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Key Points:
- Climate change will increase demands on health systems and limit their capacity
- Sociopolitical and economic effects of climate change will impair human health
- Climate change will also curtail the adaptive capacity of health systems

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Climate change and health in Earth's future

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Abstract Threats to health from climate change are increasingly recognized, yet little research into the effects upon health systems is published. However, additional demands on health systems are increasingly documented. Pathways include direct weather impacts, such as amplified heat stress, and altered ecological relationships, including alterations to the distribution and activity of pathogens and vectors. The greatest driver of demand on future health systems from climate change may be the alterations to socioeconomic systems; however, these "tertiary effects" have received less attention in the health literature. Increasing demands on health systems from climate change will impede health system capacity. Changing weather patterns and sea-level rise will reduce food production in many developing countries, thus fostering undernutrition and concomitant disease susceptibility. Associated poverty will impede people's ability to access and support health systems. Climate change will increase migration, potentially exposing migrants to endemic diseases for which they have limited resistance, transporting diseases and fostering conditions conducive to disease transmission. Specific predictions of timing and locations of migration remain elusive, hampering planning and misaligning needs and infrastructure. Food shortages, migration, falling economic activity, and failing government legitimacy following climate change are also "risk multipliers" for conflict. Injuries to combatants, undernutrition, and increased infectious disease will result. Modern conflict often sees health personnel and infrastructure deliberately targeted and disease surveillance and eradication programs obstructed. Climate change will substantially impede economic growth, reducing health system funding and limiting health system adaptation. Modern medical care may be snatched away from millions who recently obtained it.

1. Introduction

Threats to human health from climate change are receiving increased attention, with some arguing that climate change is the greatest risk to global health in the 21st century [*Costello et al*., 2009]. As might be expected for such a new and interdisciplinary enterprise, initial research into health hazards from climate change has concentrated on a few areas, whereas others have been left under-investigated [*Butler and Harley*, 2010]. One classification of the health effects [*Butler*, 2014] of climate change defines "primary" effects as those that operate directly on the human organism [*Butler and Harley*, 2010], such as heat stress and trauma from exposure to severe weather events. Such effects are increasingly recognized and understood [*Luber and McGeehin*, 2008; *Kjellstrom et al*., 2009].

In this classification, secondary effects act less directly, via ecosystem alteration and other interactions, including changes in the distribution and prevalence of diseases and vectors [*Patz and Olson*, 2006; *Zhou et al*., 2008; *Chaves and Koenraadt*, 2010; *Gething et al*., 2010]. However, "tertiary" health effects—those mediated through impacts on social, political, and economic systems—will likely have the greatest long-term impact on human health. This possibility remains relatively underexplored and scarcely recognized [*Butler and Harley*, 2010]. Its manifestations include heightened risk of conflict [*Mazo*, 2010; *Hsiang et al*., 2011], increased migration [*McMichael et al*., 2012], and growing pressures on food production systems and thus food security [*Schmidhuber and Tubiello*, 2007; *Butler*, 2010].

Despite this range of potential and existing health risks, there has been little analysis of how health systems will be impacted by climate change. Here we assess the literature to determine likely effects of climate change on health systems in the coming decades. We follow the World Health Organization's definition of a health system as consisting "of all organizations, people and actions whose primary intent is to promote, restore or maintain health" [*World Health Organization*, 2007]. Our analytic framework is twofold: we examine the impacts of climate change on the *demands* placed on health systems, and on the *capacity* of health systems to meet these demands. Analysis suggests that primary and secondary effects of climate change could affect human health in many ways, increasing pressure on health systems, but are unlikely to substantially alter health system capacity. However, the tertiary effects of climate change could both substantially impair human health and undermine capacity.

2. Primary and Secondary Health Effects

As mentioned earlier, the primary and secondary health effects of climate change have to date received the most attention. Various causal pathways that harm health and increase health system demand are documented. For example, several noncommunicable diseases, including cardiovascular and kidney diseases, will be exacerbated by increased occupational heat exposure [*Kjellstrom et al*., 2010; *Tawatsupa et al*., 2012], and increased temperature from climate change will increase morbidity and mortality [*Bi et al*., 2011; *Huang et al*., 2011]. Climate change may be contributing to the global rise in asthma, including via increased air pollution and respiratory allergies [*D'amato and Cecchi*, 2008; *Ziska and Beggs*, 2012]. More frequent and intense extreme weather events and bushfires pose additional risks to air quality and thus to a range of chronic diseases including cardiovascular diseases.

Ecological disruptions from climate change will further impact health. Vector-borne diseases will likely expand their distribution with climate change, owing to changes in humidity, temperature, and vegetation, which can impact both vector and pathogen life cycles. Diseases expected to be worsened include malaria [*Chaves and Koenraadt*, 2010], dengue [*van Kleef et al*., 2011], and some tick-borne diseases, although other factors such as governance substantially influence infectious disease dynamics. Food- and water-borne diseases, including those caused by salmonella and campylobacter, may also increase owing to climate change [*Semenza et al*., 2011].

3. Hunger

Hunger and undernutrition may increase substantially following climate change [*Schmidhuber and Tubiello*, 2007; *Butler*, 2010]. Some analysts are more confident about global food production for at least the medium term, including the Intergovernmental Panel on Climate Change [*Intergovernmental Panel on Climate Change*, 2007]. Food security is commonly defined as comprising food availability, stability, access, and utilization. The predictions of agricultural food production to 2050 vary, but worsen as this century unfolds, unless there is substantial mitigation. Agricultural production has long been predicted to shift from lower to higher latitude areas [*Intergovernmental Panel on Climate Change*, 2007; *Schmidhuber and Tubiello*, 2007]. However, some projected increases in productivity at higher latitudes may be constrained by water availability [*Tao et al*., 2011], whereas the poor quality of soil at higher latitudes has long been recognized as a major constraint, as is the relative lack of sunlight for many months [*Butler*, 2010]. Ocean acidification due to carbon dioxide absorption is likely to reduce aquatic food availability to humans. The altered chemistry interferes with the shell creation of corals and other species. Acting alone, this could kill most of the world's highly food-productive coral reefs, many of which are already harmed by overfishing and other forms of pollution. This will be disastrous for the hundreds of millions of the world's poor who rely on coral reef ecosystems for food [*Bradbury*, 2012]. Acidification also interferes directly with the development of commercially important fish and molluscs [*Cooley and Doney*, 2009; *Baumann et al*., 2012].

Destabilizing weather patterns and increasing intensity and frequency of extreme weather events also appear likely to lower the stability of food supplies, particularly affecting the poor population [*Schmidhuber and Tubiello*, 2007] such as landless agricultural laborers and subsistence farmers. Rising food prices may be of limited benefit to small farmers who often lack market power, organization, and the capacity to properly store food for sale when prices go even higher. Domestic political pressure, in conjunction with low harvests, is likely to cause some governments to limit food exports, as occurred with some grain exporters between 2007 and 2010 [*Cribb*, 2010]. This phenomenon would further diminish global food stability, and thus nutrition, by disrupting the free flow of trade. The effects might be most keenly felt in countries that are net food importers, and also by the poor in many developed countries. However, food insecurity would increase even in countries that were normally net food exporters. In the current global system, many risks associated with time-limited, localized disruption to food production are eliminated by the smoothing function of long-distance trade. A self-reinforcing spiral of export bans is a major risk following climate change.

Climate change will limit access to food for individuals, communities, and countries. Increased purchasing power relative to food prices has underpinned much of the reduction of hunger in percentage terms, as reported in recent decades. Climate change may also interact with other limits to growth to slow down economic growth, especially in many areas already beset by poverty, further hampering food access [*Schmidhuber and Tubiello*, 2007; *McMichael et al*., 2014]. Diminished health due to climate change conditions, including transmissible diseases, will further impede access to food for the poor. Food utilization may also be diminished by increased spoilage and contamination in a hotter climate [*Schmidhuber and Tubiello*, 2007; *Butler*, 2010].

Increased hunger will amplify health system burden directly through increased presentation of undernutrition, which impairs immunity and can also predispose to diabetes and other chronic diseases in later life, some of which are also associated with immune dysfunction. Decreased food security also undermines other determinants of health, as people make trade-offs to ensure calorie intake, but often at the expense of micronutrients. Other examples include children foregoing education for work and people with limited choice engaging in unsafe employment, including the sex trade. Poverty associated with food insecurity decreases the ability of populations to support their health systems, not only economically but because of the “brain drain” that constantly reduces number of skilled personnel in impoverished areas that are also often physically insecure.

4. Migration

Climate change is increasingly recognized as a major factor for increased migration, as people seek to adapt to altering conditions [*McLeman and Smit*, 2006; *Black et al*., 2011b; *White*, 2011]. The decision to migrate involves multiple forces. Push and pull are well recognized, but “glue” and “fend” are increasingly important [*Bowles et al*., 2014]. Push factors weigh in favor of relocation. Climatic reduction of agricultural productivity will likely be a push factor in many regions. Accompanying degradation of sociopolitical conditions may come as a more forceful push, should ethnic tensions or violence result. Over half of the world’s refugees are from just five countries, all beset by conflict: Afghanistan, Somalia, Iraq, Syria, and Sudan [*UNHCR*, 2013]. The civil war in Syria, to which climate change may have contributed [*Femia and Werrell*, 2013], has already created over 2 million refugees.

Glue, in contrast, describes the attachments that people have with their current location, often the ancestral home, which weigh against migration. In some areas, ecological disruption will weaken the emotional and economic ties that people have with their places and ecosystems, including for those living within traditional and other cultures making their living directly from the land. Social disruptions from climate change may further weaken these emotional attachments, as once familiar areas change their nature, a form of solastalgia.

Natural and social deterrents that limit or seek to restrict in-migration can be called “fend” factors. As population growth, climate change, and other environmental changes interact to increase migration flows, xenophobia seems likely to increase in many receiving areas. Some nations already have policies to deter migration, such as in the case of African migrants to Europe and asylum seekers to Australia, which now seeks to redirect refugees arriving by boat to nearby developing nations such as Papua New Guinea. Such practices are likely to increase with climate change [*Welzer*, 2012]. These fend policies may be intensified by degrees of social and economic exclusion of arrivals.

The perceived benefits of a potential destination exert a pull; apparent advantages may correspond to the actual benefits of a place more or less closely. At least initially, developed countries appear likely to be more insulated from the effects of climate change than developing countries because of more diversified economies, enhanced adaptive capacity, and less negative effects on local agriculture in high latitudes. Differential impacts of climate change will create a strong pull toward some areas. But high-income countries are not entirely immune. In the United States, the population of New Orleans is still lower than before Hurricane Katrina, an extreme event worsened not only by wetland clearances but probably also by climate change, including sea-level rise.

Climate change can substantially alter these four factors, directly and indirectly. Alternative causal classifications exist, demonstrating the complex pathways that determine migration decisions. For example, Black et al. identify five types of migration drivers, environmental, political, social, demographic, and economic, noting that environmental change interacts with the other four types of drivers [*Black et al*., 2011a]. The multiplicity of factors underpinning migration makes the monocausal identification of "climate migrants" almost impossible, but does not mean that climate change is not an important factor in many migration decisions [*Piguet et al*., 2011].

The multiple analytical frameworks, difficulties inherent in identifying climate migrants, and different scenarios for predicting how people will react to climate change have hampered agreement about the methodology for predicting the scale of future impact. Unsurprisingly, projections differ substantially, but tend to agree that the number of climate migrants will be in the tens or hundreds of millions by 2050 [*Gemenne*, 2011], with one of the most robust assessments predicting around 200 million or more [*Biermann and Boas*, 2010].

Migration increased by climate change is likely to directly affect health in multiple ways [*Afolayan and Adelekan*, 1999; *Barbieri and Confalonieri*, 2011; *McMichael et al*., 2012]. Migrants may be exposed to new diseases for which they have little or no genetic resistance or cultural experience [*Afolayan and Adelekan*, 1999]. The spread of disease may be enabled or hastened by migration [*Barbieri and Confalonieri*, 2011]. Much climate migration will be rural to urban, within and between developing countries [*Piguet et al*., 2011; *Black et al*., 2011b], and could lead to overcrowded and unsanitary conditions conducive to ill-health [*Locke*, 2009].

Climate migration will likely hinder health system planning and implementation. The future scale of climate migration remains hotly contested, with vastly different estimates of even current levels of environmental migration [*Gemenne*, 2011]. Little research into likely destinations of future climate migrants has occurred [*Findlay*, 2011]. Increased xenophobia and sociopolitical fend factors, including changes in migration policies, are to some extent unpredictable; this hinders accurate forecasting of likely destinations. Research funding biased toward impacts on developed countries could further impede prediction for developing countries, although small budgets and limited bureaucratic systems could preclude effective adaptation in any case. Climate change, in combination with other limits to growth and a rising global population, may accelerate our nascent "fortress world" where enclaves of privilege exist in a global context of widespread poverty and system breakdown [*Raskin et al*., 2002]. Such uncertainty increases the challenge of matching future health system resources to need, particularly given the long lead time to train and place health staff and build health infrastructure.

5. Conflict

Links between climate change and an increased risk of conflict are widely reported in the academic literature [*Cook*, 2011; *Hsiang et al*., 2011; *Zhang et al*., 2011; *Welzer*, 2012; *Hsiang et al*., 2013], and within defense communities [*Sullivan et al*., 2007; *Department of Defense*, 2010; *Jarvis et al*., 2011; *Morisetti*, 2012]. Hsiang et al. recently published a meta-analysis of 60 studies on conflict [*Hsiang et al*., 2013]. The studies included cover several millennia but focus on the last century. They find an increase of 14% in the frequency of intergroup conflict for every standard deviation in change toward warmer temperatures [*Hsiang et al*., 2013]. Other analysis shows a correlation between natural climate change, reductions in food availability, and increased conflict in Europe and China between 1500 and 1800 [*Zhang et al*., 2011]. Between 1950 and 2004, the odds of a civil conflict starting in equatorial countries affected by the El Niño Southern Oscillation were twice as high in drier, hotter El Niño years compared with wetter, cooler La Niña years [*Hsiang et al*., 2011]. Decreased economic productivity from climate change in many developing countries will sap already low tax bases, worsen corruption, impair governance, and reduce opportunities for peaceful redress of grievances. Decreased and shifting availability of essential resources, including arable land and food, will heighten frustration and could create cohorts of people with little to lose and for whom armed conflict represents their best chance to secure essential resources.

The contribution of anthropogenic climate change to conflict may have already begun. Increased desertification and drought, possibly caused by climate change, combined with a number of sociopolitical factors to contribute to the genocide in Darfur [*Mazo*, 2010; *Welzer*, 2012]. Increased grain prices, caused partly by reduced harvests owing to climate change, may have contributed to the Arab Spring and the Syrian civil war [*Werrell and Femia*, 2013].

Increased conflict would elevate health service demand through a number of pathways [*Cook*, 2011; *Jarvis et al*., 2011; *Morisetti*, 2012] including additional battle casualties, especially if the trend toward targeting of civilians continues [*Welzer*, 2012]. In regions with limited economic activity, civilians may be deliberately targeted. Mass civilian casualties and resulting refugee camps can trigger increased foreign aid, some of which can be appropriated by warlords [*Welzer*, 2012]. Conflict also facilitates the spread of disease through migration, sexual violence, malnutrition, psychological trauma, and the creation of unhygienic conditions [*Connolly et al*., 2004].

Conflict already devastates local health systems. Surveillance for new or re-emergent diseases is often impeded and disease eradication and vaccination programs can be impaired. Consequences may be regional or global [*Connolly et al*., 2004]. Health infrastructure and personnel are targeted in many conflicts, including Iraq [*Alwan*, 2011] and Pakistan [*Varley*, 2010]. Regardless of the direct losses of health personnel to violence, many choose to leave conflict zones for safety. In Iraq most doctors left their jobs and half departed the country [*Alwan*, 2011].

The longer-term consequences of increased conflict on health systems could be global. Long-lasting civil conflict would likely decrease economic growth, as whole generations miss out on educational and other opportunities, with global economic effects. Increased xenophobia and protectionism are other possibilities, and could limit options for potential migrants and minorities. Humanitarian aid is likely to fall, although military subsidies from developed to developing countries may increase, especially where this is considered to help secure access to resources.

6. Health System Funding

Without adequate mitigation, climate change will substantially impede economic growth [*Stern*, 2007], and could lead to dramatically lower standards of living in future. The release of all the methane from thawing permafrost on the East Siberian Arctic Shelf alone was recently predicted to result in damages from increased climate change costing about $60 trillion if it occurred, comparable with world economic activity in 2012 [*Whiteman et al*., 2013]. Such costs would fall heavily on the developing world [*Whiteman et al*., 2013]. Reduced economic activity could restrict funding for health systems from all sources, including governments and private users.

Without mitigation, increased competition for government and philanthropic funding may further limit investments in the health system and in other determinants of health. The economic effects of climate change in developed countries could decrease foreign aid budgets, potentially increasing refugee pressures [*Gulledge*, 2008]. Increasingly elaborate efforts to prevent immigration from developing countries overwhelmed by climate change could divert funds otherwise intended for health or aid. More frequent or intense conflict would boost defense budgets among affected countries. More frequent conflict would cause even countries not directly involved to re-evaluate their threat assessments. One response could be to further shift funding from health systems and health determinants, including social safety nets and universal education, to defense projects. This tendency could be especially pronounced where ethnic and state lines overlap, heightening the risk of conflict spill-over, as in much of Africa.

Diminished investment would decrease health research and technical developments, and impede the translation of research into common practice. Recent trends of expanding access to modern medical care could be halted or reversed.

7. Discussion

Two major new findings emerge from this review. First, tertiary effects of climate change will decrease the capacity of health systems to meet rising demands, generally in ways that reduce health system funding, functioning, and flexibility. This finding augments the now established literature demonstrating that primary and secondary effects of climate change will increase demands on health systems. The conclusions of this review add weight to the emerging literature on the tertiary effects of climate change on health, which suggest that they will also increase demands on health systems. Operating via these two pathways, tertiary climate change effects appear the class of consequences most important for human health.

Second, this review suggests that health systems could lose future adaptive capacity. This conclusion challenges the dominant emphasis on adaptation, rather than mitigation, in response to climate change [*Pielke et al*., 2007] and the current energy investment regime that favors unconventional carbon sources over cleaner fuels [*Klare*, 2013]. While health systems must struggle to adapt as far as possible to meet rising demands from climate change, without substantial mitigation their capacity to do so may be feeble, especially in the medium- and long term.

The specific risks from anthropogenic climate change outlined in this review — decreased food security, increased ill health associated with climate-induced migration and conflict, and reduced health system functioning — are probabilistically certain to occur on at least some scale. The climate has already changed. Rain-fed agriculture is already less viable in parts of the developing world. This has already fuelled migration and been implicated as a causal factor in several conflicts, in turn decreasing the capacity of local and national health systems. The severity and geographic and temporal extent of these tertiary effects depends primarily on future greenhouse gas emission scenarios. The manners in which people and polities react to the altered climate will also affect public health demands and health system capacity. However, at this stage options will be ecologically constrained by a degraded biosphere less capable of supporting some human activities. Both of these factors are likely to be shaped by the degree to which humanity views the tertiary effects of climate change as fundamentally ecological problems that are shared by humanity. Emphasis on the health effects of climate change may be useful in shifting public opinion. The public is more willing to decrease its carbon emissions when climate change is framed as a health issue [*Myers et al*., 2012]. Raising awareness that health systems are vulnerable to a focus on adaptation could strengthen public support for preventive action on climate change.

8. Conclusion

Health and health systems face increased demands from the primary, secondary, and tertiary health effects of climate change. Rising food prices and undernutrition will erode the health of many populations. Climate change migration, in response to deteriorating conditions, will stress health systems in receiving countries and cause immense psychological pain, as millions of people are forced to try to find a new home. Increased conflict in part caused by climate change will worsen health and further burden health systems, and may already be occurring.

Simultaneously, health systems and their underpinning socioeconomic bases will also face increasing pressure from climate change. Decreased economic activity and additional competition for resources, including for adaptation, defense, and border protection, will likely diminish health system funding and further impair health system cohesion. The tertiary effects of climate change will likely impede the adaptive capacity of health systems when they are most needed. Prompt mitigation would substantially decrease these risks. The world appears to be drifting toward a precipice, which future generations will descend. Our generation still has the opportunity to lessen this risk, but the time in which to act continues to diminish.

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