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SPECIAL ISSUE ON TRANS-DISCIPLINARY APPROACHES TO CLIMATE CHANGE

Heat stress mortality and desired adaptation responses of healthcare system in Poland

Anna Błażejczyk [1] · Krzysztof Błażejczyk [2] · Jarosław Baranowski [2] · Magdalena Kuchcik [2]

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Abstract Heat stress is one of the environmental factors influencing the health of individuals and the wider population. There is a large body of research to document significant increases in mortality and morbidity during heat waves all over the world. This paper presents key results of research dealing with heat-related mortality (HRM) in various cities in Poland which cover about 25% of the country's population. Daily mortality and weather data reports for the years 1991–2000 were used. The intensity of heat stress was assessed by the universal thermal climate index (UTCI). The research considers also the projections of future bioclimate to the end of twenty-first century. Brain storming discussions were applied to find necessary adaptation strategies of healthcare system (HCS) in Poland, to minimise negative effects of heat stress. In general, in days with strong and very strong heat stress, ones must expect increase in mortality (in relation to no thermal stress days) of 12 and 47%, respectively. Because of projected rise in global temperature and heat stress frequency, we must expect significant increase in HRM to the end of twenty-first century of even 165% in comparison to present days. The results of research show necessity of urgent implementation of adaptation strategies to heat in HCS.

Keywords Heat stress mortality · UTCI · Healthcare system · Bioclimate change · Adaptation · Poland

✉ Anna Błażejczyk
anna@blazejczyk.eu

Krzysztof Błażejczyk
k.blaz@twarda.pan.pl

Jarosław Baranowski
j.bar@twarda.pan.pl

Magdalena Kuchcik
mkuchcik@twarda.pan.pl

[1] Bioklimatologia, Laboratory of Bioclimatology and Environmental Ergonomics, Łukowska 17/55, 04-133 Warsaw, Poland

[2] Institute of Geography and Spatial Organization, Polish Academy of Sciences, Twarda 51/55, 00-818 Warsaw, Poland

Introduction

The influence of thermal conditions on people's state of health and mortality is now the object of research around the world. A particular danger may be posed by extreme conditions, be they of cold or heat stress; given the serious health problems (and risk of death), these can provoke (Kalkstein 1998).

The health problems related to heat stress which is a combined effect of air temperature, solar radiation, air humidity and wind reflect overloading of bodily thermoregulatory and circulatory systems seeking to adapt to stressing ambient conditions (Błażejczyk et al. 2015a; Gasparini et al. 2015; Koppe et al. 2004). Under heat stress conditions, heat equilibrium within the body is mainly regulated through increased sweating and consequent evaporation-induced cooling. However, in humid climates, evaporation of sweat from the body surface can be limited. In certain conditions, the physiological regulation of body temperature is insufficient to maintain thermal equilibrium or can lead to major health disturbances. In general, skin eruptions, heat fatigue, heat cramps, heat syncope, heat exhaustion and heat stroke are classic heat-related diseases (Michelozzi et al. 2009). Most of them are in essence the effects of varying degrees of failure of the thermoregulatory system (Köppe et al. 2004; Kampmann et al. 2012). In spite of the actual possibility of sweat evaporation, the water loss through sweating can lead to hazardous health disorders where dehydration ensues. While water loss at the level of some 2% of body mass produces only thirst and heat fatigue, greater losses than this give rise to more

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dangerous symptoms of dehydration. At 6% dehydration, there is an increase in heart rate and body temperature; while with 14% dehydration, rapid temperature increase and death are the likely consequences (*Improving*… 2009). The problem of air humidity (when sweating does not lead to cooling) and of a small gradient between body temperature and air temperature (cooling more urgent but difficult as body produces heat through metabolic processes) could be mentioned as well (Błażejczyk et al. 2014).

Most relevant research had focused on heat waves generating dramatic increases in mortality and morbidity rates (e.g. Diaz et al. 2006, 2015; Foulllet et al. 2006; Green et al. 2016; Laschewski and Jendritzky 2002; Rocklöv et al. 2014; Tan et al. 2007; Tobias et al. 2014; Vandentorren et al. 2006). Majority of authors focus on all-cause mortality rate demonstrating indisputable negative influence of extreme heat stress on human health (Dawson et al. 2008; Diaz 2014; Gasparini et al. 2015; Koppe et al. 2004; Kovats et al. 2004; Ye et al. 2011 and many others). According to the Glossary of Biometeorology (Gosling et al. 2014), the deaths occurring during the warm season and deaths attributed to heat are called as heat-related mortality (HRM). In the majority of research, authors calculate rather "excess mortality" (Gosling et al. 2009a) from time series of all-cause mortality, or from other causes and they usually do not consider ICD-10 codes.

The study conducted by Baccini et al. (2008, 2011) in 15 European cities estimated that in Central European cities, heat-linked increases in mortality are within the range 1.34–2.24%. Błażejczyk and McGregor (2008) noted a significant increase in mortality on days with both extremely cold and extremely hot conditions in 6 European cities. Similar relationships have been reported for Spain (Tobias et al. 2014), Portugal (Alcoforado et al. 2015; Burkart et al. 2015), Croatia (Zaninovic and Matzarakis 2014), Greece (Nastos and Matzarakis 2012), Austria (Muther et al. 2010b), Sweden (Röcklov et al. 2014), Brazil (Saldiva et al. 1995), the USA (White-Newson et al. 2014), Australia (Tong et al. 2010) and Taiwan (Green et al. 2016).

The duration of heat waves also plays an important role in exerting negative health impacts on the human organism. Prolonged heat waves may lead to the accumulation of heat in the body core, and after consecutive hot days without refreshing during cooler nights, individuals may suffer from thermoregulatory failure (Błażejczyk and McGregor 2008; Bouchama and Knochel 2002; Laschewski and Jendritzy 2002). Certain social factors also affect HRM, including social isolation, ethnicity and socioeconomic status (Kuchcik and Degórski 2009).

Heat stress at the individual level occurs as a person facing heightened temperatures loses the ability to thermoregulate, with the result that body temperature rises, physiological functions begin to break down or fail and in the worst-case scenarios, death ensues. Typical heat-related health effects are skin eruptions, heat fatigue, heat cramps, heat syncope, heat exhaustion and heat stroke. The increased heat load exacerbates other health problems such as cardiovascular disease (Ebi et al. 2004; *Improving*… 2009; Koken et al. 2003; Task group… 2012), ischaemic stroke (Dowson et al. 2008) and respiratory disorders (Błażejczyk et al. 2000).

There are certain groups of population facing increased risk of heat-related health problems, namely elderly people (65+), children, pregnant women, people with chronic somatic and mental disorders, and disabled persons (especially those with limited mobility) (Chan et al. 2001; Diaz et al. 2006; Flynn et al. 2005; Naughon et al. 2002; Vandentorren et al. 2006; Yaron and Niermeyer 2004; Ye et al. 2001). Individuals with chronic respiratory disorders also belong to a group of people at great risk of negative health effects due to extreme heat events. Stagnant atmospheric conditions, especially those associated with heat waves, can trap pollutants and, thus, amplify the negative health effects heat exerts on subjects suffering from those diseases (*Improving* … 2009; Ren et al. 2006; Saldiva et al. 1995). Some studies point out that chronic respiratory diseases and heat stroke are other health problems capable of being linked to extreme heat events (Green et al. 2009).

There are several indicators of heat exposure (Błażejczyk et al. 2012; Epstein and Moran 2006). The indices applied most frequently in climate-mortality research are apparent temperature (AT, Baccini et al. 2008; Green et al. 2016), effective temperature (ET, Kozłowska-Szczęsna et al. 2004), physiological equivalent temperature (PET, Nastos and Matzarakis 2012; Zaninovic and Matzarakis 2014), perceived temperature (PT, Lasczewski and Jendritzky 2002), physiological subjective temperature (PST, Błażejczyk and McGregor 2008), the Universal Thermal Climate Index (UTCI, Błażejczyk et al. 2013a, 2015b; Urban and Kisely 2014) and mean radiant temperature (Mrt, Thornsson et al. 2014).

Some research dealing with climate-human health relationships assess possible impacts of projected changes in climate variables on future morbidity and mortality rates (Åström et al. 2013, 2015; Braks et al. 2014; Ebi 2008; Gosling et al. 2009b; Grillakis et al. 2016; Kjellstrom et. al 2016; Pappenberger et al. 2014). However, in bioclimatic literature, there are only few projections of future bioclimate which we understand, according to ISB definition of biometeorology (http://www.biometeorology.org/what_is_bm/index.cfm) as multiannual information regarded the interactions between atmospheric processes and living organisms. For example, Jendritzky and Tinz (2009) have projected increase in occurrence of "very hot" PT category in Central Europe by 22–30 days a year in 2100. Thorsson et al. (2011) assessed possible increase in heat stress hours in Gothenburg using PET index. Depending on the place in the city, the number of heat stress hours can be doubled or tripled in years 2080–2099 in comparison to 1980–1999. Cheung and Hart (2014) have found 4 and 10% increase of days with UTCI > 32 °C for Hong Kong at the end of twenty-first century for B1 and A1B SRES scenarios, respectively. Błażejczyk et al. (2013a) reported triplet increase of days with UTCI > 32 °C in Warsaw (Poland) for A1B scenario. Kjellstrom et al. (this issue) also indicate significant increase in heat stress days (as assessed by UTCI) all over the world. All the mentioned research forecasts significant increase in the frequency of oppressive thermal conditions in the forthcoming decades.

The main hypothesis of the presented research is "observed increase in mortality risk in Poland in warm seasons can be explained by the increase in heat stress intensity." To verify this hypothesis, we have assessed heat stress impacts as defined by UTCI on mortality rates in 15 cities in Poland during the last decade of the twentieth century. The result of research together with interview research allowed to develop adaptation strategy for the healthcare system (HCS) in Poland to minimise negative heat stress health effects (i.e. to reduce increased risk of mortality as well as cardiovascular and respiratory morbidity).

Materials and methods

Assessment of the climate impacts on mortality rates entailed comparisons of independent epidemiological and climatological databases. The epidemiological data were adapted from daily reports on total mortality in 15 cities in Poland with a population above 200,000 (i.e. Białystok, Bydgoszcz, Gdańsk, Katowice, Kraków, Lublin, Łódź, Olsztyn, Poznań, Rzeszów, Szczecin, Toruń, Warszawa, Wrocław and Zielona Góra). The smallest cities were Zielona Góra and Olsztyn (280,000 and 209,000 inhabitants, respectively) and the greatest was Warszawa (about 1,800,000 citizens). In total, the population of studied cities represents about 22% of Polish population and 37% of urban population (Table 1).

The daily reports of all-cause mortality for the period 1991–2000 were taken from Central Statistical Office of Poland (it was only one available period with daily mortality data). According to Gosling et al. (2009a), we have calculated excess mortality from time series of all-cause mortality. ICD-10 codes which refer to heat cause of death were not indicated in available dataset. We have considered both absolute and standardised (per 100,000 inhabitants) numbers of daily deaths. For the same period, daily meteorological values for air temperature and humidity, wind speed and total cloud cover at 15 meteorological stations located in the studied cities were taken for analysis (Fig. 1). To follow long-lasting changes in the frequency of heat stress days in Poland, the data for 1966–2012 were used as well. The cities differ in mean yearly temperature. In the years 1991–2000, it varied from 7.7 °C in Gdańsk and Białystok to 9.5 °C in Wrocław. In the majority of studied cities, the last years brought increase in air temperature up to 0.5 °C in Rzeszów and Wrocław (Table 1).

The measure of environmental heat stress applied in the research was the Universal Thermal Climate Index (UTCI). The particular categories of UTCI represent different physiologically relevant categories of thermal stress. The UTCI is one of the newest climate thermal index developed by multidisciplinary team of researchers (Bröde et al. 2012). The UTCI is defined as the equivalent of air temperature of the reference condition causing the same model response as the actual condition. To calculate UTCI model considers both meteorological (air temperature, mean radiant temperature, wind speed, vapour pressure) and non-meteorological (metabolic rate and thermal resistance of clothing) variables. In the effect, UTCI provides physiologically relevant information about adaptation responses of the human organism to cold and heat (Table 2). The physiological relevance of UTCI was the reason to apply this index in the research.

For the calculation of daily values of UTCI, the BioKlima 2.6 software package was used. For the assessing heat stress during daytime hours when people are mostly exposed to outdoor climate, we have used air temperature and humidity, wind speed at 10-m-above ground and total cloud cover values observed simultaneously at 12 UTC. This observational term represents conditions in the hottest part of the day. As mean radiant temperature is necessary for UTCI calculations, we have assessed its value based on SolAlt model which uses total cloud cover and Sun altitude as input values (Błażejczyk and Matzarakis 2007). To explain possible bioclimatic cause of daily mortality, reference was made to the occurrence of particular categories of thermal stress as defined by the UTCI. In the present paper, only heat stress classes were considered. As was mentioned before, the UTCI was used in the research because of its physiological relevance. Table 2 shows specific adaptation responses of an organism in each category of heat stress. Adaptation responses to heat cause additional load of thermoregulatory and circulatory systems which can lead to health disturbances. Especially loaded are strong and very strong heat stress (SHS, VSHS).

Thus, in our research, special attention was paid for these two classes of thermal conditions. Consequently, for each city, we have grouped days with particular categories of heat stress and for each category, mean daily mortality rates were calculated:

- for days with moderate heat stress (MHS)—with UTCI values between 26.1–32.0 °C;
- for days with SHS, i.e. UTCI of 32.1–38.0 °C and
- for days with VSHS, i.e. UTCI > 38 °C.

Table 1 Characteristics of population and essential air temperature characteristics of the studied cities in Poland

City	Population (in thousands) in 2000			Mean yearly air temperaturę (°C)	
	Total	Male	Female	1991–2000	2001–2015
Szczecin	410	195	215	9.4	9.3
Gdańsk	538	256	282	7.7	8.0
Bydgoszcz	505	239	266	8.9	9.0
Toruń	327	154	173	8.9	9.0
Olsztyn	280	134	146	8.0	8.1
Białystok	590	281	309	7.7	7.7
Poznań	738	350	388	9.2	9.6
Zielona Góra	276	132	144	9.3	9.8
Łódź	775	353	422	8.7	9.1
Warszawa	1801	831	970	8.8	9.1
Lublin	470	220	250	8.1	8.4
Wrocław	635	298	337	9.5	10.0
Katowice	309	146	163	8.9	8.8
Kraków	883	417	466	8.9	9.0
Rzeszów	291	140	151	8.6	9.1
Total	8537	4006	4531	8.7	8.9

Sources: *Demographic Yearbook of Poland* 2000, Central Statistical Office, Warszawa 2001

Meteorological daily records provided by the Institute of Meteorology and Water Management

For the comparison, the mortality for days with no thermal stress (NTS) category, i.e. UTCI values between 9.1 and 26.0 °C, was taken into consideration to find relative risk of deaths in days with MHS, SHS and VSHS.

Statistical analysis of the significance of observed relationships was made with the use of STATGRAPHICS 7.2 software package. Kruskal-Wallis and multiple range tests were applied to determine which means of mortality rates

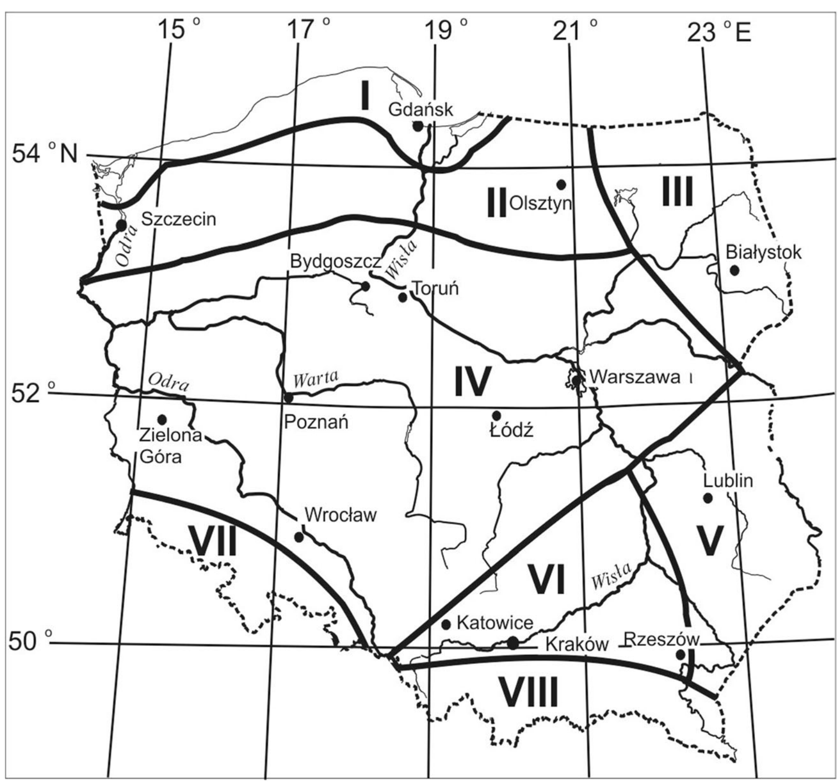


Fig. 1 Distribution of studied cities. I–VIII—Bioclimatic regions of Poland (According to Błażejczyk, 2006): I—coastal, II—lakeland, III—north-east, IV—Central, V—south-east, VI—upland, VII—Sudetic and VIII—Carpathian. Source: own elaboration

Table 2 UTCI equivalent temperature categorized in terms of thermal stress

UTCI (°C) range	Stress category	Physiological responses
Above +46	Extreme heat stress (EHS)	Increase in rectal temperature (Tre) time gradient.
		Steep decrease in total net heat loss.
		Averaged sweat rate > 650 g/h, steep increase.
+ 38 to + 46	Very strong heat stress (VSHS)	Core to skin temperature gradient < 1 °K (at 30 min).
		Increase in Tre at 30 min.
+ 32 to + 38	Strong heat stress (SHS)	Averaged sweat rate > 200 g/h.
		Increase in Tre at 120 min.
		Latent heat loss > 40 W at 30 min.
		Instantaneous change in skin temperature > 0 °K/min.
+ 26 to + 32	Moderate heat stress (MHS)	Change of slopes in sweat rate, *Tre* and skin temperature.
		Steep increase in skin wettedness.
+ 9 to + 26	No thermal stress (NTS)	Averaged sweat rate > 100 g/h.
		Latent heat loss > 40 W, averaged over time.
		Plateau in *Tre* time gradient.
+ 9 to 0	Slight cold stress (SlCS)	Local minimum of hand skin temperature (use gloves).
0 to − 13	Moderate cold stress (MCS)	Skin blood flow at 120 min lower than at 30 min (vasoconstriction).
		Face skin temperature < 15 °C (pain).
		Tre time gradient < 0 °K/h.
− 13 to − 27	Strong cold stress (SCS)	Face skin temperature < 7 °C (numbness).
		Tre time gradient < − 0.1 °K/h.
		Tre decreases from 30 to 120 min.
		Increase in core to skin temperature gradient.
− 27 to − 40	Very strong cold stress (VSCS)	Face skin temperature < 0 °C (frostbite).
		Occurrence of shivering.
		Tre time gradient < − 0.2 °K/h.
Below − 40	Extreme cold stress (ECS)	*Tre* time gradient < − 0.3 °K/h.
		Face skin temperature < 0 °C (frostbite).

Source: Blazejczyk et al. 2013b

calculated for particular categories of heat stress were significantly different from which others. The analysis lead to develop a statistical model of daily heat-related mortality (HRM) for standardised values (per 100,000 inhabitants), as observed under different categories of heat stress. The general form of the model is as follows:

$$HRM = \sum(\textit{Standardized daily mortality rates}\ \text{per}\ 100,000\ \textit{inhabitants} \times \textit{annual number of days with different heat stress category})$$

To assess possible changes in HRM at the end of twenty-first century in the present research, we have assumed according to the previous research of authors (Błażejczyk et al. 2013a; Błażejczyk et al. 2015b) three arbitral scenarios of the possible changes in the frequency of SHS + VSHS UTCI categories at the end of twenty-first century, namely small increase (SRES B1, up to 20 days in year 2100), moderate increase (SRES A1B, up to 35 days) and great increase (SRES A2, up to 50 days) in comparison to about 7 days in the last decade of twentieth century. Similar concept for the prediction of future climate (assumption of 2 °C increase of air temperature) was used by Grillakis et al. (2016).

The results of heat stress and mortality research were presented to healthcare authorities (Ministry of Health, national coordinators of treatment procedures) and practitioners (physicians, selected hospital administration, researchers) together with proposed adaptation strategies of HCS (Błażejczyk et al. 2015a). They validated the proposals and after several brain storming discussions, there was developed the catalogue of adaptation strategies of healthcare system (HCS).

Table 3 Characteristics of particular categories of heat stress, mean values for 15 studied cities, 1991–2000

Characteristics	NTS	MHS	SHS	VSHS
Average annual frequency (%)	35.8	7.4	1.7	0.2
Mean daily mortality (cases)	11.7	11.7	13.1	17.1

Source: authors' own elaboration based on daily meteorological records

Results

Seasonal differentiation of heat stress

The frequency of SHS and VSHS days in the last decade of twentieth century was on average about 2%. MHS days consist of about 7.5%. The most frequent is days with moderate cold stress (44%) and no thermal stress (36%) (Table 3). The frequency of heat stress days does not differ significantly between cities. Their amount varies from 0.2% in Gdańsk (at the Baltic Sea coast) up to 2.5% in Kraków and 2.8% in Rzeszów in south-eastern Poland (Fig. 2) which are the cities exposed to most often advections of hot subtropical and dry continental air masses (Błażejczyk, 2006; Więcław, 2004).

Different categories of heat stress are observed only from May till August. The most frequent they are is in July and August (4–10%). In the given example from Warsaw, we can see very typical for Poland seasonal pattern of heat/cold stress days (Błażejczyk et al. 2014; Nowosad et al. 2013). While in cold months (November–February), MCS and SCS are dominant then from May till September, NTS days are most frequent. However, heat stress days occur relatively often and MHS days consist of 22% in July and 26% in August (Fig. 3).

When analysing impact of climate on HRM, ones must study changes in any heat stress indicator in the past. The research made by authors for Poland (Błażejczyk et al. 2015b) shows that in the period 1996–2012, there are observed statistically significant (at $p < 0.01$) changes in the frequency of heat stress days. Their number increased from about 3 days in 1966 to about 10 days in 2012. The data shows also that in period of simultaneous epidemiological and climatological data considered in this paper (1991–2000), there are years (1992, 1994, 1995) with increased occurrence of heat stress days (Fig. 4).

Heat stress mortality

Mean annual daily mortality for studies cities is about 173 cases and varies from 3 to 6 cases daily in small cities (Olsztyn, Zielona Góra, Toruń, Rzeszów, Białystok) to 28 deaths in Łódź and 48 in Warsaw. In all cities, daily number of deaths changed depending on actual thermal stress category. In NTS and MHS, total daily number of deaths was about 176 (i.e. 11.7 per city in average). According to increase of the intensity of cold and heat stress, total daily number of deaths has raised. In SHS days, it was 196 and in VSHS— 240 cases daily. It gives respectively 13 and 17 cases for each city on average (Table 3).

The significance of the mean daily mortality values was verified using Kruskal-Wallis and multiple range tests. According to Kruskal-Wallis test, in almost all cities, means of mortality rates in particular thermal stress categories were significantly different from which others on 95% confidence level. The exception was Olsztyn where only VSCS and VSHS means differ significantly from means for other categories. Also, in the case of multiple range tests, majority of mortality means differ from which others on 95 or 90% confidence levels, especially for cold stress mortality. Thus, we can assume that means of mortality for various thermal stress categories differ significantly from which others (Table 2). Because of weak significance of differences in mortality rates in Olsztyn indicated by two used tests, this city was excluded from farther research.

Table 4 contains also relative values for risk of death in days with different thermal stress categories, in selected cities in Poland. Considering heat stress conditions, we can see that in days with MHS, mean number of deaths is very close to this

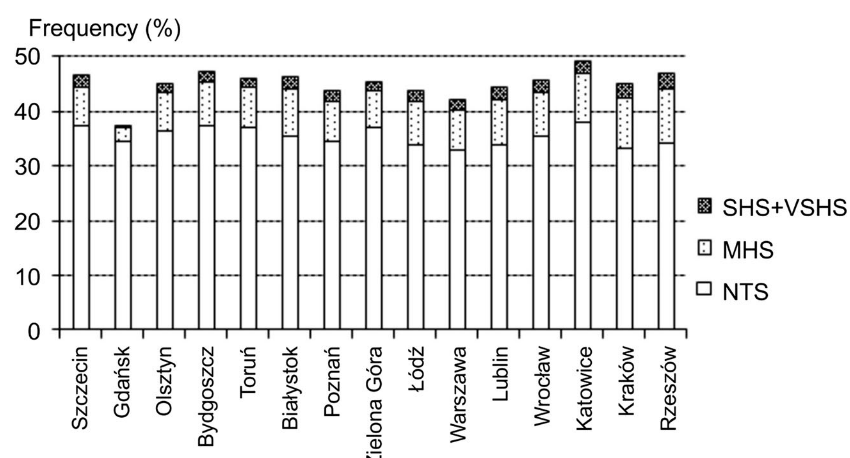


Fig. 2 Annual frequency of particular heat stress categories in studied cities, 1991–2000. Source: authors' own elaboration based on daily meteorological records

observed in NTS days. However, risk of death in days with strong and very strong heat stress is significantly higher in comparison to NTS days, with mean values of 1.12 and 1.47, respectively.

In the next step, the numbers of registered deaths were compared with the population of each city. This gave the standardised mortality indices per 100,000 citizens. In this step, the number of deaths in days with SHS and VSHS was aggregated because of small frequency of days with extreme heat stress. The indices were calculated for various categories of heat stress: thermoneutral conditions (NTS), moderate heat stress (MHS) and great heat stress (SHS + VSHS). The highest values for indices were found for Łódź and Poznań (Central Poland), and the lowest for Rzeszów (south-eastern) as well as for Białystok (north-eastern Poland) (Table 5).

To assess annual numbers of heat-related mortality (HRM), the following model was developed:

$$\mathrm{HRM} = 2.595 \times \left(population \middle/ 100,000\right) \times (annual\ number\ of\ \mathrm{SHS} + VSHS\ days) + 2.376 \times \left(population \middle/ 100,000\right) \times (annual\ number\ of\ \mathrm{MHS}\ days)$$

The developed model of HRM allows to project heat-related mortality for the ongoing century. Absolute numbers of HRM were calculated for particular regions for chosen decades of the twenty-first century. Projected changes for the population of Poland were also used for this purpose. This projection assumes a decline in the population of Poland from 38.3 million in 2010 to 28.7 million in 2100 (a 25% decrease).

By the end of the twenty-first century, the expected climate changes will be associated with an anticipated increase in HRM. At the scenario assumed great increase in heat stress days, the number of deaths can rise from the 28,000 a year observed currently to 74,500 by the end of the twenty-first century. The scenario of moderate increase forecasts 63,000 and the scenario of small increase—39,500 deaths a year in 2100. Thus, the relative increase of HRM for the mildest scenario of heat stress increase (from 7 to about 18 days) can reach about 40%. The moderate scenario of heat stress increase (from 7 to 36 days) projects HRM rise of about 120%, and the hardest scenario (increase of heat stress up to 55 days) predicts of about 165% more heat-related deaths.

Regionally, the greatest increase in HRM (177–437%) is predicted for Katowice at Silesia, Poland's most industrial region. Values for the increase in HRD greater than the average for Poland as a whole are also projected for Bydgoszcz, Łódź and Wrocław. The most limited increase in HRM is projected for the western and north-western Poland (Poznań, Szczecin, Zielona Góra) with 10–17% more deaths with comparison to present levels.

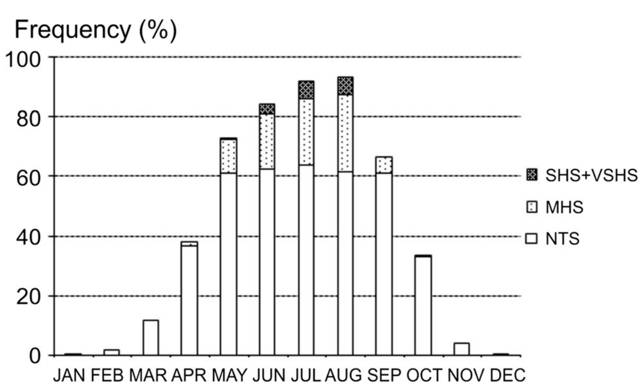


Fig. 3 Frequency of particular thermal stress categories in consecutive months, Warszawa 1991–2000. Source: authors' own elaboration based on daily meteorological records

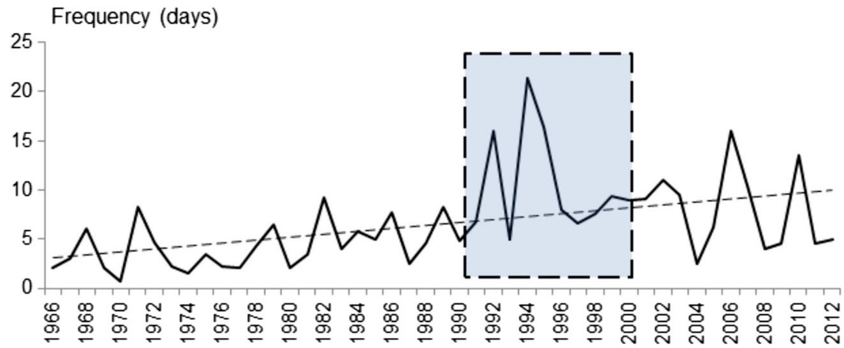
Adaptation strategies catalogue

The stewardship, management and financing functions of healthcare system in Poland are divided between three different types of institutions: the Ministry of Health, National Health Fund and territorial self-government administration. The Ministry of Health plays the principal role in HCS. It is responsible for national health policy, for major capital investments and for medical science and education. The Ministry is also responsible for preparing and implementing national health programmes, for training health care personnel, for partly funding medical equipment and for setting and monitoring health care standards (Kuszewski and Gericke 2005). The Ministry of Health addresses some tasks to territorial administration (e.g. financing of hospitals). However, the National Health Found is an agency distributed founds for any medical treatments (in hospitals, surgeries, health resorts etc.).

The last National Health Programme (NHP) for years 2016–2020 was adopted by the Council of Ministers on 4 August 2016. The strategic goal of NHP is to improve health status of the population and to enhance health-related quality of life. One of the operational tasks is dedicated to reduction of health risk caused by physical, chemical and biological factors of ambient environment. In this task, attention should be paid for research dealing with adaptation of HCS to climate change.

To develop adaptation strategies, the results of HRM research were presented at several meetings and conferences to

Fig. 4 Changes in the frequency of days with great heat stress (UTCI > 32 °C); the grey box shows period used for HRM research. Source: Błażejczyk et al. 2015b



discuss (brainstorming method) with healthcare authorities and practitioners which adaptation strategies of HCS should be applied. The developed catalogue of adaptation strategies was sent to be verified by the Ministry of Health and national coordinators of treatment procedures in cardiovascular and respiratory diseases. There were assumed that adaptation measures must be considered in two time perspectives: short term (urgent actions) and long term (permanent actions).

The short-term (urgent) adaptation would include the following:

– the fitting out of hospitals, outpatient surgeries and other HCS facilities with air conditioning and refrigeration units;
– better preparation of medical staff for urgent weather-related incidents arising, including heat stress;
– storage of seasonal supplies in sufficient quantity and
– adequate protection of workplaces exposed to climate factors (including heat waves), to ensure minimization of the negative effects.

Long term, more permanent measures will in turn entail the following:

– a watch warning system informing society and the healthcare authorities of extreme weather events capable of resulting in accidents and other health problems;
– periodic courses to upskill medical personnel as regards the diagnosis and treatment of heat-related health disorders;

Table 4 Mean values for the relative risk of death (%) on days of different heat stress categories and statistical significance of pairs of means in studied Polish cities, 1991–2000

City	Relative risk of death				Statistical significance of pairs of means						
	NTS	MHS	SHS	VSHS	Multiply range tests						Kruskal-Wallis test
					NTS–MHS	NTS–SHS	NTS–VSHS	MHS–SHS	MHS–VSHS	SHS–VSHS	Significance level
Szczecin	1.00	0.99	1.06	1.42	*	*	**	*	**	**	**
Gdańsk	1.00	1.04	1.18	–	*	*	–	*	–	–	*
Olsztyn	1.00	0.99	1.10	1.32	*	Ns	*	Ns	*	Ns	Ns
Bydgoszcz	1.00	1.00	1.12	1.69	**	**	**	**	**	**	**
Toruń	1.00	1.03	1.12	1.23	*	*	*	*	*	*	**
Białystok	1.00	1.03	1.14	1.24	*	**	*	*	*	*	*
Poznań	1.00	0.99	1.14	1.54	**	**	**	**	**	**	**
Zielona Góra	1.00	1.03	1.12	1.88	**	*	**	*	**	**	**
Łódź	1.00	103.6	1.21	1.58	**	**	**	**	**	**	**
Warszawa	1.00	1.01	1.17	1.53	**	**	**	**	**	**	**
Lublin	1.00	1.02	1.20	1.42	**	**	**	**	**	**	**
Wrocław	1.00	1.00	1.03	1.51	**	*	**	*	**	**	**
Katowice	1.00	1.01	1.05	1.36	*	*	Ns	Ns	*	*	**
Kraków	1.00	1.02	1.04	1.18	*	*	Ns	*	Ns	Ns	*
Rzeszów	1.00	1.00	1.15	1.77	**	**	**	**	**	**	**
Average	1.00	1.01	1.12	1.47	–	–	–	–	–	–	–

Source: authors' own elaboration

Ns non significant

** Significant at 95% confidence level, * significant at 90% confidence level

Table 5 Standardized daily mortality rates (per 100,000 inhabitants) in selected cities in Poland (1991–2000), observed in relation to different categories of heat stress, i.e. no thermal stress (NTS), moderate heat stress (MHS) and great heat stress (SHS + VSHS)

	NTS	MHS	SHS + VSHS
Szczecin	2.239	2.350	2.449
Gdańsk	2.204	2.330	2.609
Bydgoszcz	2.406	2.610	2.812
Toruń	2.059	2.210	2.298
Białystok	1.815	1.950	2.039
Poznań	2.715	2.800	3.234
Zielona Góra	1.742	1.950	2.061
Łódź	3.294	3.350	4.145
Warszawa	2.358	2.432	2.830
Lublin	2.027	2.320	2.470
Wrocław	2.331	2.380	2.498
Katowice	2.596	2.620	2.723
Kraków	2.339	2.400	2.533
Rzeszów	1.441	1.560	1.633
Average	2.255	2.376	2.595

Source: authors' own elaboration based on daily epidemiological records

- implementation of educational programmes dealing with the complex influences of changing climate on human health;
- modernisation of laboratories for the early diagnosis of cardiovascular disorders;
- improvement of the infrastructure at hospitals, outpatient surgeries, health resorts and other facilities within the healthcare system;
- an interactive system to monitor and register climate-related diseases, including HRM;
- funding for research on epidemiology, toxicology and climate physiology, with a view to improve knowledge of mechanisms of heat-related health disorders and
- an information system for health prophylaxis, including periodical examinations, promotion of healthy nutrition and lifestyle, pre-medical aid and appropriate reactions to extreme weather events.

Finally, only some of the above proposals of adaptation strategies of HCS to increasing heat stress seems were implemented to the national adaptation strategy to climate change (*Strategiczny plan*… 2013).

Discussion

Efforts to explain why heat stress influences human health negatively and leads to an increase in mortality need to consider the impacts of heat on cardiovascular and cerebrovascular diseases. Pathophysiological changes in the human body reflecting exposure to extreme heat can affect the circulatory system comprise hypotension, tachycardia, dehydration, increased viscosity of the blood, decreased platelet levels, hypernatremia, hyperkalemia, disseminated intravascular coagulation and rhabdomyolysis. Increase in heat-related morbidity and mortality due to cardiovascular and cerebrovascular disorders was reported by Ferrari et al. (2015), Urban et al. (2013) and Ye et al. (2001).

The majority of researches refer relative increase in mortality above defined temperature thresholds. For example, Baccini et al. (2008, 2011) estimated that in Athens, a 1 °C increase in apparent temperature (AT) above 32.7 °C is associated with a 5.54% increase in daily mortality. Similar mortality increases have been found for Rome and Milan. However, in Stockholm, a 1 °C increase of AT above 21.7 °C is seen to be linked with a 1.17% increase in daily mortality. In Central European cities, heat-linked increases in mortality are shown to be in the range 1.34–2.24%. Błażejczyk and McGregor (2008) likewise studied such relationships in 6 European cities, noting a 25% increase in mortality on days with physiologicaly subjective temperature (PST) above specific thresholds: 29 °C in Cracow and London, 37 °C in Paris and Barcelona and 45 °C in Rome and Budapest. Urban and Kysely (2014) reported 12–13% increase in cardiovascular mortality in Czech Republic at UTCI higher than 22 °C.

Kozłowska-Szczęsna et al. (2004) did not consider thermal threshold of increased mortality. They compared daily mortality with specific categories of thermal sensations and they found that mortality was significantly higher on days characterised by the ET categories ":very hot" or "extremely hot", with relative increase of 18–31%. Błażejczyk et al. (2013a) have found for Warsaw (Poland) that at UTCI higher than 32 °C, daily mortality rates increased significantly and at UTCI of about 46–50 °C, they were of about 54% more frequent than at "no thermal stress" conditions.

Projections regarding health indicators provided a basis for strategies by which healthcare systems may be adapted to observed climate change (Åstrom et al. 2015; Diaz et al. 2015; Muthers et al. 2010a; Pezzoli et al. 2016). In Poland, the functioning of the HCS is influenced by several factors (economic, physical, social, juristic and cultural) vulnerable to climate change (*Strategiczny* … 2013). The relevant economic factors consist of stable financing of the HCS (including as regards education and research), clear procedures for supporting HCS units financially, procedures for the funding of medical treatment and the availability of medical services and medicaments (Kuszewski and Gericke 2005). As physical factors, we can list specific meteorological conditions, the quality of drinking water, technical disasters (whose effects can be magnified under more oppressive weather conditions) and air pollution (Bowen and Ebi 2015). The social factors to be considered are working conditions especially in the case of outdoor occupations (*Task group* … 2012), the age structure of society and the standard of home and office equipment (Kuchcik and Degórski 2009). Also, very important are such cultural factors as awareness of the importance of hygiene and food storage, and of health prophylaxis, awareness of the importance of a clean environment, and the culture where the spending of leisure time and holidays is concerned. Legislation is also obviously of great importance to the functioning of the HCS (Kuszewski and Gericke 2005).

In 2013, the Ministry of Environment has proclamated "Strategic plan of adaptation of vulnerable sectors of economy to climate change to the year 2020 with perspective to 2030" (*Strategiczny plan*… 2013). There were defined the following priority action of HCS "Reduction of health effects of heat stress and extreme climatic events within vulnerable groups of population." As the tools of this action, there were listed (1) conducting of epidemiological, clinical and climato-physiological research for better knowledge of climate-related diseases (CRD); (2) establishing of watch warning system of dangerous climate events including heat waves and (3) establishing a database of CRD occurrence. Supporting of scientific research dealing with CRD is also implemented in the National Health Programme for the years 2016–2020.

The effects of implemented adaptation strategies can be assessed in few years. However, while assessing vulnerability of population health to climate change, we should consider whole complex of possible impacts. For example, Arbuthnott et al. (2016) indicate that in few researches, the authors report reduction of mortality risk in spite of observed increase in air temperature. It can be explained by better adaptation of population and HCSs to changing climate. This aspect of HRM in Poland needs to be undertaken in the future when epidemiological data for the longer period will be available.

Conclusions

The principal hypothesis of the research was confirmed. In days with strong and very strong heat stress, the significant increase of mortality is observed in comparison to no thermal stress conditions. Though heat stress is not very frequent observed in Poland, its occurrence makes increased risk of heat-related mortality.

Due to projected increase in heat stress frequency and intensity to the end of twenty-first century, we must expect increase in HRM. For the mildest scenario of heat stress changes, the HRM can rise of about 40% at the end of the century. In moderate scenario, HRM will rise of 120% and in the hardest scenario of heat stress increase, HRM rise can be even 165% in comparison to present days.

The healthcare system in Poland must thus make far-reaching adaptations to anticipated climate change. However, all the changes in heat stress, population health and adaptation strategies effects must be monitored to ensure expected reduction in the numbers of deaths that would otherwise occur, most especially among the elderly in society.

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