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The effect of climate change on heat-related excess mortality in Hungary at different area levels

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Abstract— According to the 5th Assessment Report of IPCC, one of the greatest health impacts of climate change will be the heat-related excess mortality. In Hungary, the National Adaptation Geo-Information System (NAGiS) helps the adaptation process of climate change. Within CRIGiS project, which was initiated to extend the NAGiS, our special subtask was the assessment of heat-related excess mortality at different area levels in the present and for two predicted future periods. This assessment is described in this paper.

The Hungarian Central Statistical Office provided the daily mortality data for the period of May 1 – Sep 30, 2005–2014. The observed daily mean temperature data for the same period at small area level (NUTS 4, Nomenclature of territorial units for statistics) were provided by the Hungarian Meteorological Service (HMS). The modeled daily mean temperature data at NUTS 4 level based on the ALADIN-Climate model for three periods, May 1 – Sep 30 of 1991–2020, 2021–2050, and 2071–2100, were also provided by HMS.

The heatwave days were defined by the 90th percentile of the frequency distribution of daily mean temperatures at different area levels. The excess mortality was computed by extracting the mean daily mortality of cool days from the number of deaths on heatwave days. As we found a difference between the frequency distributions of observed and modeled present periods, a correction was done assuring that the yearly sums of excess mortality were the same in the observed and modeled present periods. Based on the corrected threshold values the changes in the future could be predicted.

During 2005–2014, the range of daily threshold temperature was between 22.3 °C and

25.4 °C, the mean excess mortality was 15.8% on the heatwave days at NUTS 4 level. At national level, daily mortality was higher by 51 cases on heatwave days than on cool days, which corresponded to an excess of 783 death cases per year in average. According to the climate model, the number and intensity of heatwave days will increase in relation to the present situation. Assuming the same population and level of sensitivity, for 2021–2050 a 2.6-fold, for 2071–2100 a 7.4-fold increase of excess deaths is predicted causing 2030 and 5800 cases per year, respectively.

The prediction of excess mortality at different area levels in the NAGiS database will help stakeholders to prepare adaptation measures to climate change.

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

1. Introduction

Generally, the climate depends on natural and anthropogenic substances and processes that influence the Earth's energy budget (*Le Treut et al*., 2007). However, climate change occurred over the last decades is primarily driven by human actions, posing a major source of health threat for the 21th century (*McMichael et al*., 2012).

Climate extremes such as heatwaves, cold snaps, droughts, and floodings have become more frequent due to global warming. These extreme weather conditions are not only environmental issues, but they pose unique challenges to human health, both directly and indirectly (*Costello et al*., 2009; *IPCC*, 2014; *McGregor*, 2005).

Direct physiological effects include higher rates of mortality and morbidities, including respiratory, cardiovascular, and metabolic diseases. Indirect effects on health include changing disease vectors of foodborne, waterborne, and airborne diseases, as well as other pathways mediated through human systems like under-nutrition, migration *(Costello et al.*, 2009; *McMichael et al*., 2006; *Patz et al.*, 2014). Additionally, climate extremes pose an additional threat to health professionals and health systems due to the related increase in the demand for health services (*European Commission*, 2013a).

Numerous studies have been published analyzing the impact of heat-related mortality for the last 20 years. *Basu* (2009) reviewed the epidemiological studies dealing with the association of ambient temperature and mortality from a methodological point of view published in the period of 2001–2008.

Several indicators are used to characterize the daily temperature in the national and international literature. The use of simple indicators like daily maximum, minimum, and mean temperature is rather common, but complex indices including humidity, windspeed are also used, however no preferable indicator was recommended (*Barnett et al*., 2010; *Kalkstein* and *Valimon,* 1986; *Kim et al*., 2011).

The definition of heatwaves and the indicator of "high temperature" are not harmonized in practice. A common definition of heatwaves in Europe, including Hungary is the period of three or more consecutive days with temperature above a threshold value. However, mortality increases above the threshold temperature even on one day, therefore, several authors investigated this effect as well in the latest publications (*Hajat et al.*, 2006; *Rocklöw* and *Forsberg*, 2008).

The temperature thresholds also showed great variability in the literature, some studies applied the 95th percentile (*Ishigami et al.*, 2008; *Kysely et al.*, 2011). *Pascal et al.* (2013) evaluated the excess mortality above the thresholds of 97th, 98th, and 99th percentiles pointing to the problem that the different percentiles defined different days and excess mortalities. The use of the 90th percentile as threshold is now applied by multicenter studies (*De'Donato et al.*, 2015) allowing the comparison of the results by cities.

Several papers were published analyzing the temperature-mortality relationship in Budapest (*Paldy et al.*, 2005; *Hajat et al.*, 2006; *Gosling et al.*, 2007; *Ishigami et al.*, 2008; *Baccini et al.*, 2008 and *D'Ippoliti et al.*, 2010). The predicted heat-related excess mortality due to climate change was assessed by few study groups (*Gosling et al.*, 2009; *Baccini et al.*, 2011 and *Bobvos et al.*, 2011) using regional climate models.

In order to manage the above-mentioned risks on human health, adaptation strategies are essential to minimize the impact of climate change on the population's vulnerability (*McMichael et al.*, 2012). Thus, according to the World Health Organization, the most important and urgently needed measures, strategies, and policies regarding climate change adaptation and capacity building should address the reinforcement of public health infrastructures (*McMichael et al*., 2003).

The European Union addressed concerns about the impacts of the environment on public health with special regard to climate change in the European Environment & Health Action Plan 2004–2010, which was further supported by close collaboration with the WHO (*European Commission*, 2007). It was followed by the EU Strategy on Adaptation to Climate Change in 2013, with the aim to contribute to a more climate-resilient Europe. The Strategy launched the European Climate Adaptation Platform (Climate-ADAPT) in 2012 as a tool to provide the best available information for decision-making (*European Commission*, 2013b).

Hungary developed the National Climate Change Strategy in 2008 following the amendment of UNFCCC and Kyoto Protocol. The 2013 revision of the Strategy was developed by the National Adaptation Center of the Geological and Geophysical Institute of Hungary, which determined a timeline from 2014 to 2025, with an outlook to 2050. The strategy uses the National Adaptation Geo-information System (*NAGiS*, 2015) as a tool to facilitate decision-making process and policy-making regarding impact assessments and adaptation measures of climate change. NAGiS established a country-wide database, indicators, input data to serve the methodological basis for modeling the local and regional exposure, sensitivity, and adaptive capacity for different climate hazards.

Based on existing dataset of the NAGiS, the Vulnerability and Impact Studies on Tourism and Critical Infrastructure (*CRIGiS*, 2015) project aimed to prepare indicators for the assessment of climate change vulnerability. In CRIGiS, our special subtask was the assessment of heat-related excess mortality at different area levels in the present and for two predicted future periods using the ALADIN-Climate model and SRES A1B (IPCC Special Report on Emission Scenarios) scenario as default criteria in the CRIGIS project. The methods and results are described in this paper.

2. Data and methods

2.1. Observed heat-related mortality in the present period

It is very important to choose the proper spatial resolution for the statistical analysis. The daily mortality data at settlement level are not accessible due to the protection of personal data stated by law (5th Law of 2013 on Civil Book of Laws). Beyond this protection, the analysis of daily data at settlement level is not relevant due to the small number of population and the great variance of mortality data, therefore, the chosen smallest territorial unit is the so-called "small area" level (NUTS 4-Nomenclature of territorial units for statistics, 175 small areas). The assessments were carried out separately at higher levels of territorial aggregation (NUTS 3 – twenty counties, NUTS 2 – seven regions, NUTS 1 – three great regions, NUTS 0 - country level). These assessments are not the sums of the results gained at small area level, but separate analyses related to the given spatial level assuring that the assessments of heat-related mortality are uniform at the given spatial level.

Daily total mortality data were gained from the Hungarian Central Statistical Office at NUTS 4 level for the summer periods (May 1–Sept 30) of 2005–2014 for Hungary. Choosing the time frame of ten years is sufficient and enough, while during ten years the long-term change of mortality can not be detected, therefore a correction for the trend is not necessary.

In the analysis, we evaluated not only the impact of heatwaves – a period of three or more consecutive days with daily mean temperature over the threshold defined in our previous paper (*Paldy* and *Bobvos*, 2012) – but also the impact on excess mortality of high temperature of even one day. Based on the study related to Budapest (*Bobvos et al.*, 2015), the simple daily mean temperature indicator was chosen because its measurement and prediction is simpler than those of the complex indices, moreover, it is a basic, not calculated parameter of climate models. The observed daily mean temperature data for the same period at NUTS 4 level were provided by the Hungarian Meteorological Service (HMS). At higher levels of territorial aggregation, the daily mortality data were summed, daily temperature data at NUTS 4 level were averaged. As the methods of computation were the same concerning each area of the different NUTS levels, we described them in general formulas.

In order to represent the effect of heatwaves on daily mortality, daily mean excess mortality (EM_j) was defined. It can be computed for each area of the five NUTS levels described above as the mean of difference of the daily mortality during heatwave days and mean mortality during cool days at the identified area j by Eq.(1):

$$EM_j = N^{-1} * \sum_{i=1}^{1530} \left(MH_{ij} - MC_j\right) \quad if \;\; T_{ij} > TT_j \qquad \text{[cases per day]}, \quad (1)$$

where MH_{ij} represents the daily mortality cases on day i (10 years, 1530 days), MC_j is the daily mean mortality on days under threshold temperarture, N is the number of days over threshold temperature, T_{ij} is the daily mean temperature on day i, and TT_j, the threshold temperature at the given area j.

The yearly mean excess death cases can be computed as daily mean excess mortality cases multiplied by the yearly mean number of heatwave days. The number of heatwave days depends on the chosen temperature threshold. The yearly mean excess death cases decreased by the increase of threshold values, as the number of identified heatwave days decreased. On the other hand, the daily mean excess mortality cases on heatwave days increased in relation to threshold values. To define the proper threshold, the product function of the corresponding values of the two curves can be used (*Bobvos et al*., 2015). At the maximum range of the product curve, the two opposite processes were equally considered (*Fig. 1*). By analyzing the aggregated data at national level, the frequency distribution shows a maximum at the 90th percentile.

Based on the above mentioned analysis, the heat-related excess mortality was modeled by the 90th percentile of the frequency distribution of the daily mean temperatures (TP90) at the given area level (*Fig. 2.*).

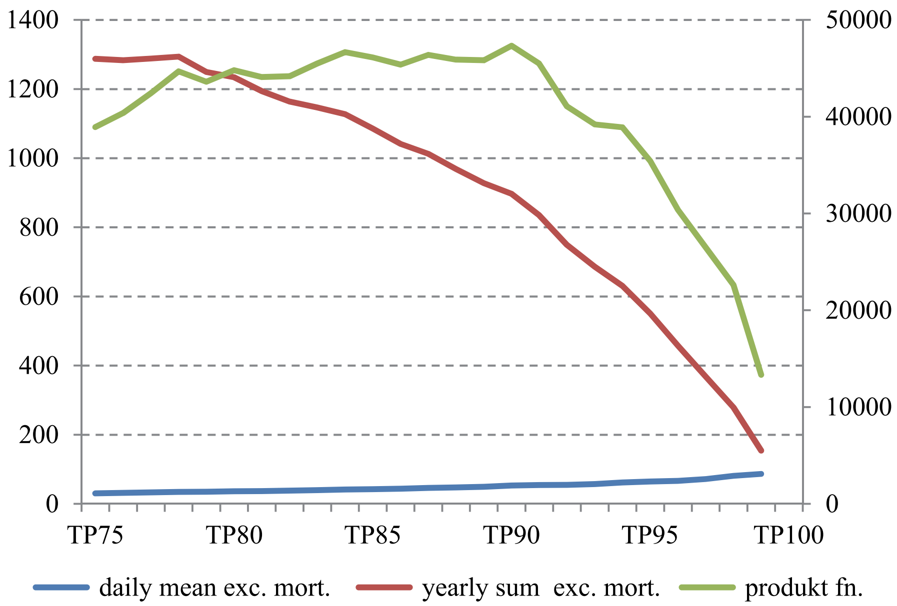

Fig. 1. The yearly mean excess mortality (case), the daily mean excess mortality on heatwave days (case) above different thresholds (TP%), as well as their product function at national level in Hungary, in the period 2005–2014.

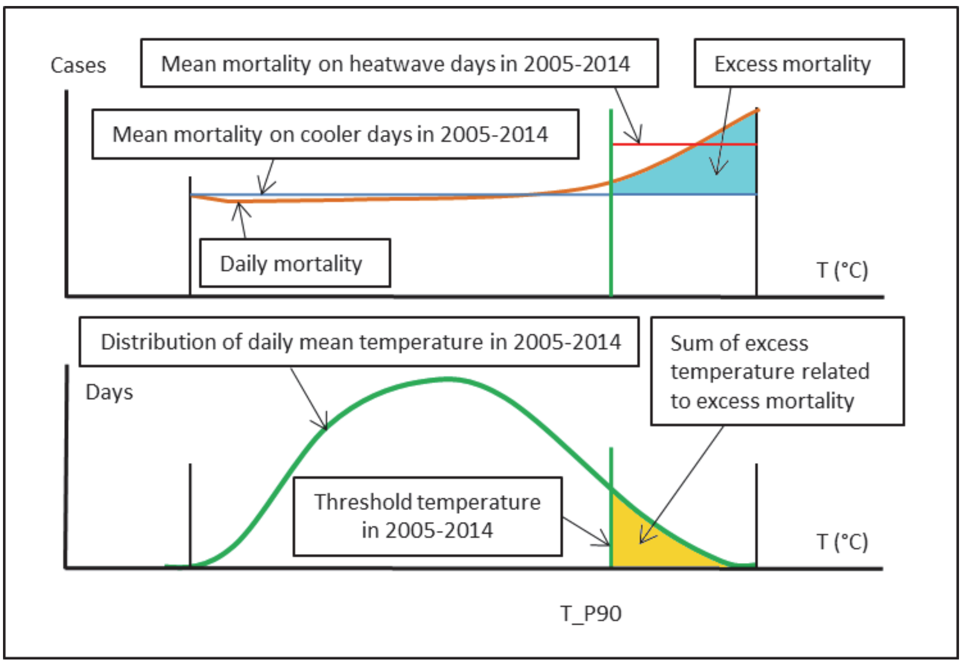

Fig. 2. Scheme of the methodological process of calculation of heat-related excess mortality.

To ensure comparability, the relative excess mortality was also computed, defining the per cent increase of mortality during the heatwaves for each area of the five NUTS levels. The relative daily mean excess mortality ($EM\%_j$) on heatwave days can be computed by Eq.(2):

$$EM\%_j = 100 * EM_j * MC_j^{-1} \qquad [\% \text{ per day}], \qquad (2)$$

where EM_j represents the daily mean excess mortality cases and MC_j is the daily mean mortality on days under threshold temperarture at the given area j.

The numbers of days above the 90th percentile of daily mean temperature in the areas at each NUTS level are equal (153 days in 10 years); however, the sum of excess temperature ($TSUM_j$) above the threshold is different due to the different distributions of daily temperature on these days. This excess temperature causing excess mortality can be computed by Eq.(3). Dividing it by ten we get the mean yearly excess temperature.

$$TSUM_j = \sum_{i=1}^{1530} \left(T_{ij} - TT_j\right) \qquad if \;\; T_{ij} > TT_j \quad [°\text{C per ten year}], \qquad (3)$$

where T_{ij} represents the daily mean temperature on day i and TT_j is the threshold temperature at the given area j.

The excess mortality related to excess temperature can be expressed as relative risk ($RR1°C_j$). It can be computed by using the daily mean excess mortality cases on days over the thresholds and the excess temperature measured on these days. This value is the percent excess mortality per 1 °C increase of temperature, it can be regarded as heat-related vulnerability indicator in present period in each area of the five NUTS levels Eq.(4):

$$RR1°C_j = N * EM_j * TSUM_j^{-1} \qquad [\% \text{ per } °\text{C}], \qquad (4)$$

where N represents the number of days over the threshold temperature, EM_j indicates the daily mean excess mortality cases, and $TSUM_j$ is the sum of excess temperature above the threshold at the given area j.

The result curve of multiplication necessary to determine the proper threshold range can also be used for diagnostic purposes. In case of small areas with few daily death cases where the relative standard deviation is greater, the result has low confidence. Therefore, a systematic analysis was carried out in order to establish an indicator of reliability with four categories:

- Category 1 (high reliability): includes those areas, where the multiplication curve had the maximum value around the 90th percentile, similarly to the curve of national level data.
- Category 2 (moderate reliability): containes those areas, where the maximum of the multiplication curve was not at the 90th percentile, although the curve had a monotonous line and the excess mortality values belonging to the 90th percentile were exact.
- Category 3 (informative): includes those areas, where the maximum of the multiplication curve was not at the 90th percentile and the shape of the curve was not monotonous. This category gives information about the possibility to define excess mortality, although the value is not reliable.
- Category 4 (unreliable): includes those areas, where the maximum of the multiplication curve was not at the 90th percentile, the shape of the curve was not monotonous, and negative values of excess mortality could be detected. Due to the great uncertainty, the data of excess mortality were not presented.

2.2. Heat-related mortality in the climate model

In order to assess the climate change related excess mortality, the modeled daily mean temperature data at NUTS 4 level based on the ALADIN-Climate model (SRES A1B) for three periods (May 1 – Sep 30 of 1991–2020, 2021–2050, and 2071–2100) were provided also by HMS.

The period of 1991–2020 can be regarded as present period of the climate model. Our aim was to relate the results of the observed present period (2005–2014) to the present period of the climate model (1991–2020). As the two periods did not have equal length, we assumed that the results of observed present period represent the whole 30 years period. As we found a difference between the frequency distribution of observed temperature and the temperature of the present period of the climate model, a correction was done. We chose a new threshold temperature in the modeled present period assuring that the mean yearly excess temperatures contributing to excess mortality were the same in the two present periods (*Fig. 3*).

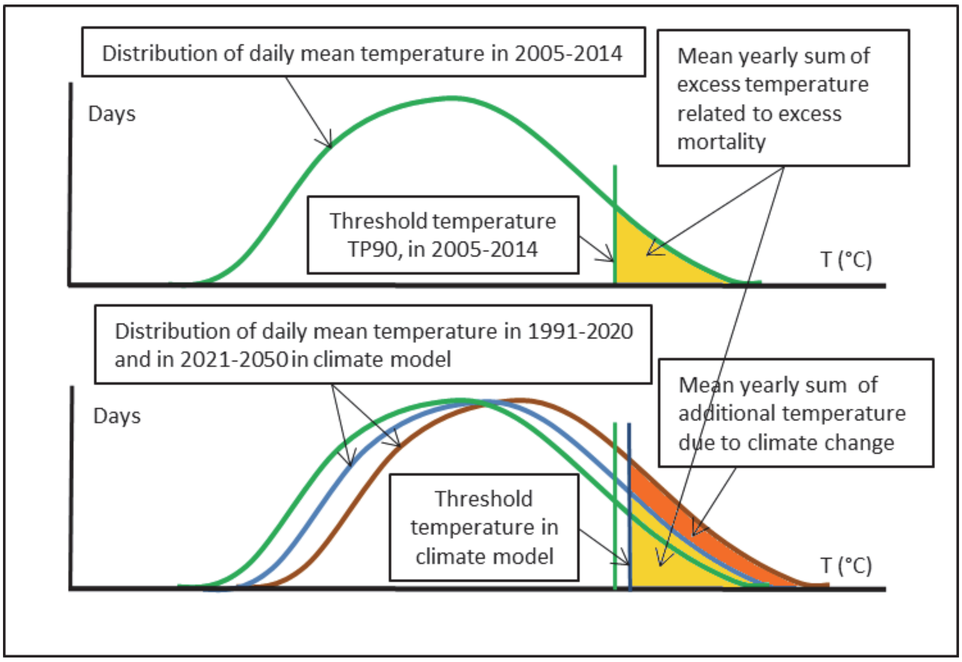

Fig. 3. Scheme of the methodological process of calculation of heat-related excess mortality in the climate model.

Based on the corrected threshold values of the modeled present period, the changes in the future could be predicted. The changes of the number and intensity of heatwave days together define the level of increasing mean yearly excess temperature, which is the additional exposure due to climate change. Assuming the same population and sensitivity level (RR1°C) in the future, this additional exposure will cause the same level of increase in excess mortality.

The calculated yearly mean excess mortality cases, which are the same in both present periods can be regarded as heat-related baseline sensitivity indicator, from the point of climate change. The excess mortality due to the increase of heat exposure predicted by the climate model serves as a potential impact indicator and (regardless to changes of adaptive capacity) as a vulnerability indicator of the heat-related mortality due to climate change.

3. Results

3.1. Characteristics of population, daily mortality data, and temperature indicators in the present period

Fig. 4 demonstrates the distribution of the mean population at NUTS 4 and NUTS 3 levels between 2005 and 2014. The mean population ranged from 6,900

(Őriszentpéter) to 1,691,000 (Budapest) at smaller area level, the mean population (excluding Budapest) was 48,000, areas belonging to cities had much bigger population. During the studied period, less than 15,000 inhabitants lived in 18 small areas. The mean population ranged from 211,000 (Nógrád) to 1,691,000 (Budapest) at NUTS 3 level, the mean population of the counties was 444,000 without Budapest.

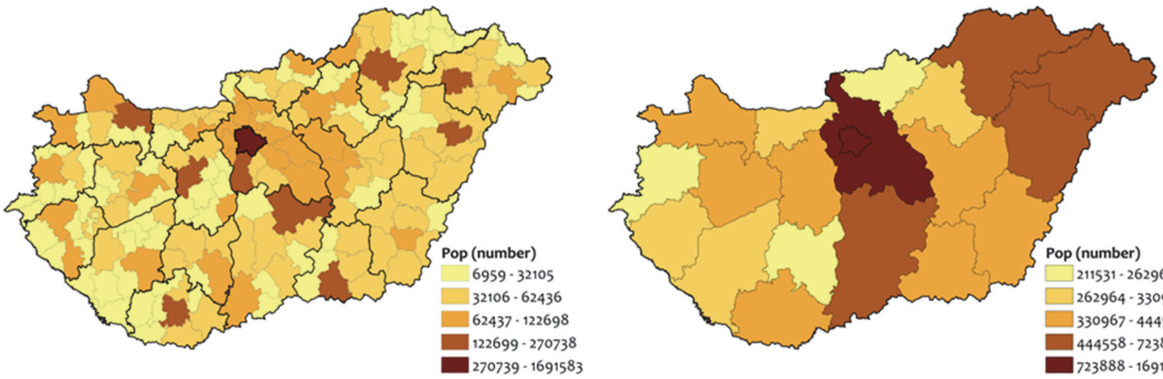

Fig. 4. Distribution of mean population (Pop, number) at NUTS 4 and NUTS 3 levels in Hungary, in the period of 2005–2014.

The mean daily mortality data on cool days at NUTS 4 and NUTS 3 levels of the investigated period is shown in *Fig. 5*. The spatial distribution of mean mortality, basically defined by the number of population is similar to the distribution of the population. The mean daily mortality ranged from 0.3 (Őriszentpéter) to 55.6 (Budapest) at NUTS 4 level. The mean mortality at NUTS 4 level without Budapest was 1.6 cases. Less than one mean daily death cases occurred in 67 small areas. The mean daily mortality ranged from 7.7 (Nógrád) to 55.6 (Budapest) at NUTS 3 level, the mean mortality was 14.3 cases without Budapest.

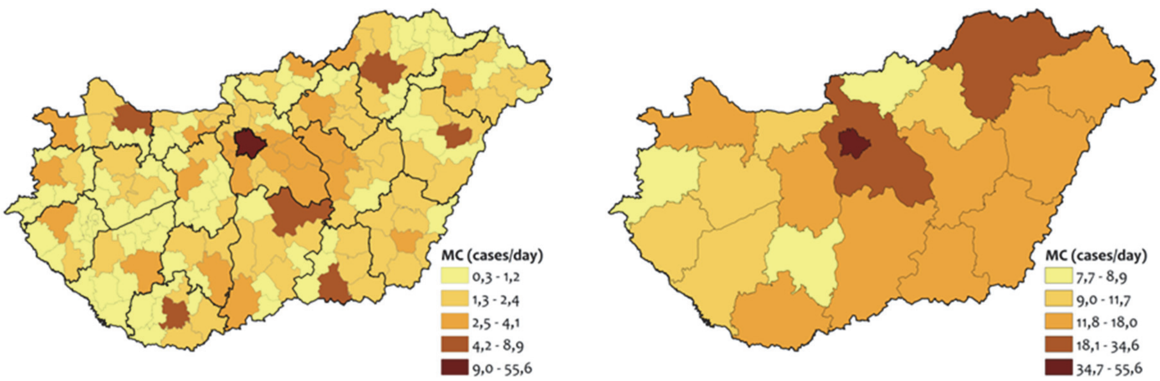

Fig. 5. Distribution of mean daily mortality on cool days (MC, cases/day) at NUTS 4 and NUTS 3 level in Hungary, in the period of 2005–2014.

The 90th percentile of the frequency distribution of the daily mean temperature at NUTS 4 and NUTS 3 levels of the investigated period is shown in *Fig. 6*. The spatial distribution of the threshold temperature was in a range of 22.3 °C and 25.4 °C at NUTS 4 level. Small areas with threshold temperature over the mean (24.3 °C) could be detected in the Great Plain and Small Plain. The highest values were registered in counties Csongrád and Békés.

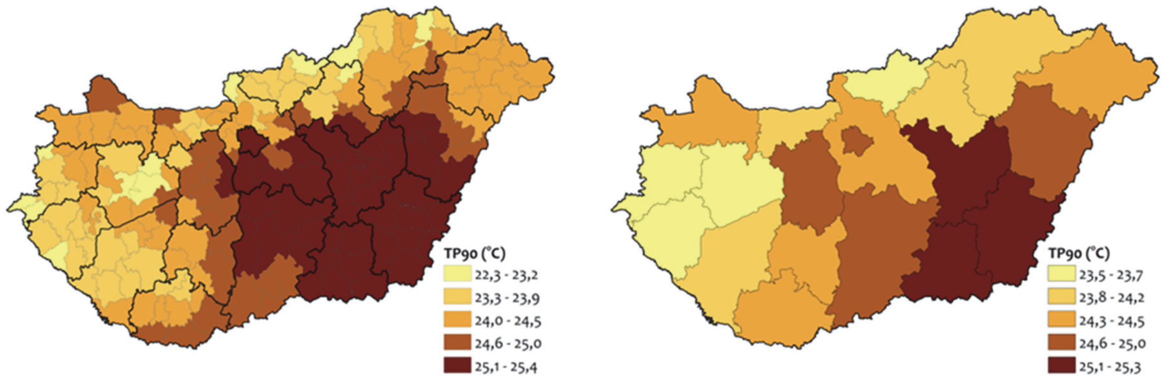

Fig. 6. The 90th percentile of the frequency distribution of the daily mean temperature (TP90, °C) at NUTS 4 and NUTS 3 level in Hungary, in the period of 2005–2014.

Maps of *Fig. 7* demonstrate the mean excess temperature of the days above the threshold in the period of 2005–2014. The number of days above the 90th percentile was 153 days in each area during the studied 10-year period, meaning 15.3 heatwave days as yearly average. The mean excess temperature was between 1.45°C and 1.82 °C at NUTS 4 level and between 1.5 °C and 1.78 °C at NUTS 3 level, respectively.

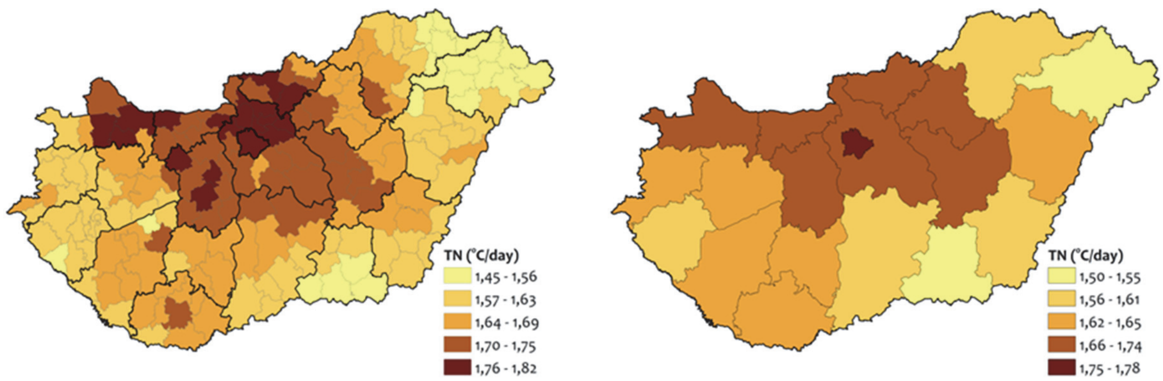

Fig. 7. The mean excess temperature above the threshold temperature (TN, °C/day) on heatwave days at NUTS 4 and NUTS 3 level in Hungary, in the period of 2005–2014.

3.2. Characteristics of heat-related excess mortality in the present and predicted future periods

The relative increase (EM%) of daily mean excess mortality on days above the 90th percentile of daily mean temperature is shown in *Fig. 8*. The mean increase of mortality on heatwave days was 15.7%/°C at national level, it was between 0.5% and 45% at NUTS 4 level and between 9% and 20% at NUTS 3 level, respectively. The excess mortality at small area level does not show a typical spatial pattern. At NUTS 3 level, the highest excess mortality can be observed in Budapest and in Veszprém county.

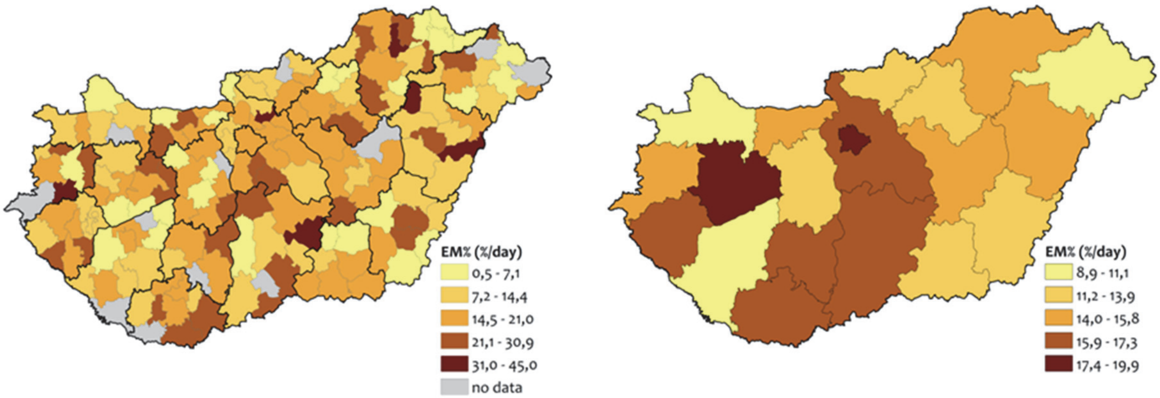

Fig. 8. The mean excess mortality above the threshold temperature on heatwave days (EM%, %/day) at NUTS 4 and NUTS 3 level in Hungary, in the period of 2005–2014.

The spatial distribution of relative excess mortality by 1 °C (RR1 °C) showed similar pattern as the relative excess mortality (*Fig. 9*). The mean increase of mortality on heatwave days was 9.5%/°C at national level, it was between 0.3%/°C and 27.4%/°C at NUTS 4 level and between 5.5%/°C and 11.2%/°C at NUTS 3 level, respectively.

According to the reliability categories at NUTS 4 level, the number of areas belonging to categories 1 and 2 was 152 (87%), while 9 small areas (5%) fell into category 3 (*Fig. 10*). 14 small areas (8%) could not be evaluated, the excess mortality data are not given, they are grouped into category 4. Regarding the analyses of higher area levels, each of the results met the criteria of category 1.

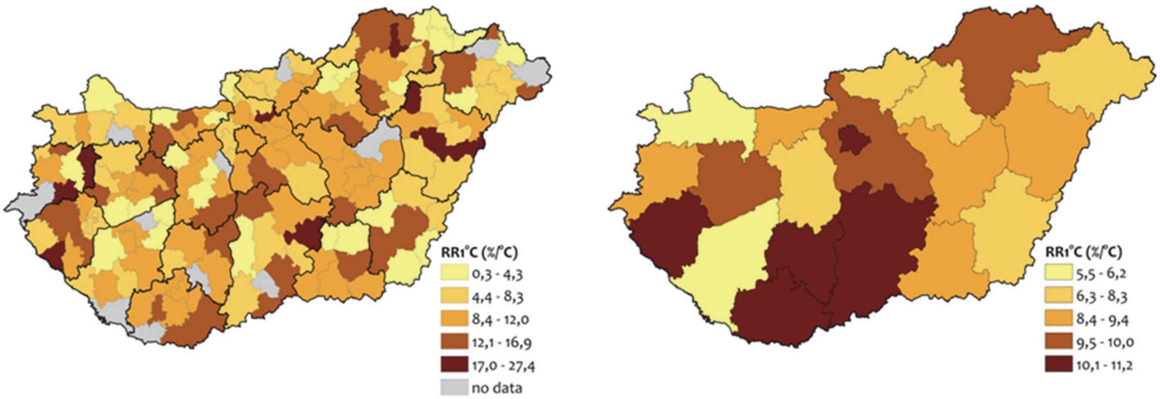

Fig. 9. The mean excess mortality per 1°C increase of temperature above the threshold on heatwave days (RR1°C, %/°C) at NUTS 4 and NUTS 3 level in Hungary, in the period of 2005–2014.

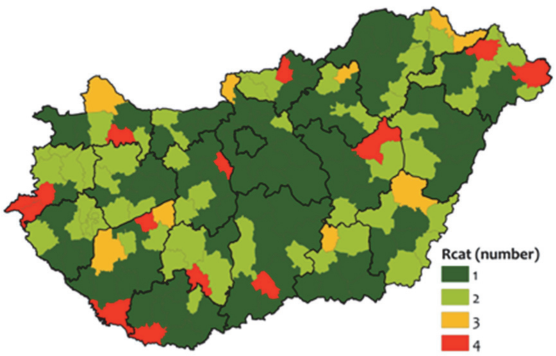

Fig. 10. Categories (Rcat, number 1 to 4) of reliability at NUTS 4 level.

At NUTS 4 level, according to the climate model, the number of yearly heatwave days will increase in relation to the present situation by 57–98% on average between 2021–2050, while the intensity (daily mean excess temperature above threshold) of heatwaves will increase by 27–55% on average (*Fig. 11*).

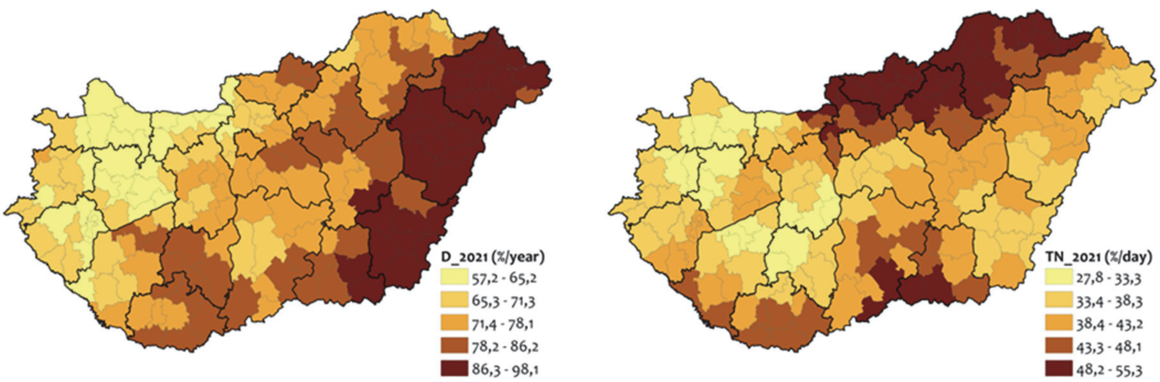

Fig. 11. Change of the number (D_2021, %/year) and intensity (TN_2021, %/day) of heatwave days in the period of 2021–2050 of the climate model in relation to 1991–2020.

At NUTS 4 level, according to the climate model, the number of yearly heatwave days will increase in relation to the present situation by 195–270% on average between 2071–2100, while the intensity (daily mean excess temperature above threshold) of heatwaves will increase by 80–133% on average (*Fig. 12*).

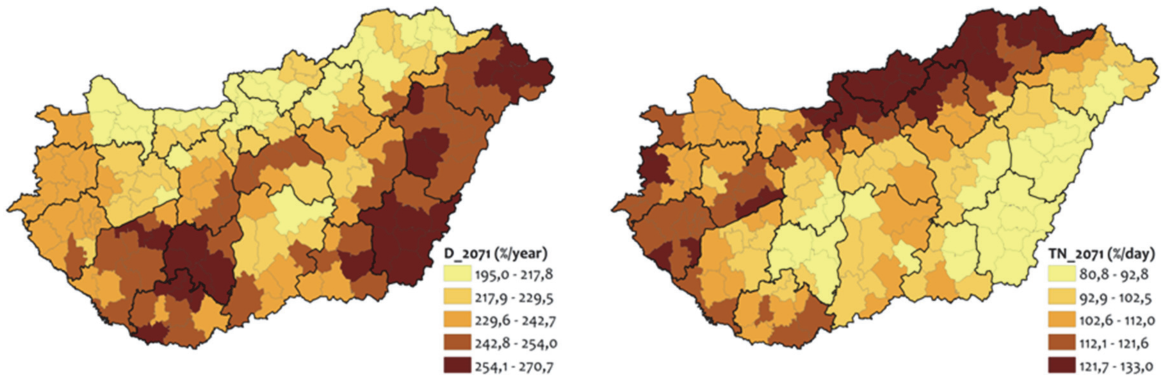

Fig. 12. Change of the number (D_2071, %/year) and intensity (TN_2071, %/day) of heatwave days in the period of 2071–2100 of the climate model in relation to 1991–2020.

The changes of the number and intensity of heatwave days together will increase for 2021–2050 in relation to the present situation, defining the level of additional heat exposure and excess mortality. The range of increase of excess death cases per year at NUTS 4 level will be between 107% and 182% compared to the period of 1991–2020. For 2071–2100, climate projection shows a change of excess mortality in the range of 531% and 668% regarding increasing exposure (*Fig. 13*).

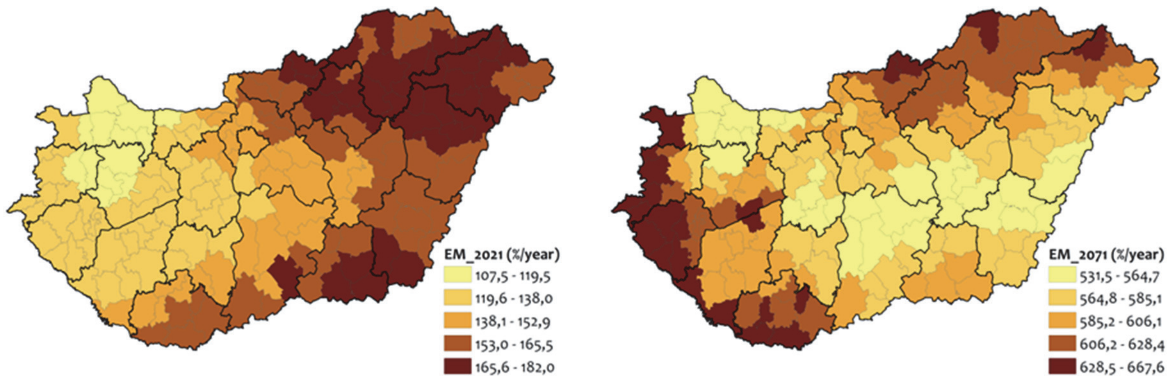

Fig. 13. Change of heatwave related mortality in the periods of 2021–2050 (EM_2021, %/year) and 2071–2100 (EM_2071, %/year)of the climate model in relation to 1991–2020 at NUTS 4 level.

At NUTS 3 level, according to the climate model, the number of yearly heatwave days will increase in relation to the present situation by 62-95% on average between 2021–2050, while the intensity (daily mean excess temperature above threshold) of heatwaves will increase by 31–51% on average (*Fig. 14*).

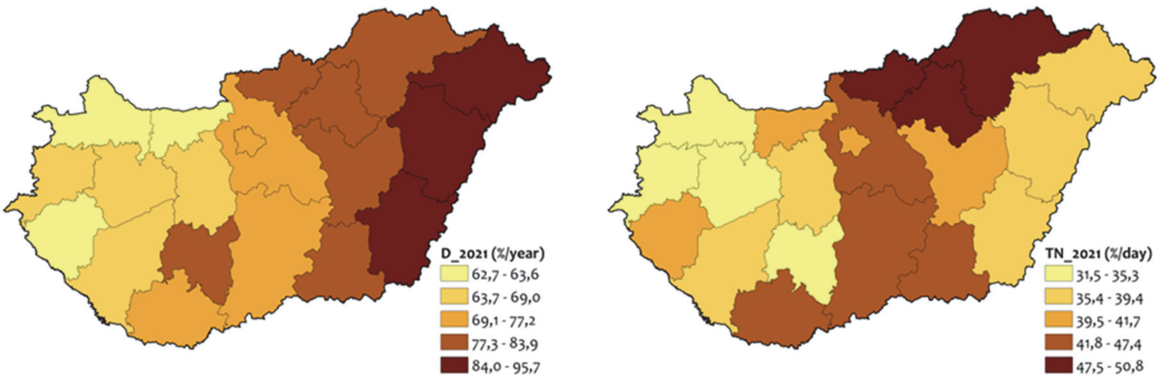

Fig. 14. Change of the number (D_2021, %/year) and intensity (TN_2021, %/day) of heatwave days in the period of 2021–2050 of the climate model in relation to 1991–2020.

At NUTS 3 level, according to the climate model, the number of yearly heatwave days will increase in relation to the present situation by 214–264% on average between 2071–2100, while the intensity (daily mean excess temperature above threshold) of heatwaves will increase by 86–127% on average (*Fig. 15*).

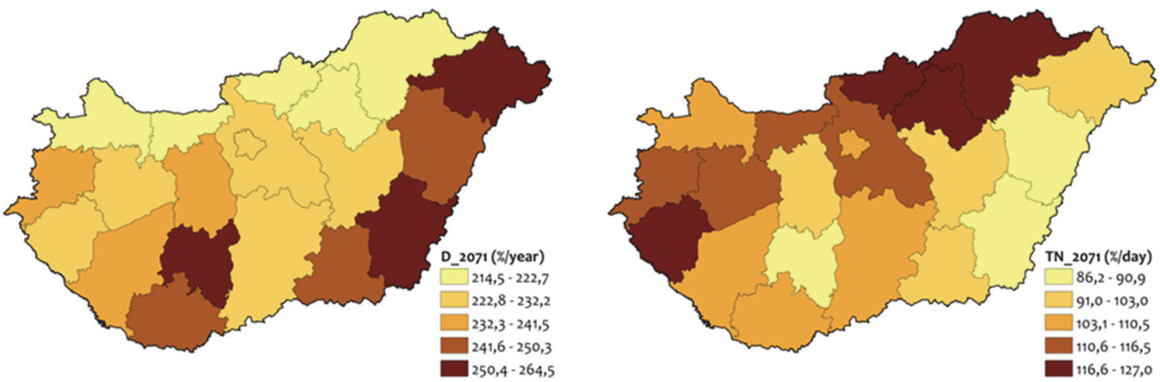

Fig. 15. Change of the number (D_2071, %/year) and intensity (TN_2071, %/day) of heatwave days in the period of 2071–2100 of the climate model in relation to 1991–2020.

The changes of number and intensity of heatwave days together will increase for 2021–2050 in relation to the present situation, defining the level of additional heat exposure and excess mortality. The range of increase of excess death cases per year at NUTS 4 level will be between 114% and 173% compared to the period of 1991–2020. For 2071–2100, climate projection shows a change of excess mortality in the range of 559% and 638% regarding increasing exposure (*Fig. 16*).

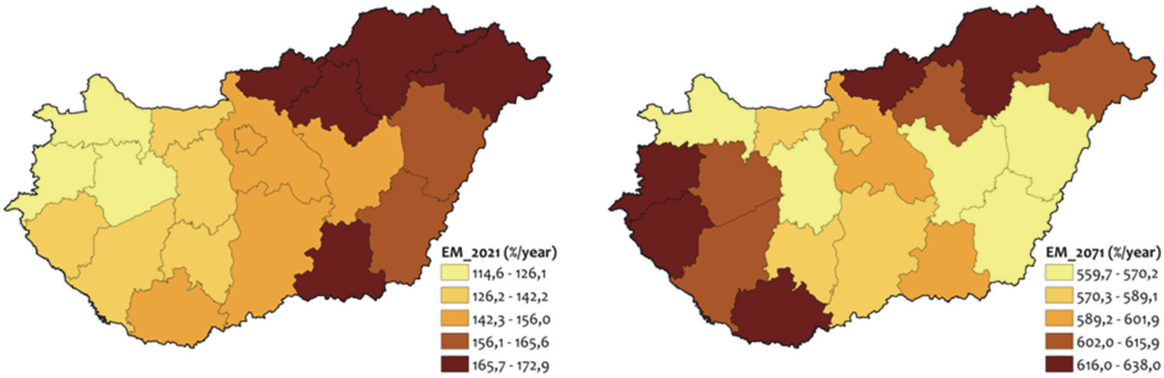

Fig. 16. Change of heatwave related mortality in the periods of 2021–2050 (EM_2021, %/year) and 2071–2100 (EM_2071, %/year) of the climate model in relation to 1991–2020 at NUTS 3 level.

3.3. Results of higher aggregated area levels

The results reported previously will be available for the experts, decision makers and laypeople in the NAGiS system. The data at regional, great regional, and national levels are necessary for long term strategic planning; they do not require regular accessibility. Therefore, the data aggregated at higher levels are summarized in *Table 1*.

At national level, daily mortality was higher by 51 cases (EM%=15.65%) on heatwave days (15.3 days/years) than on cool days, which corresponded to an excess of 783 death cases per year. According to the climate model, the number and intensity of heatwave days (D_2021, TN_2021) will increase in the period 2021-2050 in relation to the present situation, these together define the rate of increase of exposure (EM_2021=159%). Assuming the same population and sensitivity level in the future, this additional exposure will cause the same level of increase in excess mortality. For 2021–2050, a 2.6-fold increase of excess deaths is predicted causing 2,030 cases per year. For 2071–2100, climate projection shows a change of excess mortality by 640% (EM_2071), meaning a 7.4-fold increase at national level, which corresponds to 5,800 yearly excess death cases.

Table 1. Results of higher aggregated area levels

Name	NUTS code	MC	TP90	TN	EM %	RR1°C	D _2021	TN _2021	EM _2021	D _2071	TN _2071	EM _2071
		case /day	°C	°C/day	%/day	%/°C	%/year	%/day	%/year	%/year	%/day	%/year
KMR	HU10	90.16	24.51	1.74	18.43	10.61	72.51	46.35	152.4	226.6	114.1	599.5
KDR	HU21	34.97	24.25	1.64	15.11	8.99	73.36	33.99	132.2	239.7	106	599.8
NyDR	HU22	32.49	23.80	1.61	13.83	8.56	64.74	37.12	125.8	231.1	119.1	625.7
DDR	HU23	32.93	24.20	1.61	13.95	8.64	76.99	38.17	144.5	252.4	105.1	623.0
ÉMR	HU31	43.88	23.91	1.63	14.05	8.63	80.75	49.92	170.9	225.7	123.1	626.9
ÉAR	HU32	48.03	24.72	1.57	13.70	8.72	89.29	42.64	170.0	247.8	102.1	603.2
DAR	HU33	46.08	25.18	1.57	15.48	9.86	84.49	43.95	165.5	251.1	98.24	596.1
KMR	HU1	90.16	24.51	1.74	18.43	10.61	72.51	46.35	152.4	226.6	114.1	599.5
DR	HU2	99.25	24.08	1.60	14.16	8.79	73.19	36.82	137.0	242.5	112.8	629.4
AÉR	HU3	138.0	24.54	1.59	13.80	8.63	80.45	50.66	171.8	227.9	119.7	620.8
MO	HU	327.3	24.28	1.60	15.65	9.78	77.14	46.25	159.0	232.6	122.6	640.7

4. Conclusion

The final products of this analysis of the CRIGiS project are incorporated in the NAGiS database to meet the needs of different users: decision makers, experts, planners, and people having personal interest. The dataset includes maps, datasheets, descriptions of use and limitations, as well as examples.

The uncertainties of the predictions for the future can be decreased by repeating the assessments using different climate models and emission scenarios. This can easily be done, because the NAGiS database has been updated by three more climate models.

In the latest period, increasing emphasis is put on the identification of socioeconomical factors influencing heat-related excess mortality, to which the results of this study can serve as a basis.

The results computed at a yearly basis may allow the risk assessment of the heat-related excess mortality. The risk estimates can be compared to other environment-related risk estimates, helping the correct evaluation of heat-related mortality risk and the additional risk attributed to climate change and can easily be integrated in a risk assessment and management system.

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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. Community Health 65,* 64–70.

Barnett, A.G., Tong, S., and *Clements, A.CA.,* 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/isee2011/, accessed 15 Jun 2016.

Bobvos, J., Fazekas, B., and *Páldy, A.,* 2015: Assessment of heat-related mortality in Budapest from 2000 to 2010 by different indicators. *Időjárás 119,* 143–158.

Chen, K., Huang, L., Zhou, L., Ma, Z., Bi, J., and *Li, T.,* 2015: Spatial analysis of the effect of the 2010 heat wave on stroke mortality in Nanjing, China. *Sci. Rep. 2015 Jun 2;5:*10816.

Costello, A., Abbas, M., Allen, A., Ball, S., Bell, S., Bellamy, R., and *Patterson, C.,* 2009: Managing the health effects of climate change: Lancet and University College London Institute for Global Health Commission. *Lancet, 373(9676),* 1693–1733.

CRIGiS, 2015: Vulnerability and Impact Studies on Tourism and Critical Infrastructure. Available at: http://www.met.hu/KRITeR/en/kezdo/index.php, accessed 15 Jun 2016.

De' Donato, F.K., Leone, M., Scortichini, M., De Sario, M., Katsouyanni, K., Lanki, T., Basagaña, X., Ballester, F., Åström, C., Paldy, A., Pascal, M., Gasparrini, A., Menne, B., and *Michelozzi, P.,* 2015: Changes in the Effect of Heat on Mortality in the Last 20 Years in Nine European Cities. Results from the PHASE Project. *Int. J. Environ. Res. Public Health. 12,*15567–83.

European Commission, 2007: Communication from the Commission to the Council, the European Parliament and the European Economic and Social Committee - "Mid Term Review of the European Environment and Health Action Plan 2004–2010. Available at: http://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:52007DC0314, accessed 15 Jun 2016.

European Commission, 2013a: Adaptation to climate change impacts on human, animal and plant health. Available at: http://ec.europa.eu/clima/policies/adaptation/what/docs/swd_2013_136_en.pdf, accessed 15 Jun 2016.

European Commission, 2013b: Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee, and the Committee of the Regions - An EU Strategy on adaptation to climate change. Available at: http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52013DC0216&from=EN, accessed 15 Jun 2016.

Fouillet, A., Rey, G., Laurent, F., Pavillon, G., Bellec, S., Guihenneuc-Jouyaux, C., Clavel, J., Jougla, E., and *Hémon, D.,* 2006: Excess mortality related to the August 2003 heat wave in France. *Int. Arch. Occup. Environ. Health 80,*16–24.

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., McGregor, G.R., and *Lowe, J.A.,* 2009: 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.

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., Vardoulakis, S., Heaviside, C., and *Eggen, B.,* 2014: Climate change effects on human health: projections of temperature-related mortality for the UK during the 2020s, 2050s and 2080s. *J. Epidemiol. Commun. Health 68,* 641–648.
Huang, C., Barnett, A.G., Wang, X., Vaneckova, P., Fitzgerald, G., and *Tong, S.,* 2011: Projecting Future Heat-Related Mortality under Climate Change Scenarios: A Systematic Review. *Environ. Health Perspect. 119,*1681–1690.
IPCC, 2001: Technical Summary, Climate Change 2001: Impacts, Adaptation, and Vulnerability. In (Eds. *M. Manning, M. and Nobre, C.*) Report of Working Group II of the Intergovernmental Panel on Climate Change, Geneva, Switzerland, February 2001.
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: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. (Core Writing Team, R. K. Pachauri, & L. A. Meye Eds.). Geneva, Switzerland: IPCC.
Ishigami, Ai., Hajat, S., Kovats, R.S., Bisanti, L., Rognoni, M., Russo, A., and *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., and *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 Jun 2016.
Kyselý, J., Plavcová, E., Davídkovová, H., and *Kynčl, J.,* 2011: Comparison of hot and cold spell effects on cardiovascular mortality in individual population groups in the Czech Republic. *Clim. Res. 49,*113–129.
KSH, 2008: Tájékoztató a kiemelten támogatott kistérségekről. Központi Statisztikai Hivatal, Budapest.
KSH, 2014: Szépkorúak és vének - október elseje, az idősek világnapja. *Statisztikai Tükör 103.*
Le Treut, H., Somerville, R., Cubasch, U., Ding, Y., Mauritzen, C., Mokssit, A., Prather, M., 2007: Historical Overview of Climate Change. *In Solomon,S., Qin M.D., Manning, Z.,Chen, M., Marquis, K.B., Tignor M.A.,* and *Miller H.L. (Eds.):* Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
Martinez, G.S., Baccini, M., De Ridder, K., Hooyberghs, H., Lefebvre, W., Kendrovski, V., Scott, K., and *Spasenovska, M.,* 2016: Projected heat-related mortality under climate change in the metropolitan area of Skopje. *BMC Public Health. 16,*407.
McGregor, G., 2005: Projected changes in extreme weather and climate events in Europe. In (Eds. *K. Wilhelm, B. Menne, & R. Bertollini*) Extreme Weather Events and Public Health Responses. Berlin and Heidelberg, Germany: Springer-Verlag, 11–13.
McMichael, A.J., Campbell-Lendrum, D.H., Corvalán,C.F., Ebi ,K.L., Githeko,A., Scheraga J.D., and *Woodward, A.,*2003: Climate change and human health - risks and responses. WHO Geneva.
McMichael, A.J., Woodruff, R.E., and *Hales, S.,* 2006: Climate change and human health: present and future risks. *Lancet 367(9513),* 859–869.
McMichael, T., Montgomery, and *H., Costello, A.,* 2012: Health risks, present and future, from global climate change. *BMJ, 344,* e1359.
NAGiS, 2015: Newsletter 2015/1. Available at: http://nagis.hu/sites/nater.mfgi.hu/files/files/NAGIS_ Newsletter_2015_01.pdf, accessed 15 Jun 2016.
Pascal, M., Wagner, V., Le Tertre, A., Laaidi, K., Honoré, C., Bénichou, F., and *Beaudeau, P.,* 2013: Definition of temperature thresholds: the example of the French heat wave warning system. *Int. J. Biometeorol. 57,* 21–9.
Paldy, A., Bobvos, J., Vamos, A., Kovats, R. S., 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.,* 2011: Predicted Impact of Climate Change on Daily Excess Mortality and Emergency Ambulance calls between 2021–2050 and 2071–2100. *Cent. Eur. J. Occupat. Environ. Med. 17*, 445–68.
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/isee2011/, accessed 15 Jun 2016.
Paldy, A. and *Bobvos, J.,* 2012: Impact of Heat Waves on Excess Mortality in 2011 and 2012 in Hungary. *Cent. Eur. J. Occupat. Environ. Med. 18,*15–26.
Patz, J.A., Grabow, M.L., and *Limaye, V.S.,* 2014: When It Rains, It Pours: Future Climate Extremes and Health. *Ann. Glob. Health 80,* 332–344.
RKK, 2016: Long-term socio-economic forecasting for Hungary project. http://nater.rkk.hu, accessed 15 Jun 2016.
Rocklöv, J. and *Forsberg, B.*, 2008: The effect of temperature on mortality in Stockholm 1998-2003: a study of lag structures and heatwave effects. *Scand. J. Public Health 36,* 516–23.
Urban, A., Burkart, K., Kyselý, J., Schuster, C., Plavcová, E., Hanzlíková, H., Štěpánek, P., and *Lakes, T.*, 2016: Spatial Patterns of Heat-Related Cardiovascular Mortality in the Czech Republic. *Int. J. Environ. Res. Public Health 4*;13(3). pii: E284.
Vardoulakis, S., Dear, K., Hajat, S., Heaviside, C., Eggen, B., and *McMichael, A.j.*, 2014: Comparative Assessment of the Effects of Climate Change on Heat- and Cold-Related Mortality in the United Kingdom and Australia. *Environ. Health Perspect. 122,* 12.