Annals of Arid Zone 47(3&4): 443-455, 2008

Health, Climate, and Climate Change in Arid Zones

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Abstract: Human health is affected by climate and weather both directly and indirectly. Global climate change is expected to have overall negative health impacts, with the burden mostly borne by people living in low- and middle-income countries. Research has not focused explicitly on arid zones, but inferences can be made regarding impacts of likely importance, particularly those related to water scarcity, which is projected to increase in many areas. Diarrhea – which is strongly linked to water availability - remains a major killer of young children, and can have long-term health impacts on those surviving multiple episodes. Crop productivity is projected to decrease in many low latitude areas and is likely to place many millions at risk of malnutrition, mostly children. In Africa, meningitis epidemics are associated with dry climates, although vaccine availability may reduce future burdens. Climate influences the distribution and seasonality of malaria, and climate change will expand some malarious areas and decrease others; much uncertainty remains due to the importance of local non-climatic factors in determining incidence. Reducing the health impacts of climate and climate change requires diverse actions from within and beyond the health sector. Importantly, most actions will have wider benefits, including poverty reduction.

Key words: Climate, climate change, diarrhea, health, malaria, malnutrition, meningitis.

Climate, Health and Vulnerability

The influence of weather and climate on health has been recognized for thousands of years, but with the identification of anthropogenic climate change there has been renewed and intensified interest in the relationship. While climate benefits health in many ways, and indeed makes life possible – as when regular and predictable rainfall ensures the reliability of crop productivity and water supplies – it is the negative health impacts that are of increasing concern. Climate and weather may harm health directly - such as through heat waves - or indirectly, for example, by determining locations in which disease carrying mosquitoes are abundant. With the relatively rapid changes climate change is projected to bring, far in excess of what humans have dealt with since the development of agriculture, the burden of ill-health attributable to climate is expected to increase (Haines *et al*., 2006).

For climate to have an impact on health, the 'exposure' through which health is affected must be sensitive to climate. Such an exposure may take a wide range of forms: a bacteria causing diarrhea may proliferate more rapidly at higher temperatures; or, the return period of severe coastal flooding events may be reduced by changing atmospheric conditions. However, the impact an exposure actually has on health depends on the vulnerability of the exposed population.

Rapidly reproducing diarrheal pathogens will have the greatest impact on populations with poor water and sanitation provision; coastal flooding will cause greater harm to populations without adequate warning or protection systems. In general then, the climate-health relationship is complex and has different impacts on different people: it is often indirect; it is moderated by socioeconomic conditions; and, people living in poverty usually have greater vulnerability. Table 1 summarizes the known effects of climate and weather on health (Kovats and Akhtar, 2008).

Anthropogenic Climate Change and Health

A great deal of work has been done on modelling the future impacts of climate change on various global physical and ecological systems (IPCC, 2007). However, despite the relatively small changes in climate over the last 100 years (most of which has been since the 1970s) – including a global mean temperature shift of just 0.74 degrees (IPCC, 2007) – observations are strongly suggestive that impacts are already occurring (Rosenzweig *et al.*, 2008). Rosenzweig *et al.* (2008) examined almost 30,000 data series describing geographically widespread physical (including spring peak river discharge and permafrost melt) and biological (such as leaf unfurling and migration timing) systems and concluded that at the global scale and on most continents, significant changes in the systems were consistent with observed warming. Not only were the changes attributed to changing climate, they were attributed to human-induced climate change. While human health wasn't considered in this study, given our reliance on natural

Table 1. Summary of known effects of weather and climate on health

Health outcome	Known effects of weather
Heat stress	Deaths from cardio-respiratory disease increase with high and low temperatures Heat-related illness and death due to heat waves
Air pollution-related mortality and morbidity	Weather affects air pollutant concentrations Weather affects distribution, seasonality and production of aeroallergens
Health impacts of weather disasters	Floods, landslides and windstorms cause direct effects (deaths and injuries) and indirect effects (infectious disease, loss of food supplies, long-term psychological morbidity)
Mosquito-borne diseases, tick-borne diseases (e.g. malaria, dengue)	Higher temperatures reduce the development time of pathogens in vectors and increase potential transmission to humans Vector species require specific climatic conditions (temperature, humidity) to be sufficiently abundant to maintain transmission
Water-/food-borne diseases	Survival of important bacterial pathogens is related to temperature Extreme rainfall can affect the transport of disease organisms into the water supply Outbreaks of water-borne disease have been associated with contamination caused by heavy rainfall and flooding, associated with inadequate sanitation Increases in drought conditions may affect water availability and water quality (chemical and microbiological load) due to extreme low flows

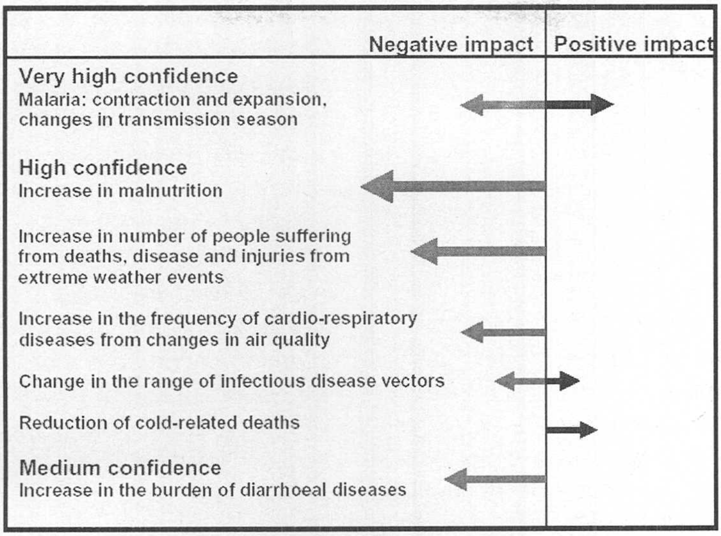

Fig. 1. Direction and magnitude of change of selected health impacts of climate change (confidence levels are assigned based on IPCC guidelines, see original source for details) (Source: Confalonieri et al., 2007).

systems, it is not unreasonable to infer some of these changes have affected human well-being.

Estimates of the impact climate change has already had on health have been made by the World Health Organization (McMichael *et al.*, 2004). The study considered heat and cold stress, diarrhea, malnutrition, floods and malaria; only some of the likely impacts, but the only ones for which quantitative models were available. Against a baseline climate of 1961-90, the burden of disease attributable to climate change in the year 2000 was estimated to be 150,000 deaths (0.3% of all deaths), and 0.4% of the overall global burden of disease (which combines death, disease and disability). This represents a relatively small proportion of all ill-health and death, but as climate change accelerates it is anticipated the size and importance of the burden will increase. Further, probably more important than the actual numbers is that most of the burden fell on people – more specifically, children – living in poverty in low latitude regions who already had high rates of mortality and morbidity. Climate change does, and will, widen global health inequalities.

Looking to the future, the IPCC has outlined the full range of health impacts climate change may have on human health (Confalonieri *et al.*, 2007), albeit without quantification. Anticipated to increase, for example, are deaths due to malnutrition, heatwaves, floods, fires and droughts. Vector-borne diseases are expected to have changed ranges and seasons. Some causes of death, such as cold-related deaths, are likely to decrease, but on balance, overall health impacts will be negative. Figure 1 shows the anticipated health impacts of climate change as described by the Intergovernmental Panel on Climate Change (IPCC).

Arid Climates and Health Risks

To date, there have been no comprehensive research studies on climate and health specifically focusing on arid or semi-arid zones that we are aware of. However, many countries have undertaken climate impact and vulnerability assessments that include health issues. When the conditions defining and existing in arid zones are considered those health impacts likely to be of particular relevance may be inferred.

Of principle importance, of course, is rainfall. Limited water access is associated with much ill-health through death, disease, and time wasted collecting water that could otherwise be spent on other activities (such as child care and education) (Cairncross *et al*., 2007). Close to a fifth of the global population lack access to adequate water resources, two-thirds of whom live in Asia, and this is estimated to be associated with 1.7 million deaths each year (Bates *et al*., 2008). Reliable water is also critical to ensuring food production. Water availability for humans and crops is determined by more than rainfall, but with projections suggesting that, in general and notwithstanding uncertainties, dry lands will become drier and expand, and that there will be more land in extreme drought at any one time (Bates *et al*., 2008), it seems reasonable to assume that, in the future, reduced rainfall will potentially have significant health impacts in arid zones. Temperature is also expected to rise in most arid zones (IPCC, 2007).

But health impacts due to climate, as described earlier, are greatly influenced by the conditions in which people live (Haines *et al*., 2006). Populations in which poverty is rife and livelihoods are fragile and lack diversity will be especially vulnerable. Pre-existing poor health will increase susceptibility to further health impacts. In sum, those arid zones in which living conditions are already difficult, and in which climatic conditions 'worsen', are likely to be most affected.

In this paper, we briefly review selected health impacts of climate change likely to be of importance in arid zones. We consider water access and children's health; climate impacts on crop productivity and malnutrition; dry climates and meningitis; and the influence of climate on vector borne disease.

Selected Health Impacts of Relevance in Arid Zones

Water, children's health and diarrheal disease

The lack of sufficient water to meet even basic drinking, sanitation and hygiene requirements causes a significant portion of the global burden disease, principally through diarrhea (Cairncross and Valdemanis, 2006). In low-income countries, diarrhea is the third leading cause of death (after lower respiratory infection and coronary heart disease), and it ranks fifth globally (Mathers *et al*., 2008). Most of the burden falls on children aged under 5. While there has been a general decline in child mortality, including those due to diarrhea, which fell from 4.6 million to 2.5 million annually between the 70s and the 90s, diarrhea still accounts for around a fifth of all child deaths (Kosek *et al.*, 2003).

Despite these gains, recent decades have seen no real improvement in the number of episodes of diarrhea a child is likely to suffer. On average, children in developing countries still experience 3.2 cases per child per year, with many children having perhaps 7 or 8 episodes (Kosek *et al.*, 2003). A case of diarrhea may seem relatively benign, but in fact, studies have linked multiple episodes of diarrhea in childhood to long-term problems including reduced growth and cognitive function, and possibly chronic disease including hypertension (Guerrant *et al.*, 2002; Lawlor *et al.*, 2006). Checkley *et al.* (2008) recently found that for every 5 episodes of diarrhea a child experiences before the age of two, the odds of irreversible stunting (being short for age: an outcome associated with chronic malnutrition) increased by 13% (95% CI 7-19%) (Checkley *et al.*, 2008). Stunting increases the risk of death and disease due to various infections and may cause long-term health problems (Black *et al.*, 2008). Thus diarrhea not only claims many young lives; it causes life long poor health in individuals, and may also retard the economic growth of a country.

Climate and weather influence diarrhea in multiple ways. As temperature increases, so does the survival of bacteria and protozoa – the dominant causes of diarrhea in low and middle income countries (McMichael *et al.*, 2004). Many studies have looked at how temperature influences cause-specific diarrhea (i.e. that caused by a particular pathogen), but only two have quantified the relationship between temperature and all-cause diarrhea (Checkley *et al.*, 2000; Singh *et al.*, 2001). One study was conducted in Lima, Peru (Checkley *et al.*, 2000), and the other covered a number of Pacific Islands (Singh *et al.*, 2001); that is, they represent few climate zones. Both focused on diarrhea cases reported to the health services, meaning only a portion of all cases were identified. In combining the findings of these studies, it has been suggested that for each 1 degree rise in temperature, diarrhea incidence increases by 5% (95% CI -10%) in countries with a GDP/capita <=US$ 6000 (1990 value); once wealth exceeds this level, it is assumed climate has little impact on diarrhea (McMichael *et al.*, 2004).

Rainfall has a more complex relationship with diarrhea (McMichael *et al.*, 2004). High rainfall may cause pathogen containing run-off (for example, from animal faeces) to contaminate water supplies leading to diarrhea outbreaks. Studies have demonstrated this link in developed countries, but the relative importance of short-lived outbreaks in countries with high underlying rates of diarrhea is unclear. On the other hand, low rainfall may reduce water availability over the longer term, limiting people's access to clean drinking water and water for personal hygiene. Lloyd *et al.* (2007) looked at how rainfall over at least a 12-month period influenced diarrhea incidence over globally dispersed sites, controlling for various socio-economic factors. While data quality and methodological issues mean the results must be interpreted cautiously, it was estimated that diarrhea incidence increased by 4% (95% CI 1-7%) for each 10 mm/month decrease in rainfall. Comparing broad climate zones, there was weak but suggestive evidence that diarrhea was more likely in arid zones compared to areas with temperate, tropical and boreal forest climates.

Overall, it seems reasonable to assume that in the future, children living in arid zones may be particularly affected by increasing rates of diarrhea unless significant and widespread improvements are made in water and sanitation provision. The problem is likely to be greatest in areas that experience increasing water scarcity and rising temperatures on a background of poverty and a lack of basic infrastructure. Further, diarrhea has a synergistic relationship with malnutrition (Black *et al.*, 2008), which is discussed in the next section.

Food security and malnutrition

The general consensus amongst scientists is that climate change will reduce global food security, and that this in turn will impact negatively on human health (Confalonieri *et al.*, 2007). Food security and nutrition are influenced by more than crop productivity (that is, food availability) (Schmidhuber and Tubiello, 2007). As important are supply stability (reduced by factors including extreme weather events and pests); access to food (impacted by, for example, global trade, prices, and entitlements); and, ability to utilize food (as when a child with frequent diarrhea has access to food but fails to obtain nutritional benefits) (Schmidhuber and Tubiello, 2007). That each of these factors influences health shows the complexity of the climate-food-health relationship.

As with diarrhea, a large proportion of the current burden of malnutrition is borne by young children, which causes one-third of deaths and ill-health in under 5s (Black *et al.*, 2008). Additionally, malnutrition is concentrated in relatively few countries. In terms of numbers affected, four-fifths of malnourished children live in 20 countries in Africa, Asia, the Middle East, and the Western Pacific; in terms of mortality, only 1% of malnutrition deaths occur outside Asia, Africa and the Middle East (Black *et al.*, 2008). Figure 2 shows the global distribution of malnutrition (as stunting) for the most recent year available.

Future food availability and access have been modelled in a number of studies (Fischer *et al.*, 2005; Parry *et al.*, 1999, 2004; Rosenzweig and Parry, 1994; Tubiello and Fischer, 2007). Common to all was a focus on wheat, maize, rice and soy - which contribute about half of the calories consumed by the world's poor (Lobell *et al.*, 2008) – and the use of a global food trade model (the Basic Linked System) to estimate food access. In general, projections indicate that climate change will increase yields in temperate latitudes, but due to increased evapotranspiration and decreased soil moisture, yields will decline in dry areas. Estimates suggest that, depending on the scenario, an additional 5 to 170 million people will be at risk of hunger by the 2080s; the wide range being largely due to the greater relative impact of socioeconomic conditions compared to climate. Considering affected regions, Sub-Saharan Africa is expected to surpass Asia as the most food insecure region, and may account for 40-50% of hunger in the 2080s compared to around 24% now (Schmidhuber and Tubiello, 2007).

Two recent studies have considered future climate and crop productivity, albeit

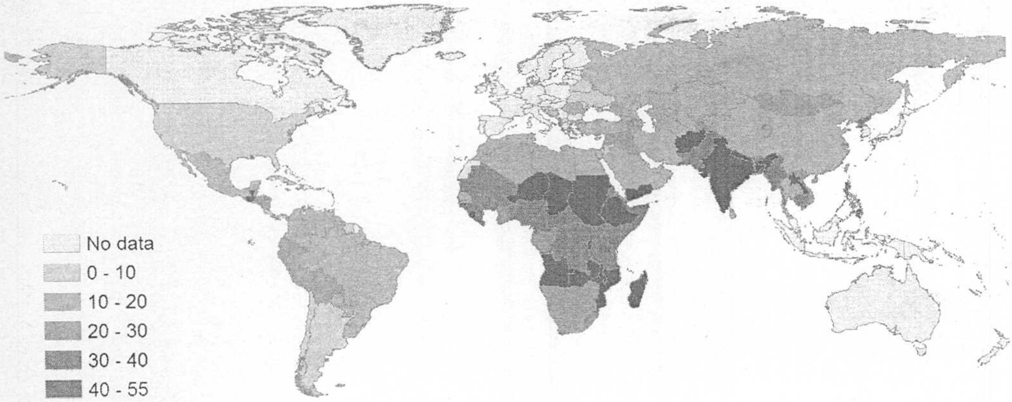

Fig. 2. Global distribution of malnutrition, as stunting in children aged less than 5 years, by country for the most recent available year. Data source: Food and Agriculture Organization http://www.fao.org/faostat/foodsecurity/index_en.htm*
**Stunting indicates a child is two or more standard deviations below the average height of children of the same age using the World Health Organization Child Growth Standards. For details, see http://www.who.int/childgrowth/en/*

without considering food access or health outcomes. Lobell *et al.* (2008) expanded the range of crops modelled to include those of greatest importance in 12 food insecure regions and focused on the 2030s. Despite uncertainties, it was clear that a number of important crops are likely to show temperature and/or rainfall influenced yield reductions in the near future, particularly in South Asia and Southern Africa. Battisti and Naylor (2009), concentrated on temperature ranges during growing seasons rather than specific crops. The authors concluded that, by the end of the 21st century, there is a 90% probability that the growing season temperature will exceed even the most extreme temperatures seen during 1900-2006 in many parts of the world, probably resulting in considerable yield reductions. Areas likely to be most affected include large parts of tropical and sub-tropical Asia and Africa, parts of South, Central and North America, and parts of the Middle East. Such changes could place 3 billion people, most who depend on agriculture for their livelihoods, at risk.

In light of the above, there is reasonable confidence that climate change will bring increased hunger, with a number of arid areas likely to be affected. And while this will negatively impact on health, estimating the impact is less straightforward than it appears. Intuitively, lack of food may seem to be by far the most important determinant of malnutrition; but while food supply is critical, so are a range of other factors. Underlying health, low birth weight, water and sanitation provision, and female education, for example, all impact on malnutrition (World Bank, 2008). Pruss-Ustun and Corvalan (2006) suggest that 50% of malnutrition is caused by factors other than food, mostly water and sanitation provision. Smith and Haddad (1999) found that of the reduction in child malnutrition between 1970 and 1995, 43% could be attributed to women's education; more than the 26% that was attributed to improved per capita food availability. The true contribution of different factors is contested, but it is evident that while climate change poses a threat to food production, socio-economic conditions will have a major influence on how this ultimately affects health. Whatever the relative influences, without adapting agriculture and ensuring socio-economic development, the burden of malnutrition is likely increase significantly.

Meningococcal meningitis in dry areas

Meningitis refers to the infection of the lining of the brain and spinal column, known as the meninges. It may be caused by a number of infectious agents, but the bacteria *Neiserria meningitidis* is commonly implicated in epidemics. The usual symptoms include fever, headache, stiff neck and light sensitivity. Even when treated, up to 10% of people die within as little as 24-48 hours; hence, meningitis is a medical emergency (WHO, 2003).

Disease transmission is via droplets from the respiratory system, making close contact with an infected person a risk factor (WHO, 2003). If meningitis occurs in populations in which overcrowded living conditions or movement of large numbers of people are common, cases can rapidly spread from the few to the many. Such is the situation in the African 'Meningitis Belt', an area in which environmental conditions are conducive to meningitis and social conditions (such as pilgrimages and journeys to large markets) facilitate its spread (WHO, 2003). Figure 3 shows the location of the Meningitis Belt.

The Meningitis Belt was first defined in 1963 and comprises the strip of countries running from Senegal to Ethiopia; home to around 300 million people. The Belt lies largely within the low humidity area with an annual rainfall of between 300 and 1100 mm (Cuevas *et al.*, 2007). More than two-thirds of meningitis epidemics occur within the area, and the driest parts tend to be affected more frequently and by larger epidemics than, for example, forested areas (Cuevas *et al.*, 2007). In 1996, the largest recorded meningitis epidemic ever occurred in the Meningitis Belt, with 250,000 cases and 2,500 deaths. After this event, there were another 220,000 reported cases by 2002 (WHO, 2003).

During the 1980s, infection patterns in Africa were observed to be changing, with the southern Sahel and areas around the Rift Valley and Great Lakes becoming increasingly affected (Confalonieri *et al.*, 2007). At least part of this shift may have been due to regional climate change and/or changing land use. Interestingly, as for the Meningitis Belt, the newly affected areas were largely defined by the 300-1100 mm mean annual rainfall zone (Cuevas *et al.*, 2007). Such patterns have led to speculation that, outside Africa, areas with similar ecological conditions to those in the Meningitis Belt may be particularly susceptible to outbreaks (Cuevas *et al.*, 2007). Certainly Moscow, China, Nepal, and India – all with areas having conditions similar to the Meningitis Belt – have experienced outbreaks in the past. However,

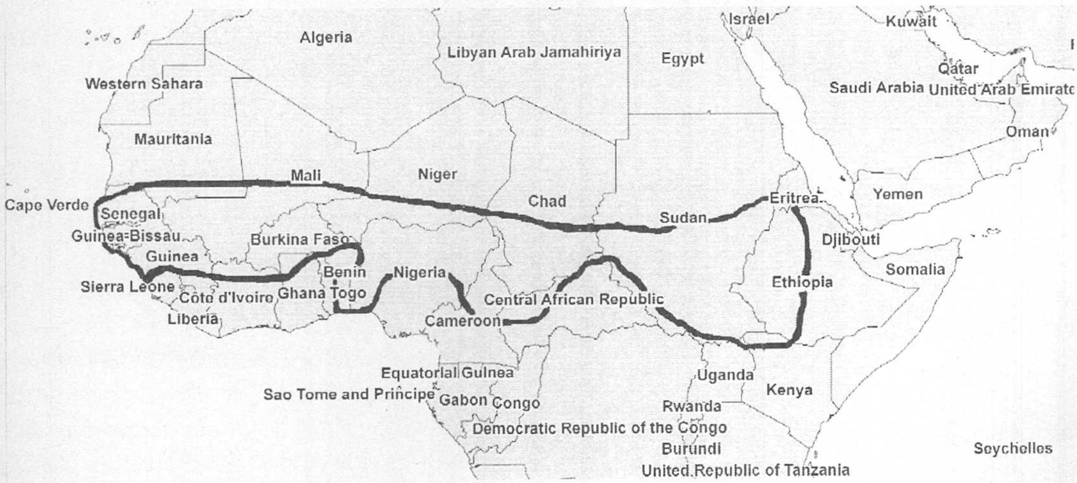

Fig. 3. The enclosed area show the meningitis belts (Source: World Health Organization (Copyright 2007). http://gamapserver.who.int/mapLibrary/Files/Maps/AFRO_incidence_95_2003.ng [The boundaries and names shown and the designations used on this map do not imply the expression of any opinion whatsoever on the part of the World Health Organization concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. Dotted lines represent approximate border lines for which there may not yet be full agreement.])

more research on this possibility is needed. Further, the possible impacts of climate change on future meningitis have not been investigated; an area complicated by the fact that, gladly, effective meningitis vaccines are becoming more readily available (Cuevas *et al.*, 2007).

The links between the environment and meningitis, and the need to respond to outbreaks rapidly, have led to the ongoing development of risk mapping and early warning systems. Molesworth *et al.* (2003) quantified the relationship between the location of epidemics and absolute humidity, dust, rainfall, land cover type and population density, and developed a model which predicted the spatial distribution of epidemics within Africa with 84% sensitivity and 67% specificity. Models predicting the incidence of epidemics –which may be useful for providing early warnings - are at an earlier stage of development, but incidence has been linked to rainfall, wind speed, dust and vegetation greenness (Jackou-Boulama *et al.*, 2005; Sultan *et al.*, 2005; Thomson *et al.*, 2006). Even with the anticipated wider availability of vaccines in the near future, it has been suggested that models should continue to be developed, as they are likely to prove useful in prioritizing areas for vaccination, assessing vaccination efficacy, and providing early warning to unvaccinated populations (Cuevas *et al.*, 2007).

Despite linking the locations of epidemics (spatially, temporally, intensity level) with climate and environment, there is a poor understanding of causal factors, although low humidity, dryness, dust and wind speed appear to be implicated (Confalonieri *et al.*, 2007).

Malaria

Malaria is caused by *Plasmodium* species parasites transmitted to humans via infected mosquitoes. Around half the global population live in malarious areas, which cover more than 100 countries in Sub-Saharan Africa (where the majority of the cases occur), Asia, Latin America, the Middle East and parts of Europe. There were 250 million cases of malaria in 2006, leading to 800,000 deaths, mostly in children living in Africa (WHO, 2009).

Climate influences the spatial distribution, intensity, transmission and seasonality of malaria (Confalonieri *et al.*, 2007). The majority of studies on the climate-malaria relationship have been conducted in Africa, but work has also been done in Europe, Asia, South America, and Australia (Ying *et al.*, 2008). In general, malaria is positively correlated with temperature, although too hot temperatures reduce mosquitoes (Ying *et al.*, 2008). Studies on rainfall have more mixed results, with some studies showing a positive correlation with malaria and others no association (Ying *et al.*, 2008). During drought, there tend to be fewer mosquitoes, but over this time, the number of non-immune people rises; consequently, when the drought finally breaks and mosquito activity increases, malaria may increase (Confalonieri *et al.*, 2007). For example, heavy rainfall events are associated with malaria epidemics in the Thar deset in India (Bouma and vander Kay, 1995; Mathur *et al.*, 1992).

On the other hand, drought has been seen to increase mosquitoes due to decreased predator activity and water stagnation. However, sustained dry conditions are likely to decrease malaria as water is required for breeding, and there is some evidence suggesting long-term decreases in rainfall result in less malaria (Confalonieri *et al.*, 2007).

In spite of the climate-malaria association, for a number of reasons, much uncertainty remains. Data sources are relatively few; apparent associations (or the lack of) with climate may be confounded by improved case reporting, new disease control programmes or population changes; malaria has complex dynamics, etc. (Kovats *et al.*, 2001; Rogers and Randolph, 2006). Further, due to the importance of non-climatic factors acting at the local scale, not only is research difficult, but generalizability of results is often questionable (McMichael *et al.*, 2004). A location may have a climate suitable to support malaria, but whether or not cases appear is dependent on many other factors.

Bearing the uncertainties in mind, it is anticipated that climate change will impact on malaria (Confalonieri *et al.*, 2007). It was estimated that in 2000 over 27,000 malaria deaths could be attributed to climate change (McMichael *et al.*, 2004). Looking ahead, the IPCC (Confalonieri *et al.*, 2007) suggests that in Africa some malarious areas will expand while others will contract. Outside Africa, the general lack of robust malaria spatial models means less can be said. The potential area for malaria transmission may expand in some central Asian regions, including parts of India, and contract in central America and around the Amazon (Confaloniei *et al.*, 2007). However, the future malaria burden will depend upon the capacity of the country to control the disease.

Conclusions

As has been discussed, climate impacts health in many ways, but a number of important generalizations may be made. Firstly, climate rarely acts alone in harming health; the conditions in which people live almost always play a major role. If a weather anomaly leads to crop loss, it is those people without resources to obtain food from elsewhere who go hungry. Even when the impact is more direct, such as in a coastal flood, the poor and unprepared will suffer more than the rich. Following from this, climate change will predominately affect those least able to adapt; once again, this is those people already living in adverse conditions.

Secondly, reducing and avoiding the climate impacts on health requires a range of actions. Strengthened health services providing, for example, disease surveillance, meningitis vaccines and malaria control programmes are required. Further, poor health itself is a vulnerability to climate-caused health impacts – the sick get sicker; thus general health services are essential. But, as will have become evident, protecting and improving health needs action beyond the health sector. Water and sanitation provision must be expanded; agricultural practices must prepare for changing conditions, etc.

Overall, means of reducing the negative health effects of climate and climate change are, almost always, means of improving people's lives generally. Health services, water and sanitation, access to food, and living beyond the poverty line can be seen as basic human rights. Directing attention to these issues through the climate-health relationship is just one way of moving towards a more equitable world. The particular climates of arid zones are likely to mean some health impacts are more likely than others, but, in most cases, underlying living conditions will play a large role in determining how these health impacts manifest.

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