Climate, climate change and human health in Asian cities

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ABSTRACT Climate change will affect the health of urban populations. It represents a range of environmental hazards and will affect populations where the current burden of climate-sensitive disease is high – such as the urban poor in low- and middle-income countries. Understanding the current impact of weather and climate variability on the health of urban populations is the first step towards assessing future impacts. In this paper, we have reviewed the scientific evidence for the effects of temperature, rainfall and extreme events on human health, in particular the impacts of heat waves and floods. The methods for assessing the risks of climate change are undergoing development, and there is a need to shift the focus from global and regional to local studies. Sectoral approaches to climate change impact assessments often ignore the effects on health. There is a need to better describe the risks to health from extreme weather events as well as improve the effectiveness of public health interventions. Improving the resilience of cities to climate change also requires improvements in the urban infrastructure, but such improvements may not be achieved quickly enough to avoid an increased burden of disease due to global climate change.

KEYWORDS cities / climate change / diarrhoeal disease / floods / heat stroke / heat waves / mortality

I. INTRODUCTION

Climate change will affect the health of urban populations. Current attempts to reduce carbon emissions are insufficient to avoid further climate warming, and so the policy and research agendas are moving from mitigation (controlling greenhouse gas emissions) to adaptation (responding to climate change), and from global to local studies of impacts and responses.

Irrespective of global climate change, cities alter their local climate, particularly by reducing rainfall and increasing night time temperatures.(1) The "urban heat island" effect is caused by day time heat being retained by the fabric of the buildings and by a reduction in cooling vegetation. In temperate latitudes, this has the effect of raising night time temperatures by 1–5°C. In tropical cities, the mean monthly urban heat island intensities can reach 10°C by the end of the night, especially during the dry season.(2) Urban heat islands are measured as the difference in temperature between inside the city and the surrounding areas. The magnitude of the urban heat island is, in general, proportional to the size of the city.(3) Urban areas

1. WMO (1996), *Climate and Urban Development*, WMO No 844, WMO, Geneva.

2. See reference 1.

3. Oke, T R (1973), "City size and the urban heat island", *Atmospheric Environment* Vol 7, pages 769–779; also Oke, T R (1997), "Urban climates and global environmental change",

also cause considerable intensification of rain, hail and thunderstorms. Due to these factors and to their location by rivers or in coastal zones, cities are particularly prone to floods.

Cities are a significant source of greenhouse gas emissions and have an important role to play in mitigation.(4) In this paper, however, we shall focus only on the potential impacts of climate change on the health of urban populations. Currently, populations in cities are having to deal with a range of environmental hazards,(5) and global climate change is likely to exacerbate many of these problems. We have reviewed the published literature for the health effects of climate and weather (including extreme weather) in urban settlements in Asia. We then discuss these environmental health hazards in the context of future social and environmental changes, and regional climate changes in particular.

Adapting to climate change in cities in low- and middle-income countries is now an additional concern for local governments,(6) and we will briefly discuss the public health interventions that can reduce the current impacts on health of weather and climate. Priority should be given to adaptation measures that provide immediate improvements to the health of urban populations.

II. CLIMATE CHANGE AND HEALTH

The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) was published in 2007. The report confirms that climate change is already taking place(7) and also assesses future changes in climate at the regional scale. Very few city-level projections are available, as confidence in the output of climate models decreases with the higher the spatial resolution.

With respect to urban populations and human health in Asia, the key results of the IPCC report are:

- regional freshwater resources will be strongly affected by, and vulnerable to, climate change;
- increased rainfall intensity, particularly during the summer monsoon, in temperate and tropical Asia;
- increased risk of weather disasters, particularly flood events; and
- vulnerability of coastal cities due to climate change and sea level rise.

The greatest concern about the impacts of climate change on human health is regarding changes in freshwater resources, food supplies and increases in extreme weather events such as floods and droughts(8) (Table 1). The Indian National Assessment of Vulnerability and Adaptation has addressed the potential impact of climate change on malaria,(9) and other reviews have described the impacts on health of heat waves(10) and flood events.(11) However, there is a lack of good scientific information on the assessment of the potential impacts of climate change on health in Asian populations.

The potential impacts of climate change on natural disasters have been described in previous papers in this journal,(12) in particular the vulnerability of Asian cities in coastal zones.(13) Table 2 describes the range of environmental risks to coastal megacities. Historically, cities in Southeast Asia have been most affected by storm surges in terms of numbers of deaths.(14)

in R D Thompson and A H Perry (editors), *Applied Climatology: Principles and Practice*, Routledge, London, pages 273–287.

4. Kjellstrom, T, S Friel, J Dixon, C F Corvalan, E Rehfuess, D Campbell-Lendrum et al. (2007), "Urban environmental health hazards and health equity," *Journal of Urban Health* Vol 84 (Supplement 1), May, pages 86–97.

5. Bull-Kamanga, L, K Diagne, A Lavell, E Leon, F Lerise, H MacGregor et al. (2003), "From everyday hazards to disasters: the accumulation of risk in urban areas, *Environment & Urbanization* Vol 15, No 1, April, pages 193–204; also Gupta, I and A Mitra (2002), "Basic amenities and urban health in urban India", *National Medical Journal of India* Vol 15 (Supplement 1), pages 26–31.

6. Satterthwaite, D, S Huq, M Pelling, H Reid and P Romero Lankao (2007), "Adapting to climate change in urban areas: the possibilities and constraints in low- and middle-income countries", Human Settlements Discussion Paper Series – Climate Change and Cities 1, International Institute for Environment and Development, London, 107 pages.

7. IPCC (2007), *Climate Change 2007: The Physical Science Basis*, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge and New York.

8. van Aalst, M K (2006), "The impact of climate change on the risk of natural disasters", *Disasters* Vol 30, No 1, pages 5–18; also Klein, R J T, R J Nicholls and F Thomalla (2003), "The resilience of coastal megacities to weather-related hazards", in A Kreimer, M Arnold and A Carlin (editors), *Building Safer Cities: The Future of Disaster Risk*, World Bank, Washington DC, pages 101–120; and Confalonieri, U, B Menne, R Akhtar, K Ebi, M Hauengue, R S Kovats, B Revich and A Woodward (2007), "Human health", Chapter 8 in Martin Parry, Osvaldo Canziani, Jean Palutikof, Paul van der Linden and Clair Hanson

TABLE 1
Summary of known effects of weather and climate on urban 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

III. CLIMATE, WATER SUPPLIES AND SANITATION AND HEALTH

Climate is a key determinant of water availability. Surface water availability depends on the timing and volume of precipitation. The current burden of disease as a result of inadequate access to improved water and sanitation has long been recognized, particularly the very high rates of infant mortality in deprived urban areas.(15) There are clear social and economic reasons for the lack of access to improved water at the household level. However, cities in both high- and low-income countries have experienced failures in supply due to extreme drought events. It is also known that access to water within cities is not equally distributed, and any reductions in supply are likely to have a greater impact on impoverished populations.

Climate change may affect water supplies to populations in cities through a range of mechanisms. Rivers that are sustained by glacier melt in the summer season, for example in the Hindu Kush–Himalaya region, are likely to experience increased river flows in the short term as glaciers melt due to higher temperatures. However, the contribution of glacier melt will gradually decrease over the next few decades. Current trends in glacial melt suggest that the Ganga, Indus, Brahmaputra and other rivers in the northern Indian plain could become seasonal rivers in the near future.(16) Thus, cities that rely on glacial melt water will eventually lose this source and will have to seek alternatives, such as reservoirs or deep groundwater wells. Demand for groundwater may increase in other areas where the availability of surface water decreases.

For cities that rely on coastal aquifers, sea-level rise and any decrease in groundwater recharge levels will exacerbate saltwater intrusion (Table 2).

(editors), *Climate Change 2007: Impacts, Adaptation and Vulnerability*, Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge and New York, pages 391–431.

9. Dhiman, R C, T Adak and S K Subbarao (2004), "Impact of climate change on malaria in India with emphasis on selected sites", in A K Gosain, S K Sharma, S Bhattacharya, G Amit and S Rao (editors), *Proceedings of the Workshop on Vulnerability Assessment and Adaptation due to Climate Change on Indian Water Resources, Coastal Zones and Human Health*, 27–28 June, Indian Institute of Technology, Delhi, and Ministry of Environment and Forests, Government of India, New Delhi, pages 127–133.

10. Akhtar, R (2007), "Climate change and health and heat wave mortality in India", *Global Environmental Research* Vol 11, No 1, pages 51–57; also Cruz, R V, H Harasawa, M Lal and Wu Shaohong with Y Anokhin, B Punsalmaa, Y Honda, M Jafari,

TABLE 2
Major weather-related hazards and the occurrence of subsidence in coastal megacities during the twentieth century

City	Erosion	Storm and wind damage: Hurricane landfall[(1)]	Storm and wind damage: Extra-tropical storms	Flooding: River	Flooding: Surge	Salinization	Major subsidence
Tokyo	Y	Y(3)	–	Y	Y	?	Y
Bombay	Y	Y(<1)	–	–	Y	?	–?
Lagos	Y	–	–	–	Y	?	?
Dhaka	–	Y(<1)	–	Y	–	Y	Y?
Karachi	Y	Y(<0.1)	–	–	Y	?	–?
New York	Y	Y(<1)	Y	–	Y	?	–
Jakarta	Y	–	–	Y	–	?	Y
Calcutta	–	Y(<1)	–	Y	–	Y	Y?
Metro Manila	Y	Y(>3)	–	–	Y	?	Y
Shanghai	–	Y(1)	–	Y	Y	Y	Y
Los Angeles	Y	–	Y	–	Y	–	Y[(2)]
Buenos Aires	Y	–	Y	Y	Y	?	–?
Cairo	–	–	Y	Y	–	–	–?
Istanbul	Y	–	Y	–	Y	?	–
Rio de Janeiro	Y	–	–	–	Y	–	–
Osaka	Y	Y(3)	–	Y	Y	?	Y
Tianjin	–	Y(<0.1)	Y	Y	Y	Y	Y
Bangkok	Y	Y(<1)	–	Y	Y	?	Y
Seoul	–	Y(1-3)	Y	Y	–	–	–?
Lima	Y	–	–	?	Y	–	–
Madras	Y	Y(<1)	–	–	Y	?	?

Y = yes; – = no; ? = uncertain
(1) The relative frequency of hurricane landfall is indicated by the annual occurrence of tropical storms and cyclones (Beaufort force 8 and above).
(2) Due to oil and gas extraction, rather than groundwater withdrawal.

SOURCE: Klein, R J T, R J Nicholls and F Thomalla (2003), "The resilience of coastal megacities to weather-related hazards", in A Kreimer, M Arnold and A Carlin (editors), *Building Safer Cities: The Future of Disaster Risk,* World Bank, Washington DC, pages 101–120; and Nicholls, R J (1995), "Coastal megacities and climate change", *Geojournal* Vol 37, No 3, pages 1–11.

Inland aquifers are also at risk of saltwater intrusion from neighbouring aquifers, as groundwater recharge decreases. Shallow aquifers in arid and semi-arid regions are at risk of salinization as a result of increased evapotranspiration.

Climate impact assessments are often conducted at the river catchment level and converted to water availability per capita or withdrawal to resource ratio. Such indicators are useful to some extent, but provide no information on the level of access to water, the quality of water or any differences between rural or urban areas. Climate change is likely to cause a decline in environmental water resource availability in certain cities, where water resource management is poor or non-existent. This will have a negative impact on water availability at the household level, particularly in the households of the urban poor.

Congxian Li and Nguyen Huu Ninh (2007), "Asia", Chapter 10 in Parry et al. (editors), see reference 8, pages 469–506.

11. Alam, Mozaharul and MD Golam Rabbani (2007), "Vulnerabilities and responses to climate change for Dhaka", *Environment & Urbanization* Vol 19, No 1, April, pages 81–97.

12. de Sherbinin, Alex, Andrew Schiller and Alex Pulsipher (2007), "The vulnerability of global cities to climate hazards", *Environment & Urbanization* Vol 19, No 1, April, pages 39–64.

The impact of climate change on water availability is likely to be one of the most significant for the health of populations.[17] However, due to the complexity of the factors that determine access to clean water (social, political, environmental), the impacts on health are not well addressed in the literature on climate impacts. A substantial amount of endemic diarrhoeal disease is transmitted via the faecal-oral route. Although disease rates can be reduced very cost-effectively by improvements in hygiene behaviour, such improvements require access to sufficient quantities of water. Esrey et al.[18] cite a number of studies where improvements in water quality failed to deliver a significant reduction in diarrhoeal disease in places where water availability was limited.

Heavy rainfall and flooding is also an important issue for environmental health in urban areas,[19] as surface water is quickly contaminated during heavy rainfall events. In July 2005, severe flooding occurred in Mumbai, India. The city received 944 millimetres of rainfall in a 24-hour period, compared to an average of 21.7 centimetres of rainfall per year. The consequent flooding affected many households, including those in the more affluent parts of the city. Most metropolitan cities in India, including Mumbai, have poor urban drainage systems, which are easily blocked and are more vulnerable today even to short spells of rain. The flooding in Mumbai was exacerbated by blocked canals and drains.

Urban poor populations often experience increased rates of infectious disease after flood events. Increases in cholera,[20] cryptosporidiosis and typhoid fever have been reported in low- and middle-income countries.[21] Flood-related increases in diarrhoeal disease have been reported in India[22] and Bangladesh.[23]

There are relatively few studies that have investigated the effects of rainfall on morbidity, particularly diarrhoeal disease. A recent study using hospital visit data in Dhaka found that rates of disease increased during both high and low rainfall extremes.[24] The number of non-cholera diarrhoeal cases increased by approximately 5 per cent for every 10 millimetres increase in rainfall above a threshold of 52 millimetres (averaged over eight weeks). In addition, the number of cases increased by around 4 per cent for every 10 millimetres below the same threshold. Diarrhoeal disease morbidity was also shown to increase at higher temperatures, particularly in the populations with lower socioeconomic status.

After the floods of 2000 and 2001 in Mumbai, outbreaks of leptospirosis were reported in children living in informal settlements[25] and the prevalence of leptospirosis increased eight-fold following the major flood event in July 2005.[26] Two hospital-based observational studies found that the risk of disease was associated with children either playing in the floodwater or wading through it while going to school and, in some cases, with floodwater inside the house.[27] However, these studies, like many other observational studies of flood impacts, did not use a control group, making it difficult to establish the level of baseline or pre-flood morbidity for comparison.[28]

Flooding also may lead to the contamination of waters with chemicals, heavy metals or other hazardous substances, either from storage or from chemicals already in the environment (for example, pesticides).[29] There is little published evidence demonstrating a causal effect of chemical contamination on the pattern of morbidity and mortality following flooding events because it is difficult to assess individual exposures.[30]

13. See reference 8, Klein et al. (2003); also McGranahan, Gordon, Deborah Balk and Bridget Anderson (2007), "The rising tide: assessing the risks of climate change and human settlements in low-elevation coastal zones", *Environment & Urbanization* Vol 19, No 1, April, pages 17–37; and Nicholls, R J (1995), "Coastal megacities and climate change", *Geojournal* Vol 37, No 3, pages 1–11.

14. Nicholls, R J (2003), "An expert assessment of storm surge hotspots", Flood Hazard Research Centre, Enfield, UK.

15. Kosek, M, C Bern and R L Guerrant (2003), "The global burden of diarrhoeal disease, as estimated from studies published between 1992 and 2000", *Bulletin of the World Health Organization* Vol 8, No 3, pages 197–204; also Bhandari, N, R Bahl, S Taneja, J Martines and M K Bhan (2002), "Pathways to infant mortality in urban slums in Delhi, India: implications for improving the quality of community and hospital-based programmes", *Journal of Health, Population and Nutrition* Vol 20, No 2, pages 148–155.

16. See reference 10, Cruz et al. (2007).

17. See reference 8, Confalonieri et al. (2007).

18. Esrey, S A, J B Potash, L Roberts and C Shiff (1991), "Effects of improved water supply and sanitation on ascariasis, diarrhoea, dracunculiasis, hookworm infection, schistosomiasis and trachoma", *Bulletin of the World Health Organization* Vol 69, No 5, pages 609–621.

19. Parkinson, J (2003), "Drainage and stormwater management strategies for low-income urban communities", *Environment & Urbanization* Vol 15, No 2, October, pages 115–126; also Mitchell, G (2005), "Mapping hazard from urban non-point pollution: a screening model to support sustainable urban drainage planning", *Journal of Environmental Management* Vol 74, pages 1–9.

20. Gabastou, J, C Pesantes, S Escalente, Y Narvez, E Vela, L Garcia et al. (2002),

Increases in population densities and industrial development in areas subject to natural disasters increases the potential for mass human exposure to hazardous materials released during disasters. The contamination of floodwaters (and the longer-term contamination of soil) is a particular problem for populations situated near factories and industrial areas.

Inadequate drainage resulting in stagnant water is also a cause of mosquito-borne diseases such as malaria in urban areas. The effects of climate on such disease transmission is well understood from laboratory studies – as temperatures increase, the extrinsic incubation period (i.e. the time the parasites need to mature) decreases; this has been shown to be the case for dengue[(31)] and malaria.[(32)] However, rainfall effects that drive the abundance of mosquitoes depend on the vector's local ecology. For urban vectors of dengue, such as *Aedes*, the effects of rainfall patterns are more complex.[(33)] Climate warming may increase the risk of outbreaks of dengue in urban areas where temperature is currently a limiting factor in disease transmission.

IV. HIGH TEMPERATURES AND HEAT WAVE EVENTS

Heat is an environmental and occupational hazard. The risk of heat-related mortality increases with natural ageing, but persons with particular social and/or physical vulnerability are also at risk.[(34)] There are important differences in vulnerability between populations, depending on climate, culture, infrastructure (housing) and other factors. Episodes of extreme temperature can have significant impacts on health, and present a challenge for public health and local government services.

Human populations are "acclimatized" to their local climate, in physiological, behavioural and cultural terms, but there are clear limits to the amount of heat exposure an individual can tolerate. The capacity of populations to adapt to varied climates and environments is considerable, but people do not live comfortably in temperatures outside the range of 17–31°C. The tolerance range of an individual is usually much less than this, and will narrow with age or disability.

Global climate change is likely to be accompanied by an increase in the frequency and intensity of heat waves, and by warmer summers and milder cold seasons. Even small increases in average temperature can result in big shifts in the frequency of extremes. The impact of extreme summer heat on human health may be exacerbated by increases in humidity.[(35)] In 2002, a heat wave was reported to have killed 622 people in the southern Indian state of Andhra Pradesh. Information from news reports indicated that daily wage earners such as labourers and rickshaw pullers were at risk, who have no option but to work outdoors under any conditions. National and state governments issued advice during heat waves, such as to stay indoors and drink water.

High temperatures are also an important occupational health hazard. In order to cope with heat, an instinctive adaptive action by a worker is to reduce work intensity or increase the frequency of short breaks. Therefore, one direct effect of a higher number of very hot days is likely to be a "slowing down" in work and other daily activities.[(36)] This may result in "self-pacing" and a reduction in productivity, or it will incur risks to the health of workers unless proper occupational health management is implemented.[(37)]

"Caracteristicas de la epidemia de colera de 1998 en Ecuador durante el fenomeno de El Niño" (Characteristics of the cholera epidemic of 1998 in Ecuador during El Niño), *Revista Panamerica de Salud Publica* Vol 12, No 3, pages 157–164; also WHO (1998), "Cholera in 1997", *The Weekly Epidemiological Record* Vol 73, pages 201–208.

21. Ahern, M J, R S Kovats, P Wilkinson, R Few and F Matthies (2005), "Global health impacts of floods: epidemiological evidence", *Epidemiological Review* Vol 27, pages 36–46.

22. Mondal, N C, R Biswas and A Manna (2001), "Risk factors of diarrhoea among flood victims: a controlled epidemiological study", *Indian Journal of Public Health* Vol 45, pages 122–127.

23. Kunii, O, S Nakamura, R Abdur and S Wakai (2007), "The impact on health and risk factors of the diarrhoea epidemics in the 1998 Bangladesh floods", *Public Health* Vol 116, No 2, pages 68–74; also Schwartz, B S, J B Harris, A I Khan, R C Larocque, D A Sack, M A Malek et al. (2006), "Diarrhoeal epidemics in Dhaka, Bangladesh, during three consecutive floods: 1988, 1998 and 2004", *American Journal of Tropical Medicine and Hygiene* Vol 74, No 6, pages 1067–1073.

24. Hashizume, M, B Armstrong, S Hajat, Y Wagatsuma, A S Faruque, Y Hayashi et al. (2007), "Association between climate variability and hospital visits for non-cholera diarrhoea in Bangladesh: effects and vulnerable groups", *International Journal of Epidemiology* Vol 36, No 5, pages 1030–1037.

25. Karande, S, H Kulkarni, M Kulkarni, A De and A Varaija (2002), "Leptospirosis in children in Mumbai slums", *Indian Journal of Paediatrics* Vol 69, No 10, pages 855–858.

26. Maskey, M, J S Shastri, K Saraswathi, R Surpam and N Vaidya (2006), "Leptospirosis in Mumbai: post-deluge outbreak 2005", *Indian Journal of Medical Microbiology* Vol 24 (Supplement 4), pages 337–338.

27. See reference 26; also Karande, S, M Bhatt, A Kelkar,

In general, urban populations experience the highest heat load in cities in the dry tropics.[38] It is not clear how climate change will interact with local climate modifications due to the built environment,[39] but clearly the two causes of increased temperature will increase the heat load for urban populations and will also increase the risks to health. A central question in estimating future heat-related mortality is the rate at which populations will adapt to a warmer climate. Populations are likely to acclimatize to warmer climates through a range of behavioural, physiological and technological adaptations. The initial physiological acclimatization to hot environments can take place in a few days, but complete acclimatization may take several years. The rate at which changes in infrastructure will take place is likely to be much slower, however, for cities in the tropics. There will also be little benefit from the reduction in the number of "cold" days, as these are few and have little effect on mortality in comparison with winter effects in temperate populations.

In tropical regions, very high heat load exposure in urban areas will become more frequent. Persons living in informal structures may be more exposed to high temperatures. In Europe, the prevention of deaths in the community as a result of extreme high temperatures (heat waves) is now an issue of public health concern. It is likely that methods for addressing heat wave impacts on health will be developed in Asian cities, and some pilot projects have already been established in China.[40]

Global climate change may also exacerbate outdoor air pollution in Asian cities. Urban environmental problems such as outdoor air pollution have, in general, been decreasing steadily in developed countries because of active control measures. In low-income countries, increasing traffic and exhaust as well as industrial emissions are raising concentrations of SO_2, NO_x, O_3 and suspended particulate matter, which are known to be damaging to human health.[41] Delhi has high levels of urban pollution as a result of rapid industrialization and large numbers of small-scale industries in residential areas. Studies in Europe have shown that climate change may increase the number of days with high levels of tropospheric ozone (a secondary air pollutant).[42]

V. LONGER-TERM CHANGES AND THE FUTURE HEALTH OF POPULATIONS IN CITIES

In recent decades, there have been improvements in the health of populations in cities, but these improvements are not equally distributed and high health burdens persist in the urban poor, particularly those living in informal settlements and slums.[43] The traditional approach to climate risk assessment – the top-down scenario-based approach – is undertaken at the regional or national level. Very few city assessments have been undertaken. Larger-scale studies rely on national projections of economic growth and do not address important inequalities within countries (or cities), and so do not focus on the impacts on the most vulnerable populations.[44]

One approach, in the near term, is to assume that current trends in household income and health status will continue. For slum populations, this would mean a decline in health status and an increase in vulnerability to climate change. In the longer term (projections to the 2050s), one might assume some improvements in health and an improved capacity to

M Kulkarni, A De and A Varaija (2003), "An observational study to detect leptospirosis in Mumbai, India, 2000", *Archives of Diseases of Childhood* Vol 88, No 12, pages 1070–1075.

28. See reference 21.

29. Young, S, L Balluz and J Malilay (2004), "Natural and technologic hazardous material releases during and after natural disasters: a review", *Science of the Total Environment* Vol 322, pages 3–20.

30. See reference 21; also Euripidou, E and V Murray (2004), "Public health impacts of floods and chemical contamination", *Journal of Public Health* Vol 26, No 4, pages 376–383.

31. Koopman, J S, D R Prevots, M A Marin, H G Dantes, M L Aquino, I M Longini Jr et al. (1991), "Determinants and predictors of dengue infection on Mexico", *American Journal of Epidemiology* Vol 133, pages 1168–1178.

32. MacDonald, G (1957), *The Epidemiology and Control of Malaria*, Oxford University Press, UK.

33. Gubler, D J (1998), "Resurgent vector-borne diseases as a global health problem", *Emerging Infectious Diseases* Vol 4, Special Issue, pages 442–450.

34. Kovats, R S and S Hajat (2008), "Heat stress and public health: a critical review", *Annual Review of Public Health* (in press).

35. Gaffen, D J and R J Ross (1998), "Increased summertime heat stress in the US", *Nature* Vol 396, pages 529–530.

36. Kjellstrom, T (2000), *Climate Change, Heat Exposure and Labour Productivity*, Proceedings of the 12th Conference of the International Society for Environmental Epidemiology (ISEE), 19–23 August, Buffalo, USA.

37. Mairiaux, P and J Malchaire (1985), "Workers self-pacing in hot conditions: a case study", *Applied Ergonomics* Vol 16, No 2, pages 85–90.

adapt to climate change. An assessment of future health impacts should be undertaken using both optimistic and pessimistic assumptions about future health status. It is also important to consider that there are likely to be limits to the amount of climate change that can be managed (or adapted to). In particular, limits to water availability as a result of overexploitation and environmental degradation are likely to cause significant negative impacts on health.

VI. RESPONDING TO CLIMATE CHANGE: ADAPTATION AND HEALTH AT THE CITY LEVEL

Urban populations, particularly poor urban populations, are currently not well adapted to climate and weather events. There is a particularly large burden of disease in urban poor populations due to temperature and rainfall extremes, and reducing this burden should be a priority for city governments.

A prerequisite for the prevention of adverse health effects from extreme events is knowledge about the nature of the risk. Although public awareness increases following a natural disaster, it is often short lived. There is a clear need to develop and evaluate effective public health interventions for extreme weather events, such as heat health-warning systems to reduce the impact of heat waves. However, the implication of the French heat wave of 2003 was that not only were public health officers unprepared but the entire infrastructure was unprepared for such extreme temperatures. It will take many decades to adapt housing in order to maintain comfortable indoor temperatures in the face of prolonged extreme outdoor temperatures, especially in ways that will not increase energy consumption.

Many low-income countries have now begun to assess their needs for adaptation under the National Adaptation Programme of Action (NAPA) process of the UN Framework Convention on Climate Change (UNFCCC). So far, the focus on NAPAs has been on impacts in agriculture, forestry and water resources management. Of those published so far in Asian countries, health effects are addressed in Bangladesh and Bhutan. The methods and tools for assessing the future risks to health from climate change are still being developed.[45] City-specific vulnerability assessments have also been undertaken in Dhaka[46] and in Cochin, India.[47]

There will always be uncertainties about the magnitude of adverse impacts of climate change, particularly relating to future changes in rainfall. We are confident, however, that the burden of ill-effects will most probably fall predominantly on those populations who have contributed little to greenhouse gas emissions.

More assessments of the impacts of climate change on health at the city level are needed in order to inform decision making. We support the recent recommendations from the World Bank:[48]

- reliable and comprehensive assessments of risk vulnerabilities for exposed cities, and the dissemination of such information;
- establishment of early warning systems and evacuation plans, including emergency preparedness and neighbourhood response systems;
- improved efficiency of the water supply management;

38. Jauregui, E (1991), "The human climate of tropical cities: an overview", *International Journal of Biometeorology* Vol 35, pages 151–160.

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- improving health educational and institutional capacity in urban environment management; and
- regularizing property rights for informal settlements and other measures to allow low-income groups to buy, rent or build good-quality housing on safe sites.

VII. CONCLUSIONS

Climate change represents a range of environmental hazards and will affect populations where the current burden of climate-sensitive disease is high – such as the urban poor in low- and middle-income countries. It is not the rapid development, size and density of cities that are the main determinants of vulnerability but, rather, the increased populations in hazard zones, flood plains, coastal hazard risk zones and unstable hillsides vulnerable to landslides.(49) The scientific evidence, although limited for low-income populations, indicates that current weather extremes have significant impacts on human health, particularly the impacts of heat waves, floods and heavy rainfall events. The methods for assessing the risks of climate change are undergoing development and there is a need to shift the focus from global and regional to local studies. Sectoral approaches to climate change impact assessments often ignore the effects on health. There is a need to better describe the risks to health as well as improve the effectiveness of public health interventions. Improving the resilience of cities to climate change also requires improvements in the urban infrastructure, and such improvements may not be achieved quickly enough to avoid an increased burden of disease due to global climate change.

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