growing demand to develop and use indicators which can provide comparable information of the impact of heat on mortality in different geographic and climatic regions. Therefore, the WHO – in collaboration with WHO Member States – developed a set of climate change related health indicators (categorized into exposure, effect, and action) within the frame of the CEHAPIS project (*WHO*, 2011). This project recommends using two types of temperature indicators for heat exposure. The authors aimed to assess heat-related excess mortality by using the CEHAPIS methodology in addition to indicators used in the Hungarian Heat Alert System in order to provide a recommendation for a more precise detection of the health effects in Budapest.

2. Data and methods

In this paper, the heat wave-related daily excess mortality was analyzed for the summer period (May 16–Sept 15) of 2000–2010 for Budapest. Daily mortality data were gained from the Central Statistical Office of 1995–2010 for Budapest. All natural cause mortality (International Classification of Diseases codes ICD-9: 1–799) was characterized by the daily total mortality (M 0-X) and that of the age group 65 years and above (M 65+). Meteorological variables of the Pestszentlőrinc measuring station were retrieved from the Global Surface Summary of the Day Data (*GSOD,* 2010) archived in the National Climatic Data Centre (NCDC) at National Oceanic and Atmospheric Administration (NOAA) for 1990–2010. The Pestszentlőrinc monitoring station was regarded as an urban background meteorological station of Budapest. Daily temperature was characterized by four indicators: mean (T) and maximum daily temperatures

(Tx), and mean (AT) and maximum (ATx) daily apparent temperatures in ˚C. Apparent mean and maximum temperatures (*Kalkstein* and *Valimont,* 1986) were used as indices of thermal discomfort based on air temperature (T) and dew point temperature (T_{dp}) according to the following formula:

$$AT = -2.653 + 0.994(T) + 0.0153(T_{dp})^2. \quad (1)$$

To follow the changes in the temperature, a 10-year fixed reference period of 1990–1999 was chosen. The hot days were identified by the 90th percentile of the frequency distribution of temperature indicators, where the daily mean temperature value was 25 °C, being a threshold of the Hungarian Heat Alert System. A heat wave was defined as three or more consecutive days with temperatures above this threshold.

After the initial description of the data, linear trend analyses were carried out to detect the changes in time. An assessment was done to compare the number of heat waves identified by the different temperature indicators in relation to the threshold. The number of heat waves and the number of days of heat waves corresponding to the 90th percentile threshold were defined by year, respectively for the whole period.

The effect of heat waves on daily mortality – absolute excess mortality (*EM,* in case number) – was defined as the difference of the mortality during heat waves (observed mortality: M_o) and the expected mortality (M_e) computed form the daily mortality of the previous five years (reference periods of mortality) excluding the daily mortality of days of heat waves in the given years:

$$EM = \sum(M_0 - M_e). \quad (2)$$

The relative excess mortality was also computed in a similar way, defining the percent increase of mortality during the heat waves of a given summer period. The mean relative excess mortality (*EM*%, in percent) of the heat wave days (L) of a summer period can be computed by the following formula:

$$EM\% = 100 \sum(M_0 - M_e)L^{-1}. \quad (3)$$

To characterize the whole period, the sum and mean of excess mortality due to heat wave days were calculated above different percentiles in case of each indicator. To define the optimal threshold ranges, the product of the two data was used.

3. Results

3.1. Characteristics of mortality data and temperature indicators

Mortality data of the investigated period are shown in *Table 1*. The summer mean daily mortality of the whole period was 60.8 of the total population and 44.7 of the age group 65 years and over. Maximum daily mortalities were recorded in both age groups in 2007. The standard deviation (SD) was also the highest in that year. Total mortality showed a significant decreasing tendency by 0.33 cases per year in the total population and by 0.21 cases in the older age group.

Table 1. Yearly descriptive statistics of daily mortality of the total population and age group 65 and over years in the summer (cases), periods of 2000–2010 in Budapest

	2000	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**mean**
M 0-X min	43	46	38	38	40	39	36	35	35	39	36	38.6
M 0-X mean	62.9	62.9	61.3	58.8	61.3	60.8	62.6	61.2	58.2	57.5	60.8	60.8
M 0-X max	106	93	97	89	83	93	99	113	80	82	107	94.7
M 0-X SD	10.5	8.5	10.0	9.7	9.0	9.2	10.9	12.7	9.4	7.7	10.7	9.8
M 65+ min	29	33	28	26	28	29	25	22	22	26	25	26.6
M 65+ mean	46.1	46.7	45.2	43.1	44.9	44.4	45.1	44.9	42.3	42.7	45.8	44.7
M 65+ max	77	72	77	67	65	68	77	95	61	64	78	72.8
M 65+ SD	8.6	7.5	8.4	8.1	6.9	7.3	8.3	10.8	7.2	6.6	8.9	8.0

Table 2 contains the temperature data of the period. The mean of the daily mean temperatures were between 20 °C and 21 °C, the mean of the maximum daily temperatures was around 25–26 °C. Based on the daily mean temperature, the hottest year was 2003, while the daily maximum value was the highest in 2007, when the daily mean temperature was over 32 °C and the daily maximum was over 40 °C. The strongest heat wave was recorded in 2007, when several new record temperature values were measured.

3.2. Associations between the threshold values of temperature indicators and the number of defined heat wave days.

Fig 1 shows the values of the four temperature indicators in relation to different percentiles (p%) of the reference period – between 1990 and 1999 – of the study.

The shapes of the curves of the corresponding indicator pairs were similar in the range of p50–p80. The values of apparent temperature were lower in the cooler periods; the difference reached 2 °C in relation to the values of simple temperature indicators. The threshold values of the apparent temperature were somewhat greater, by 0.2–0.3 °C, in the hottest range. The value of the 90th percentile corresponded to the threshold temperature of the Hungarian Heat Alert System (mean daily temperature, T=25 °C), the exact threshold values were T=25.1 °C, AT=25.5°C, Tx=32.8 °C, and ATx=32.0°C.

Table 2. Yearly descriptive statistics of temperature indicators (°C) in the summer, periods of 2000–2010 in Budapest

	2000	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**mean**
T min	11.8	10.4	12.9	13.2	10.7	9.9	11.2	9.3	11.7	10.1	8.8	10.9
T mean	20.8	20.2	21.5	22.3	19.7	20.2	20.4	21.7	21.0	21.1	20.0	20.8
T max	29.6	28.8	28.7	29.5	28.2	28.6	28.5	32.3	27.1	27.7	28.7	28.9
Tx min	14.7	14.5	16.1	16.1	14.0	11.7	13.1	11.1	14.6	12.7	10.1	13.5
Tx mean	26.9	25.6	27.0	28.5	25.4	25.2	26.0	27.8	27.0	26.9	24.9	26.5
Tx max	38.0	36.0	35.4	38.3	34.4	35.2	35.9	40.6	36.1	35.0	35.2	36.4
AT min	10.3	8.4	10.7	10.6	8.0	8.0	9.6	7.5	9.1	8.3	6.6	8.8
AT mean	19.8	19.7	21.4	21.8	19.0	20.0	20.5	21.3	20.6	20.4	20.5	20.5
AT max	29.9	30.0	29.1	28.9	28.6	31.5	31.8	32.6	28.4	29.1	31.9	30.2
ATx min	13.2	12.7	13.9	15.2	11.3	10.3	11.5	9.3	12.0	10.9	7.9	11.6
ATx mean	25.9	25.1	26.9	27.9	24.7	25.1	26.1	27.4	26.5	26.2	25.4	26.1
ATx max	37.0	37.2	36.8	37.7	34.8	37.6	37.5	40.7	37.4	35.7	38.3	37.3

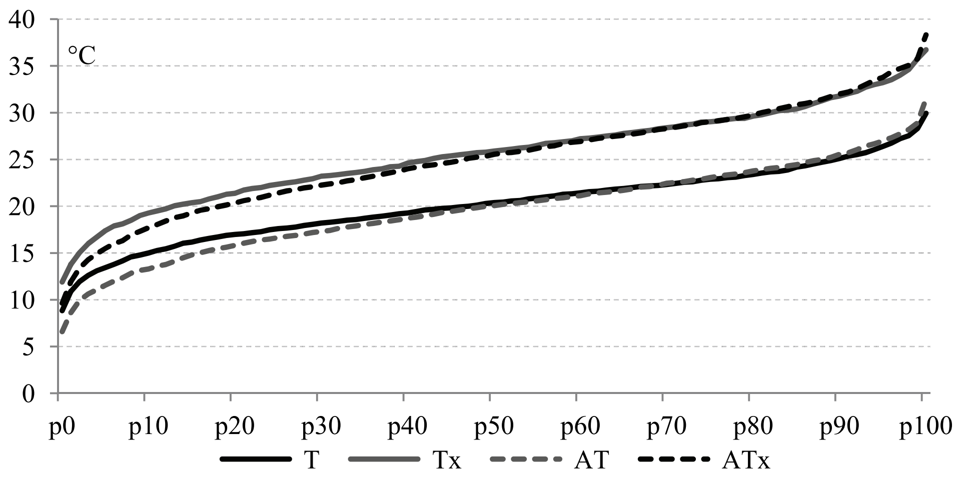

Fig. 1. Values of the four temperature indicators (°C) in relation to the percentiles between 1990 and 1999 in Budapest.

The temperature indicators identified different numbers of heat wave days in the period of 2000–2010. *Fig. 2* demonstrates the numbers of heat wave days by different threshold values in the warmer intervals. It can be observed that apparent temperature indicators defined more heat wave days. This means that the different indicators identified the same number of heat waves by different percentiles. The curves of the *T-Tx* and *AT-ATx* indicator pairs crossed each other several times in relation to threshold values.

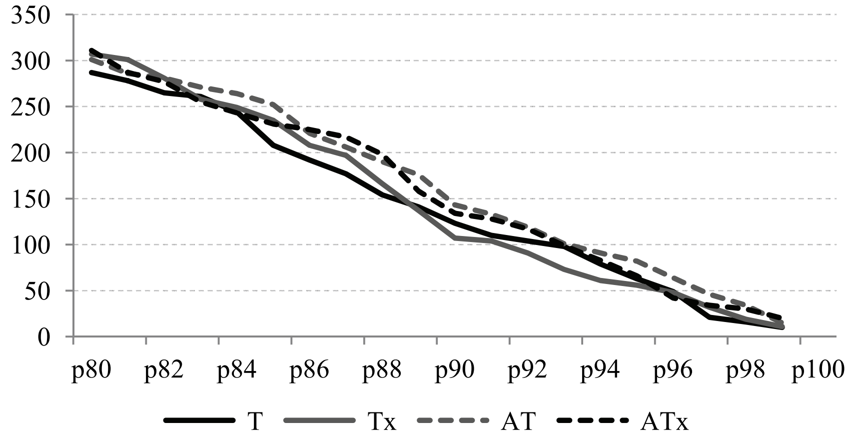

Fig. 2. Number of heat wave days defined by the four indicators in relation to percentiles between 2000 and 2010 in Budapest.

Fig. 3 represents the number of heat waves lasting for three or more days defined by the 90th percentile by different indicators. In some years, the number of heat waves defined by different indicators was the same (2001, 2005); however, the number of heat waves was different in most of the years. In the period from 2006 to 2010, the differences in the number of heat waves became bigger and more frequent. The yearly mean numbers of heat waves were 1.9–2.5 events.

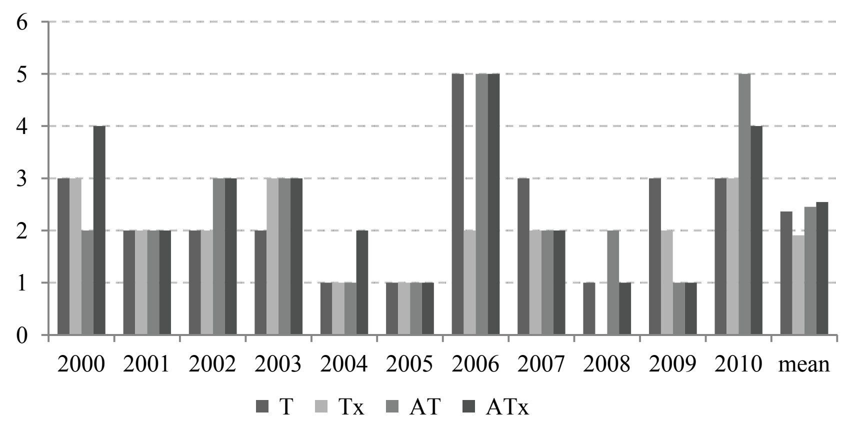

Fig. 3. The number of heat waves defined by the 90th percentile of indicators between 2000 and 2010 in Budapest.

Fig. 4 represents the number of heat wave days defined by the 90th percentile by different indicators. The numbers of heat wave days were different in each year. The differences became greater and more frequent in the last five years. The yearly mean numbers of heat wave days were between 10 and 13 days.

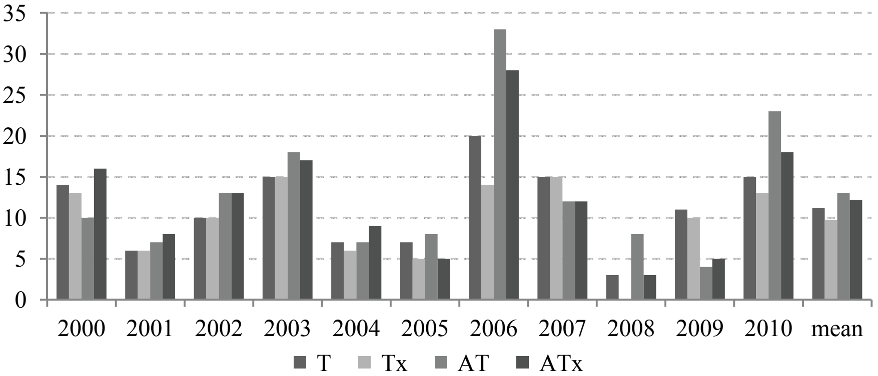

Fig. 4. The number of heat wave days defined by the 90th percentile of indicators between 2000 and 2010 in Budapest.

Based on the previous results, we can state that different heat wave days were identified by the different indicators. It was necessary to test to what extent the heat wave days were defined by the indicators as identical. *Fig. 5* shows the number of heat wave days defined by the indicator pairs, furthermore, the number of identical heat wave days defined by both indicators for the whole study period. The most heat wave days were identified by the indicator pairs *AT* and *ATx* (143 and 134 days, respsctively), while 123 and 107 days were identified by *T* and *Tx*. The number of identical heat wave days was between 88 and 129 days, meaning a correspondence of a range of 66–87% by indicators.

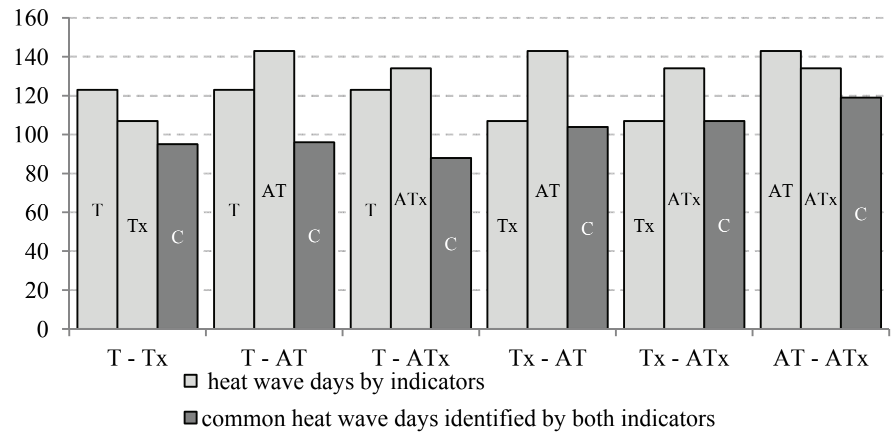

Fig. 5. The number of heat wave days identified by indicator pairs at the 90th percentile threshold value and the number of common heat wave days identified by both indicators between 2000 and 2010 in Budapest.

3.3. *Associations of heat and mortality*

The association between daily mortality and temperature has a U or J shape in general. In case of Budapest, the curve has a typical J shape. *Fig. 6* shows the difference of the daily mortality from the mean mortality in relation to daily mean temperature in the total population and in the group over 65 years. The approximate curve was produced by a cubic spline function having 4 degrees of freedom. The shape of the curves were similar, however, the effect of the temperature was somewhat bigger in the older age group. There was a higher mortality on cooler (<10 °C mean temperature), and warmer days (>23 °C mean temperature). The daily mortality significantly increased on days with higher mean temperature; the difference was greater than 40% on the hottest days. Concerning daily mortality, the optimal temperature range was between 17–20 °C. The shapes of the curves of the other indicators were similar.

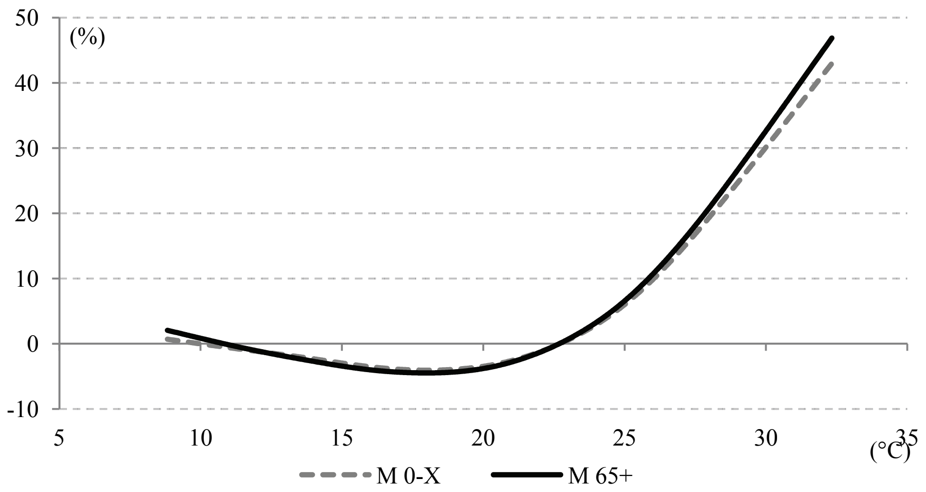

Fig. 6. Characteristics of association of daily mortality (percent differences from mean mortality) and daily mean temperature between 2000 and 2010 in Budapest.

3.4. *Effect of heat waves on mortality*

Fig. 7 shows the calculated daily expected total mortality (M_e) during the studied period and the total observed mortality (M_o) of the heat wave days by years. The expected daily mortality calculated on the basis of a 5-year moving reference period showed a decreasing tendency in relation to time. An excess mortality could be observed on the heat wave days in each year. In 2008, no heat wave was defined by the *Tx* indicator; therefore, no excess mortality was shown. The observed mortality was higher than expected mortality in every year. The association was similar in the older age group as well (not shown).

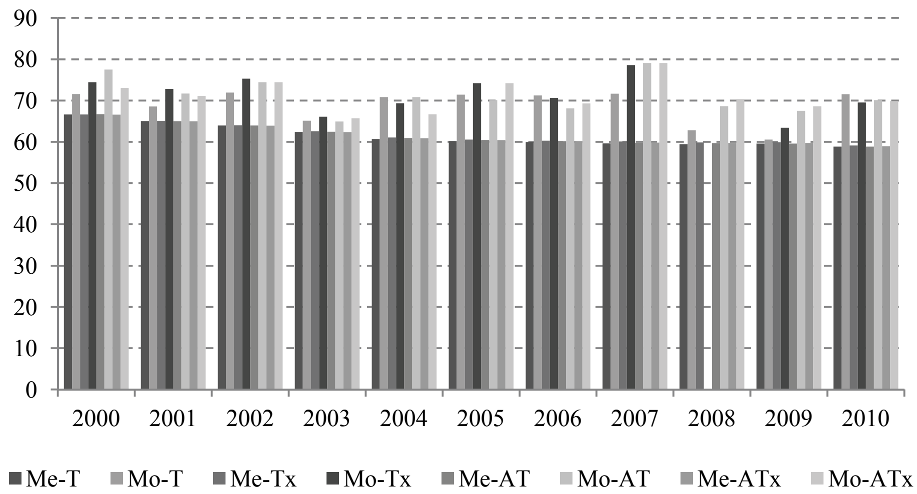

Fig. 7. The expected daily total mortality (M_e) and the observed total mortality (M_o) during the heat wave days defined by the four indicators between 2000 and 2010 in Budapest.

Fig. 8 shows the difference between observed and expected mortality: the excess mortality by years. The yearly numbers of excess mortality due to heat waves showed great variability. The lowest excess mortality was observed in 2008, and it was also very low in 2009 and 2001. The highest excess mortality was recorded in 2007, due to the strongest heat wave ever recorded. In that year, the number of excess death cases was 230–270 in the total population and 202–240 cases in the older age group during the 15 heat wave days by the different indicators. Similarly high excess mortality was observed in 2006 and 2010. There were great differences in the number of excess death cases in those years, when the indicators identified considerably different numbers of heat wave days (in 2006, 2008, and 2010). An average of 102–122 excess mortality cases could be attributed to heat waves in the total population, whereas there were 86–96 cases in the older age group defined by the different indicators. The mean percent excess mortality was between 15–18%; however, it surpassed 30% in 2007.

3.5. The relationship of excess mortality and different threshold values

The sum of death cases decreased by the increase of temperature threshold values as the number of identified heat wave days decreased. On the other hand, excess mortality increased on days with increasing temperature, while the mean excess mortality on identified heat wave days increased in relation to threshold values. To define the proper threshold, the product of the corresponding values of the two curves can be used. At the maximum range of the product curve, the two opposite processes were equally considered. *Fig. 9* represents the sum of total excess mortality, the mean excess mortality above different percentiles, as well as the product of the two datasets in case of daily mean temperature indicator. The shapes of the curves of the sum of total excess mortality and the mean excess mortality changed more steeply over the 80th percentile, the value of their product started to increase over this percentile. Above the 95th percentile, the total excess mortality started to decrease significantly, while the excess mortality on heat wave days changed in the opposite direction. The range between the 85th and 95th percentiles met the criteria of the threshold value the best. The chosen threshold of daily mean temperature is 25 °C, which is the national alert threshold, corresponding to the 90th percentile seemed to be a suitable cut-off point. The shapes of the curves of the other indicators were similar (not shown).

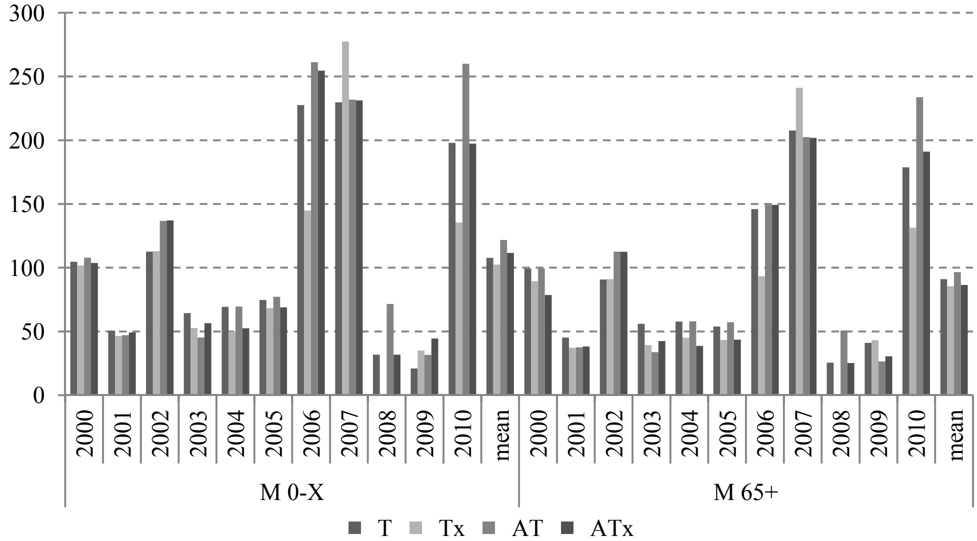

Fig. 8. The difference between expected and observed mortality in the total population and in the older age group between 2000 and 2010 in Budapest.

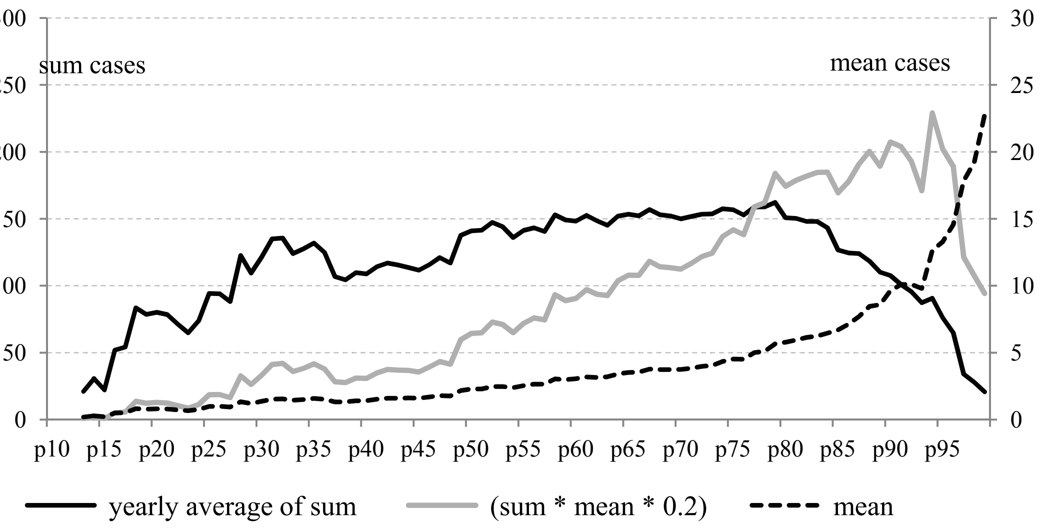

Fig. 9. The sum of total excess mortality, the mean excess mortality of heat wave days above thresholds, as well as their product in case of daily mean temperature indicator between 2000 and 2010 in Budapest.

The increase of the mean excess mortality on heat wave days in relation to the threshold values differed by the different temperature indicators (*Fig 10*). Similar values of excess mortality could be observed within the range of 85th–92nd percentiles of temperature indicators. In the range of higher temperatures, the differences between the shapes of the curves were bigger, the highest excess mortality could be observed when using the daily mean temperature indicator. In case of the other three indictors, considerably lower increase of excess mortality was related to the increase of threshold values. Excess mortality increased only over the threshold value corresponding to the 99th percentile.

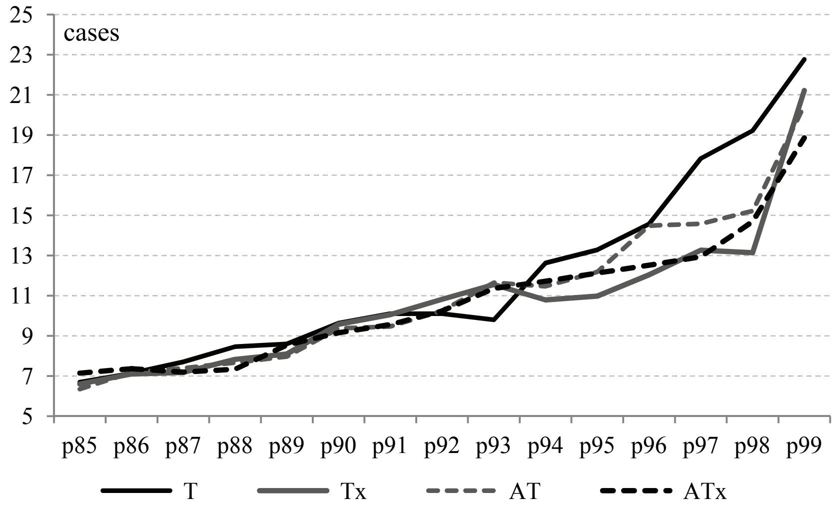

Fig. 10. The mean excess mortality on days above threshold by different indicators between 2000 and 2010 in Budapest.

4. Discussion

Heat related mortality was studied very intensively in the last two decades all around the world. The adverse impact was shown with great certainty. Several methods were used to characterize heat waves; different indicators were elaborated and applied.

The majority of studies used simple temperature parameters to characterize the impact of heat, while others applied more complex thermal indices based on different meteorological factors like humidity, radiation, wind speed, etc. Many papers tested several indicators in order to find the most suitable temperature predictor to detect heat-related excess mortality (*Barnett et al.,* 2010; *Kim et al.,* 2011; *Vaneckova et al.,* 2011; *Yu et al.,* 2011; *Morabito et al.,* 2014). The results could not identify the best indicator, the use of complex indices did not prove to be more efficient in determining the impact. Furthermore, the computation of complex indices is troublesome, their forecast is more ambiguous.

There is no universal definition of heat waves; the threshold values also show great variability. Health endpoints also vary, different age and cause-specific mortalities, as well as different groups (sex, race, socio-economic state, etc.) are studied. The results within multicenter studies can be compared due to the applied common methodology.

There is an increasing need to have comparable results in the public health system. The CEHAPIS methodology aims to monitor the change of heat related mortality in relation to climate change in the long run. The major concept was to develop simple indicators and computation for wide range use and comparability. Similarly to climate models, a 10-year reference period of the temperature indicators (daily maximum and daily apparent maximum temperature) is used in order to follow the future changes. The methodology describes heat waves as days with at least three consecutive days above the threshold value of temperature indicators defined as the 95th percentile of the reference temperature. The methodology recommends assessing the impact on cities with more than 500,000 inhabitants. Mortality, excluding external causes of the total and the 65 years and older population, is used to characterize vulnerability. A moving reference period (five years prior to the year of study year) of mortality is chosen to follow the changes of sensitivity (aging, adaptation, etc.). The expected (baseline) mortality, i.e., the average daily number of deaths is calculated using daily mortality in the reference period excluding the daily number of deaths on heat wave days. In the present paper, two simple temperature indices (T, Tx) and two other ones including humidity (AT, ATx) were used. The calculations did not need sophisticated statistical methods.

The mortality data of Budapest showed a significantly decreasing tendency. The use of a moving reference period could handle this tendency when calculating the expected values, i.e., the baseline decreased from year to year. No trend could be observed in the temperature data, as well as in the number of heat waves or heat wave days. It can be supposed that the increasing tendency of temperature due to heat waves will be detectable by these indicators using longer time series.

The different indicators identified different numbers of heat wave days by different threshold values in the warmer intervals. Using the same percentiles, the number of heat waves and the number of heat wave days were different in most of the years. Furthermore, the number of identical heat wave days defined by the indicator pairs showed great variability. This meant that the chosen temperature indicator considerably defined the length and number of heat waves and consequently, influenced the number of excess death cases of the given year. This phenomenon was detected in case of defined threshold as the result of calculated excess mortality showed. It should always be taken into consideration; however, this is a general feature of each other methodology as well.

The product function provides help to determine the optimal indicator and threshold. The range between the 85th and 95th percentiles was found to meet the criteria of the threshold values the best. This range is wide enough to make a choice based on several criteria. If we would like to detect the most cases of excess mortality, then we should choose a lower threshold value that can identify more heat waves. If we would like to identify heat waves with bigger numbers of excess death cases, then we have to choose a threshold of a higher percentile. When we would like to compare the impact of heat in several cities, we should choose a common threshold suitable for each city. Further analyses are necessary to test the applicability of the method in multicenter studies.

The mean excess mortality on days above threshold by different indicators can provide further assistance to choose the suitable indicator. Similar values of excess mortality can be observed within the range of the 85th – 92nd percentiles of temperature indicators. Within this range, the indicators are similarly sensitive and effective. In the range of higher temperatures above the 92nd percentile, the differences of the shapes of curves are bigger. The highest excess mortality can be observed when using the daily mean temperature indicator, therefore, it is more effective. On the other hand, the other three indicators are less sensitive in the range of the 94th–98th percentiles; they can effectively identify excess mortality on very hot days. Further analyses are required to answer the question, to what extent the Budapest findings can be used in other cities.

The threshold in this study – the national alert threshold, which is the 25 °C daily mean temperature, corresponding to the 90th percentile – seems to be a suitable cut-off point. This threshold, lower than the one recommended by the CEHAPIS methodology, was chosen, while an excess death rate of 7% was detected at this cut off point of the sensitivity curve. This increase of mortality already requires actions according to the public health authorities.

5. Conclusion

The aim of the study was to develop a simpler method than time series analysis to identify excess mortality attributable to heat. The methodology is suitable to assess the changes of weather and climatic conditions to follow the impact of heat on daily mortality. The results are in accordance with the findings of previous studies.

At the chosen threshold value of 90th percentile, the mean excess mortality of the whole period computed by using the four indicators did not differed considerably, although the identified heat wave days varied to some extent. The use of apparent temperature indicators is not more advantageous and their prediction is more complicated. The apparent temperatures as well as the maximum temperature indicator are able to identify high excess mortality mainly on very hot days, while the daily mean temperature indicator is effective in a wider threshold range. Based on these results, the use of daily mean temperature is recommended.

The thorough analysis of threshold values is desirable using longer time series of the data of different cities. By this comparative analysis, we can get an answer to whether the system based on the daily mean temperature can be generalized.

References

Baccini, M., Biggeri, A., Accetta, G., Kosatsky, T., Katsouyanni, K., Analitis, A., Anderson, H. R., Bisanti, L., D'Ippoliti, D., Danova, J., Forsberg, B., Medina, S., Paldy, A., Rabczenko, D., Schindler, C., and *Michelozzi, P.,* 2008: Heat effects on mortality in 15 European cities. *Epidemiology 19,* 711–719.

Baccini M., Kosatsky T., Analitis A., Anderson H. R., D'Ovidio M., Menne B., Michelozzi P., and *Biggeri, A.,* 2011: PHEWE Collaborative Group. Impact of heat on mortality in 15 European cities: attributable deaths under different weather scenarios. *J Epidemiol. Commun. Health 65,* 64–70.

Barnett, A.G., Tong, S., and *Clements, A.C.A.,* 2010: What measure of temperature is the best predictor of mortality? *Environ. Res. 110,* 604–611.

Basu, R., 2009: High ambient temperature and mortality: a review of epidemiologic studies from 2001 to 2008. *Environ. Health 8,* 40.

Bobvos, J. and *Paldy, A.,* 2009: Impact of Heat on the Urban and Rural Population in Hungary. *Epidemiology 20, S127.*

Bobvos, J., Solymosi, N., and *Paldy, A.,* 2011: Climate change and heat-related mortality in Budapest - comparative methods of impact estimation of temperature change. *Environ. Health Perspect.* Available at: http://ehp.niehs.nih.gov/isee/, accessed 15 April 2014.

D'Ippoliti, D., Michelozzi, P., Marino, C., de'Donato, F., Menne, B., Katsouyanni, K., Kirchmayer, K., Analitis, A., Medina-Ramón, M., Paldy, A., Atkinson, R., Kovats, R.S., Bisanti, L., Schneider, A., Lefranc, A., Iñigue. C., and *Perucci, C.A.,* 2010: The impact of heat waves on mortality in 9 European cities: results from the EuroHEAT project. *Environ. Health 9,* 37.

Gosling, S.N., McGregor, G.R., and *Paldy, A.,* 2007: Climate change and heat-related mortality in six cities Part 1: model construction and validation. *Int. J. Biometeorol. 51,* 525–540.

Gosling, S.N., Lowe, J.A., McGregor, G.R., Pelling, M., and *Malamud, B.D.,* 2009a: Associations between elevated atmospheric temperature and human mortality: a critical review of the literature. *Climatic Change 92,* 299–341.

Gosling, S N., McGregor, G.R., and *Lowe, J.A.,* 2009b: Climate change and heat-related mortality in six cities Part 2: climate model evaluation and projected impacts from changes in the mean and variability of temperature with climate change. *Int. J. Biometeorol. 53,* 31–51.

GSOD, 2010: Global surface summary of the day data Version 7. At National Climatic Data Centre (NCDC). Available at: ftp://ftp.ncdc.noaa.gov/pub/data/gsod/, accessed 15 April 2014.

Hajat, S., Armstrong, B., Baccini, M., Biggeri, A., Bisanti, L., Russo, A., Paldy, A., Menne, B., and *Kosatsky, T.,* 2006: Impact of high temperatures on mortality: is there an added heat wave effect? *Epidemiology 17,* 632–638.

Hajat, S., Kosatky, T., 2010: Heat-related mortality: a review and exploration of heterogeneity. *J. Epidemiol. Commun. Health 64,* 753–760.

IPCC, 2013*:* Climate Change 2013: The Physical Science Basis. Summary for Policymakers*.* In: (Eds.: *Stocker, T.F., Qin, D., Plattner, G.K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A., Xia, Y., Bex, V., Midgley, P.M.*) Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC, 2014: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Summary for Policymakers. In: (Eds. *Aldunce, P., Ometto, J.P., Raholijao, N., Yasuhara, K.*) Final draft of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Available at: http://ipcc-wg2.gov/AR5/images/uploads/IPCC_WG2AR5_SPM_Approved.pdf, accessed 15 April 2014.

Ishigami, Ai., Hajat, S., Kovats, R. S., Bisanti, L., Rognoni, M., Russo, A., Paldy, A., 2008: An ecological time-series study of heat-related mortality in three European cities. *Environ. Health . 7,* 5.

Kalkstein, L.S. and *Valimont, K.M.,* 1986: An evaluation of summer discomfort in the United States using a relative climatological index. *Bull. Am. Meteorol. Soc. 67*, 842–848.

Kim, Y.M., Kim, S., Cheong, H.K., Kim, E.H., 2011: Comparison of temperature indexes for the impact assessment of heat stress on heat-related mortality. *Environ. Health Toxicol. 26,* Available at: http://dx.doi.org/10.5620/eht.2011.26.e2011009, accessed 15 April 2014.

Kovats, R S. and *Ebi, K.L.,* 2006: Heatwaves and public health in Europe. *Eur. J. Publ.Health 16,* 592–599.

Kovats, R.S. and *Hajat, S.,* 2008: Heat stress and public health: a critical review. *Ann. Rev. Publ. Health 29,* 41–55.

Morabito, M., Crisci, A., Messeri, A., Capecchi, V., Modesti, P. A., Gensini, G. F., and *Orlandini, S.,* 2014: Environmental Temperature and Thermal Indices: What Is the Most Effective Predictor of Heat-Related Mortality in Different Geographical Contexts? *Sci. World J.* Available at: http://dx.doi.org/10.1155/2014/961750 , accessed 15 April 2014.

Paldy, A., Bobvos, J., Vamos, A., Kovats, R.S., and *Hajat, S.,* 2005: The effect of temperature and heat waves on daily mortality in Budapest, Hungary, 1970–2000. In: (Eds. *Kirch, W., Menne, B., Bertollini, R.*) Extreme weather events and public health responses. Springer, New York, 99–107.

Paldy, A. and *Bobvos, J.,* 2009: Impact of the Unusual Heatwave of 2007 on Mortality in Hungary . *Epidemiology 20(6),* S126–S127.

Paldy, A., Juhasz, A., Bobvos, J., and *Nagy, CS.,* 2011: Modelling of the association of health impacts of exposure to 2007-heatwave and the effect modifiers at small area level in Hungary . *Environ. Health Perspect.* Available at: http://ehp.niehs.nih.gov/isee/, accessed 15 April 2014.

Vaneckova, P., Neville, G., Tippett, V., Aitken, P., Fitzgerald, G., Tong, S., 2011: Do biometeorological indices improve modeling outcomes of heat-related mortality? *J. Appl. Meteorol. Climatol. 50,* 1165–1176.

WHO, 2011: Tools for the monitoring of Parma Conference commitments. Report of the meeting 25–26 November 2010. Available at:http://www.euro.who.int/data/assets/pdf_file /0019/134380/e94788.pdf, accessed 15 April 2014.

Yu, W., Guo, Y., Ye, X., Wang, X., Huang, C., Pan, X., and *Tong, S.,* 2011: The effect of various temperature indicators on different mortality categories in a subtropical city of Brisbane, Australia. *Sci.Total Environ. 409,* 3431–3437.