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ORIGINAL ARTICLE

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Climate change and human health in Latin America: drivers, effects, and policies

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Abstract Many people would be increasingly affected by living under critical conditions in Latin America if, as expected, global warming aggravates disease and pest transmission processes. Heat waves and air pollution would increase heat-related diseases and illness episodes in large cities. Fire smoke has been associated with irritation of the throat, lung and eyes, and respiratory problems. Climate extreme increases associated with climate change would cause physical damage, population displacement, and adverse effects on food production, freshwater availability and quality. It would also increase the risks of infectious and vector-borne diseases. Climate change impacts the geographical range, seasonality, and the incidence rate of vector-borne diseases, such as malaria. Climate-related ecological changes may expand cholera transmission, particularly among populations in low-laying tropical coastal areas. El Niño conditions may affect the incidence of infectious diseases, such as malaria. Ocean warming would increase temperature-sensitive toxins produced by phytoplankton, which could cause more frequent contamination of seafood. A clearer understanding on the current role of climate change in disease patterns will be able to improve forecasts of potential future impacts of projected climate change and support action to reduce such impacts.

Keywords Latin America · Climate · Human health

Introduction

The most widely discussed aspect of global environmental change is the human impact on the world's climate. Scientists predict that our increasing generation of greenhouse gases, mainly carbon dioxide emissions plus various other heat-trapping gases such as methane and variety of man made halocarbons, will change the world's climate (IPCC 2001a). This process has contributed to the strong recent increase in world average temperature (McMichael 2001b).

In Latin America, as well as in other regions of the world, climate fluctuations have left great imprints and scars on the history of mankind. Historical analyses reveal widespread diseases, social disruption and disease outbreaks in response to the more acute quasi-periodic El Niño Southern Oscillation (ENSO) cycle (Fagan 1999). Climate change would influence and indeed is already influencing the functioning of many ecosystems and the seasonal cycles and geographic range of plants and creatures (IPCC 2001b), affecting food production and water availability. Likewise, there would be health impacts in human populations. Overall, scientists assess that most health impacts would be adverse. However, it should be noted that some impacts would be beneficial (i.e., reduction of cold weather health effects, McMichael and Githeko 2001).

In spite of the importance of environmental conditions in health and sanitation issues, historically, most environmental health problems have entailed specific risks within a local context. In the past, the common symptoms of human environmental impact have been urban-industrial air pollution, chemically polluted waterways and the manifestations of urban squalor in rich and poor countries. These local health hazards are now being supplemented with those due to changes in some of the planet's great biophysical and ecological systems, and hence there are additional and larger-scale environmental health problems (Vitousek et al. 1997). We have begun to alter the conditions of life on Earth, even as we remain largely ignorant of the long-term consequences (McMichael 2001b). We are depleting or disrupting many of the ecological and geophysical systems that provide life-support such as nature's "goods and services" (Daily 1997). Tropical climate, poor water and food security, low socio-economic status and

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political instability define the regions that would be most vulnerable to the health effects of climate change. Many Latin American countries have these conditions in common.

Climate-related drivers of health effects

The World Health Organization defines human health as "a state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity". The different aspects of well-being are related to weather and climate; basically, they depend on the social and economical conditions of the community. In fact, these define the characteristics of the local environment, including those of the available health services and their associated infrastructure; the availability of food and water, and the characteristics of their dwellings, which includes sanitation services. Latin America has a large tropical and subtropical environment. Its inhabitants already are exposed to a number of infectious diseases and pests that are typical of these environments. Those living in poverty are most vulnerable communities. As a result, more people living under critical conditions in Latin America would be increasingly affected if, as expected, global warming exacerbates disease and pest transmission processes, among other impacts. Several distinct processes can be expected to drive the health effects of climate change in Latin America.

Long-term changes in temperature and precipitation

Direct effects of climate change, such as heat waves or severe droughts, are difficult to predict, but are anticipated to become more prevalent under climate change scenarios. Heat waves, often exacerbated by increased humidity and urban air pollution, would cause an increase in heat-related diseases and illnesses episodes (Gawith et al. 1999; IPCC 2001b). The impact of climate change on mortality from thermal stress in developing country cities may be significant. High temperatures and air pollutants, especially particulates, act synergistically to influence human mortality (Canziani et al. 1998). Populations in larger Latin American cities (e.g., Mexico City, São Paulo, Caracas, La Habana) may be especially vulnerable because they lack the resources to adapt to heat waves (McMichael and Githeko 2001).

Changes to El Niño/Southern Oscillation

ENSO events may affect the incidence of infectious diseases around the world through its regional effects on weather (Kovats 2000). The climate effects of El Niño are the strongest in many developing countries that are poorly equipped to deal with weather extremes. Another reported effect during the 1997–1998 El Niño episode was an increase of temperatures in Lima, Peru, up to 5 C above normal, and the number of daily admissions for diarrhea increased to 200% compare with the previous rate. The excess admissions were related to El Niño episode, admissions for diarrhea increased by 8% per 1 C increase in temperature. The effects of El Niño over temperature on the number of admissions for diarrhea were greater during the winter months (Checkley et al. 2000). If these findings are reproducible in other regions, then diarrhea diseases may increase by millions of cases worldwide with each degree of temperature above normal, and the more significant effect was during the winter season.

The effects of natural events vary by region, and the same weather condition may have the opposite effect in different areas for the same disease (e.g., a dry year may induce malaria epidemics in humid regions but cause malaria decreases in arid regions) (McMichael and Kovats 2000). For example, ENSO has been associated to severe drought, as in Iquitos, Peru, and the State of Roraima, Brazil, where malaria cases have drastically decreased (OPS 1998; Confalonieri and Costa-Dias 2000). In 1997–1998, El Niño-driven droughts contributed to the development of expansive forests fires in Indonesia, Mexico, Central America (more than 400,000 ha in Guatemala, Nicaragua, Honduras, El Salvador, Costa Rica) and South America (Roraima, Amazonia, and the temperate forest in Argentina and Chile), Florida, Canada and other parts of the world (AID 1998).

The periodic occurrence of severe drought associated with El Niño in the agricultural region in North Eastern Brazil has resulted in occasional famines (Kovats 2000). In 1999, such conditions extended from North Eastern Brazil to Panama (WMO 2000); water supplies were contaminated when rivers and streams stopped flowing.

Extreme events

Any regional increases in climate extremes (storms, floods, cyclones, etc.) associated with climate change would cause physical damage, population displacement, adverse effects on food production, freshwater availability and quality, and would increase the risks of infectious diseases epidemics, particularly in developing countries (Tables 1, 2) (McMichael and Githeko 2001). Populations are becoming more, rather than less, vulnerable to disasters in developing countries (McMichael and Kovats 2000). Flooding is the most common of all environmental hazards (Kovats 2000). Heavy rains on the coast of Venezuela displaced 80,000–100,000 people and caused 20,000–50,000 deaths in 1999, as well as enormous damage in their infrastructure (Grasses et al. 2000).

Hurricane Mitch, which devastated Central America, was identified as one of the worst extreme events in Central America for the last decades. Fuelled by a heated Caribbean, the storm unleashed torrents that killed at least 11,000 people. The event affected Guatemala

Table 1 Pathways by which above-average rainfall can affect health (derived from Kovats et al. 1999)

Event	Type	Description	Potential health impact
Heavy precipitation event	Meteorological	"Extreme event"	Increased or decreased mosquito abundance
Flood	Hydrological	River/stream overtops its banks	Changes in mosquito abundance; contamination of surface water
Flood	Social	Property or crops damaged	Changes in mosquito abundance; contamination of water with faecal matter and rat urine (leptospirosis)
Flood	Catastrophic flood "disaster"	Persons killed, injured, > 10 killed and/or 200 affected, and/or government call for external assistance	Changes in mosquito abundance; contamination of water with faecal matter and rat urine and increased risk of respiratory and diarrhoeal disease; deaths (drowning); injuries; health effects associated with population displacement; loss of food supply; psychosocial impacts

(the number of cholera cases increased fourfold), Belize, and Nicaragua (the number of cholera cases was six times the usual reported cases, OPS 1999). Honduras reported thousands of cases of cholera, malaria and dengue fever (PAHO 1999; OPS 1999; Epstein 2000).

A number of slums and shantytowns located on hills, as well as human settlements located in flood-prone areas, are subject to periodic natural disasters that adversely affect human health (Canziani et al. 1998). There is evidence that the number of people vulnerable to hydrological hazards is increasing as populations rise, and the alternative settlements sites decrease. Economic and social pressures, force marginalized people into flood-prone urban locations (Blaikie et al. 1994). Examples of unplanned urban growth in Latin America are Mexico City, Rio de Janeiro, São Paulo, Caracas, and Buenos Aires.

Specific health effects

Although climate change is one of the factors in human health, its effects may occur in combination with vector-borne diseases, infectious diseases, variations in daily and weekly mortality and hospitalization rates, and deaths and illnesses by extreme events (McMichael and Githeko 2001; WHO 2001).

Disease

It is well established that climate is an important determinant of the spatial and temporal distribution of vectors and pathogens. The effects of climate change become most evident if adaptive measures falter or cannot be extended to all population at risk (Hales et al. 2002). Rainfall can promote transmission by creating ground pools and other breeding sites, but heavy rains can have a flushing effect, cleansing such sites of their vectors. Shorter and milder winters will increase the survival of parasites through winter, especially for subtropical species. The increasing energy levels in the atmosphere are likely to alter wind patterns and so affect dispersal patterns of flying insects. Climate induced migrations of parasite-infested hosts may also occur. One effect of higher concentrations of CO_2 in this

Table 2 Pathways by which below-average rainfall can affect health (derived from Kovats et al. 1999)

Event	Type	Description	Potential health impact
Drought	Meteorological	Evaporation exceeds water absorption, soil moisture decreases	Changes in vector abundance if vector breeds in dried-up river beds
Drought	Agricultural	Drier than normal conditions leading to reduced crop yield	Depends on socio-economic factors, i.e., other sources of food available, including the means to acquire them
Drought	Social	Reduction in food supply or income, reduction in water supply and quality	Food shortage, illness, malnutrition (increased infection risk); increased risk of diseases associated with lack of water for hygiene
Drought	Food shortage/ famine/drought disaster	Food shortage leading to death, > 10 killed, and/or 200 affected and/or government call for external assistance	Deaths (starvation); malnutrition (increased infection risk); health impact associated with population displacement

century could be enhanced water use efficiency and biomass in plants that are not limited by lack of nutrients (Wittwer 1995). This tendency will provide more shelter for free-living stages of parasites, such as worms and ticks (Chakraborty et al. 1998). The overall results are likely to be higher survival of free-living stages of parasites and vectors of disease through the winter or dry season (Sutherst 2001).

Malaria is the most important vector-borne disease. Because of the existence of critical climate thresholds, changes can occur in malaria incidence and even small changes in climate (Patz et al. 2002). Climate change scenarios consistently project increases in run-off over the North West of South America where malaria is known to be endemic (Githeko et al. 2000). In Brazil, satellite images depict a widespread typical "fish bone" pattern of deforestation where roads have opened the tropical forest to localized development. In these "edge" areas, malaria has resurged and probably has been influenced by changes in both land development and regional climate (Epstein 1997). The southern limits of malaria distribution may be affected by climate change in South America. High temperatures would probably raise the maximum altitude for transmission and could bring malaria back to major cities such as Quito, Ecuador and Mexico City, where it has not been seen for many decades. Its stability of occurrence would remain low; therefore, control measures should be relatively effective in such situations. However, increased stability and prevalence might be more of a problem at lower altitudes, which are at the present limits of transmissions. On the other hand, climate change might affect the likelihood that the introduction of anthropophilic mosquito to a new location could drastically alter transmission potential by altering stability, leading to disease transmission (Reiter 2001).

There are still important uncertainties, however. In theory, a change in climate would be expected to cause changes in the geographical range, seasonality (intra-annual variability), and in the incidence rate (with or without changes in geographical or seasonal patterns) (Kovats et al. 2000, 2001). The influence of climatic factors is complex and varies according to the region and the ecology of the vectors concerned. Patz (2002) concluded that the question of vector-borne diseases and long-term climate change is still not resolved, there is a lack of unequivocal quantitative evidence in either direction. Conditions may become more unfavorable for *Anopheles darlingi*, a major malaria vector in the region if temperature may extend its distribution in Southern Argentina and if rainfall decreases (Carcavallo and Curto de Casas 1996).

There are other vector-borne diseases to be concerned about. Models of dengue fever indicate that the largest changes are likely to occur in places where mosquitoes breeding already occurs today, with potentially increased transmission intensity as a result of temperature rise, but where development of the virus is limited by temperature during part of the year. Projected temperature increases are not likely to affect transmission significantly due to transmission intensity in tropical endemic countries where it is limited primarily by herd immunity rather than temperature (Gubler 1998). The southern limit of leishmaniasis and its vectors in South America are the extreme north of Argentina (Curto de Casas and Carcavallo 1995; Marcondes et al. 1997). Climate change could affect the geographical distribution of these vector species in Brazil, Paraguay, Bolivia, and Argentina (Carcavallo and Curto de Casas 1996). Temperature affects the major components of vectorial capacity of the triatome bugs for Chagas disease (Carcavallo and Curto de Casas 1996; WHO 1998; Moreno and Carcavallo 1999), as well as the number of blood-feedings of mosquitoes and, therefore, there are the possibilities of infective direct contacts (Catalá 1991; Catalá et al. 1992).

The overcrowded and poor-serviced and suburban settlements also provide a potential breeding ground for disease hosts (e.g., rats, mice, cockroaches, and flies) and disease organisms, increasing the population's vulnerability (Canziani et al. 1998). For example, in Rio de Janeiro, most deaths due to flood episodes result either from mudslides associated with the storms that caused the flooding or from leptospirosis, an infectious disease transmitted from the urban sewage rat (Roberts et al. 2001). Settlements that surround large cities, where discarded non-biodegradable containers serve as ideal mosquito breeding sites, provide especially vulnerable settings; milder "cold" seasons and weather extremes can both help precipitate large outbreaks (Epstein 1997).

In the cities of the semi-arid north-eastern Brazil, prolonged droughts during early 1980s and 1990s, provoked rural–urban migration of subsistence farmers, and a re-emergence of kala-azar (Confalonieri 2003). In the cities of São Luís and Teresinha, important epidemics were observed in 1983–1985 and 1992–1994, periods that coincided with major droughts caused by El Niño. In the State of Maranhão (Brazil), close to the Amazon Region, an important increase of imported malaria was also observed in the early 1980s, which subsequently became more frequent that the autochthonous form of the disease. The most plausible explanation for these increases is drought-driven human migration (Githeko et al. 2000). Along the Caribbean Coast of Colombia, the heaviest August rainfall followed a 1995 summer heat wave in 50 years, ending a long drought that accompanied the preceding, prolonged El Niño conditions of 1990–1995. The heat and flooding precipitated a cluster of diseases involving mosquitoes (Venezuela equine encephalitis and dengue fever), rodents (*leptospirosis*), and toxic algae (that killed 350 t of fish in their largest coastal lagoon). In 1995, there were substantial outbreaks of *leptospirosis* in Central America and Colombia, as heavy (La Niña) rains, following the prolonged El Niño drought, drove rodents scurrying from their burrows (Epstein 1997).

Acute diarrhea diseases have higher incidence in Cuba during the warm and rainy season, when ecological conditions are favorable for bacteria, viruses and protozoa reproduction (Ortíz et al. 2000). Diarrhea presents a highly seasonal pattern with more cases during warmer seasons, as shown by hospital admissions in Brazil (Guerrant et al. 1996). Climate-related ecological changes may enhance primary and secondary transmission of cholera in developing countries, particularly among populations settled in low-laying coastal areas in the tropics (McMichael and Githeko 2001). In the Americas, the first case of the current cholera outbreak was reported in Peru in 1991 (OPS 1998). Colwell and Huq (1994) have collected data in Bangladesh and Peru suggesting that cholera has a complex route of transmission that is influenced by climate. Particularly, sea surface temperature and sea level variations show an annual cycle similar to the cholera case data (Lobitz et al. 2000). It has been suggested that the spread of *Vibrio cholerae* may be related to the development of various algae and zooplankton. Increased coastal algae blooms (sensitive to changes in climatic conditions) may amplify *V. cholerae* and enhance transmission (Epstein 2000).

Food insecurity and stress

Developing countries already struggle with large and growing populations, and malnutrition rates would be particularly vulnerable to changes in food production (Patz 1998). Changes in the distribution of plant pests have implications for food safety. Ocean warming would increase the number of temperature-sensitive toxins produced by phytoplankton, causing contamination of seafood more often an increased frequency of poisoning. Coral diseases are now sweeping through the Caribbean, and diseases that distress marine habitat, such as coral or sea grasses, can also affect the fish stocks for which these areas serve as nurseries (Epstein 1997).

Control of ambient conditions in the food production process, including animal husbandry and slaughtering, to avoid the adverse effects of climate change is highly recommended (Mata et al. 2001). Malaria epidemics following drought occur in South America (as a result of changes in vector breeding sites) meaning that there can be a complicated interaction between the incidence of food insecurity—resulting from the drought and also reducing people's health and making them more susceptible to malaria—and the vector itself (Bouma and Van der Kaay 1996).

Effects of deteriorating air quality

Fire smoke carries a large amount of fine particles, which exacerbate respiratory problems, such as asthma and chronic obstructive pulmonary disease, and irritation of eyes (Duclos et al. 1990; Kovats et al. 1999; Patz and Balbus 2001). The smoke plume produced by the Central American forest fires traveled northward along the Gulf of Mexico coast and affected air quality extending well up into the Midwestern United States. As similar fire events may be expected more frequently in the future, epidemiological surveillance should be implemented in risk areas. Daily, seasonal, and inter-annual variation in the abundance of many aeroallergens, particularly pollen, is associated with meteorological factors. An increase in temperature, it may be argued, has significant effects on the distribution and overgrowth of allergenic plants. Higher temperatures and lower rainfall at the time of pollen dispersal are likely to result in higher concentrations of airborne pollen during the peak season (Emberlin 1994; Rosas et al. 1989). Climate change may affect the length of the allergy season. In addition, the effect of higher ambient levels of CO_2 may affect pollen production (McMichael and Githeko 2001).

A relationship between concentrations of algae and weather parameters (temperature and vapor pressure) in Mexico has been correlated. Dispersion of algae has received much attention during recent years due to associated inhalant allergies and other respiratory disorders (Rosas et al. 1989). The high degree of seasonality (dry-rainy season) in the airborne enteric bacterial, particles and protein concentrations could also be associated with temperature and vapor pressure in Mexico City (Rosas et al. 1994, 1995). Basidiomycete spores also showed a marked seasonal distribution with their greatest abundance during the wet season (Calderón et al. 1995).

Potential policy responses

The world's climate appears now to be changing at an unprecedented rate. Although there is a strong demand for information on the early impacts of climate change on health, there is very little equivalent information on health and health-related outcomes (Kovats et al. 2001), particularly in developing countries. Careful consideration should therefore be given to maximizing the chances of detection of these changes on human health effects. New approaches need to be developed in order to assess the pattern and plausibility of diverse studies of health impacts. Because many developing countries have poorly developed surveillance system, including emerging and re-emerging infectious diseases. It be considered setting up long-term surveillance programs to specifically monitor-sensitive aspects of climate change effects on health impacts (such as malaria, dengue, allergies, respiratory diseases, cholera and possible confounders) over the coming decades, both in rural and urban areas in Latin America. Ministries of Health should play a central role in this response—but should also remember that finding enduring solutions will depend on cross-sectoral communication and convergence (McMichael 2002).

To achieve cross-sectoral responsibility in the decision-making process regarding climate change, it is necessary to give access to relevant, transparent and comprehensive environmental information to all sectors, and to adopt indicators that measure changes across economic, social and environmental dimensions, among these human health impacts. It is therefore necessary to make the information available and useful to the different types of users, to widen and intensify the dissemination of this information, and to provide capacity building for the management of this information (e.g., advances in telecommunications could make it possible to monitor diseases and co-ordinate data collection).

A central clearinghouse is needed for storing region and country-specific data and information on diseases that are influenced by climatic variations. The data should not be limited to vector-borne diseases but should include other ailments, such as asthma, which may be related to environmental changes, including climate variation (Ortíz et al. 1997). The difficulty of providing researchers with access to disease data is because this type of information is often politically sensitive. The clearinghouse would provide an online and hardcopy catalogue of specialized health data sets to help researchers locate pertinent climate and health data to provide guidance on other data that need to be collected; interact with local authorities to improve the catalogue contents, service and delivery of information; and establish and apply quality control procedures to data. In Mexico, there was developed a clearinghouse regarding environmental data in Mexico and Central America. The clearinghouse has been very useful for environmental researchers and decision makers.

Some indication of the possible effects of climate change can be gained from the impact of short-term climatic variation (weather) on human health. The development of early health warning systems is an area where collaboration between the meteorological and health sectors can improve disaster and disease outbreak preparedness. Early warning for likely upsurges in vector-borne diseases would allow the health sector to target vector control programs and other activities. The effective implementation of such systems requires closer collaboration between researchers, health professionals and meteorological services. Systems should be part of a program to strengthen the capacity of local communities to identify ways in which they are vulnerable to extreme weather and to enhance their preparedness to reduce impacts. There is an urgent need for the coordination of early warning and preparedness activities at the level of national governments (Kovats et al. 1999).

There is a need in Latin America to identify areas where populations are vulnerable to the health impacts of climate change, being populations with the fewest resources would be the most vulnerable to the adverse health effects of climate change. Epidemiological surveillance of risk areas would allow having better knowledge of how climate change may impact human health. There are areas where diseases are likely to respond to a change in climate and where the population at risk is large with limited capacity to respond to emerging disease threats (Kovats et al. 2001). Populations at particular risk should be identified so that they can be helped to manage their resources and take necessary steps to decrease their vulnerability. Maintaining the integrity of ecosystems, such as forest habitat and wetlands, can provide defense against outbreaks of the opportunists that carry diseases, and provide a buffer against climate vagaries and extremes, whether or not there is any change in the overall climate regime. Early interventions can save money and lives (Epstein 1997).

A clearer understanding about the current role of climate change in disease patterns will enable scientists to improve forecasts of future potential impacts of projected climate change and support action to reduce such impacts. Further, confirmed effects on humans are likely to have a larger impact on the international policy debate over mitigation of greenhouse gases emissions than effects on common fauna (Kovats et al. 2001). Different scenarios predict health adverse consequences in different regions of the world in these coming decades due to climate change (Hales et al. 2002; Lieshout et al. 2004; Kovats et al. 2005). The sooner we estimate and communicate these consequences; the better will be our chance of averting future retrograde policy decisions (McMichael 2001a).

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