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REVIEW

Public health impact of global heating due to climate change: potential effects on chronic non-communicable diseases

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Abstract

Objectives Several categories of ill health important at the global level are likely to be affected by climate change. To date the focus of this association has been on communicable diseases and injuries. This paper briefly analyzes potential impacts of global climate change on chronic non-communicable diseases (NCDs).

Method We reviewed the limited available evidence of the relationships between climate exposure and chronic and NCDs. We further reviewed likely mechanisms and pathways for climatic influences on chronic disease occurrence and impacts on pre-existing chronic diseases.

Results There are negative impacts of climatic factors and climate change on some physiological functions and on cardio-vascular and kidney diseases. Chronic disease risks are likely to increase with climate change and related increase in air pollution, malnutrition, and extreme weather events.

Conclusions There are substantial research gaps in this arena. The health sector has a major role in facilitating further research and monitoring the health impacts of global climate change. Such work will also contribute to global efforts for the prevention and control of chronic NCDs in our ageing and urbanizing global population.

Keywords Climate change · Chronic diseases · Non-communicable diseases · Cardiovascular disease · Kidney disease · Causal pathways

Global and local climate change

Global climate change presents a threat to the biological and ecological systems integral to the life and health of humans and other species on this planet according to the Inter-Governmental Panel on Climate Change (IPCC 2007). All regions of the planet are expected to become warmer in the future. The average global temperature is expected to increase between 1.8 and 4.0°C by the year 2100. In many densely populated tropical regions, where maximum temperatures already exceed 40°C, temperatures may increase by as much as 1–3°C by 2020 and between 3 and 5°C by 2080 (IPCC 2007).

Additional heat exposure will occur in many urban areas due to the "heat island effect", adding 4–5°C (Oke 1973) and increasing the risk of heat stroke in cities. Extreme weather events are expected to increase in frequency (IPCC 2007). In low and middle income countries with long coastlines, millions of people will be affected by flooding, leading to displacement and poverty among "environmental refugees". Others will suffer from loss of drinking water as glaciers disappear or lack of food due to damaged agricultural systems (IPCC 2007).

Since its first brief assessment of climate change and health in 1989 the World Health Organization (WHO) has published several substantial reviews highlighting growing concern at the international level, including a recent call for intensified research efforts (WHO 2009). In 2008, a World Health Assembly (WHA) resolution on Climate Change and Health was adopted (WHA61.19). The consensus is

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that large populations will be affected by extreme weather situations, heat stress, water and food scarcity, and an increase in communicable and vector-borne diseases, non-communicable diseases (NCDs), and mental stress (IPCC 2007; McMichael et al. 2003; Patz et al. 2007; WHO 2009). Table 1 identifies potential exposure routes and the resulting health impacts. Many of these effects are dependent on the degree of local climate change and where exposed humans spend their time, while others are associated with climate change in a wider geographic area (e.g. increase of vector-borne diseases).

It has taken 20 years to get global environmental and climate change and its health impacts onto the international agenda. Even so, in a recent assessment of the progress in five major areas of global public health over the past decade (Beaglehole and Bonita 2008), it is clear that there is still much to be achieved in the area of climate and health (Costello et al. 2009).

While the threat of climate change is a health issue and needs to be framed as such by the public health movement (Costello et al. 2009), the impact of climate change on chronic NCDs has received little attention. From a global perspective, such diseases have historically been considered a problem of high-income countries, while lower income countries focused on the major problems of communicable diseases and malnutrition. However, NCDs are now the major causes of death (WHO 2005) in all regions of the world except for sub-Saharan Africa. Recent WHA resolutions on NCDs (e.g. WHA53.17 in 2000 and WHA61.14 in 2008) are aimed at strengthening control and management of the chronic NCD epidemic.

This brief review aims at highlighting the potential impacts of climate change on this group of diseases in order to encourage more field research and health impact assessment on this topic. The review focuses on published information of direct relevance to any climate change impacts on population health and is therefore selective.

Definitions of chronic conditions and extent of the problem

NCDs are often "chronic" but also include some acute conditions (including those that occur repeatedly and frequently as a result of exposures to climate conditions) and acute exacerbations or complications of chronic conditions. A universally accepted definition of "chronic diseases" is not available. Furthermore, there is also a distinction between chronic diseases and chronic conditions, the latter being defined by WHO as "health problems that require ongoing management over a period of years or decades" (WHO 2005). This definition incorporates chronic communicable diseases, such as HIV/AIDS, as well as the long-term disabling effects of injuries and acute diseases from which recovery is incomplete. Here our focus is on NCDs to separate our analysis from that focusing on communicable diseases associated with climate change.

The most common NCDs (heart disease, stroke, cancer, type 2 diabetes and respiratory diseases) account for 60% of the 58 million global annual deaths and 46% of the global burden of disease in disability-adjusted life years (DALYs) (WHO 2005). These diseases increasingly affect people from low income as well as high income countries. This broad range of diseases is mainly attributable to a few, largely preventable, risk factors: tobacco use, diets high in fat, salt and sugar leading to raised blood pressure and

Table 1 Likely ill health effects of climate change factors ordered by exposure route and type of ill health issue

Ill health, disease or injury issue related to climate change	Exposure route	Ill health issue type (N, C or I)
Heat exhaustion at work or in daily life	Direct: heat	N
Accidents related to heat exhaustion	Direct: heat	I
Clinical effects of heat on persons with chronic diseases	Direct: heat	N
Heat stroke illness and death	Direct: heat	N
Injuries and drowning due to extreme weather	Direct: extreme weather	I
Epidemics and drowning due to flooding of coastal areas (sea level rise)	Direct: extreme weather and sea level rise	N, C, I
Heart and lung effects due to air pollution	Indirect: air pollution	N
Diarrheal diseases	Indirect: water and food pollution	C
Malnutrition	Indirect: lack of food	N, C
Suicides among farmers	Indirect: lack of income and food	I
Vector-borne diseases, e.g. malaria, dengue	Indirect: ecologic change for vectors	C
Mental health effects among environmental refugees	Indirect: lack of basic necessities and social support	N

N non-communicable, chronic disease or mental health issue, *C* communicable or infectious disease issue, *I* injury issue obesity, and low physical activity levels (WHO 2005). These risk factors are in turn a result of industrialization, urbanization, economic development and increasing food market globalization (WHO 2005). Urban air pollution (WHO 2006), occupational stress and other hazardous exposures (Rosenstock et al. 2005), including increasing heat stress due to climate change, are important additional risk factors for NCDs.

Increased heat exposure is an obvious and important pathway for climate change effects on health. IPCC expects all parts of the planet to experience more heat exposure in the future (IPCC 2007), while the local extent of heating will vary. Increased heat and climate variability will also influence other exposure routes (Fig. 1), which are moderated by socio-economic status and other variables. The following sections will analyze the mechanisms behind the different effect pathways.

Impact of direct heat exposure on chronic diseases

Cardiovascular health and mortality

Under climate change projections the frequency of excessive heat exposures and acute heat stroke effects will increase (IPCC 2007). One could argue that these effects become "chronic" when the exposure is repeated frequently. Several studies have reported increased mortality during heat waves, including in large cities in developing countries (Hajat et al. 2005). Heat mortality appears primarily due to effects on the cardiovascular and respiratory systems, "over-loading" these systems with the physiological reactions to heat exposure (Parsons 2003). These reactions include increased core body temperature, increased heart rate, shift of blood flow from central organs to skin, increased sweating, and associated dehydration if sufficient replacement liquid is not taken in (Parsons 2003). Studies have indicated an increased risk of cardiac thrombosis related to dehydration at high temperatures in Finland (Nayha 2005) and another study in Belgium (Nawrot et al. 2005) identifies endothelial dysfunction as a potential mechanism for the cardiovascular effects.

The heat wave in Europe in 2003 is an example of what might become more common due to climate change (Poumadere et al. 2005). In Paris, mortality more than doubled during the heat wave (up to six times higher than normal on the worst day). Across Europe it accounted for maybe as many as 70,000 additional deaths, especially from respiratory and cardiovascular causes (Hoffman et al. 2008; Robine et al. 2008). In addition to increased mortality,

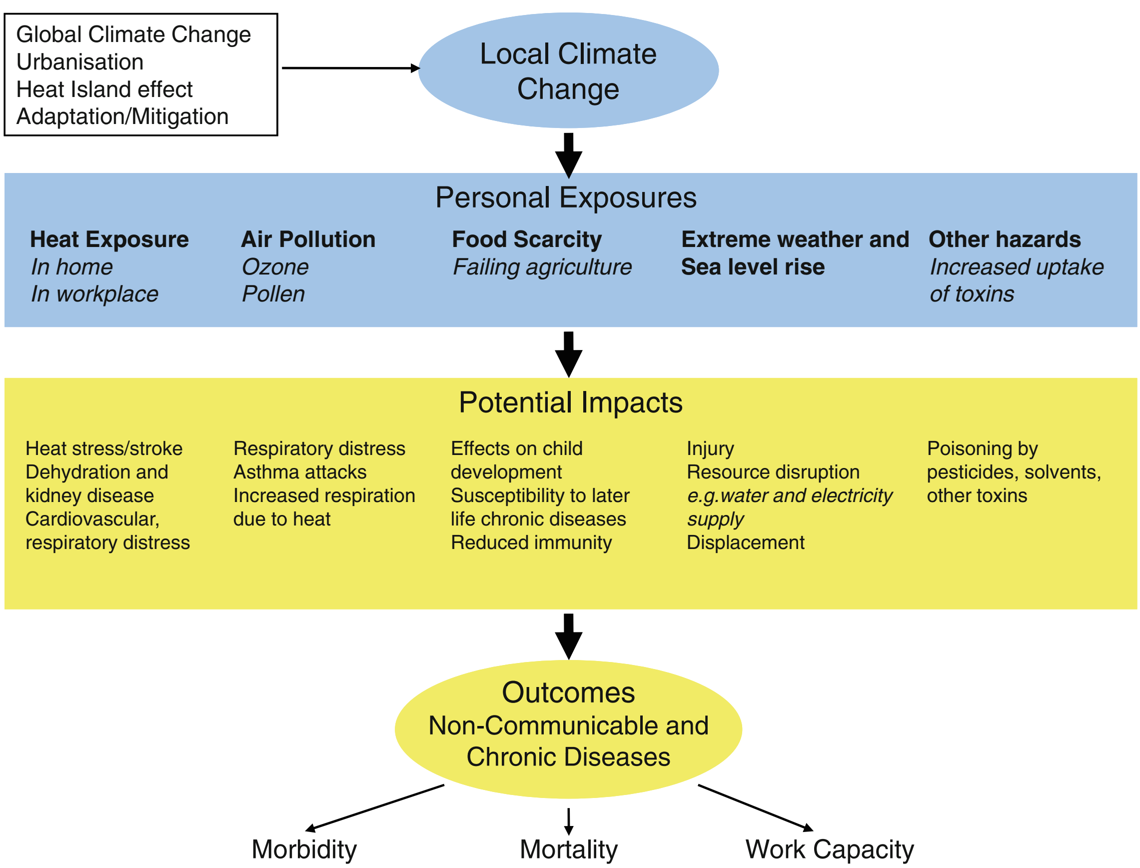

Fig. 1 Pathways for climate related exposures and potential non-communicable and chronic disease effects

emergency admissions to hospital and attendance at health services also increased during heat waves (Bi et al. 2008; Nitschke et al. 2007). A heat wave in California in 2006 resulted in large increases in hospital admissions from cardiovascular and other illnesses (Knowlton et al. 2008). A study undertaken in the Gulf States modeling likely future scenarios predicted a significant increase in mortality rates due to respiratory and cardiovascular diseases linked to heat stress, as well as vector-borne diseases by 2070 (Hussein and Chaudhary 2008).

Dehydration and kidney diseases

Studies of troops deployed in hot, arid climates have demonstrated an increase in the occurrence of kidney stones in relation to exposure to higher mean temperatures (Cramer and Forrest 2006). Dehydration increases the concentration of calcium and other compounds in the urine, which facilitates the formation of kidney stones (Cramer and Forrest 2006). Currently, differences in mean annual temperatures are estimated to account for 70% of the geographic variation in kidney stone disease in the USA (Brikowski et al. 2008). A hotter climate across the USA is predicted to contribute to an additional 1.6–2.3 million new cases by 2050 (Brikowski et al. 2008).

In addition to kidney stone disease, there is evidence that during heat waves there is an increase in hospitalisations for acute renal failure and other kidney diseases. For example, during the severe heat wave in Chicago in 1995, there was a significant increase of hospital admissions for acute renal failure and co-morbidity of renal disease (Semenza et al. 1997). The 2006 heat wave in California there was significant increases of emergency department (ED) visits and hospital admissions (Knowlton et al. 2008). The ED increase was 3% for all causes and 2% for cardiovascular diseases. However, the highest increases were for electrolyte imbalance (16%), acute renal failure (15%) and nephritis and nephritic syndrome (6%). The increases of hospital admissions were also highest for these kidney diseases and electrolyte imbalance (5–11%) (Knowlton et al. 2008). In Adelaide, Australia, the incidence rate ratio for hospital admissions for renal diseases during heat wave days was 1.10 compared to non-heat wave days and for acute renal failure was 1.26 (Hansen et al. 2008). This study showed that the highest incidence ratios occurred among men in the age group 15–64 years, raising the issue of the role of physical activity during work as a potential cause of dehydration and renal problems.

Another group with renal disease problems potentially influenced by heat exposure is coastland male farmers in hot Central American countries. In a study in El Salvador chronic renal failure was surprisingly common (prevalence = 12.7% among adult farmers) (Garcia-Trabanino et al. 2005). The usual risk factors (for example diabetes and hypertension) were only present among a third of the patients and exposures to pesticides and alcohol did not appear to be important risk factors (Garcia-Trabanino et al. 2005). One could hypothesize that repeated daily dehydration during very hot and heavy laboring work could be an important risk factor for renal disease in this population (Schrier et al. 1970), as the workers do not always have access to sufficient drinking water during work.

Deteriorating clinical status of people with pre-existing chronic diseases

The adverse impacts of heat exposure on cardio-vascular diseases during heat waves generally occur among people with pre-existing disease (Poumadere et al. 2005). In clinical practice patients with acute heart symptoms should be protected from heat exposure, as such exposure causes, for instance, skin blood vessels to expand and blood pressure to drop creating lower blood flow to the heart muscle (Parsons 2003). Studies half a century ago could document the effects of intra-hospital heat on cardiovascular patients, because hospital wards without air conditioning existed at that time even in high-income countries. One example is the study by Burch and DePasquale in 1962 where 88 cardiovascular patients in an air-conditioned ward were compared with 75 similar patients in a non-air-conditioned ward (Burch and DePasquale 1962). The patients in the air-conditioned ward compensated more quickly from symptoms of congestive heart failure, slept better, were calm and quiet, and required less nursing care than the patients in the non-air-conditioned ward. Patients that did not clinically improve while in the non-air-conditioned ward were moved to the cool air-conditioned ward and the study reports: “In these cases, without exception, improvement in the clinical course developed and in some patients the improvement was dramatic”. It is also stated that patients with stroke or high blood pressure are better off in cooler air-conditioned wards (Burch and DePasquale 1962).

For many people with multiple sclerosis (MS), one of the most common disabling neurological diseases of young adulthood, symptoms are worsened by heat exposure (Smith and McDonald 1999). This “Uhthoff’s syndrome” was first described in 1890 by Wilhelm Uhthoff (Selhorst and Saul 1995) after observations that visual symptoms were worsened with exercise in those with optic neuritis. It has now been shown to be a result of delayed nerve conduction when core body temperature increases (Smith and McDonald 1999). This occurs in patients with prolonged nerve conduction but not in those with a normal conduction test (Humm et al. 2004).

Obesity is one of the leading common chronic conditions in high-income countries and within the top ten leading risk factors for disease burden in low and middle income countries (Lopez et al. 2006). It is, in turn, a risk factor for heat-related ill health, even among young, relatively fit, military personnel (Chung and Pin 1996). Physical exercise tests during 6 days of heat exposure (38°C) of lean and obese 9–12-year-old boys showed the latter to be less heat acclimatized (reached higher core body temperatures) and less able to acclimate (less reduction of heart rate by day six) than the former (Dougherty et al. 2009). Other chronic disease associated with obesity, such as type II diabetes (Mokdad et al. 2003), are also likely to be negatively affected by increased heat exposure due to climate change.

Unbalanced physiological function and reduced work ability

A working person creates internal body heat that needs to be emitted primarily via the skin (Parsons 2003). In a hot and humid tropical environment the cooling mechanism of sweating is sometimes insufficient resulting in core body temperature increasing beyond the normal 37°C. Above 38°C heat strain produces sluggishness and lack of concentration (Bridger 2003). Beyond 39°C, more serious organ damage, unconsciousness (heat stroke), and even death can occur (Parsons 2003). The clinical manifestations of heat strain are exacerbated by pre-existing disease or malnutrition (Parsons 2003). Poor people in tropical countries are at particular risk, because they are more at risk for these factors, the heat exposures are very high during the hot season and many of them have to work physically very hard in outdoor jobs (Kjellstrom 2009).

A hard working person may sweat more than 5 l per work shift (Parsons 2003), and this water loss has to be replaced in order to avoid dehydration. A net water loss of more than 2–3 l/day risks damage to the kidneys and other organs (Black and Jones 1979). High heat exposure during heavy exercise creates a high risk of dehydration and associated acute renal damage (Schrier et al. 1970). The protection of workers from excessive heat exposure and the provision of sufficient clean water for re-hydration during the working day, are essential elements of occupational health tropical countries (Parsons 2003).

High heat exposure can affect the ability to perform general and work-related physical activity, particularly heavy labor (Parsons 2003). Reduction in work output or slowing of work will be necessary if body cooling cannot be achieved by sweating or other cooling mechanisms, to avoid heat stroke (Bridger 2003). This will negatively impact worker productivity or "work capacity" (Axelson 1974; Kjellstrom 2000; Kjellstrom 2009). The physiological effects of heat stress can also reduce psychological performance with increased mistakes in daily activities and increased accidental injuries (Ramsey et al. 1983; Ramsey 1995).

Impacts via increased air pollution

Increasing ambient temperatures in cities will enhance the production of tropospheric ozone, formed by the interaction between motor vehicle emissions (nitrogen oxides and volatile organic compounds) and solar UV-radiation (Krzyzanowski et al. 2005). Ozone exposure at ground level causes respiratory track irritation and heart and lung disease mortality (WHO 2006). Increased exposure to air pollution may also arise due to increased respiration as a physiological response to heat exposure (Parsons 2003).

Combined cardiovascular effects of exposure to heat and air pollutants during hot seasons have been reported in many cities (Kinney 2008). During the heat wave in France in 2003 ozone pollution contributed significantly to the additional mortality during the heat wave (Filleul et al. 2006). Ozone exposure was associated with 2.5–85.3% of the additional deaths depending on the city. Another study (Dear et al. 2005), using a different method, found for Paris that heat and ozone contributed equally to the increased daily mortality. Aero-allergens are another type of pollutants that may increase with climate change, potentially affecting many people via asthma and hay-fever (Beggs 2004). The main impact of climate change may be a shift in the start of the pollen season (Van Vliet et al. 2002).

Impacts via other factors

Based on estimations of the impacts of droughts and climate disasters on food production, malnutrition is estimated to represent the largest impact on climate change related mortality for the period 1990–2000 (McMichael et al. 2004).

Foetal, antenatal and childhood under-nutrition and malnutrition can have major impacts on the susceptibility to later life development of cardiovascular disease, obesity, diabetes and other metabolic disorders (Barker 1997; Gluckman and Hanson 2006).

Malnutrition in early life also causes stunting of physical growth, and in extreme cases marasmus (severe wasting) or kwashiorkor (malnutrition with edema), as well as increasing susceptibility to diarrhea and infections (Muller and Krawinkel 2005).

Sea level rise has the potential to force displacement of millions of persons both in urban and rural coastal areas of such countries (McGranahan et al. 2007).

Insufficient healthcare and medication resources to meet chronic disease related needs of environmental refugees during Hurricane Katrina (in New Orleans, Louisiana and nearby US States) demonstrated a marked vulnerability of these displaced populations (Jhung et al. 2007). Elderly rest home patients and poor people were particularly affected.

Conclusions and recommendations for action

The burden of chronic NCDs, largely heart disease, stroke, cancer, type II diabetes and chronic obstructive pulmonary disease, has increased rapidly in most regions of the world and is projected to increase further as life expectancy continues to improve. From a global perspective, chronic diseases have been historically considered as a problem in high-income countries, while lower income countries focused on the major problems of communicable diseases and malnutrition. However, in all regions of the world except for sub-Saharan Africa, NCDs are now the major causes of death.

This paper highlights a number of mechanisms by which increasing population heat exposure and other environmental changes related to global climate change may affect NCDs causing acute or chronic health impacts. Cardiovascular, renal and respiratory diseases may be particularly affected, and people in low and middle income countries are at particular risk due to limited resources for prevention. It follows that in the climate change and health evaluations and action plans a greater focus on NCDs is warranted.

The health sector has a major role in identifying possibilities for preventive actions and in assisting affected people. This sector should work in collaboration with meteorological and environmental services to identify changes in the living and working environment that may indicate risks for occurrence of particular climate related health problems. Improved prevention would include forecasting and sentinel case identification for climate related NCDs and other chronic conditions.

In this way the climate change and health research, monitoring, surveillance and prevention activities would support the global efforts to improve prevention and control of NCDs and chronic diseases.

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