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The effect of global warming on mortality

ABSTRACT

There is a significant relationship between ambient temperature and mortality. In healthy individuals with no underlying co-morbid conditions, there is an efficient heat regulation system which enables the body to effectively handle thermal stress. However, in vulnerable groups, especially in elderly over the age of 65 years, infants and individuals with co-morbid cardiovascular and/or respiratory conditions, there is a deficiency in thermoregulation. When temperatures exceed a certain limit, being cold winter spells or heat waves, there is an increase in the number of deaths. In particular, it has been shown that at temperatures above 27 °C, the daily mortality rate increases more rapidly per degree rise compared to when it drops below 27 °C.

This is especially of relevance with the current emergency of global warming. Besides the direct effect of temperature rises on human health, global warming will have a negative impact on primary producers and livestock, leading to malnutrition, which will in turn lead to a myriad of health related issues. This is further exacerbated by environmental pollution.

Public health measures that countries should follow should include not only health-related information strategies aiming to reduce the exposure to heat for vulnerable individuals and the community, but improved urban planning and reduction in energy consumption, among many others. This will reduce the carbon footprint and help avert global warming, thus reducing mortality.

1. Introduction

Naked skin, sweat glands and bipedalism have offered an evolutionary survival mechanism in humans to be able to especially regulate high temperatures [1]. Ambient temperature is related to mortality, especially in susceptible individuals, who lack an efficient thermoregulatory system to cope with thermal stress [2]. Heat and cold-related deaths are often mis-classified and rarely coded as being deaths directly caused due to cold or hot temperatures [3]. These are instead attributed to the underlying pre-existing conditions such as cardiovascular, respiratory and other causes, which in themselves do contribute to increased susceptibility and vulnerability to extremes in temperature [4].

One of the main challenges in associating mortality to climate change is first of all by having standard definitions of what is a heat wave and what is a cold spell [5,6]. The vulnerability curve, that is how much the mortality rate change with the heat intensity is still unknown. It is also important to understand that, not only does climate change have a direct impact on our health, but it also has a multitude of indirect impacts which effect our environment. This leads to a negative impact on primary producers and livestock, leading to malnutrition, which will in turn lead to a myriad of health related issues [7]. Global warming, which is exacerbated with environmental pollution, has also been associated with an increase in adverse health effects, including vector-borne, waterborne and foodborne diseases, respiratory and allergic disorders, mental health problems and collective violence [8,9].

2. Definition of heatwaves

One of the main factors which contribute to disparity when recoding data related to climate change and mortality is the consensus on the definition which surround 'heat waves' and 'cold spells'. Heat wave is a prolonged period of excessive heat and is an extreme weather event associated with climate change. The definitions of heat wave vary by location with different geography, climate and acclimatization of the local people. Therefore, when conducting epidemiological studies, a local definition of heat wave is needed whenever studies are carried out, in order to better characterize the quantitative association between mortality risk and heatwaves. Based on the different definitions in temperature metric, intensity, threshold, and duration different heat wave definitions can be drawn out. Such studies can better pinpoint the significant association with heat waves daily mortality in different countries [10]. The resultant vulnerability curves can help improve the heat-health warning systems and avoid tragic consequences such as the 2003 European heat wave which resulted in more than 70,000 deaths [11] and the 2010 Russian heat wave where over 11,000 people died [12]. Of course, exacerbating factors also caused by the excessive heat, like bush fires and the resultant smoke, together with the lack of agricultural crops, will further contribute to mortality [13]. Of note, humidity further contributes to heat tolerance. A wet-bulb temperature (TW) of 35 °C marks the upper physiological limit that humans can tolerate, and much lower values have serious health consequences. Comprehensive evaluation of data from weather stations shows that, over the last forty years, the frequency of extreme humid heat has more than doubled, and that some coastal subtropical locations have already reported a TW of 35 °C [14].

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3. The impact of heat waves on mortality rates

Heatwaves have a negative impact on mortality in high, middle and low-income countries [15,16]. An international study across 400 communities in 18 countries indicates that high temperatures create a substantial health burden. People living in moderate hot and moderate cold areas may more sensitive to heat waves than those living in hot and cold areas [17]. Interestingly, the effects of high temperatures over consecutive days are similar to what is experienced if high temperature days occur independently. However, another study conducted in 19 French cities shows that, while the population is better adapted to warm temperatures, this is applicable only to a certain intensity (above percentile 99) when heat becomes an acute health emergency due to the rapid increase in mortality risk at very high temperatures percentiles [18]. This is also evident in other regions such as Northwest India, where there is a significant rise in health risks associated with heat waves in communities with high baseline temperatures [19].

Different physiological mechanisms are triggered by heat exposure (inflammatory response, ischemia, disseminated intravascular coagulation, heat cytotoxicity and rhabdomyolysis). These mechanisms can critically impact the brain, heart, lungs, kidneys, intestines, liver, pancreas and other vital organs. There is evidence that heat can trigger at least twenty-seven different pathways by which these physiological mechanisms triggered can lead to organ failure and possibly death [20].

4. Definition of cold spells

Cold spells (or cold waves) have been described as an excessive long periods of extreme cold or sudden temperature drop. Official meteorological definitions of a cold spell include "at least 8 °C temperature decrease in 24 h or at least 10 °C temperature decrease in 48 h or at least 12 °C temperature decrease in 72 h with daily minimum temperature below 4 °C" [21] or even more generally, "a rapid fall in temperature within 24 hours to temperatures requiring substantially increased protection to agriculture, industry, commerce, and social activities" [22]. However, while the former definition is based on the absolute threshold and may not be easily applied at national and international level due to temperature variation and diverse climates and spatial difference, the latter definition is very vague when it comes to assess the impact on mortality. For Kysely et al., a cold spell was defined a period of days with temperature of no more than −3.5 °C [23], while Lee et al. defined it as a period where daily mean temperature was below 5th percentile, 3rd percentile, and 1st percentile for two or more consecutive days [24]. Earlier research generally focused on the duration and severity of cold days, with varying definitions. A recent study carried out in China in order to find the optimum model to predict the health impact of the whole nation, concluded that the best definition of a cold spell is when there are at least two consecutive days with daily mean temperature below the 5th percentile [25]. A particular challenge when studying the effect of the health impacts of extremely cold weather is that places with adverse weather conditions such as the Arctic towns in the circumpolar region have very small population sizes, making it difficult to carry out proper statistical analysis [26].

5. The impact of cold spells on mortality rates

Compared with heat waves, there has been overall less research carried out to investigate the harmful health effects of cold spells [27], especially in developing countries where the population is more vulnerable. Cold spells represent a significant public health burden, mostly caused by moderate temperatures (between percentiles 2.5 and 25). In France, a study carried out between 2000 and 2010 showed that 3.9% [CI 95% 3.2:4.6] of the total mortality was attributed to cold, as compared to 1.2% [1.1:1.2] due to heat [18]. This corresponded to another bigger multicountry observational study, where 74,225,200 deaths were analysed in various periods between 1985 and 2012 in 384 locations in Australia, Brazil, Canada, China, Italy, Japan, South Korea, Spain, Sweden, Taiwan, Thailand, UK, and USA. Even in this study, more temperature-attributable deaths were caused by cold (7·29%, 7·02–7·49) than by heat (0·42%, 0·39–0·44) [28]. A time-series analysis carried out in 272 locations in China, concluded that, the mortality risk of extreme cold temperature (at −1.4 °C, the 2.5th centile) lasted for more than two weeks, in contrast to the risk of extreme hot temperature (at 29.0 °C, the 97.5th centile) which appeared immediately and lasted only for a maximum of three days [29]. The cold-induced cardiovascular morbidity increases in young and middle-age people (RR = 1.009, 95% CI: 1.004–1.015) and also in the elderly (RR = 1.013, 95% CI: 1.007–1.018) [30].

6. Demographics

Infants, children, pregnant women, older people, chronically ill, outdoor workers, socio-economically disadvantaged and urban dwellers are the most heat vulnerable; with the food systems and the health sector facing the highest heat-health challenges [31].

6.1. *The effect of age*

Age is an important variable when investigating the effect of climate change and mortality. Children have been higher core temperature responses and lower sweat rates, leading to lower thermoregulatory capabilities when compared to adults. The increasingly common childhood diseases and comorbidities, such as obesity, respiratory disorders and the onset of preventable 'adult' diseases, can adversely affect the long-term health effects of future generations due to the rapidly changing climate [32]. Similarly, undernutrition as a consequence of drought or other factors has serious short and long term consequences on infants and children [33].

A multi-city study in Korea showed that there is a significantly positive association between infant mortality from total deaths or sudden infant death syndrome (SIDS) and ambient temperature, with an overall hazard ratio of infant mortality for a 1 °C increase during 1 month before death being 1.52 (95% CI, 1.46–1.57) for total deaths and 1.50 (95% CI, 1.35–1.66) for SIDS [34]. Similar findings were noted in Montreal, Canada where high ambient temperature was associated with SIDS, especially at 3 to 12 months of age [35].

Direct and indirect effects of climate change place children at risk of mental health consequences including depression, anxiety, phobias, sleep disorders and substance abuse, which in turn can lead to adverse adult mental health outcomes and eventually contribute to an increase in mortality [36].

The elderly are a high-risk population for mortality related to extremes of temperature, being vulnerable to both cold spells [25] and heatwaves [37]. The sudomotor function is attenuated by aging due to nerve demyelination and the decreased peripheral sensitivity to acetylcholine [38]. Particular risk factors for heat-related deaths include cardiovascular, pulmonary, mental and other chronic illnesses; lower fitness levels polypharmacy; as well as having a lack of mobility; living on the top floor; lack of air conditioning; living alone; being unable to care for oneself; and reluctance to change behaviour during a heat wave [39,40]. These health-related, socio-economic and behavioural risk factors which are more prevalent among the elderly, increase the risk of dying during extremes of temperature. A study carried out in Malta, which is a small island nation in the middle of the Mediterranean Sea, with a temperate climate, 27 °C was identified as the optimum average temperature during which mortality rate was at its lowest. During the period 1992–2005 in summer, the average mean apparent temperature was 29.93 °C with an average mortality rate of 0.57/10,000 in persons under 65 years versus 12.46/100,000 in persons over the age of 65. In contrast, in winter, the average mean apparent temperature was 11.57 °C with an average mortality rate of 0.64/10,000 in persons under 65 years versus 18.07/100,000 in persons over the age of 65. In particular, it has been shown that at temperatures above 27 °C, the daily mortality rate increases more rapidly per degree rise compared to when it drops below 27 °C [3]. So even in a temperate climate like in the Mediterranean, it is recommended that health advice is issued both during heat waves and cold spells. This is comparable to other European cities where high ambient summer temperatures influence daily mortality, particularly effecting the elderly [41,42]. Elderly women are at higher risk of dying than men according to gender-stratified data on mortality after heat waves [43]. This may be related to biological factors, as women show less sudomotor activity than men, and also behavioural factors [38]. There are also ethnic variations in the function of the sudomotor system, with residents of tropical areas sweating less and more slowly than those residing in temperate areas. Short-term heat acclimation enhances the sweating response, and conversely, seasonal change or migration leading to long-term heat acclimation, diminishes the sweating response [38].

6.2. The link with co-morbid conditions

Co-morbid conditions exacerbate the risk of heat-related mortality. Higher cardiovascular mortality has been associated with low and high temperatures in many countries, including Brazil [44], United States [45], United Kingdom and China [37]. Exposure to cold, heat and especially heatwaves are associated with an increased risk of myocardial infarction [46].

6.3. The effect of the location

Interactions between health, mortality and climate are very specific to individual location and latitude. There is a variation between populations in the optimum or threshold temperature, and may be a function of the adaptation to local climate. Generally, it has been shown that the warmer the climate, heat related mortality is detected at higher threshold temperatures [17]. Similarly, residents in subtropical climates such as southern China are more vulnerable to cold spells [25]. In cold climates effecting towns located in the North Polar area, heatwaves are detrimental to health to the same extent as cold spells, and in both scenarios, the adverse health effects of temperature extremes are delayed rather than immediate with time lags between the temperature wave and observed increase in mortality varying between 8 and 14 days [26].

Urban environments are considered more at risk of increased temperate-related mortality. There is an increased mortality impact associated with higher population density, fine particles, gross domestic product (GDP) and income inequality (measured by the Gini index) [47]. However, temperature variability has also been shown to have a negative impact even in rural areas. A case in point is a study carried out in China, where rural areas generally suffer greater mortality related to temperature variability than urban areas in the warm season [48].

7. Environmental pollution, global warming and mortality

In a time-series analysis involving more than 600 cities in 24 countries mostly in the northern hemisphere, there is a strong association between daily mortality (all-cause mortality, cardiovascular and respiratory) in locations with lower annual mean concentrations of particulate matter and higher annual mean temperatures [49]. This correlates well to previous studies assessing cumulative effects of the multiple environmental factors influencing mortality [50]. The synergic effect between high temperature and air pollution on mortality has also been shown in other regions such as in Northeast Asia [51].

The increased release of carbon dioxide, methane, and nitrous oxide in the Earth's atmosphere as resulted in increased average temperature due to the greenhouse effect. This has lead to an increase in morbidity and mortality due to a cascade of adverse events [52]. Of note is the increased rate of soil degradation, loss of productivity of agricultural land and desertification, with the consequent loss of biodiversity and degradation of ecosystems. The reduced fresh-water resources are leading to acidification of the oceans. The disruption and depletion of stratospheric ozone is associated with increased mortality [53]. Human susceptibility to fatal diseases might be further aggravated due to alterations in the human immune system caused by increased exposure to ultraviolet radiation and malnutrition. This is because the overall environmental pollution is leading to a rise in non-communicable and communicable disease. These include injuries and deaths during natural disasters, malnutrition during famine, apart from the increased mortality during climate changes due to complications in chronically ill patients. The accumulation of toxic substances in the food chain can lead to the creation of habitats suitable to the transmission of human and animal pathogens. Climate change is influencing the quantity and quality of food that is produced, as well as its equitable distribution [54]. Low to middle-income countries are particularly vulnerable to a changing climate [55,56].

Climate change is leading to a change in distribution of infectious diseases. Floods lead to more insect breeding sites, drive rodents from burrows, and contaminate clean water systems. These lead to increased cases of leptospirosis, campylobacter infections, and cryptosporidiosis [57,58]. Water-borne pathogens and pathogens transmitted by vectors are particularly sensitive to climate change because they spend a good part of their life cycle in a cold-blooded host invertebrate whose temperature is similar to the environment [52]. A warmer climate presents more favorable conditions for the survival and the completion of the life cycle of the vector, going as far as to speed it up as in the case of mosquitoes. Diseases transmitted by mosquitoes include some of the most widespread worldwide illnesses such as malaria and viral diseases. The ranges of several vector-borne diseases or their vectors are already changing in altitude due to warming [59]. The same applies for tick-borne diseases such as tick-borne encephalitis, which have increased in the past years in cold regions [52]. Climate-related increases in sea temperature lead to higher incidence of cholera, seafood intoxication and other waterborne infectious and toxin-related illnesses. Meteorological factors might also possibly have a role in the COVID-19 transmission after controlling for population migration, but further studies will need to be carried out to investigate this [60].

8. The way forward

It is about time to move from a state of global inaction to a transformation in public health in order to decrease the mortality related to climate change [61]. Countries have started to include climate change as a key consideration in their national public health policies. For example, developed countries are designing urban areas to include more vegetation in a move to reduce heat-related mortality [62]. This is because heat waves are associated with the "urban heat island (UHI) effect" that can increase the ambient temperature in urban regions, exacerbated by higher population density and more pollution, thus posing a serious threat on the health of residents, with an increased risk of mortality [10,63].

However, further efforts are needed to develop evidence-based responses and gather the necessary support from partner ministries. Cooperation needs to be strengthened between the services of human, animal and plant health [59]. Funding needs to be accessed for activities related to health and climate change. Not only do action plans need to be drawn up in the event of extreme weather conditions, in order to be better prepared and to react in the best way, but also to obtain more reliable information on how to avoid the risks of climate change while maintaining international cooperation. Population health is typically listed as one of the national priorities for each individual country, but there is a lack of clarity on implementation processes. While there is evidence of progress at both national and international levels, efforts are needed to increase the capacity of health systems to manage the health risks of climate change, particularly in low- to middle-income countries

[55]. The resilience of health systems needs to be enhanced in order to ensure a sustainable path in improving population and global health [64].

Declaration of competing interest

The authors declare that they have no conflict of interest.

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