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Impacts of climate change on health with respect to water, sanitation and hygiene: summary of publications

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[1] Consortium comprises Harewelle International Limited, NR International, Practical Action Consulting, Cranfield University and AEA Energy and Environment

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1. Description of enquiry

Request to DEW Point:
Undertake a search of the recent (say last 5 years) academic and grey literature on the likely impacts of climate change in sub-Saharan Africa and South Asia on human health. Our interest is especially on those health issues related to water supply, sanitation (in the broad sense) and hygiene, but the search should not necessarily be limited to these. Provide a list of documents with brief notes summarising their content (if the abstracts are of good quality, these will do); provide the documents themselves (in electronic form); and provide a 2-3 page summary report, based on a reading of the documents, supplemented if time permits with a skim-read of the documents themselves. Target should be about 25-30 relevant articles or documents, with at least half being from the academic peer-reviewed literature.

2. Impacts of climate change on health with respect to water, sanitation and hygiene: summary of publications

By Alison Parker, Centre for Water Science, Cranfield University

This report aims to list academic papers and reports which describe the impacts on health of climate change. It focuses on the health impacts related to water, sanitation and hygiene. Firstly, it is necessary to define what diseases and conditions can arise from poor water and sanitation provision. The best review is provided by Mara and Alabaster (1995): http://www.personal.leeds.ac.uk/~cen6ddm/pdf%27s%201972-1999/e19.pdf.

This paper lists the diseases relating to water and sanitation. Due to the time constraints of this project, this report focuses on these disease aspects, with some focus on unspecified diarrhoeal disease and illness arising from poor chemical water quality. Further health impacts will arise from increased water stress, as water stress will cause migration and violent conflict, but these are not described here.

2.1 Findings

There has been relatively little work on the impact of climate change on water and vector borne diseases. Until climate change became a widely recognized phenomenon there were few attempts to correlate climate and disease occurrence; hence there is little historic data to analyze (McMichael et al 2006). The literature that does exist tends to concentrate on a small number of case studies, for example malaria in the East Africa highlands (Hay et al 2004, Zhou et al 2004, Pascual et al 2006, Paaijmans et al 2009) and India (Anon, 2007, Bhattachnaya et al 2008), and diarrhoeal disease in Bangladesh (Koelle 2005, McMichael at al 2006, Hasizume 2007, 2008). Typically these case studies are revisited and debated; there is not an even worldwide distribution of case studies in the academic literature. The grey literature (UNICEF 2008, WHO 2008, World Vision International 2009, UNICEF 2009) typically tries to make worldwide generalizations from these specific and controversial case studies and as such should be treated with caution.

More specifically, the debate on malaria transmission centres around the question of whether the spread of malaria into high altitude areas is caused by climate change or by increased drug resistance (Thomas et al 2004, van Lieshoult et al 2004, Patz et al 2005, McMichael et al 2006, Shea et al 2007, Byass 2009, Markandya and Chiabai 2009, World Vision International 2009). It is also thought that whilst climate change may cause some areas to become more favourable for malaria transmission, some will become less so, so the disease burden on Africa as a whole will remain approximately constant (Haines et al 2006, WHO

2008), although the transmission season may also lengthen (Haines et al 2006). There are also a few papers which discuss the impact of climate change on vector borne diseases generally (Sutherst 2004, Shea et al 2007, Patz et al 2008, Reiter 2008, WHO 2008).

Less controversially, cholera transmission has been linked to increased precipitation and warmer temperatures, so some areas will experience a greater number of cholera outbreaks under a changed climate (Patz et al 2005, McMichael et al 2006). Cholera prevalence has also been linked to El Nino weather patterns (Koelle 2005).

There has been a limited amount of work linking general diarrhoeal disease to climate (World Vision International 2009). For example, it has been linked to increased precipitation (Hashizume 2007, Taylor et al 2008, UNICEF 2008), increased temperatures (Hashizume 2007, 2008, IPCC 2008), low humidity (Hashizume 2008) and high river levels (Hashizume 2008).

Flooding is the most widely cited climatic change that will impact human health, as it will increase exposure to pathogens. While many authors refer to it only briefly (Haines et al 2006, McMichael et al 2006, Tibbetts 2007, IPCC 2008, WHO 2008, Markandya and Chiabai 2009, Sasaki 2009, UNICEF 2009), Ahern et al (2005) provide a more detailed review.

Conversely, droughts were infrequently mentioned, apart from the indirect effects of water scarcity. The only exception was a paper linking chikungunya fever to droughts, probably through high temperatures and unsafe water storage (Chretien 2007).

Other health impacts of climate change are discussed more briefly in the literature, although it is acknowledged that there are a few models linking large-scale climate change to impacts at a household level (IPCC 2008). The impacts include:

- decreased river flows causing contaminants (both microbiological and chemical) to become more concentrated (IPCC 2008, WHO 2008, Costello 2009, World Vision International 2009)
- warmer temperatures increasing pathogen replication (UNICEF 2008)
- water scarcity compromising hygiene (IPCC 2008, WHO 2008)
- water scarcity leading to increased greywater recycling which can expose populations to contaminants (WHO 2008)
- warmer temperatures increasing the growth of toxic algal blooms in lakes (McMichael et al 2006, IPCC 2008)
- water scarcity leading to people sharing water with their livestock, which increases their exposure to pathogens (Tibbets 2007)
- lakes and wetlands shrinking in size, so that birds and mosquitoes are in closer contact leading to the transmission of West Nile virus (Tibbets 2007)
- salinization of water supplies affecting maternal health (Khan, undated).

2.2 About the publications presented in this report

Reports and academic papers are listed below. Reports from an international perspective are listed first, followed by reports referring to specific countries. Where an abstract or summary has been provided by the reports' authors, this is given. For reports describing climate change impacts generally, a summary of the impacts relating to water and sanitation has been given *in italics.* Where the report is open access, a url has been given. Reports accessed only by subscription are provided in pdf form separately.

3. Publications

3.1 Publications with a global perspective

Climate change and children: a human security challenge
UNICEF and the Innocenti Research Centre (2008)
The study reviews the implications of climate change for children and future generations, drawing on relevant experiences in different sectors and countries of promoting child rights and well-being. It traces in considerable detail the pathways through which shifts in temperature and precipitation patterns create serious additional barriers to the achievement of the child survival, development and protection goals embraced by the international community. The role of children as vital participants and agents of change emerges as a key theme.
The report describes some health issues caused by climate change and related to water, sanitation and hygiene. It states that warmer temperatures will increase the replication rates of water borne diseases and that diarrhoeal disease will increase with the amount of rainfall. It also hints that climate refugees may end up living in peri-urban areas with inadequate infrastructure.
http://www.unicef-irc.org/publications/pdf/climate_change.pdf

Global climate change and child health: a review of pathways, impacts and measures to improve the evidence base
UNICEF (2009)
This paper reviews the published evidence of pathways and impacts of global climate change on child health. The review was occasioned by the recognition that most of the work to date on climate change and health lacks clear focus on the children's dimension, while the climate change and children literature tends to be brief or imprecise on the complex health aspects. Studies were identified by searching the PubMed database for articles published before April 2009. Publications by agencies (e.g., UNICEF, WHO, IPPC) were also included based upon review. A list of references was developed that provide evidence to the linkages between climate change and health outcomes, and on specific health outcomes for children. The analysis explores the hypothesis of disproportionate vulnerability of children's health to environmental factors, specifically those most closely related to climate change. Based upon scientific and policy research conducted to date there is found to be substantial evidence of disproportionate vulnerability of children in response to climate change. The diseases likely to be potentiated by climate change are already the primary causes of child morbidity and mortality, including vector-borne diseases, water-borne diseases and air-borne diseases. For this reason further research, assessment and monitoring of child health in respect to climate change is critical. Proposals are made for governments to integrate environmental health indicators into data collection in order to accurately assess the state of child health in relation to other age groups and its sensitivity to climate change.
The report points out that natural disaster like floods and droughts affect human interactions with water resources and therefore exposure to pathogens.
http://www.unicef-irc.org/publications/pdf/idp_2009_03.pdf

Managing the health effects of climate change
Costello A, Abbas M, Allen A, Ball S, Bell S, Bellamy R, Friel S, Groce N, Johnson A, Kett M, Lee M, Levy C, Maslin M, McCoy D, McGuire B, Montgomery H, Napier D, Pagel C, Patel J, Antonio J, de Oliveira P, Redclift N, Rees H, Rogger D, Scott J, Stephenson J, Twigg J, Wolff J, Patterson C, The Lancet 373 (9676), 1693 - 1733, 2009
Climate change could be the biggest global health threat of the 21st century. Effects on health of climate change will be felt by most populations in the next decades and put the lives and wellbeing of billions of people at increased risk. During this century, the earth's average surface temperature rises are likely to exceed the safe threshold of 2°C above pre-industrial average temperature.

This report outlines the major threats—both direct and indirect—to global health from climate change through changing patterns of disease, water and food insecurity, vulnerable shelter and human settlements, extreme climatic events, and population migration. Although vector-borne diseases will expand their reach and death tolls, the indirect effects of climate change on water, food security, and extreme climatic events are likely to have the biggest effect on global health.
A new advocacy and public health movement is needed urgently to bring together governments, international agencies, non-governmental organisations, communities, and academics from all disciplines to adapt to the effects of climate change on health.
This report highlights the increased water stress that many populations will experience. It also highlights how river water quality will decrease, as reduced river flows will increase the concentration of contaminants and increased temperature will increase microbiological activity.
http://www.thelancet.com/journals/lancet/article/PIIS0140-6736(09)60935-1/fulltext

Protecting Health from Climate Change
WHO (2008)
This report highlights the fact that increased evaporation and the removal of glaciers that provide freshwater to many communities will reduce freshwater availability. This will compromise hygiene and increase diarrhoeal disease. Unusually low levels of water will increase contamination concentrations. Water stress will also necessitate the need for new water supplies, which may include recycled wastewater. Unless properly managed, greywater schemes may increase exposure to microbial contaminants and chemicals. Floods will contaminate freshwater supplies and create opportunities for mosquitoes to breed. More extremely, they will also cause drownings and physical injuries. Malaria and dengue transmission is increased in hot, humid areas with standing water – these conditions may become more or less prevalent in a changed climate.
http://www.who.int/world-health-day/toolkit/report_web.pdf

Climate Change and Water
IPCC Technical Paper VI (2008)
This report describes some of the health impacts of various climate scenarios. Vulnerability to flooding is reduced when the infrastructure is in place to remove solid waste, manage waste water and supply potable water. Flooding has lead to water supply contamination. Decreased river flows (due to decreased rainfall) will have a greater concentration of pathogens and chemicals. Water scarcity will also reduce effective hygiene. Higher temperatures have been associated with increased diarrhoeal disease algal blooms that produce toxins in lakes. Droughts have also been linked to increased meningitis in Africa, although the exact causal mechanism is unknown. There report also makes the point that climate change is expected to increase water scarcity, but it is difficult to assess what this means at the household level for the availability of water, and therefore for health and hygiene. There is a lack of information linking large-scale modelling of climate change to small-scale impacts at the population or household level.
http://www.ipcc.ch/pdf/technical-papers/climate-change-water-en.pdf

Climate change and human health: impacts, vulnerability, and mitigation
Haines A, Kovats RS, Campbell-Lendrum D and Corvalan C, The Lancet 367 (9528), 2101-2109, 2006
It is now widely accepted that climate change is occurring as a result of the accumulation of greenhouse gases in the atmosphere arising from the combustion of fossil fuels. Climate change may affect health through a range of pathways—eg, as a result of increased frequency and intensity of heat waves, reduction in cold-related deaths, increased floods and droughts, changes in the distribution of vector-borne diseases, and effects on the risk of disasters and malnutrition. The overall balance of effects on health is likely to be negative and populations in low-income countries are likely to be particularly vulnerable to the adverse

effects. The experience of the 2003 heat wave in Europe shows that high-income countries might also be adversely affected. Adaptation to climate change requires public-health strategies and improved surveillance. Mitigation of climate change by reducing the use of fossil fuels and increasing the use of a number of renewable energy technologies should improve health in the near term by reducing exposure to air pollution.
This paper cites evidence that diarrheal disease increases following floods, and that vector-borne diseases like malaria have annual variations that can be partly explained by climatic factors including temperature, humidity, altered rainfall, soil moisture, sea level rise and seasonality. They cite a paper which states that overall, the population at risk form malaria will only increase by 5-7%, as areas where the climate causes malaria to be more prevalent will be countered by areas where it becomes less prevalent, although the transmission season will lengthen.

Climate change and human health: present and future risks
McMichael AJ, Woodruff RE and Hales S, The Lancet, 367 (9513), 859-869, 2006
There is near unanimous scientific consensus that greenhouse gas emissions generated by human activity will change Earth's climate. The recent (globally averaged) warming by 0·5°C is partly attributable to such anthropogenic emissions. Climate change will affect human health in many ways—mostly adversely. Here, we summarise the epidemiological evidence of how climate variations and trends affect various health outcomes. We assess the little evidence there is that recent global warming has already affected some health outcomes. We review the published estimates of future health effects of climate change over coming decades. Research so far has mostly focused on thermal stress, extreme weather events, and infectious diseases, with some attention to estimates of future regional food yields and hunger prevalence. An emerging broader approach addresses a wider spectrum of health risks due to the social, demographic, and economic disruptions of climate change. Evidence and anticipation of adverse health effects will strengthen the case for pre-emptive policies, and will also guide priorities for planned adaptive strategies.
This paper starts by pointing out that before the prospect of anthropogenic climate change emerged, epidemiologists were not greatly interested in climate-health relationships. However, it does point out that excessive rainfall facilitates entry of human sewage and animal wastes into waterways and drinking water supplies, potentiating water-borne diseases. Cholera will proliferate more rapidly in warmer temperatures, and epidemics may start in previously cholera free areas. For example, increasing cholera outbreaks have been strongly related to the changes in intensity of the El Nino cycle in Bangladesh. Climate change is also amplifying harmful algal blooms. The paper also discusses the debate around malaria and dengue increases in East Africa.

Impact of regional climate change on human health
Patz JA, Campbell-Lendrum D, Holloway T and Foley JA, Nature 438, 310-317, 2005
The World Health Organisation estimates that the warming and precipitation trends due to anthropogenic climate change of the past 30 years already claim over 150,000 lives annually. Many prevalent human diseases are linked to climate fluctuations, from cardiovascular mortality and respiratory illnesses due to heatwaves, to altered transmission of infectious diseases and malnutrition from crop failures. Uncertainty remains in attributing the expansion or resurgence of diseases to climate change, owing to lack of long-term, high-quality data sets as well as the large influence of socio-economic factors and changes in immunity and drug resistance. Here we review the growing evidence that climate–health relationships pose increasing health risks under future projections of climate change and that the warming trend over recent decades has already contributed to increased morbidity and mortality in many regions of the world. Potentially vulnerable regions include the temperate latitudes, which are projected to warm disproportionately, the regions around the Pacific and Indian oceans that are currently subjected to large rainfall variability due to the El Niño/Southern Oscillation, sub-Saharan Africa, and sprawling cities where the urban heat island effect could intensify extreme climatic events.

This paper discusses the debate on the impact of climate change on malaria, dengue and cholera transmission rates.

Global climate change
Shea KM, and the Committee on Environmental Health, Paediatrics, published online, 2007
There is a broad scientific consensus that the global climate is warming, the process is accelerating, and that human activities are very likely (>90% probability) the main cause. This warming will have effects on ecosystems and human health, many of them adverse. Children will experience both the direct and indirect effects of climate change. Actions taken by individuals, communities, businesses, and governments will affect the magnitude and rate of global climate change and resultant health impacts. This technical report reviews the nature of the global problem and anticipated health effects on children and supports the recommendations in the accompanying policy statement on climate change and children's health.
This paper points out the simple fact that increased storms and floods will provide standing water for mosquitoes and other vectors to breed. It points out that there is no easy formula that predicts climate change–related infection risk with confidence, but it does state that climate change is expanding the range of host mosquitoes to higher altitudes and higher latitude, and that warmer temperatures speed the development of the parasite within the host vector.
http://pediatrics.aappublications.org/cgi/reprint/peds.2007-2646v1

Driven to Extremes: Health Effects of Climate Change
Tibbetts J,Environmental Health Perspectives, 115 (4), 2007
During droughts, water quality may decrease as people share water with their livestock. During floods, pathogens are washed from sewers, farms and streets into drinking water supplies. A drought followed by flooding also encourages rodent and rodent-borne disease outbreaks as rodent populations boom in the wake of replenished water supplies. When water sites shrink, mosquitoes and infected birds become concentrated in the same places, and this enhances the transmission of the West Nile virus.
http://ehp.niehs.nih.gov/members/2007/115-4/focus.html

Climate change and malaria: analysis of the SRES climate and socio-economic scenarios
M van Lieshout, RS Kovats, MTJ Livermore and P Martens, Glob Environ Change 14**,** 87–99, 2004
The distribution and seasonal transmission of malaria is affected by climate, as both vector and parasite are sensitive to temperature. A global model of malaria transmission has been developed to estimate the potential impact of climate change on seasonal transmission and populations at risk of the disease (MIASMA v.2.2). “Population at risk” is defined as the population living in areas where climate conditions are suitable for malaria transmission. This assessment describes model simulations driven by the latest scenarios from the IPCC. The climate scenarios were derived from the Hadley Centre model HadCM3 runs with four SRES emissions scenarios: A1FI, A2, B1 and B2. The additional population at risk was determined under each of the SRES population scenarios by downscaling national estimates to the 0.5×0.5° scale grid and re-aggregating by region. Additional population at risk due to climate change are projected in East Africa, central Asia, China and areas around the southern limit of the distribution in South America. Decreases in the transmission season are indicated in many areas where reductions in precipitation are projected by the Hadley Centre model, such as the Amazon and in Central America. The outcomes of the malaria model are sensitive to (1) spatial distribution of precipitation projections and (2) population growth in those areas where there is new risk due to climate change. This paper describes a new method for describing vulnerability to the potential impacts of climate change. Countries were classified according to their current vulnerability and malaria control status using expert judgement. This vulnerability incorporates both socio-economic status, as a measure for

adaptive capacity, and climate as malaria at the fringes of its climate-determined distribution is easier to control than malaria in tropical endemic regions. Thus, current malaria control status is used as an indicator of adaptive capacity. For those countries that currently have a limited capacity to control the disease, the model estimates additional populations at risk by 2080s in the range of 90 m (A1FI) to 200 m (B2b). The greatest impact under B2 reflects population growth in risk areas in Eurasia and Africa. Climate-induced changes in the potential distribution of malaria is projected in the poor and vulnerable regions of the world. However, climate change is not likely to affect malaria transmission in the poorest countries where the climate is already highly favourable for transmission

Global change and human vulnerability to vector-borne diseases
RW Sutherst, Clin Microbiol Rev 17, 136–173, 2004
Global change includes climate change and climate variability, land use, water storage and irrigation, human population growth and urbanization, trade and travel, and chemical pollution. Impacts on vector-borne diseases, including malaria, dengue fever, infections by other arboviruses, schistosomiasis, trypanosomiasis, onchocerciasis, and leishmaniasis are reviewed. While climate change is global in nature and poses unknown future risks to humans and natural ecosystems, other local changes are occurring more rapidly on a global scale and are having significant effects on vector-borne diseases. History is invaluable as a pointer to future risks, but direct extrapolation is no longer possible because the climate is changing. Researchers are therefore embracing computer simulation models and global change scenarios to explore the risks. Credible ranking of the extent to which different vector-borne diseases will be affected awaits a rigorous analysis. Adaptation to the changes is threatened by the ongoing loss of drugs and pesticides due to the selection of resistant strains of pathogens and vectors. The vulnerability of communities to the changes in impacts depends on their adaptive capacity, which requires both appropriate technology and responsive public health systems. The availability of resources in turn depends on social stability, economic wealth, and priority allocation of resources to public health.

Climate Change Threats to Health
World Vision International, 2009
Acute malnutrition, also called wasting, develops because children lose weight or can't gain weight. It is usually associated with emergencies where food supplies are scarce and disease outbreaks rampant. In its most serious form (severe acute malnutrition) children are visibly wasted and have oedema. For young children (aged 6-59 months) it can be detected by measuring the middle upper arm circumference (MUAC). Over recent years climate change has emerged as a new driver of malnutrition. In the wake of the 2008 food crisis, the number of children with this life-threatening condition escalated, increasing mortality rates by 5-20 times. The climate emergency is poised to exacerbate children's risk to physical injury, malnutrition and infection. For decades World Vision has worked with developing communities to help them carry an already heavy health burden from malnutrition, diarrhoea and vector-borne diseases. With climate change threatening to unravel decades of development, efforts to curb existing vulnerabilities and mainstream child-focused adaptation into development programming must be urgently stepped up. Ultimately the success of humanity adapting to a continually changing environment will be intrinsically tied to protecting the life of children.
By 2030 it is estimated that climate change will have increased the risk of diarrhoeal disease in some regions by 10%. Higher temperatures have been associated with increased cases of diarrhoea. This is due in part to an increase in the concentration of pathogens in water supplies. The paper also states that the geographical area affected by malaria will increase, particularly to high altitude area, where populations have less natural immunity.
http://www.worldvision.com.au/Libraries/3_3_1_Climate_Change/Climate_Change_Series_Part_3_-_Climate_Change_Threats_to_Health_-_The_Vulnerability_of_Children.sflb.ashx

Climate change and mosquito-borne disease: knowing the horse before hitching the cart

P. Reiter Rev. sci. tech. Off. int. Epiz., 27 (2), 383-398, 2008

Speculations on the potential impacts of climate change on human health often focus on the mosquito-borne diseases but ignore the complex interplay of the multitude of factors that are generally dominant in the dynamics of their transmission. A holistic view of this complexity – particularly the ecology and behaviour of the host and the ecology and behaviour of the vector – is the only valid starting point for assessing the significance of climate in the prevalence and incidence of these diseases.

Valuing Climate Change Impacts on Human Health: Empirical Evidence from the Literature

Markandya A and Chiabai A, Int J Environ Res Public Health., 6(2): 759–786, 2009

There is a broad consensus that climate change will increase the costs arising from diseases such as malaria and diarrhoea and, furthermore, that the largest increases will be in developing countries. One of the problems is the lack of studies measuring these costs systematically and in detail. This paper critically reviews a number of studies about the costs of planned adaptation in the health context, and compares current health expenditures with MDGs which are felt to be inadequate when considering climate change impacts. The analysis serves also as a critical investigation of the methodologies used and aims at identifying research weaknesses and gaps.

This paper comments that extreme events will lead to water contamination. It also comments briefly on the debate surrounding the change in population exposed to malaria.

http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2672348/

Disease Emergence from Global Climate and Land Use Change

Patz, JA, Olson, SH, Uejio, CK, Gibbs, HK, Med Clin N Am 92 1473–1491, 2008

Climate change and land use change can affect multiple infectious diseases of humans, acting either independently or synergistically. Although in isolated cases, disease resurgence has been attributed to recent warming trends, some of the long-term and complex problems posed by climate change may not be readily discernible from other causal factors. Expanded efforts, therefore, in empiric and future scenario-based risk assessment are required to anticipate these problems. Moreover, the many health impacts of climate and land use change must be examined in the context of the myriad other environmental and behavioural determinants of disease. Health risks are but one of many sectors expected to be affected by climate and ecologic change and represent the interconnected context in which decision makers must implement strategies. To optimize prevention capabilities, upstream environmental approaches must be part of any intervention, rather than assaults on single agents of disease. Clinicians must develop stronger ties, not only to public health officials and scientists, but also to earth and environmental scientists and policy makers. Without such efforts, we risk practicing medicine in an unsustainable manner and will inevitably benefit our current generation at the cost of generations to come.

Cholera outbreaks have been linked to algal blooms caused by increased sea surface temperatures in Bangladesh. The paper also discusses in detail how climate change might affect a variety of mosquito-borne diseases, as mosquitoes are cold blooded and hence very sensitive to temperature changes. It also discusses the sensitivity of other water borne vectors to climate.

http://www.sage.wisc.edu/pubs/articles/M-Z/patz/Patz-Olson-Uejio-Gibbs_DiseaseEmerg.pdf

Global health impacts of floods: Epidemiological evidence

Ahern MJ, Kovats RS, Wilkinson P, Few R, Matthies S, Epidemiology Review 27:36–45, 2005

This paper claims that studies linking floods and diarrhoeal mortality are inconclusive, but does cite a number of studies which link specific disease occurrence (both water and vector-borne) to floods.

http://epirev.oxfordjournals.org/cgi/content/full/27/1/36

3.2 Publications focusing on Africa

Mixed picture for changes in stable malaria distribution with future climate in Africa
CJ Thomas, G Davies and CE Dunn, *Trends Parasitol* 20**,** 216–220, 2004
Our models indicate that in the next 30–40 years, the effects of climate change on stable falciparum malaria zones in Africa are probably complex and spatially heterogeneous, and that range contractions are more likely than expansions. Notably, we did not find evidence that the highlands are particularly vulnerable to change in this period. It is only by the second half of this century that increases in the potential for stable transmission in the highlands due to climate change were projected to be strong and, even here, the response was patchy. While not denying the need to reduce greenhouse gas emissions to reduce long-term adverse impact, we suggest that climate change is unlikely to lead to widespread expansion in the distribution of stable malaria in Africa during the next few decades.
This review states that malaria outbreaks may become less predictable in a changed climate. It is generally cynical about the certainty of predicted changes in malaria transmission. A study is also cited that found that reservoirs constructed to combat water stress in Ethiopia created microclimates with increased malaria. Other studies are cited linking malaria to climate change in specific African countries. It also comments more generally on the methods for linking climate to disease prevalence.
http://journals.sfu.ca/coaction/index.php/gha/article/view/2065/2502

Shifting suitability for malaria vectors across Africa with warming climates.
Peterson AT, BMC Infect Dis, 9 (59), 2009
Climates are changing rapidly, producing warm climate conditions globally not previously observed in modern history. Malaria is of great concern as a cause of human mortality and morbidity, particularly across Africa, thanks in large part to the presence there of a particularly competent suite of mosquito vector species.
I derive spatially explicit estimates of human populations living in regions newly suitable climatically for populations of two key *Anopheles gambiae* vector complex species in Africa over the coming 50 years, based on ecological niche model projections over two global climate models, two scenarios of climate change, and detailed spatial summaries of human population distributions.
For both species, under all scenarios, given the changing spatial distribution of appropriate conditions and the current population distribution, the models predict a reduction of 11.3–30.2% in the percentage of the overall population living in areas climatically suitable for these vector species in coming decades, but reductions and increases are focused in different regions: malaria vector suitability is likely to decrease in West Africa, but increase in eastern and southern Africa.
Climate change effects on African malaria vectors shift their distributional potential from west to east and south, which has implications for overall numbers of people exposed to these vector species. Although the total is reduced, malaria is likely to pose novel public health problems in areas where it has not previously been common.
http://www.biomedcentral.com/content/pdf/1471-2334-9-59.pdf

Climate change and population health in Africa: where are the scientists?
Peter Byass Global Health Action 2009.
Despite a growing awareness of Africans' vulnerability to climate change, there is relatively little empirical evidence published about the effects of climate on population health in Africa. This review brings together some of the generalised predictions about the potential continent-wide effects of climate change with examples of the relatively few locally documented population studies in which climate change and health interact. Although ecologically determined diseases such as malaria are obvious candidates for susceptibility to

climate change, wider health effects also need to be considered, particularly among populations where adequacy of food and water supplies may already be marginal.
http://journals.sfu.ca/coaction/index.php/gha/article/view/2065/2502

Understanding the link between malaria risk and climate
Paaijmans KP, Read AF, Thomas MB, *PNAS* 106 (33), 13844-13849, 2009
The incubation period for malaria parasites within the mosquito is exquisitely temperature-sensitive, so that temperature is a major determinant of malaria risk. Epidemiological models are increasingly used to guide allocation of disease control resources and to assess the likely impact of climate change on global malaria burdens. Temperature-based malaria transmission is generally incorporated into these models using mean monthly temperatures, yet temperatures fluctuate throughout the diurnal cycle. Here we use a thermodynamic malaria development model to demonstrate that temperature fluctuation can substantially alter the incubation period of the parasite, and hence malaria transmission rates. We find that, in general, temperature fluctuation reduces the impact of increases in mean temperature. Diurnal temperature fluctuation around means >21°C slows parasite development compared with constant temperatures, whereas fluctuation around <21°C speeds development. Consequently, models which ignore diurnal variation overestimate malaria risk in warmer environments and underestimate risk in cooler environments. To illustrate the implications further, we explore the influence of diurnal temperature fluctuation on malaria transmission at a site in the Kenyan Highlands. Based on local meteorological data, we find that the annual epidemics of malaria at this site cannot be explained without invoking the influence of diurnal temperature fluctuation. Moreover, while temperature fluctuation reduces the relative influence of a subtle warming trend apparent over the last 20 years, it nonetheless makes the effects biologically more significant. Such effects of short-term temperature fluctuations have not previously been considered but are central to understanding current malaria transmission and the consequences of climate change.

Malaria resurgence in the East African highlands: Temperature trends revisited
M. Pascual, J. A. Ahumada L. F. Chaves, X. Rodó, and M. Bouma, PNAS, 103 (15) 5829-5834, 2006
The incidence of malaria in the East African highlands has increased since the end of the 1970s. The role of climate change in the exacerbation of the disease has been controversial, and the specific influence of rising temperature (warming) has been highly debated following a previous study reporting no evidence to support a trend in temperature. We revisit this result using the same temperature data, now updated to the present from 1950 to 2002 for four high-altitude sites in East Africa where malaria has become a serious public health problem. With both nonparametric and parametric statistical analyses, we find evidence for a significant warming trend at all sites. To assess the biological significance of this trend, we drive a dynamical model for the population dynamics of the mosquito vector with the temperature time series and the corresponding detrended versions. This approach suggests that the observed temperature changes would be significantly amplified by the mosquito population dynamics with a difference in the biological response at least 1 order of magnitude larger than that in the environmental variable. Our results emphasize the importance of considering not just the statistical significance of climate trends but also their biological implications with dynamical models.

Association between climate variability and malaria epidemics in the East African highlands
Zhou G, Minakawa N, Githeko AK, Yan G, PNAS 101 (8), 2375–2380, 2004
The causes of the recent re-emergence of *Plasmodium falciparum* epidemic malaria in the East African highlands are controversial. Regional climate changes have been invoked as a major factor; however, assessing the impact of climate in malaria resurgence is difficult due to high spatial and temporal climate variability and the lack of long-term data series on malaria cases from different sites. Climate variability, defined as short-term fluctuations

around the mean climate state, may be epidemiologically more relevant than mean temperature change, but its effects on malaria epidemics have not been rigorously examined. Here we used nonlinear mixed-regression model to investigate the association between auto regression (number of malaria outpatients during the previous time period), seasonality and climate variability, and the number of monthly malaria outpatients of the past 10–20 years in seven highland sites in East Africa. The model explained 65–81% of the variance in the number of monthly malaria outpatients. Nonlinear and synergistic effects of temperature and rainfall on the number of malaria outpatients were found in all seven sites. The net variance in the number of monthly malaria outpatients caused by auto regression and seasonality varied among sites and ranged from 18 to 63% (mean = 38.6%), whereas 12–63% (mean = 36.1%) of variance is attributed to climate variability. Our results suggest that there was a high spatial variation in the sensitivity of malaria outpatient number to climate fluctuations in the highlands, and that climate variability played an important role in initiating malaria epidemics in the East African highlands.

Climate variability and malaria epidemics in the highlands of East Africa.
Hay SI, Shanks GD, Stern DI, Snow RW, Randolph SE, Rogers DJ, *Trends Parasitol* 21*,* 52–53*, 2005*
Malaria epidemics in the highlands of East Africa garner significant research attention, due, in part, to their proposed sensitivity to climate change. In a recent article, Zhou et al. claim that increases in climate variance, rather than simple increases in climate mean values, have had an important role in the resurgence of malaria epidemics in the East African highlands since the early 1980s. If proven, this would be an interesting result but we believe that the methods used do not test the hypothesis suggested.
This article critiques Zhou (2004).

Drought-associated Chikungunya emergence along coastal East Africa
Chretien, J-P. Anyamba, A. Bedno, S. A. Breiman, R. F. Sang, R. Sergon, K. Powers, A. M. Onyango, C. O. Small, J. Tucker, C. J. Am J Trop Med Hyg, 76(3), 405–7, 2007
Epidemics of chikungunya fever, an *Aedes* spp.-borne viral disease, affected hundreds of thousands of people in western Indian Ocean islands and India during 2005–2006. The initial outbreaks occurred in coastal Kenya (Lamu, then Mombasa) in 2004. We investigated eco-climatic conditions associated with chikungunya fever emergence along coastal Kenya using epidemiologic investigations and satellite data. Unusually dry, warm conditions preceded the outbreaks, including the driest since 1998 for some of the coastal regions. Infrequent replenishment of domestic water stores and elevated temperatures may have facilitated Chikungunya virus transmission. These results suggest that drought-affected populations may be at heightened risk for chikungunya fever, and underscore the need for safe water storage during drought relief operations.
http://www.ajtmh.org/cgi/content/full/76/3/405

Increased risk of diarrhoeal diseases from climate change: evidence from communities supplied by groundwater in Uganda
Taylor R, Miret-Gaspa M, Tumwine J, Mileham L, Flynn, R, Howard G, Kulabako, R, Groundwater and Climate in Africa, Kampala, Uganda, 24-28 June 2008
The incidence of diarrhoeal diseases rises dramatically during the rainy season in the humid tropics where there is considerable reliance upon unpiped, groundwater-fed sources including wells and springs for domestic water supplies. Interruption of faecal-oral transmission of pathogenic microorganisms is problematic in rapidly urbanising areas of sub-Saharan Africa where access to adequate sanitation is critically limited and there are a range of contaminant pathways to water sources drawing groundwater from weathered crystalline rock aquifers. In the city of Kampala (Uganda), our high-frequency sampling of protected springs shows gross but ephemeral contamination by thermotolerant (faecal) bacteria in response to heavy rainfall events (> 10 mm·day^{-1}). Through dynamical downscaling of future

climates predicted by the HadCM3 general circulation model (SRES A2 forcing scenario) using the regional climate model, PRECIS, we show further that the frequency of heavy rainfall events is projected increase substantially over the 20th century in Uganda. Strong correlations between sanitary risk scores and bacteriological contamination of groundwater-fed sources stress, however, the importance of improved community hygiene in mitigating the increased risk of diarrhoeal diseases posed by climate change.
http://www.gwclim.org/presentations/session1/taylor.pdf

Impact of Drainage Networks on Cholera Outbreaks in Lusaka, Zambia
Sasaki S, Suzuki H, Fujino Y,Kimura Y, Cheelo M, Am J Public Health, 99, 1982–1987, 2009
Objectives: We investigated the association between precipitation patterns and cholera outbreaks and the preventative roles of drainage networks against outbreaks in Lusaka, Zambia.
Methods: We collected data on 6542 registered cholera patients in the 2003–2004 outbreak season and on 6045 cholera patients in the 2005–2006 season. Correlations between monthly cholera incidences and amount of precipitation were examined. The distribution pattern of the disease was analyzed by a kriging spatial analysis method. We analyzed cholera case distribution and spatiotemporal cluster by using 2590 cholera cases traced with a global positioning system in the 2005–2006 season. The association between drainage networks and cholera cases was analyzed with regression analysis.
Results: Increased precipitation was associated with the occurrence of cholera outbreaks, and insufficient drainage networks were statistically associated with cholera incidences.
Conclusions: Insufficient coverage of drainage networks elevated the risk of cholera outbreaks. Integrated development is required to upgrade high-risk areas with sufficient infrastructure for a long-term cholera prevention strategy.

3.3 Publications focusing on the South Asia and Pacific regions

Refractory periods and climate forcing in cholera dynamics
Koelle, K., Rodo, X., Pascual, M., Yunus, M. & Mostafa, G. Nature 436, 696–700 (2005)
Outbreaks of many infectious diseases, including cholera, malaria and dengue, vary over characteristic periods longer than 1 year. Evidence that climate variability drives these interannual cycles has been highly controversial, chiefly because it is difficult to isolate the contribution of environmental forcing while taking into account nonlinear epidemiological dynamics generated by mechanisms such as host immunity. Here we show that a critical interplay of environmental forcing, specifically climate variability, and temporary immunity explains the interannual disease cycles present in a four-decade cholera time series from Matlab, Bangladesh. We reconstruct the transmission rate, the key epidemiological parameter affected by extrinsic forcing, over time for the predominant strain (El Tor) with a nonlinear population model that permits a contributing effect of intrinsic immunity. Transmission shows clear interannual variability with a strong correspondence to climate patterns at long periods (over 7 years, for monsoon rains and Brahmaputra river discharge) and at shorter periods (under 7 years, for flood extent in Bangladesh, sea surface temperatures in the Bay of Bengal and the El Niño–Southern Oscillation). The importance of the interplay between extrinsic and intrinsic factors in determining disease dynamics is illustrated during refractory periods, when population susceptibility levels are low as the result of immunity and the size of cholera outbreaks only weakly reflects climate forcing.

Rotavirus infections and climate variability in Dhaka Bangladesh: a time-series analysis
Hashizume M, Armstrong B, Hajat S, Wagatsuma Y, Faruque ASG, Hayatshi T, Sack DA, Epidemiology and Infection, 136 (9), 1281-1289, 2008
Attempts to explain the clear seasonality of rotavirus infections have been made by relating disease incidence to climate factors; however, few studies have disentangled the effects of

weather from other factors that might cause seasonality. We investigated the relationships between hospital visits for rotavirus diarrhoea and temperature, humidity and river level, in Dhaka, Bangladesh, using time-series analysis adjusting for other confounding seasonal factors. There was strong evidence for an increase in rotavirus diarrhoea at high temperatures, by 40·2% for each 1°C increase above a threshold (29°C). Relative humidity had a linear inverse relationship with the number of cases of rotavirus diarrhoea. River level, above a threshold (4·8 m), was associated with an increase in cases of rotavirus diarrhoea, by 5·5% per 10-cm river-level rise. Our findings provide evidence that factors associated with high temperature, low humidity and high river-level increase the incidence of rotavirus diarrhoea in Dhaka.

Association between climate variability and hospital visits for non-cholera diarrhoea in Bangladesh: effects and vulnerable groups

Hashizume M, Armstrong B, Hajat S, Wagatsuma Y, Faruque ASG, Hayashi T, Sack DA, Int. J. Epidemiol. Advance Access published July 30, 2007

We estimated the effects of rainfall and temperature on the number of non-cholera diarrhoea cases and identified population factors potentially affecting vulnerability to the effect of the climate factors in Dhaka, Bangladesh. Weekly rainfall, temperature and number of hospital visits for non-cholera diarrhoea were analysed by time-series regression. A Poisson regression model was used to model the relationships controlling for seasonally varying factors other than the weather variables. Modifications of weather effects were investigated by fitting the models separately to incidence series according to their characteristics (sex, age, socio-economic, hygiene and sanitation status). The number of non-cholera diarrhoea cases per week increased by 5.1% (95% CI: 3.3–6.8) for every 10 mm increase above the threshold of 52 mm of average rainfall over lags 0–8 weeks. The number of cases also increased by 3.9% (95% CI: 0.6–7.2) for every 10 mm decrease below the same threshold of rainfall. Ambient temperature was also positively associated with the number of non-cholera diarrhoea cases. There was no evidence for the modification of both 'high and low rainfall' effects by individual characteristics, while the effect of temperature was higher amongst those individuals at a lower educational attainment and unsanitary toilet users. The number of non-cholera diarrhoea cases increased both above and below a threshold level with high and low rainfall in the preceding weeks. The number of cases also increased with higher temperature, particularly in those individuals at a lower socio-economic and sanitation status.

Climate change and its impact on health in Bangladesh

Rahman A, WHO Regional Health Forum 12(1), 2008

Climate change will increase flooding which is linked to diarrhoea, cholera, skin and eye diseases. Vector-borne diseases will have a lengthened transmission season.

http://www.searo.who.int/LinkFiles/Regional_Health_Forum_Volume_12_No_1_Climate_change_and_its_impact.pdf

Human health impacts of Climate Change in a selected population of Bangladesh, with particular focus on environmental salinization of water and adverse maternal health outcomes

Anerie Khan, Imperial College

The projected changes in climate are likely to bring about adverse effects on human health, the majority of which will fall disproportionately on poorer populations. Bangladesh has been identified as of the 27 countries most vulnerable to these impacts. Most of the land area suffers from natural and man-made hazards both in terms of acute climate events (floods and drought) and environmental degradation (salinization and soil degradation), which are likely to be exacerbated. Currently 20 million people in the Bangladesh coast are affected by varying degrees of salinity in surface and groundwater – the main source of drinking water.

We will measure variation in salt composition in drinking water sources in coastal villages and perform a hospital based case-control study on the association between salt water intake and the risk of developing (pre)eclampsia and hypertension among pregnant women

in the same areas. We will develop a model that includes different sea-level rise scenarios, the corresponding salinity intrusion and the burden of disease from hypertension associated among women.
The WHO has designated health impacts of long-term consumption of highly saline water as a priority for investigation under its Public Health Initiative. By quantitatively assessing the impacts of climate change on human health, we hope to put forward reliable adaptation options to reduce those impacts.

Climate change and malaria in India
Bhattacharya S, Sharma C, Dhiman C and Mitra AP Current Science, 90 (3), 369–375, 2006
The focus in this paper is to understand the likely influence of climate change on vector production and malaria transmission in India. A set of transmission windows typical to India have been developed, in terms of different temperature ranges for a particular range of relative humidity, by analysing the present climate trends and corresponding malaria incidences. Using these transmission window criteria, the most endemic malarious regions emerge as the central and eastern Indian regions of the country covering Madhya Pradesh, Jharkhand, Chhatisgarh, Orissa, West Bengal and Assam in the current climate conditions. Applying the same criteria under the future climate change conditions (results of HadRM2 using 1S92a scenario) in 2050s, it is projected that malaria is likely to persist in Orissa, West Bengal and southern parts of Assam, bordering north of West Bengal. However, it may shift from the central Indian region to the south western coastal states of Maharashtra, Karnataka and Kerala. Also the northern states, including Himachal Pradesh and Arunachal Pradesh, Nagaland, Manipur and Mizoram in the northeast may become malaria prone. The duration of the transmission windows is likely to widen in northern and western states and shorten in the southern states. The extent of vulnerability due to malaria depends on the prevailing socio-economic conditions. The increase or decrease in vulnerability due to climate change in the 2050s will therefore depend on the developmental path followed by India. Therefore it is important to understand the current adaptation mechanisms and improve the coping capacities of the vulnerable section of the population by helping to enhance their accessibility to health services, improved surveillance and forecasting technologies.
http://www.ias.ac.in/currsci/feb102006/369.pdf

Workshop of climate change and health in south east and east Asian countries, 2-5 July 2007, Kuala Lumpur, Malaysia. Country Report – India
Climate change may spread malaria to new areas, particularly high altitude areas.
http://www.whoindia.org/LinkFiles/Health_&_Environment_Country_report_Climate_Change_KL_Workshop.pdf

Climate Variability and Change and Their Potential Health Effects in Small Island States: Information for Adaptation Planning in the Health Sector
Ebi KL, Lewis ND, Corvalan C, *Environmental Health Perspectives* 114 (12) 2006
Small island states are likely the countries most vulnerable to climate variability and long-term climate change. Climate models suggest that small island states will experience warmer temperatures and changes in rainfall, soil moisture budgets, prevailing winds (speed and direction), and patterns of wave action. El Niño events likely will strengthen short-term and interannual climate variations. In addition, global mean sea level is projected to increase by 0.09–0.88 m by 2100, with variable effects on regional and local sea level. To better understand the potential human health consequences of these projected changes, a series of workshops and a conference organized by the World Health Organization, in partnership with the World Meteorological Organization and the United Nations Environment Programme, addressed the following issues: the current distribution and burden of climate-sensitive diseases in small island states, the potential future health impacts of climate variability and change, the interventions currently used to reduce the burden of climate-sensitive diseases, additional interventions that are needed to adapt to current and future health impacts, and the health implications of climate variability and change in other sectors. Information on these

issues is synthesized and key recommendations are identified for improving the capacity of the health sector to anticipate and prepare for climate variability and change in small island states.
This report points out that small island states typically rely on a single source for their water supply, so they are especially vulnerable to changes in precipitation or rising sea levels.
http://ehp.niehs.nih.gov/members/2006/8429/8429.pdf