Journal of
Climate Change Research
2020, 1(4): 67-75
DOI: 10.30488/CCR.2020.252534.1028

Assessment of mortality risk in Poland due to cold and heat stress and predictions to 2100

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

[1] Institute of Geography and Spatial Organization, Polish Academy of Sciences, Twarda 51/55, 00-818 Warszawa, Poland
[2] Bioklimatologia. Laboratory of Bioclimatology and Environmental Ergonomics, Lukowska 17/55, 04-133 Warszawa, Poland

Keywords
Heat stress
Cold stress
Mortality
climate change
Adaptation
Poland

Corresponding author
Krzysztof Błażejczyk
k.blaz@twarda.pan.pl

Article history
Received: June, 27
Revised: October, 2
Accepted: October, 27

Abstract
Cold and heat stress are environmental factors influencing the state of health of individuals and the wider population. There is a large number of research to document significant increases in mortality and morbidity during cold and heat waves in every climate zone. In spite of the well-documented nature of heat/cold-related health problems, only in few countries local or national authorities have developed any special adaptation strategies for their healthcare systems (HCS), with a view to addressing predicted increases in the frequency and severity of cold- and heat-stress events. Such strategies draw on epidemiological and climatological research. For example in Poland in the years 2012-2015 research project pursued to study regional differentiation in climate-related diseases in Poland, with regional-level predictions for their occurrence through to 2100. The results of the project were applied in a national strategy for adaptation to climate change This paper presents key results of the part of this project dealing with heat- and cold related mortality in various regions of Poland. Overall, in the near future a 4-28% increase in the number of days imposing heat stress is anticipated, and may result in heat-related mortality significantly higher by the last decade of the 21st century than in the years 1991-2000 (at a level between 137 and 277%).

Introduction

Climate and weather strongly influence human health and wellbeing. Several weather conditions involved acute health effects were reported (Błażejczyk 2009; Błażejczyk et al. 2015; Fers 1995; Kalkstein 1998; Lasczewski and Jendritzky 2002; McGregor 2001). At most of research the attention is paid to heat waves that dramatically influence mortality and morbidity rates (Dessai 2002; Diaz et al. 2006; Kuchcik 2017; Laschewski and Jendritzky 2002; Tan et al. 2007). In middle and northern latitudes cold related health disturbances are mainly noted (Błażejczyk et al. 1998; Eng and Mercer 1998; Eurowinter Group 1997; Gyllerup 1998; Herring and Hoppa 1997; Keatinge and Donaldson 1998).

The influence of thermal conditions on people's state of health and mortality is now the object of great deal of research around the world. The magnitude of thermal impacts depends, not only on air temperature, but also on intensity of solar radiation, air humidity and wind speed (Błażejczyk et al. 2015; Gasparini et al. 2015; Koppe et al. 2004). 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 extreme thermal conditions in question are commonly known as cold waves or heat waves, and is known that the effects of both can be either reduced or magnified in line with socio-economic factors, as well as the level of organisation and operations of states' healthcare systems (Kuchcik and Degórski 2009; Kuchcik 2017).

The health problems related to high air temperature reflect overloading of bodily thermoregulatory and circulatory systems seeking to adapt to stressing ambient conditions. The physiological regulation of body temperature may prove insufficient for the maintenance of thermal equilibrium, with major health disturbances then induced. In general, skin eruptions, heat fatigue, heat cramps, heat syncope, heat exhaustion and heat stroke are classic heat-related diseases, and most in essence arise from varying degrees of failure of the thermoregulatory system (Beaumont and Bullard

Please cite this article as Błażejczyk K, Błażejczyk A, Baranowski J, Kuchcik M (2020) Assessment of mortality risk in Poland due to cold and heat stress and predictions to 2100. Journal of Climate Change Research. 1(4): 49-57.

1965; Elizondo and Bullard 1971; Garden et al. 1966; Givoni and Goldman 1973; Kenney 1985; Koppe et al. 2004).

Most relevant research had focused on heat waves generating dramatic increases in mortality and morbidity rates (Dessai 2002; Diaz et al. 2006; Kuchcik 2017; Laschewski and Jendritzky 2002; Pascal et al. 2005; Tan et al. 2007). However, at daily relationships between ambient conditions and mortality are considered, it is possible to observe an increase with both high and low temperatures, with observed relationships displaying a U- or V-shaped pattern.. The negative impact of extreme heat and cold on human health is indisputable and observed in every climate zone (Alcoforado et al. 2015; Baccini et al. 2008, 2011; Blazejczyk 2009; Błażejczyk and McGregor 2008; Błażejczyk et al. 2018; Burkhart et al. 2015; Dawson et al. 2008; Diaz 2014; Gasparini et al. 2015; Green et al. 2016; Koppe et al. 2004; Kovats et al. 2004; Muther et al. 2010; Nastos and Matzarakis 2012; Röcklov et al. 2014; Saldiva et al. 1995; Tobias et al. 2014; White-Newson et al. 2014; Ye et al. 2011; Zaninovic and Matzarakis 2013).

In cold environment increased convection is the main way of heat loss. Thermoregulatory system tries to minimise heat loss from the body by reduction of peripheral blood flow. It leads to decrease in skin temperature and consequently to increase in thermal insulation of skin tissue. Additionally, in severe cold the shivering thermogenesis is activated (Broede et al. 2012). The negative effects of these processes are great increase of blood pressure (frequently leading do infarct), reduction of immunological ability of an organism (which lead to virus and bacteriological infections) and great risk of frostbite of body extremities.

There are certain groups of population facing increased risk of heat- and cold-related health problems, namely: elderly people (65+), children, pregnant women, people with chronic somatic and mental disorders or disabled persons (Chan et al. 2001; Diaz et al. 2006; Fouillet et al. 2006; Flynn et al. 2005; Naughon et al. 2002; Tan et al 2007; Vandentorren et al. 2006; Yaron and Niermeyer 2004). Also, individuals with chronic respiratory disorders (like bronchial asthma or chronic obstructive pulmonary disease) belong to a group of people at great risk of negative health effects due to extreme thermal events (Kuchcik 2017).

There are several thermal indicators used in climate-human health research. In the latest research the Universal Thermal Climate Index (UTCI) is frequently applied (Błażejczyk et al. 2013, 2015, 2018; Urban and Kisely 2014).

The aim of the paper is to assess heat and cold stress impacts on mortality rates in Poland during the last decade of the 20th century and to predict of heat-related deaths (HRD) and cold-related deaths (CRD) in consecutive decades of the 21st century.

Materials and methods

Assessment of the climate impacts on HRD and CRD bases on 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) over the period 1993-2001. For the same period, daily meteorological values for air temperature and humidity, wind speed and total cloud cover at 15 meteorological stations located in above listed cities were considered.

The research comprises stage 1: statistical modelling based on past (climatological and epidemiological) data, and stage 2: projections for HRD and CRD in relation to three scenarios for climate change A1B, A2 and B1. In the first stage empirical mortality and climate data with daily resolution are used to find statistical models of past relationships. In the second stage statistical relationships models are apply to assess potential impacts of climate change on climate related mortality (Figure 1).

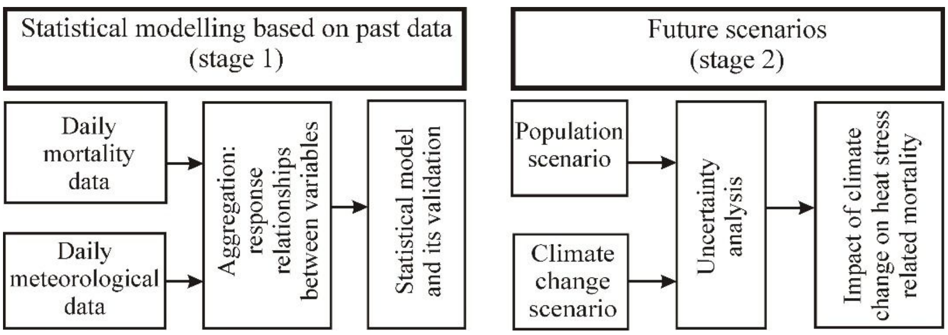

Figure 1. Methodological scheme generating projections as regards climate-related diseases
Source: adapted from Gosling et al. (2009).

The environmental measure of heat and cold stress applied was the Universal Thermal Climate Index (UTCI), for which daily values were calculated using the BioKlima 2.6 software package. Midday values for air temperature and humidity, wind speed at 10 m above ground and total cloud cover were used. To explain variability in daily total mortality, reference was made to the frequency of occurrence of particular categories of thermal stress as defined by the UTCI. Mean daily mortalities observed with different categories of thermal stress were calculated:

- for days with great heat stress (GHS), i.e. UTCI >32ºC,
- for days with moderate heat stress (MHS) – with UTCI values between 26.1 and 32.0ºC,
- for days with thermoneutral conditions (TN), i.e. UTCI of 0-26°C,
- for days with moderate cold stress (MCS), i.e. UTCI between -13.0 and 0.0ºC,
- for days with great cold stress (GCS), i.e. UTCI <-13ºC).

The search for a statistical models of HRD and CRD entailed the application of standardised values (per 100 000 inhabitants) for daily mortality, as observed under different categories of heat stress.

The second stage of the research saw statistical models of HRD and CRD applied in the supplying of projections for the years 2021-2100. These projections for climate elements were adapted from the METEONORM 7 software package, which generates a set of variables for consecutive decades of the 21st century using average values for climate elements obtained from 18 climate models as a part of the 4th assessment report of the IPCC (Meehl et al. 2007). The simulations were made for three different emission scenarios (SRES): B1 (low), A1B (temperate) and A2 (high) (Nakicenovic et al. 2003). For every decade of the 21st century hourly data for essential meteorological elements (global solar radiation, air temperature and humidity and wind speed) were projected for a so-called "typical climatic year". These variables (selected for midday hours, i.e. 12 UTC) were then used in calculation the Universal Thermal Climate Index (UTCI) using BioKlima 2.6 software package. The analysis of projected meteorological variables and thermal stress then made use of data for 43 stations selected to represent different administrative regions of Poland.

Results

Stage 1 – statistical modelling of HRD and CRD

In the period 1966-2012 annual number of great cold stress days (UTCI<-13ºC) and great heat stress days (UTCI>32ºC) has changed significantly (at p=0.01 level) over the territory of Poland (Błażejczyk et al. 2015). The number of GCS days decreased in average from about 60 in the beginning to about 30 in the end of the period. However, GHS days increased from 3 to about 10 yearly. While in the beginning of the GCS days were 12 times more frequent then GHS days then in 2012 such ratio was only about 3 (Figure 2).

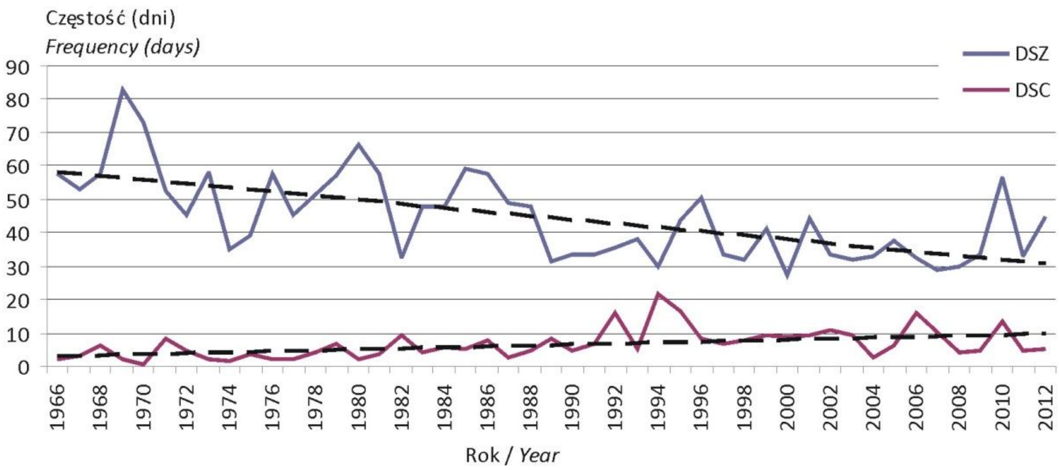

Figure 2. Changes in the frequency of days with great cold stress (DSZ) and great heat stress (DSC) Source: own elaboration.

The period for common presence of mortality and meteorological data is shorter then meteorological period alone. For every day of common period we have calculated UTCI values which were categorised according to used assessment scale. Comparing daily UTCI and daily total mortality rates the relative risk of death (RRD) was defined for particular thermal stress categories. As the basic level (assumed as

100%) the deaths observed in days with thermoneutral conditions (TN) in particular months were used. For particular categories of thermal stress the relative risk of death is: 115.0% - for GCS, 105.5% - for MCS, 105.3% - for MHS and 114.8% - for GHS.

In the next step the numbers of registered deaths were compared with the population of each city. This gave the daily standardised mortality rates (SMR) per 100000 citizens. The SMR values were calculated individually for particular categories of thermal stress: great cold stress (SMR_GCS), moderate cold stress (SMR_MCS), thermoneutral conditions (SMR_TN), moderate heat stress (SMR_MHS), and great heat stress (SMR_GHS) (Table 1).

Table 1. Daily standardised mortality rates (SMR, per 100 000 inhabitants) in Poland (1993-2001), for different categories of thermal stress, i.e. great cold stress (GCS), moderate cold stress (MCS), thermoneutral conditions (TN), moderate heat stress (MHS) and great heat stress (GHS)

Region	SMR				
	GCS	MCS	TN	MHS	GHS
Poland	2.539	2.331	2.209	2.325	2.535

Source: authors' own elaboration

Using the above founding the following statistical models were applied to assess numbers of heat- and cold-related deaths (HRD, CRD),:
- for moderate cold stress (MCS):
CRD = 2.331·(population/100 000)·annual number of MCS days,
- for great cold stress (GCS):
CRD = 2.539·(population/100 000)·annual number of GCS days,
- for moderate heat stress (MHS):
HRD = 2.325·(population/100 000)·annual number of MHS days,
- for great heat stress (GHS):
HRD = 2.535·(population/100 000)·annual number of GHS days.

Stage 2 - projections for changes of CRD and HRD

Projected values for key components of the climate allowed for the calculations of UTCI, as a basis upon which to assess mortality risks posed by heat and cold stress. In general, in the case of Central Europe, climate models predict a slight increase in global solar radiation by up to about 4% by the end of the 21st century. In the summer months (when heat stress is to be anticipated) the differences between SRES scenarios prove to be non-significant.

Simulations show that consecutive decades of the 21st century UTCI values will rise gradually. In the case of UTCI_mean, the mildest B1 scenario predicts an increase of 8.8°C, while the most severe scenario A2 anticipates an increase of 10.6°C. Maximum values for UTCI by the last decade may reach 41.2°C (in scenario B1), and even 43.6°C under scenario A2 (as compared with 39.7°C during the reference period) (Figure 3).

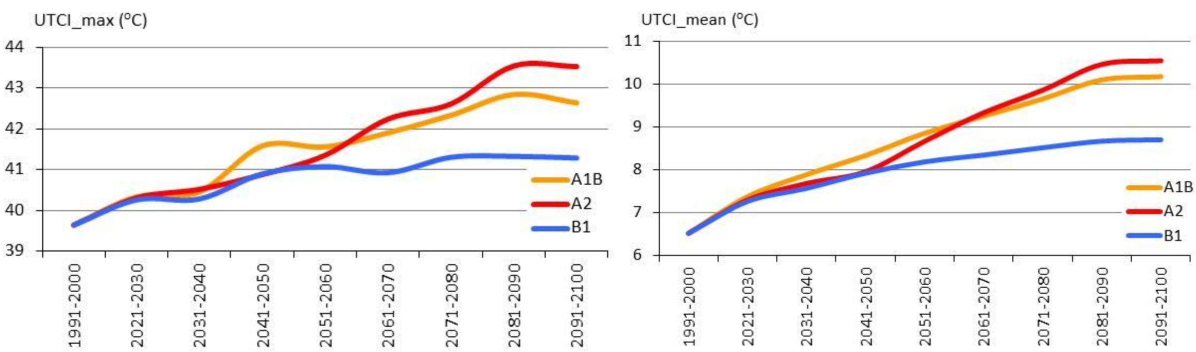

Figure 3. As projected in line with the A1B, A2 and B1 SRES scenarios, maximum (UTCI_max) and annual average (UTCI_mean) values for the UTCI index in consecutive decades of the 21st century and in observed period (1991-2000); spatial average for 43 stations in Poland.
Source: authors' own elaboration

We must also expect a great increase in numbers of days with great heat stress. While in the reference period GHS arose on just 2% of the days in the year, by the last decade of the century this is expected to have risen 6-7 fold. While the A1B and A2 scenarios project that 12-15% of the days in the year will feature GHS, the B2 scenario expects it on only 5% of days. On the other hand the number of days with great cold stress will decrease gradually in the forthcoming decades from about 10% yearly in historical period to 6-8% (depending on SRES scenario) in the end of 21st century (Figure 4).

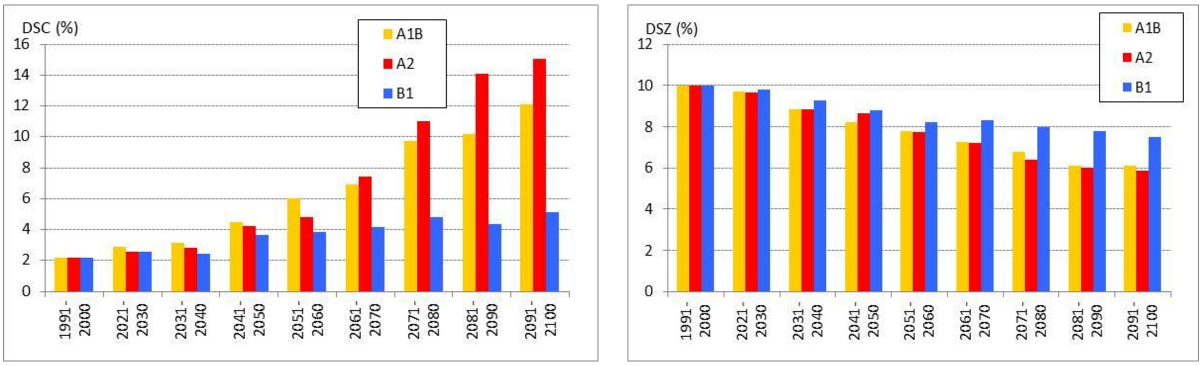

Figure 4. Predicted by various SRES scenarios (A1B, A2, B1) frequency of days with great heat stress (DSC) and great cold stress (DSZ) in consecutive decades of 21st century as well as in the years 1991-2000; spatial average for 43 stations in Poland.
Source: own elaboration

Projections of heat-related deaths (HRDs) and cold related deaths (CRDs) were made using the models presented above. Absolute numbers of HRDs and CRDs were calculated for successive decades of the 21st century. Projected changes for the population of Poland were also used for HRD and CRD modelling. 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 21st century, the predicted climate changes will be associated with an anticipated increase in HRD and decrease in CRD. The most major HRD increase is that projected under scenario A2, from the 28,000 deaths a year observed currently to 75,000 by the end of the 21st century. The A1B scenario forecasts 63,000 and the B1 scenario 35,500 deaths a year (Figure 5). The relative changes for HRD thus range from 137% of the present level under scenario B1 to 277% of the present level with A2.

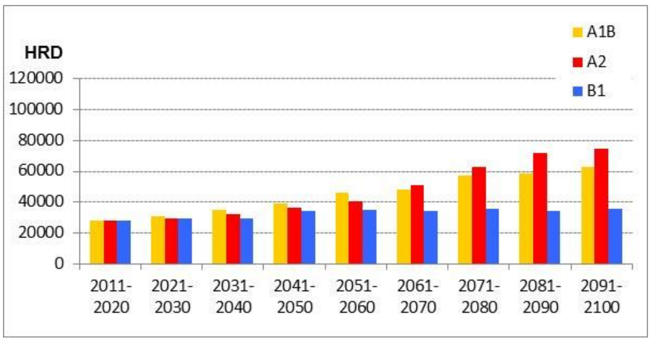

Figure 5. Projections for yearly death tolls associated with heat stress (HRD) in Poland in successive decades of the 21st century, and in relation to the A1B, A2 and B1 SRES scenarios; spatial average for 43 stations in Poland.
Source: authors' own elaboration

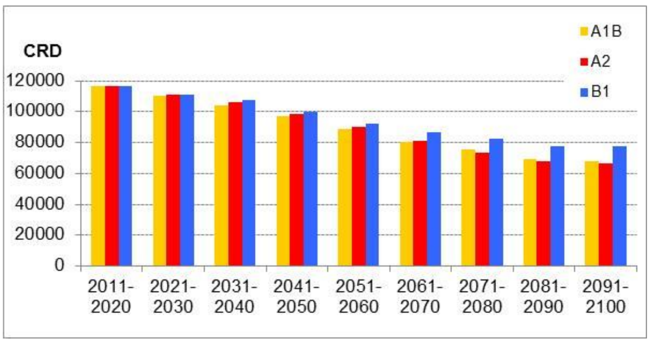

Figure 6. Projections of yearly amount of deaths caused by cold stress in Poland in consecutive decades of 21st century when considering different SRES scenarios (A1B, A2, B1); spatial average for 43 stations in Poland. Source: own elaboration

In case of CRD their number will decrease from about 118 000 in the first decade of 21st century to about 65-80 thousands in the years 2090-2100. While predictions for A1B and A2 scenarios are similar for each other than in B1 scenario decrease in CRD is slightly weaker (Figure 6).

Comparing the total numbers of CRDs and HRDs in consecutive periods of 21st century with deaths values in years 2001-2010 one can see that number of heat-related deaths will increase significantly (independently on the reduction in population). The greatest increase (up to about 270% in years 2081-2100) is predicted by A2 SRES scenario. For B1 scenario is projected smaller HRDs increase (about 136%). The number of cold-related deaths will decrease gradually. However, differences between SRES scenarios are smaller than in case of HRDs (from 59% at A2 to 69% at B1 scenario) (Table 2).

Table 2. Annual numbers of heat and cold-related deaths in particular decades of the 21st century, expressed as a percentage of current levels

Mortality measure	SRES Scenario								
	A1B			A2			B1		
	2021-2040	2051-2070	2081-2100	2021-2040	2051-2070	2081-2100	2021-2040	2051-2070	2081-2100
heat-related deaths	128.8	192.6	235.5	120.9	177.0	272.1	113.6	135.5	135.7
cold-related deaths	101.2	80.4	65.3	95.6	75.5	59.2	96.0	79.2	69.1

Source: authors' own elaboration

Discussion

Pathophysiological changes in the human body reflected exposure to extreme heat and extreme cold can affect the circulatory and respiratory systems. Increase in heat-related morbidity and mortality due to cardio- and cerebrovascular disorders was reported by Ferrari et al. (2015), Urban et al. (2013), Ye et al. (2001) and Ebi et al. (2004). Dawson et al. (2008) noted that a 1°C increase in mean temperature led to a 2.1% increase in ischemic stroke and Koken et al. (2003) estimated that a 1°C increase in maximum temperature resulted in 17.5% increase in acute myocardial infarction.

The majority of research refer relative increase in mortality above or below defined temperature thresholds. For example Baccini et al. (2008, 2011) estimated that a 1°C increase in apparent temperature (AT) in Mediterranean cities above 32.7°C is associated with a 5% increase in daily mortality. In Stockholm AT threshold is 21.7°C.

Błażejczyk and McGregor (2008) noted 6 European cities. In mortality on hot and cold days with specific physiologicaly subjective temperature. However, depending on region the thresholds change on both, cold and heat stress conditions. Similar founding is reported by Kuchcik (2018) for 9 Polish cities represented different climate features.

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” as well as “very cold” and “extremely cold”.

Błażejczyk et al (2013) have found for Warsaw (Poland) that at UTCI higher than 32ºC daily mortality rates increased significantly and at UTCI of about 46-50ºC they were of about 54% more frequent than at “no thermal stress” conditions. Increase in mortality was also observed at UTCI lower than -13°C (strong, very strong cold stress). Similar mortality increase was noted in another Polish cities (Błażejczyk et al. 2015, 2018).

Projections regarding health indicators provided a basis for strategies by which healthcare systems may be adapted to observed climate change (Åstrom et al. 2015; Błażejczyk et al. 2015; Diaz et al. 2015; Muthers et al. 2010a; Pezzoli et al. 2016). In Poland the functioning of the healthcare system (HCS) in changing climate is declared in National Health Programme (Strategiczny 2013). It lists the relevant climatic, economic, financial, organizational, medical and cultural factors which play role in developed adaptation strategy. In the “Strategic plan of adaptation of vulnerable sectors of economy to climate change to the year 2020 with perspective to 2030” (Strategiczny 2013) priority action of HCS is declared as “Reduction of health effects of heat stress and extreme climatic events within vulnerable groups of population”. As the tools of this action there are listed: 1) conducting of epidemiological, clinical and climato-physiological research for better knowledge of climate related diseases, 2) establishing of watch warning system of dengerous climate events including heat waves, 3) establishing a database of climate related diseases occurrence, 4) supporting of scientific research dealing with climate related diseases.

Conclusions

Meteorological factors strongly influence human health which is clearly visible in daily and seasonal mortality rates.

Climate projections for Poland suggest that the 21st century will bring a gradual increase in the intensity and frequency of heat stress. On the other hand significant decrease in cold stress is predicted. Severe changes in climate conditions will lead to a significant increase in risk of death due to heat stress and reduced risk of cold-related deaths.

The healthcare system in Poland must thus make far-reaching adaptations to anticipated climate change. A key part of that effort will seek to minimise health problems caused by heat stress, and can ensure a reduction in the numbers of deaths that would otherwise occur, most especially among the elderly in society.

In spite of general heating of climate in the region where Poland lies we must still expect significant impact of cold stress on human health and mortality.-

Acknowledgments

The work presented here was supported by Grant from the Polish National Centre for Research (NCN) No. 2011/01/B/ST10/06972 "Assessment of climate change impacts on population health in various regions of Poland, and predictions to the year 2100"

References

Alcoforado MJ, Marques D, Garcia RAC, Canario P, Nunes MF, Nogueira H, Cravosa A (2015) Weather and climate versus mortality in Lisbon (Portugal) since the 19th century. Applied Geography. 57:133–141.

Åström C, Ebi KL, Langner J, Forsberg B (2015) Developing a Heatwave Early Warning System for Sweden: Evaluating Sensitivity of Different Epidemiological Modelling Approaches to Forecast Temperatures. nternational Journal of Environmental Research and Public Health 12:254–267.

Baccini M, Biggeri A, Accetta G, Kosatsky T, Katsouyanni K, Analitis A, Anderson H, Bisanti L, Danova J (2008) Heat effect on mortality in 15 European cities. Epidemiology. 19:711–719.

Baccini M, Kosatsky T, Analitis A, Anderson HR, d'Ovidio M, Menne B, Michelozzi P, Biggeri A, Accetta G, de Sario M, d'Ippoliti D, Marino C, Katsouyanni K, Ballester F, Bisanti L, Cadum E, Forsberg B, Forastiere F, Goodman PG, Hojs A, Kirchmayer U, Medina S, Paldy A, Schindler C, Sunyer J, Perucci CA, McGregor G, Kassomenos P, Atkinson R, Medina S, Clancy L, Pekkanen J, Woityniak B, Jolliffe I, Jendritzky G, Blazejczyk K, Huth R, Cegnar T, Iniguez C, Monceau G, Kalkstein LS (2011) Impact of heat on mortality in 15 European cities: attributable deaths under different weather scenarios. Journal of Epidemiology and Community Health. 65(1):64–70

Beaumont van W, Bullard RW (1965) Sweating: Direct influence of skin temperature. Science. 147(3664):1465–1467

Błażejczyk A, Błażejczyk K, Baranowski J, Kuchcik M (2018) Heat stress mortality and desired adaptation responses of healthcare system in Poland. International Journal of Biometeorology. 62, 3: 307-318

Błażejczyk K (2009) The consequences of the changes in global climate for human health. Papers on Global Change. 16:87–110

Błażejczyk K, Baranowski J, Błażejczyk A (2015) Wpływ klimatu na stan zdrowia w Polsce: stan aktualny oraz prognoza do 2100 roku (Climate impacts to population health in Poland; current state and projections to the year 2100) . Wyd. Akademickie SEDNO, Warszawa

Błażejczyk K, Idzikowska D, Błażejczyk A (2013) Forecast changes for heat and cold stress in Warsaw in the 21st century, and their possible influence on mortality risk. Papers on Global Change. 20:47–62

Błażejczyk K, McGregor G (2008) Mortality in European cities and its relations to biothermal conditions, [in:] K Klysik, J Wibig, K Fortuniak (eds), Klimat i bioklimat miast, Wydawnictwo Uniwersytetu Łódzkiego:313–324

Chan NY, Stacey MT, Smith AE, Ebi KL, Wilson TF (2001) An empirical mechanistic framework for heat-related illness. Climate Research. 16:133–143

Dawson J, Weir C, Wright F, Bryden C, Aslanysan S, Lees K (2008) Associations between meteorological variables and acute stroke hospital admissions in the West of Scotland. Acta Neurologica Scandinavica. 117:85–89

Díaz J (2014) Heat Waves' Influence on Health: Some Uncertainties about Their Impact. Journal of Earth Science and Climatic Change 5:3.

Díaz J, Carmona R, Mirón IJ, Ortiz C, León I, Linares C (2015) Geographical variation in relative risks associated with heat: Update of Spain's Heat Wave Prevention Plan. Environment International. 85:273–283.

Diaz J, Linares C, Tobias A (2006) Impact of extreme temperatures on daily mortality in Madrid (Spain) among the 45-64 age-group. International Journal of Biometeorology. 50:342–348

Ebi K, Exuzides K, Lau E, Kelsh M, Barnston A (2004) Weather changes associated with hospitalization for cardiovascular diseases and stroke in California, 1983-1998. International Journal of Biometeorology. 49:48–58

Elizondo RS, Bullard RW (1971) Local determination of sweating and the assessment of the "Set point". International Journal of Biometeorology. 15(2-4):273–280

Ferrari J, Shiue I, Seyfang L, Matzarakis A, Lang1 W, the Austrian Stroke Registry Collaborators (2015) Weather as physiologically equivalent was not associated with ischemic stroke onsets in Vienna, 2004-2010. Environmental Science and Pollution Research. DOI 10.1007/s11356-015-4494-7

Flynn A, McGreevy C, Mulkerrin E (2005) Why do older patients die in a heatwave? Q J Med. 98:227–229.

Fouillet A, Rey G, Laurent F, Pavillon G, Bellec S, Guihenneuc-Jouyaux C, Clavel J, Jougla E, Hémon D (2006) Excess mortality related to the August 2003 heat wave in France. International Archives of Occupational and Environmental Health. 80:16–24

Gasparrini A, Guo Y, Hashizume M, Lavigne E, Zanobetti A, Schwartz J, Tobias A, Tong S, Rocklöv J, Forsberg B, Leone M, de Sario M, Bell ML, Guo Y-LL, Wu C-fu, Kan H, Yi S-M, de Sousa Zanotti Stagliorio Coelho M, Saldiva PHN, Honda Y, Kim H, Armstrong B (2015) Mortality risk attributable to high and low ambient temperature: a multicountry observational study. www.thelancet.com Published online May 21, 2015; http://dx.doi.org/10.1016/S0140-6736 (14) 62114-0

Givoni B, Goldman RF (1973) Predicting effects of heat acclimatization on heart rate and rectal temperature. Journal of Applied Physiology. 35(6):875–879

Gosling SN, McGregor GR, Lowe JA (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. International Journal of Biometeorology. 53: 31-51

Green JS, Kalkstein LS, Kim KR, Choi Y-J, Lee D-G (2016) The application of the European heat wave of 2003 to Korean cities to analyze impacts on heat-related mortality. International Journal of Biometeorology. 60:231–243

Kalkstein LS (1998) Climate and human mortality: relationships and mitigating measures. Advances in Bioclimatology. 5:161–177

Kenney WL (1985) A review of comparative responses of men and women to heat stress. Environmental Research. 37(1):1–11

Koken P, Piver W, Ye F, Elixhauser A, Olsen L, Portier C (2003) Temperature, air pollution, and hospitalization for cardiovascular diseases among elderly people in Denver. Environmental Health Perspectives. 111:1312–1317

Koppe C, Kovats S, Jendritzky G, Menne B (2004) Heat-waves: risks and responses. Health and Global Environmental Change Series, No. 2, WHO Europe, Copenhagen, Denmark

Kovats R, Hajat S, Wilkinson P (2004) Contrasting pattern of mortality and hospital admissions during hot weather and heat waves in Greater London, UK. Occupational and Environmental Medicine. 61:893–898

Kozłowska-Szczęsna T, Krawczyk B, Kuchcik M (2004) Wpływ środowiska atmosferycznego na zdrowie i samopoczucie człowieka (Influence of the atmosphere on human health and wellbeing). IGiPZ PAN, Monografie 4, Warszawa

Kuchcik M (2017) Zmiany warunków termicznych w Polsce na przełomie XX i XXI wieku i ich wpływ na umieralność (Changes of thermal conditions in Poland at the turn of 20th and 21st century in Poland and their impact on mortality), Prace Geograficzne IGiPZ PAN, 263, Warszawa

Kuchcik M, Degórski M (2009) Heat- and cold-related mortality in the north-east of Poland as an example of the socio-economic effects of extreme hydrometeorological events in the Polish Lowland. Geographia Polonica. 82(1):69–78

Laschewski G, Jendritzky G (2002) Effects of the thermal environment on human health: an investigation of 30 years of daily mortality data from SW Germany. Climate Research. 21: 91–103.

Meehl GA, Stocker TF, Collins WD, Friedlingstein P, Gaye AT, Gregory JM, Kitoh A, Knutti R, Murphy JM, Noda A, Raper SCB, Watterson IG, Weaver AJ, Zhao Z-C (2007) Global climate projections. [in:] Climate Change 2007: The physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S.,D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

Muthers S, Matzarakis A, Koch E (2010) Climate Change and Mortality in Vienna - A Human-Biometeorological Analysis Based on Regional Climate Modeling. International Journal of Environmental Research and Public Health. 7:2965–2977

Nakicenovic N, Alcamo J, Davis G, de Vries B, Fenhann J, Gaffin S, Gregory K, Griibler A, Jung TY, Kram T, La Rovere EL, Michaelis L, Mori S, Morita T, Pepper W, Pitcher H, Price L, Riahi K, Roehrl A, Rogner H-H, Sankovski A, Schlesinger

M, Shukla P, Smith S, Swart R, van Rooijen S, Victor N, DadiTodea DA (2000) Special report on emissions scenarios. A Special Report of Working Group III of the Intergovernmental Panel on Climate Change, Cambridge University Press

Nastos PT, Matzarakis A (2012) The effect of air temperature and human thermal indices on mortality in Athens, Greece. Theoretical and Applied Climatology. 108:591-599.

Naughton M, Henderson A, Mirabelli M, Kaiser R, Wilhelm J, Kieszak S, Rubin C, McGeehin M (2002) Heat-related mortality during 1999 heat wave in Chicago. American Journal of Preventive Medicine. 22:221–227

Pappenberger F, Jendritzky G, Staiger H, Dutra E, di Giuseppe F, Richardson DS, Cloke HL (2014) Global forecasting of thermal health hazards: the skill of probabilistic predictions of the Universal Thermal Climate Index (UTCI). International Journal of Biometeorology. DOI 10.1007/s00484-014-0843-3

Pezzoli A, Santos Dávila JL, d'Elia E (2016) Climate and Human Health: Relations, Projections, and Future Implementations. Climate. 4, 18; doi:10.3390/cli4020018

Rocklöv J, Forsberg B, Ebi K, Bellander T (2014) Susceptibility to mortality related to temperature and heat and cold wave duration in the population of Stockholm County, Sweden. Global Health Action. 7: 22737; http://dx.doi.org/10.3402/gha.v7.22737

Saldiva P, Pope C, Schwartz J, Dockery D, Lichtenfels A, Salge J, Barone I, Bohm G (1995) Air pollution and mortality in elderly people: a time-series study in Sao Paulo, Brazil. Archives of Environmental Health. 50:159–63

Strategiczny plan adaptacji dla sektorów i obszarów wrażliwych na zmiany klimatu do roku 2020 z perspektywą do roku 2030 (2013) Ministerstwo Środowiska, [Strategic plan of adaptation of vulnerable sectors of economy to climate change to the year 2020 with perspective to 2030. Ministry of Environment], Warszawa; https://www.mos.gov.pl/fileadmin/user_upload/SPA_2020.pdf

Tan J, Zheng Y, Song G, Kalkstein LS, Kalkstein AJ, Tang X (2007) Heat wave impacts on mortality in Shanghai, 1998 and 2003. International Journal of Biometeorology. 51:193-200

Tobías A, Armstrong B, Gasparrini A, Diaz J (2014) Effects of high summer temperatures on mortality in 50 Spanish cities. Environmental Health 13:48; http://www.ehjournal.net/content/13/1/48.

Tong S, Ren C, Becker N (2010) Excess deaths during the 2004 heat wave in Brisbane, Australia. International Journal of Biometeorology. 54:393–400

Urban A, Davídkovová H, Kyselý J (2013) Heat- and cold-stress effects on cardiovascular mortality and morbidity among urban and rural populations in the Czech Republic. International Journal of Biometeorology DOI 10.1007/s00484-013-0693-4

Urban A, Kyselý J (2014) Comparison of UTCI with Other Thermal Indices in the Assessment of Heat and Cold Effects on Cardiovascular Mortality in the Czech Republic. International Journal of Environmental Research and Public Health. 11: 952–967.

Vandentorren S, Bretin P, Zeghnoun A, Mandereau-Bruno L, Croisier A, Cochet C, Riberon J, Siberan I, Declercq B, Ledrans M (2006) August 2003 heat wave in France: risk factors for death of elderly people living at home. European Journal of Public Health. 16:583–591

White-Newsome JL, Ekwurzel B, Baer-Schultz M, Ebi KL, O'Neill MS, Anderson GB (2014) Survey of County-Level Heat Preparedness and Response to the 2011 Summer Heat in 30 U.S. States. Environm Health Perspectives. 122, 6, June 2014, http://dx.doi.org/10.1289/ehp.1306693

Yaron M, Niermeyer S (2004) Clinical description of heat illness in children, Melbourne, Australia-a commentary. Wilderness & Environmental Medicine. 15:291–292

Ye X, Wolff R, Yu W, Vaneckova P, Pan X, Tong S (2011) Ambient temperature and morbidity: a review of epidemiological evidence. Environmental Health Perspective Online 8 August 2011:pp.42

Zaninović K, Matzarakis A (2013) Impact of heat waves on mortality in Croatia. International Journal of Biometeorology. DOI 10.1007/s00484-013-0706-3