Climate and health in informal urban settlements

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This paper guides those who are interested in the current and potential health impact of climate change on urban populations in low- and middle-income countries. It describes the sources and types of health data available to assess current disease burdens and the relative importance of environmental risk factors. This includes how to identify sources of mortality and morbidity data in cities. It also shows how health data are incorporated into survey designs with examples of how this can assess weather and climate related disaster impacts on health in particular cities. Such work is challenging when routine health data (including the recording of causes of death) are not available.

Contents

Acronyms

AIS	AIDS Indicator Survey
AMMP	Adult Mortality and Morbidity Project (Tanzania)
APHRC	Africa Population and Health Research Centre
DALY	disability-adjusted life-year
DHS	Demographic and Health Survey
GBD	Global Burden of Disease
EM-DAT	Emergency Events Database
HFA	Hyogo Framework for Action
HIV	human immunodeficiency virus
ICDDR,B	International Centre for Diarrhoeal Disease Research, Bangladesh
IDSR	integrated disease surveillance and response
IIED	International Institute for Environment and Development
INDEPTH	International Network for the Demographic Evaluation of Populations and their Health
IPCC	Intergovernmental Panel on Climate Change
MIS	Malaria Indicator Survey
NCD	non-communicable disease
NUHDSS	Nairobi Urban Health and Demographic Surveillance Site
OECD	Organisation for Economic Cooperation and Development
STI	sexually transmitted infection
SVRS	sample vital registration
WHO	World Health Organization
UN	United Nations
UNIDSR	United Nations Office for Disaster Risk Reduction
YLL	years of life lost

Glossary

Resources to find more detailed and technical definitions of the below terms include the IPCC glossaries (for climate) (IPCC, 2013a), the Dictionary of Epidemiology (for health) (Porta, 2008), the World Health Organization website (for health, www.whot.int) and the OECD glossaries (general, http://stats.oecd.org/glossary/). Most of the below definitions are based on these resources.

Attributable risk:	The excess risk in a population exposed to a risk factor compared to an unexposed population.
Burden of disease:	The amount of death and/or disability in a population.
Climate:	Narrowly defined, climate refers to the average weather. The classical averaging period is 30 years.
Climate change:	A change in the state of the climate that can be identified statistically by changes in the mean (or variability) of its properties and persists for an extended period.
Cross-sectional study:	An observational study that involves collecting data on a population or a representative sample of a population at a single point in time.
Disability-adjusted life-year (DALY):	DALYs measure of the potential years of life lost due to premature mortality and/or disability from a disease or risk factor for disease. One DALY can be thought of as one year of healthy life `lost'.
Episode analysis:	A study that investigates how a discrete event, such as a flood or a heat wave, impacts health.
Exposure-response function:	The estimated change in a health outcome associated with a given level of exposure to a stressor after a certain amount of exposure time.
Informal settlement:	A settlement where the occupants have no legal claim to the land. Informal settlements are characterised by a lack of systematic planning and poor infrastructure.
Morbidity:	The state of ill-health resulting from a disease or injury.
Natural hazard:	Severe or extreme weather such as a flood or drought. When a natural hazard affects a vulnerable population to produce serious damage (to health or the economy), it is classified as a disaster.
Relative risk:	The ratio of the probability of occurrence of an event (death or disease) in an exposed compared to an unexposed group (or population).
Surveillance (data):	The ongoing collection, collation, and analysis of data. At its best, surveillance is active and systematic, recording long-term data on populations residing in established surveillance sites. Surveillance sites are often used as an alternative to vital registration where vital registration is inadequate or incomplete.
Time-series regression:	A commonly used study design in environmental epidemiology to investigate associations between short-term environmental exposures (particularly weather variables and air pollution) and health (often mortality or hospital admissions). Most often, time-series studies explore how day-to-day variations in exposure affect day-to-day changes in health.
Urbanisation:	The increasing concentration of people in urban areas.
Vital registration:	Government records of births and deaths in a population under a defined jurisdiction.

Executive summary

Rapid unplanned development with poor urban infrastructure is a leading cause of disease in populations in Africa and South Asia. Many urban populations are currently not well adapted to extreme weather, and now the climate is changing. Climate change is expected to negatively impact on health through increasing seasonal temperatures, changing rainfall patterns, increases in frequency of weather and climate extremes, and sea level rise

This report describes the sources and types of health data available to assess the current effects of climate and weather exposures on urban populations in Africa and Asia, with a focus on informal settlements in Dar es Salaam (Tanzania), Ibadan (Nigeria), Nairobi (Kenya), and Dhaka (Bangladesh).

Current disease burdens have been estimated for specific environmental factors (e.g. household air pollution, outdoor air pollution, water/sanitation) and for specific diseases. However, scientific evidence regarding the environmental determinants of health is limited in informal settlements. Recent burden of disease analysis has only been conducted for Nairobi. An older project estimated disease burdens in Dar es Salaam, but it was not been updated in the past decade. There are no comparable studies for Dhaka or Ibadan.

Observational studies can improve our understanding of how populations respond to extreme weather events. Several epidemiological study designs can be used to assess the relationship between weather and climate variables, and human health, including episode analyses, time-series regression and cross-sectional studies. The main sources of health data available in the four cities are described. Data from long-term demographic surveillance sites provide the most useful health information, and these are available for populations in Nairobi and Dhaka. A key data limitation is the poor coverage of vital registration systems in all four cities.

Urban populations are particularly vulnerable to disasters, due to the concentration of persons and infrastructure. Global level disaster data related to health are limited to mortality data associated with specific events and often impacts in populations in informal settlements are not identified. Current knowledge of the impacts of weather disasters (floods, heat waves, and droughts) is derived from published studies, indicators on a range of impacts on mortality, injuries, infectious diseases and nutrition-related outcomes.

1 Introduction

Unplanned development with poor infrastructure is a leading cause of disease in urban populations in Africa and South Asia (Alirol *et al*., 2011, Alwan, 2011). Both regions are also experiencing other rapid environmental changes, including climate change, land degradation, pollution of air and water, and the loss of environmental resources.

Climate change in particular has become a research priority, as the potential scale of future adverse health impacts has becomes clearer (Hales, 2014). However, there is still little research on the likely impacts of climate change on specific urban populations, particularly in lower income countries. A first step in estimating the potential future impacts of climate change is to understand how the health of populations is affected by climate factors, including extreme weather events. This brief report describes the sources and types of health data available to assess the current effects of climate and weather on urban health in Africa and Asia, with a focus on informal settlements. It also briefly describes some key study epidemiological designs. The report has been developed for the International Institute for Environment and Development (IIED) and is aimed at researchers working on climate change impacts in informal settlements.

The specific objectives of this report are to:

- describe the current environmental burden of disease in selected sites, as well as the relative importance of different environmental risk factors;
- identify sources of mortality and morbidity data in the sites of interest;
- describe how to apply health data in some basic study designs (for observational weather and health studies); and,
- describe weather- and climate-related disaster impacts on health, and data sources in the sites of interest.

This report focuses on four cities in Africa and Asia with large populations in informal settlements:

- Dar es Salaam, Tanzania
- Ibadan, Nigeria
- Nairobi, Kenya
- Dhaka, Bangladesh.

2

Climate change and urban health

More than half the world's population currently lives in urban areas. While this threshold is not expected to be crossed in Asia until 2020 or Africa until 2035, urban populations there are growing rapidly and almost all future population growth is projected to occur in cities in low- and middle-income countries (UN Department of Economics and Social Affairs, 2012). Africa has had the fastest rate of urban population growth among the world's regions and among the fastest growth in levels of urbanisation (UN Department of Economics and Social Affairs, 2012).

At present, about 40 per cent of Sub-Saharan Africa's and 30 per cent of South Asia's urban population are estimated to live in urban `slums' (UN Human Settlements Programme, 2012). In absolute terms, this is about 200 million people in each region.[1] Projections suggest that the global slum population could double from close to one billion at present to two billion by 2030 (UN Human Settlements Programme, 2003).

Urban populations, particularly poor urban populations, are currently not well adapted to climate and weather events, with high population density often increasing vulnerability (principally to flooding) (See Table 1). However, the burden of disease in urban poor populations due to temperature and rainfall extremes is not well described (Kovats and Akhtar, 2008).

A prerequisite for the prevention of adverse health effects from extreme events is good evidence about the nature of the risk. Several models of risk are available within different disciplines and policy areas (public health, disaster risk reduction, climate change adaptation) but these are often poorly linked together.

To help understand how environmental risk factors influence population health, it is important to be familiar with the existing evidence base regarding current health burdens. This evidence is derived from observational studies and risk assessments. However, the lack of routine health data that are available, and are of good quality, remains a significant barrier to this kind of research.

[1] Estimates of urban slum populations for other `developing regions' are (in thousands) – North Africa: 13,000; Latin America and Caribbean: 110,000; Eastern Asia: 210,000; South-eastern Asia: 80,000; Western Asia: 36,000; Oceania 600 UN HUMAN SETTLEMENTS PROGRAMME 2012. State of the World's Cities 2012/2013: Prosperity of Cities. Nairobi: UN-HABITAT.

Table 1: Potential impacts of climate change on urban areas

CHANGED AVERAGE CONDITIONS		CHANGED EXTREMES (FREQUENCY, INTENSITY)	
CHANGE	IMPACTS	CHANGE	IMPACTS
Increased temperature	Increased energy demands for cooling; worsening air quality; urban heat-island effect; changes in vector habitats, changes in infectious disease dynamics.	Tropical cyclones and heavy rainfall events[a]	Increased risk of flooding and landslides; displacement; damage to infrastructure, businesses, and homes; crop loss.
Increases or decreases in precipitation	In-migration of rural populations due to loss of livelihoods; declines in agricultural production; disrupted food supply; changed vector habitats.	Drought	Water shortages; crop loss; increased food prices; disruption of hydroelectricity; increased rural-urban migration
Sea level rise	Coastal flooding; salinisation; loss of agricultural land.	Heatwaves	Increase in frequency and intensity of heatwaves. Risk of power failures associated with surge in energy demand.

Source: Adapted from World Disasters Report 2010 (International Federation of Red Cross and Red Crescent Societies, 2010).

[a] heavy rainfall generally accompanies tropical cyclones

Climate change in Africa

Climate change is projected to cause an increase in annual and seasonal temperatures in all regions of Africa, although rates of warming are less than those projected at higher latitudes (IPCC, 2013b). Precipitation projections are less certain, as climate models are less consistent in their seasonal mean rainfall responses. These inconsistencies are explained in part by the poor representation of rainfall in climate models, and also because rainfall patterns are governed by complex teleconnections and feedback mechanisms linked to climate patterns in other regions in the world. Other factors that complicate African climatology include dust aerosol concentrations and sea-surface temperature anomalies (which are particularly important in the Sahel region and southern Africa), deforestation in the equatorial region, and soil moisture in southern Africa. These uncertainties make it difficult to provide precise estimations of future impacts, but overall the most recent (AR5) IPCC Assessment (IPCC, 2013b) anticipates the following future effects:

- Regional temperature changes, warming across all sub-regions.
- Regional rainfall change, with drying over southern Africa, but other regional changes are less certain.
- Increases in the frequency and intensity of rainfall and temperature extremes.
- Sea level rise.

These changes should be interpreted in the context of vulnerability. For example, populations in Africa are known to be vulnerable to drought, particularly in the Sahel, the Horn of Africa, and Southern Africa (Washington *et al.*, 2008) and some regions (West Africa) have already experienced more intense and longer droughts.

Climate change in Asia

The IPCC has assessed the scientific evidence for both observed and future changes in climate in Asia (Hijioka, 2014). Over the last half century there has been a general warming trend as well as an increase in temperature extremes. Patterns of change in precipitation are less consistent, with both increases and decreases seen across the region. In South Asia, observations suggest there has been an increase in heavy rainfall events. For tropical and extra-tropical cyclones it not possible to identify any trends over short time scales (i.e. decades), but observations are suggestive of increased activity in some sub-regions, and decreased activity in others.

In the future and under a low emissions scenario, an increase in average temperature of less than 2°C is projected by the end of the 21st Century (relative to temperature at the end of the 20th Century). Under a high emissions scenario, a temperature increase of more than 2°C is projected for the region, with an increase of more than 3°C in Southeast Asia. For precipitation, under a low emission scenario, there is expected to be little change in variability in southern parts of Asia by the end of the century. Under high emissions, precipitation is projected to increase in southern areas late in the century. For tropical and extra-tropical cyclones, projections suggest that climate change will have varying effects by sub-region, but there is low confidence in projected sub-regional impacts on event frequency and wind intensity. Changes in tropical cyclones and the monsoon may bring greater extremes in rainfall extremes in South Asia.

3

The current burden of disease: the environmental and social determinants of health

Burden of disease – concept and methods

`Burden of disease' estimates, also called `disease burdens', refer to the amount of deaths and/or disability in a population. Disease burdens can be attributed to a specific disease (e.g. lung cancer) or risk factor for disease (e.g. particulate air pollution), and have an important role to play in designing public health strategies. Murray (1994) describes four key benefits to measuring disease burdens:

1) To help set health service priorities.
2) To help set research priorities.
3) To help identify disadvantaged groups and target interventions accordingly.
4) To provide a comparable measure for planning and evaluating interventions and programmes.

There are a number of different measures that can be used to estimate the burden of disease in a population. *Mortality burdens*, which quantify only the number of attributable deaths, are the most basic and require relatively little data. Mortality burdens can often be collated directly from vital registration data (death certificates). A more sophisticated measure is the quantification of the *years of life lost* (YLL) that results from a given disease or risk factor. YLL combines the age of death with an estimate of life expectancy at the time of death to calculate the amount of life that was lost prematurely (Romeder and McWhinnie, 1977). The advantage of YLL compared to mortality burdens, is that YLL accounts for the difference in loss that occurs when a younger person dies. For example, a death in a 15 year old will contribute more YLL than a death in a 50 year old in the same population. This would not be captured with an estimate of mortality burdens alone.

It is also possible to integrate information on both death and disability into composite measures of health burdens (Gold *et al.*, 2002). These measures, for example the Disability Adjusted Life Year (DALY) preferred by the World Health Organization, combine YLL with estimates of years lived with disability into a single measure that estimates the amount of healthy life lost from a given disease or risk factor. The extent of disease-specific disability (in terms of time and severity) associated with a given disease is normally determined by expert opinion or survey methods that assign disability weights to different diseases based on specified criteria such as loss of mobility or pain (Gold *et al.*, 2002).

The Global Burden of Disease project (discussed further below) provides disability weights for diseases on a scale from 0–1 where a score of 1 represents perfect health (Institute of Health Metrics, 2012). For example, HIV/AIDS without antiretroviral treatment has a disability weight of 0.5 (rounded). Therefore, if an HIV patient lives for five years after acquiring the disease and then dies 15 years prematurely as a result of it, the DALY calculation is as follows:

15 + (0.5*5) = 17.5 DALYs.

In other words, this person has lost 17.5 years of healthy life due to HIV/AIDS.

The above discussion provides only a brief summary of some of the methods used to quantify disease burdens. There are many other technical issues, for example whether to discount expected future disease burdens and whether to weight disease burdens differently depending on the age of the individual. These issues have been discussed in detail elsewhere (Anand and Hanson, 1997, Murray *et al.*, 2003, Murray, 1994).

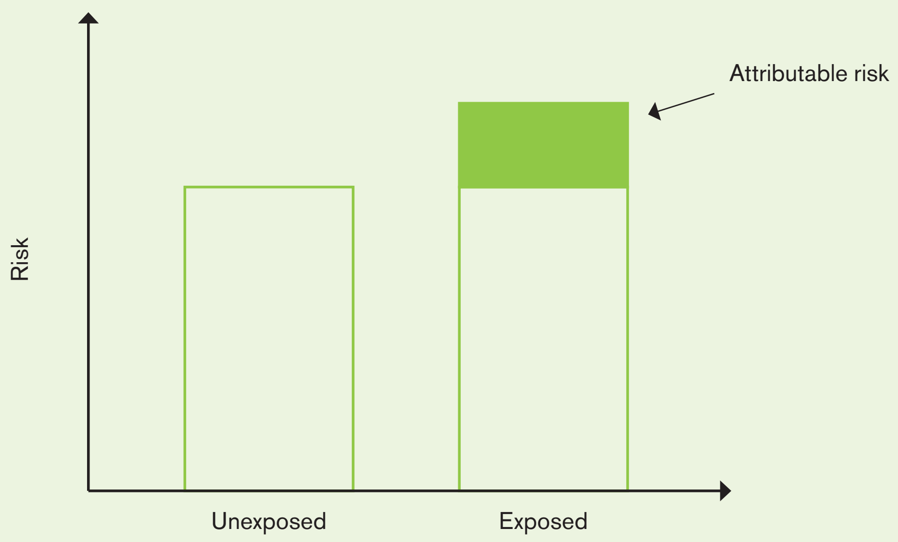
Methods for quantifying burdens attributable to environmental risk factors

It is well known that exposure to certain environmental hazards leads to disease. Important examples include indoor and outdoor air pollution, certain chemicals and lack of access to clean water and sanitation (Lim *et al.*, 2013). The `attributable risk' in a population is the percentage of the disease burden in that population that results from exposure to a given risk factor (Pruss-Ustun *et al.*, 2003). It is normally determined by comparing risk levels in an `exposed' and `unexposed' population (Figure 1). Note that there can still be a risk of disease in those `unexposed' to the risk factor of interest because the disease may also have other causes. The attributable risk provides an indication how much (what fraction) of the disease burden could be prevented by eliminating or minimising exposure to the risk factor.

Estimating disease burdens from environmental risk factors requires three types of data (Pruss-Ustun *et al.*, 2003):

1) The distribution of exposure in the study population
2) An exposure-response relationship
3) The total disease burden (of the disease of interest) in the population.

Figure 1: The attributable risk is the excess risk in an exposed population compared to an unexposed population



Source: Adapted from Pruss-Ustun *et al.* (2003).

Determining the distribution of exposure is often the most difficult aspect of a burden of disease study. For some environmental risks, exposure will be categorical, for example whether or not a household has access to an improved water supply. With other risk factors, such as outdoor air pollution, everyone will be exposed at some level, but the levels will vary widely across the population. How to determine exposure will therefore depend on the risk factor of interest and may be estimated through survey data or more complex methods. Outdoor air pollution, for example, may be estimated by combining monitoring data and a land-use regression model, while exposure to indoor air pollution may be based on personal pollution monitoring and/or time activity budgets.

Exposure-response functions estimate the excess risk of death or disability (the `response') that is associated with exposure over a specified period of time. Exposure-response functions are normally taken from the published literature and are derived from epidemiological studies. The quality of evidence determining the exposure-response function will vary depending on the risk factor, but the function is ideally derived from a meta-analysis of many published studies that are comparable.

Estimates of the burden of disease in a population may come from various sources, as described above. What specific disease should be the focus of the study clearly depends on the risk factor of interest. Air pollution studies tend to focus on all-cause and cardio-respiratory outcomes, while water and sanitation studies may look at disease burdens from diarrhoeal diseases (Lim *et al.*, 2013). Prior to conducting a burden of disease study, it is important to construct a causal web that maps the pathways to health linking the risk factor to the appropriate disease(s) (Pruss-Ustun *et al.*, 2003).

Once the three types of data are acquired, there are two main (and related) methods for estimating the disease burdens attributable to the environmental risk factor. The first and probably most common is the method used in the Global Burden of Disease study (see below) and in many WHO analyses (Pruss-Ustun *et al.*, 2003, Murray *et al.*, 2003). This method uses the `Impact Fraction' to specify how the disease burden would be different given a change in the level of exposure, and is calculated as follows (Pruss-Ustun *et al.*, 2003, Murray *et al.*, 2003):

$$IF = \frac{\Sigma P_i RR_i - \Sigma P'_i RR'_i}{\Sigma P_i RR_i}$$

where P_i refers to the proportion of the population at each exposure level i and RR_i refers to relative risk at each exposure level i. P'_i refers to the proportion of the population at each exposure level after a change in exposure.

In other words, the equation calculates the percentage of the disease burden that will be affected after an intervention (or other shock) that changes the distribution of exposure. An example is provided in Box 1. Note that if the point of the study is to determine the *total* burden of disease in a population that is attributable to a risk factor, which is effectively the same as determining the percentage that could be eliminated if the exposure were completely removed, the second part of the numerator could be replaced with a `1'.

$$IF = \frac{\Sigma P_i RR_i - 1}{\Sigma P_i RR_i}$$

`1' represents zero exposure because 100 per cent of the population will have an excess risk of 1 (i.e. no excess risk). See the second part of Box 1 for an example.

The equations above assume categorical exposure, but a generalised impact fraction can also be used (Pruss-Ustun *et al.*, 2003, Murray *et al.*, 2003). Furthermore, if relative risks are available for subpopulations (e.g. by age and/or sex), and the corresponding exposure is known, impact fractions should be calculated accordingly.

Once the impact fraction is determined, it is multiplied by the total burden of disease, *TB*, to give the burden of disease attributable to the risk factor, *AB* (Pruss-Ustun *et al.*, 2003):

$$AB = IF * TB$$

The second method for quantifying disease burdens is to use life tables. Life tables rely on actuarial methods to follow populations through time, thus providing a number of advantages, particularly with regard to the timing of impacts. For example, the above method effectively assumes that changing the distribution of an exposure will have immediate impacts, whereas many diseases (e.g. lung cancer) only occur after a long induction period and risks will not necessarily subside immediately if a risk factor is removed.

These issues can be incorporated more easily into life tables. Life tables also ensure that the number of deaths always equals the number of births – which is important when investigating potential impacts on disease burdens from multiple interventions – and allows the calculation of changes to life expectancy. Life tables have been described in detail elsewhere (Miller and Hurley, 2003, Miller and Hurley, 2006), but they are an important alternative to using the Impact Fraction. Life table models can be freely downloaded and populated with minimal additional data (Miller, 2014). The two methods have similar data requirements, and rely on similar and related methods, but life tables always require cause-specific (for the causes under study) estimates of mortality and population at each age.

BOX 1

The following provides a very simple example of how to quantify the burden of diarrhoeal disease attributable to lack of sanitation and the potential health improvement of an intervention to increase sanitation coverage.

Let us assume that hypothetical Country A has a population where 75 per cent is covered by adequate sanitation and 25 per cent is not. Assume (hypothetically) that lack of sanitation increases the risk of death from diarrhoea 10 times (relative risk = 10), whereas having sanitation obviously confers no excess risk (relative risk = 1). We are interested in answering two questions:

1) What is the burden of disease currently attributable to lack of sanitation?

2) How many life years lost could be averted by increasing coverage of sanitation by 10 per cent (so 85 per cent of the population is covered).

Beginning with the second question, we first calculate the impact fraction:

$$IF = \frac{[(0.75 * 1) + (0.25 * 10)] - [(0.85 * 1) + (0.15 * 10)]}{[(0.75 * 1) + (0.25 * 10)]} = 0.28$$

If the total burden of diarrhoeal disease in Country A is 150,000 LY lost annually, then increasing sanitation coverage by 10 per cent could reduce the burden by 28 per cent, or 42,000 LY (150,000*0.28).

Answering the first question is very similar, but `1' can replace the second term of the numerator. It is mathematically equivalent to calculating the disease burden that would be averted if the entire population had sanitation (100per cent of the population had a relative risk of 1).

$$IF = \frac{[(0.75 * 1) + (0.25 * 10)] - 1}{[(0.75 * 1) + (0.25 * 10)]} = 0.69$$

Lack of sanitation in Country A is therefore responsible for 69 per cent of the loss of 150,000 life years, or 103,500 life years.

The Global Burden of Disease assessments

The Global Burden of Disease (GBD) project was first established by WHO, but the most recent assessment was undertaken by the Institute of Health Metrics and Evaluation (IHME) (Institute of Health Metrics, 2013a). These assessments periodically estimate health burdens for a range of diseases and risk factors for nearly 200 countries (and globally) and enable the tracking of trends over time.

The results below are from the GBD 2010 project, which were reported in a series of papers in *The Lancet* (Dec. 15 2012, vol. 380;9859). There are also more specific data available from the IHME website (Institute of Health Metrics, 2013b) and through additional WHO analyses (World Health Organization, 2013). The calculations use methods largely akin to those described above.

GBD data show that for the WHO Africa region, most of the top 10 causes of death were similar in 2000 compared to 2011, with the exception of measles which dropped out of the top 20 entirely in 2011 (Figure 1) (World Health Organization, 2013). In terms of the disease burdens, trends over time generally showed improvements in health, with total DALYs and DALYS per 100,000 population lower in 2011 for most of the top 10 causes. There was more fluctuation in the rankings of the 10–20 most common causes, although most also showed an absolute decline (Figure 2). Road injury is a notable exception, as it increased over the time period, in rank and rate. The same burden of disease data for the Asia region are not reported here, but are freely available from the WHO (World Health Organization, 2013).

GBD estimates are also available for some specific risk factors for disease, with the most recent assessment focusing on risk factors for non-communicable diseases (NCDs). Environmental risk factors are not addressed comprehensively, but the latest estimates do include

Figure 2: Leading causes of DALYS, 2000 and 2011, WHO Africa Region

2000

Rank	Cause	DALYs (000s)	% DALYs	DALYs per 100,000 population
1	HIV/AIDS	76711	10.8	11686
2	Lower respiratory infections	71645	10.1	10914
3	Diarrhoeal diseases	70579	10.0	10752
4	Malaria	66500	9.4	10130
5	Preterm birth complications	38091	5.4	5803
6	Measles	37115	5.2	5654
7	Birth asphyxia and birth trauma	29094	4.1	4432
8	Protein-energy malnutrition	23849	3.4	3633
9	Meningitis	16275	2.3	2479
10	Congenital anomalies	13102	1.9	1996
11	Maternal conditions	12844	1.8	1957
12	Stroke	10620	1.5	1618
13	Iron-deficiency anaemia	10516	1.5	1602
14	Tuberculosis	10200	1.4	1554
15	Neonatal sepsis and infections	10191	1.4	1552
16	Road injury	9931	1.4	1513
17	Ischaemic heart disease	8180	1.2	1246
18	Unipolar depressive disorders	6699	0.9	1020
19	Syphilis	6290	0.9	958
20	Fire, heat and hot substances	6212	0.9	946

2011

Rank	Cause	DALYs (000s)	% DALYs	DALYs per 100,000 population
1	Lower respiratory infections	69797	10.3	8141
2	HIV/AIDS	67750	10.0	7902
3	Diarrhoeal diseases	54878	8.1	6401
4	Malaria	50389	7.5	5877
5	Preterm birth complications	38906	5.8	4538
6	Birth asphyxia and birth trauma	30771	4.6	3589
7	Protein-energy malnutrition	23303	3.5	2718
8	Meningitis	17564	2.6	2049
9	Congenital anomalies	15432	2.3	1800
10	Road injury	12954	1.9	1511
11	Neonatal sepsis and infections	12584	1.9	1468
12	Iron-deficiency anaemia	12512	1.9	1459
13	Stroke	12443	1.8	1451
14	Endocrine, blood, immune disorders	11363	1.7	1325
15	Maternal conditions	10332	1.5	1205
16	Ischaemic heart disease	9605	1.4	1120
17	Tuberculosis	9406	1.4	1097
18	Unipolar depressive disorders	8529	1.3	995
19	Interpersonal violence	7990	1.2	932
20	Epilepsy	7506	1.1	875

Source: World Health Organization (2013), based on the GBD 2010 study.

many of the most important risk factors: household (including indoor) air pollution; outdoor air pollution (particulates and tropospheric ozone); water and sanitation; and exposure to lead and radon. The study also assessed a range of occupational exposures.

Table 2 displays GBD 2010 data for sub-Saharan Africa and for Kenya, Tanzania and Nigeria (Institute of Health Metrics, 2013b). The top causes (risk factors) of death are similar across the countries with many environmental risk factors amongst the top 25. Air pollution (indoor and outdoor) and unimproved water and sanitation together account for a large proportion of the disease burdens.

Table 2: Mean ranks of risk factors in sub-Saharan Africa (SSA) and for, Kenya, Tanzania and Nigeria.

RISK FACTOR	MEAN RANK[a]			
	SSA	KENYA	TANZANIA	NIGERIA
Child underweight	1	1	2	1
Household air pollution	2 (2,6191,300)	2 (937,326)	1 (1,283,090)	2 (4,016,250)
Suboptimal breastfeeding	3	3	3	4
Alcohol use	4	7	5	3
Iron deficiency	5	4	4	5
High blood pressure	6	5	7	6
Dietary risks	7	6	8	7
Smoking	8	8	9	12
Vitamin A deficiency	9	12	16	10
Occupational risks	10	9	6	9
Sanitation	11 (7,044,960)	10 (217,784)	11 (221,141)	13 (914,562)
High fasting plasma glucose	12	11	10	11
Ambient PM pollution	13 (5,688,910)	22 (27,112)	22 (23,733)	8 (1,465,070)
Unimproved water	14 (5,109,540)	13 (154,262)	14 (149,080)	15 (814,272)
High body-mass index	15	14	12	14
Zinc deficiency	16	16	13	16
Physical activity	17	18	18	17
Drug use	18	15	17	18
Intimate partner violence	19	17	15	19
Lead	20 (1,121,510)	20 (36,675)	19 (40,707)	21 (120,875)
High total cholesterol	21	21	20	22
Childhood sexual abuse	22	19	21	20
Low bone mineral density	23	23	23	23
Ambient ozone pollution	24 (50,439)	25 (136)	24 (935)	24 (7,700)
Radon	25 (32,565)	24 (735)	25 (1,034)	25 (3,156)

[a] Mean ranks incorporate uncertainty (not shown), so may not be fully consistent with the mean DALY estimates.

DALY estimates are provided in parentheses for the environmental risk factors (Institute of Health Metrics, 2013b).

Disease burdens in selected cities

The following two sections describe key findings from burden of disease studies in Dar es Salaam, Nairobi and Dhaka (Ibadan was not included because no relevant study was identified). The discussion is limited to large studies that have incorporated many causes of death, thus making the results comparable; single cause-specific studies do not allow the reported health burdens to be placed in context.

These studies unfortunately have not explored disease burdens attributable to environmental risk factors, such as in the GBD project. It is also important to note that the studies were conducted separately, and therefore are not directly comparable with each other, as estimation methods and time periods differ.

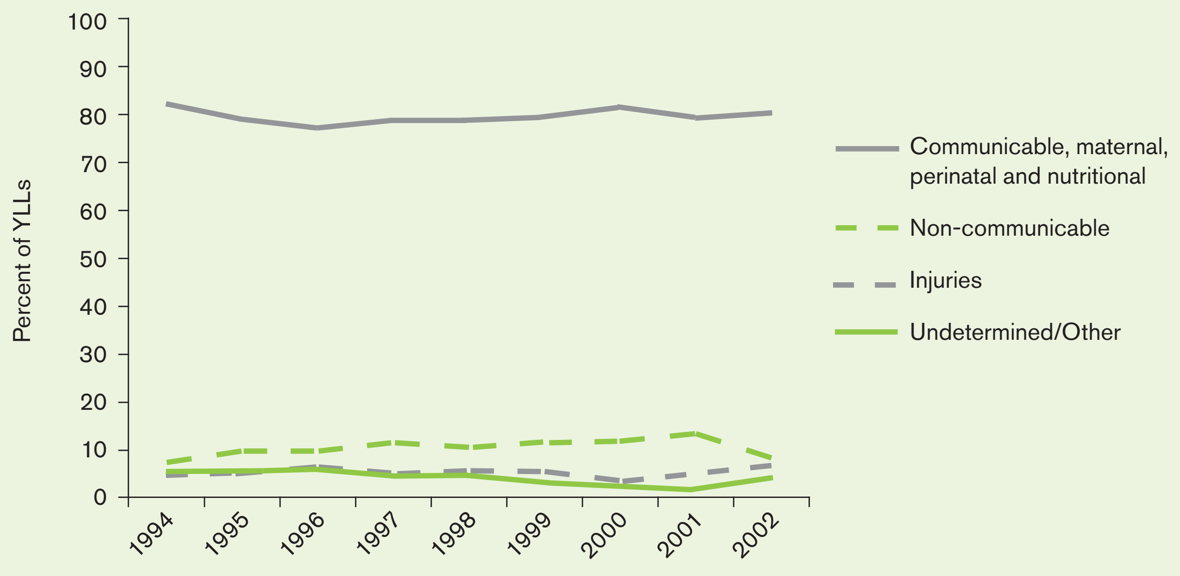
Dar es Salaam

During the late 1990s and early 2000s, a large multi-institutional collaboration called the Adult Mortality and Morbidity Project (AMMP) estimated disease burdens in Tanzania based on a national surveillance system. The project collected information from multiple sentinal sites, including one in Dar es Salaam, and published their findings in a series of reports and academic papers which include time-series of the main causes of death, estimates of YLL and the proportion of the burdens that were preventable.[2] The following is a short summary of the results. Unfortunately, discussions with some of the project investigators indicate that comparable surveillance and analyses no longer occurs and therefore the most recent estimates are now over a decade old.

The Dar es Salaam sentinel site was located in the Temeke and Ilala municipalities, representing about 14,000 households, covered a range of living conditions and included variation in socio-economic conditions and population density. At the time, the site was assumed to represent 8.6 per cent of Tanzania's population.

Time series data of the percentage of YLLs coming from select broad causes of death indicate that there was relatively little change during the course of the project (1994–2002) (Figure 3) (Adult Morbidity and Mortality Project, 2004). Non-communicable diseases and injuries made up a relatively small proportion of the total disease burden: <20 per cent combined in any given year. The analyses also indicated that in all years, a large percentage of the mortality burdens were potentially preventable using established interventions or groups of interventions (time-series not shown, see Figure 3 below for 2002 data).

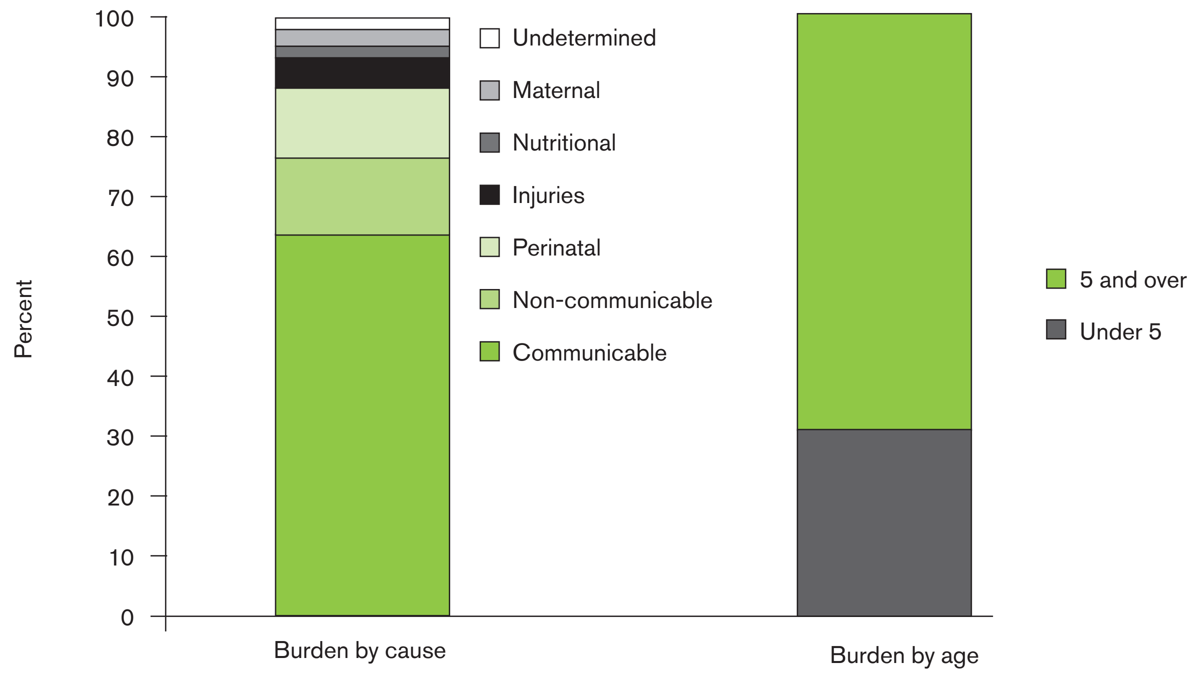
Figure 3: Percentage of the burden of disease attributable to different broad causes over time, Dar es Salaam.



Source: Adult Morbidity and Mortality Project, 2004.

[2] The following website provides details of the project including collaborators, methods and project outputs: http://research.ncl.ac.uk/ammp/

Figure 4: Percent of disease burden (YLL) by cause and age group, Dar es Salaam, 2001.



Source: Ministry of Health (Tanzania)/AMMP) (Ministry of Health (Tanzania)/AMMP, undated (circa 2002/2003))

Figure 4 presents more disaggregated data for 2001. It shows, as noted above, that communicable diseases were by far the greatest contributor to Dar es Salaam's disease burden, with non-communicable diseases and perinatal causes also important (Ministry of Health (Tanzania)/AMMP, undated (circa 2002/2003)). The figure also illustrates the disproportionate disease burden experienced by children under five. Table 3 provides detail on the leading causes of death (not YLL) in 2002 for different age-sex strata.

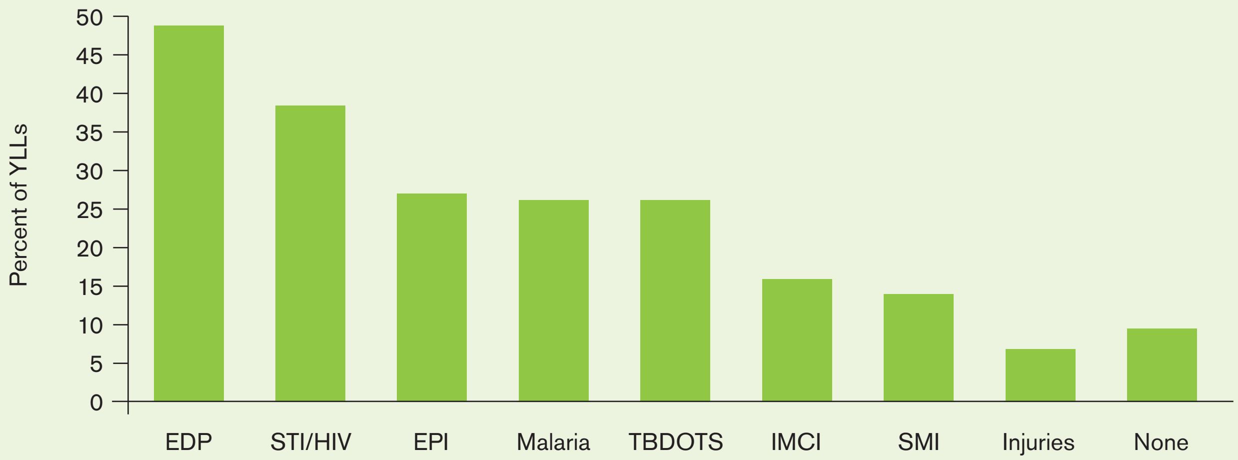
In terms of diseases that can be prevented (by policy and practice) in Dar es Salaam, estimates indicate that established interventions have the potential to substantially improve population health (Figure 5) (Adult Morbidity and Mortality Project, 2004). Many interventions would reduce burdens by a quarter or more, particularly the provision of drugs (pharmaceuticals) and HIV/STI-related interventions.

Table 3: Top causes of death for different age-sex strata, 2002.

	MALES		FEMALES	
AGE	CAUSE	% OF DEATHS	CAUSE	% OF DEATHS
0–4	Acute febrile illness	35.9	Acute febrile illness	44.0
	Birth injury and/or asphyxia	11.5	Still birth	16.0
	Still birth	11.5	Acute respiratory infections	12.0
	HIV/AIDS/TB	7.7	Anaemia	8.0
	Other perinatal causes	7.7	Birth injury and/or asphyxia	6.0
5–14	Acute febrile illness	54.5	Acute febrile illness	66.7
	Unintentional injuries	18.2	Unintentional injuries	16.7
	Anaemia	9.1	HIV/AIDS/TB	16.7
	Diarrhoeal diseases	9.1		
	HIV/AIDS/TB	9.1		
15–19	HIV/AIDS/TB	50.3	HIV/AIDS/TB	61.9
	Acute febrile illness	18.5	Acute febrile illness	14.8
	Unintentional injuries	9.2	Cardiovascular disorders	3.7
	Cardiovascular disorders	6.9	Unintentional injuries	3.2
	Acute abdominal conditions	2.3	Neoplasms	2.6
60+	Acute febrile illness	25.0	Cardiovascular disorders	32.7
	HIV/AIDS/TB	21.9	Acute febrile illness	26.9
	Cardiovascular disorders	12.5	HIV/AIDS/TB	13.5
	Renal disorders	6.2	Neoplasms	7.7
	Neoplasms	6.2	Diarrhoeal diseases	7.7

Source: Adult Morbidity and Mortality Project, 2004.

Figure 5: Proportion of mortality burden that is preventable by specific interventions, Dar es Salaam, 2002.



EDP = Essential drugs programme kits, STI/HIV = HIV preventation, treatment and syndromic management of sexually transmitted infections, EPI = expanded programme on immunusation, Malaria = malaria prevention and case management, TBDOTS = tuberculosis directly observed treatment, IMCI = integrated management of childhood diseases, SMI = safe motherhood initiative, Injuries = injury prevention and care
Source: Adult Morbidity and Mortality Project, 2004.

Nairobi

The key source of cause-specific burden of disease estimates for Nairobi comes from a study by Kyobutungi *et al.* (Kyobutungi *et al.*, 2008). Their study used the demographic surveillance area data of the Nairobi Urban Health and Demographic Surveillance Systems (NUHDSS) to quantify disease burdens in two of Nairobi's large slums. The demographic surveillance system collects information from approximately 56,000 residents of the Korogocho and Viwandani slums and the study used data from the three calendar year period from 2003–2005. The age structure of the study population is similar to that of Nairobi province as a whole. Cause of death was determined by verbal autopsy.

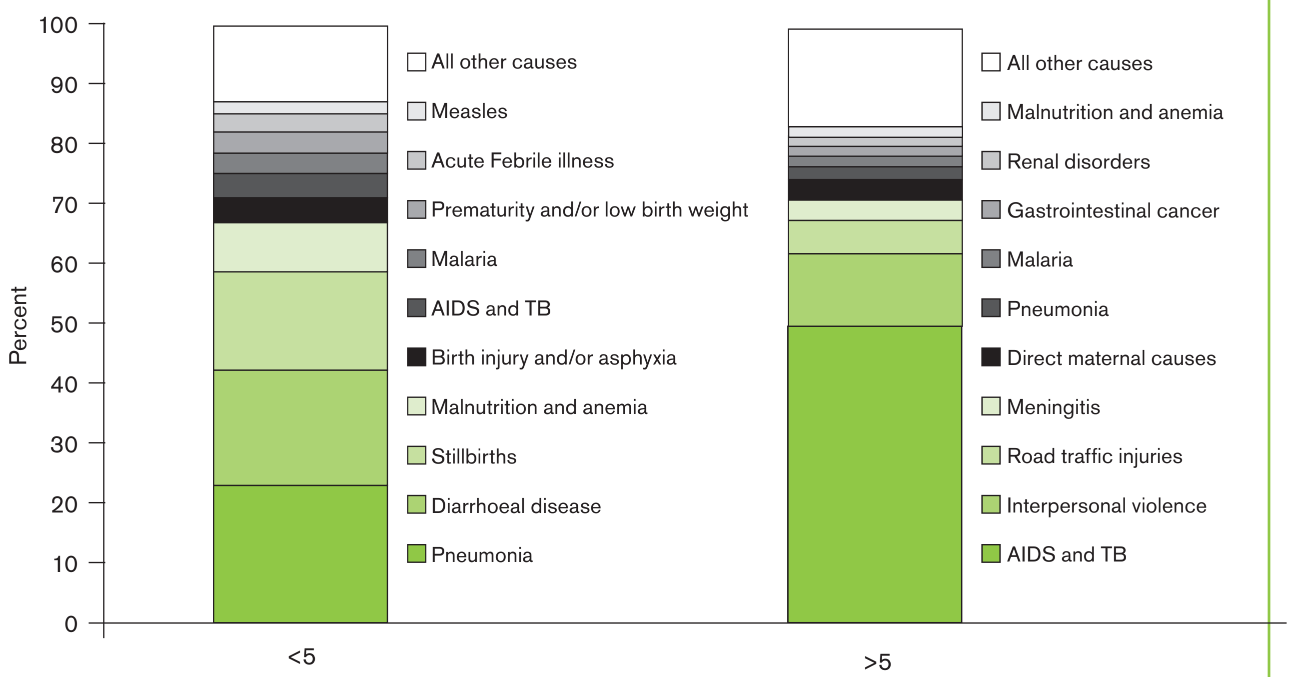
Burdens in the population were 205 YLL per 1,000 person years, but rates differed substantially by age: the rate in children under five years was 692/1000 person years whereas it was 160/1000 in those aged five and older. The rate was higher among males under five, but higher among females in those aged 15 and older. The main causes of death also differed between children and the rest of the population (Figure 6). In children, large disease burdens were attributable to pneumonia, diarrhoea and stillbirths, while the older population had the highest proportion from HIV/AIDS and interpersonal violence. HIV/AIDS alone contributed nearly 50 per cent of the disease burden.

Dhaka

We were not able to identify any large burden of disease studies for Dhaka. A 1999 study explored causes of child mortality in three of Dhaka's slums (Agargoan, Kamalapure and Mohammedpure) based on a non-random cross-sectional survey, sampling from every second or third household in the study area (Hussain *et al.*, 1999). The survey included 1,500 households and focused on children under nine years, collecting data from household heads and determining causes of death through verbal autopsy. Respondents were asked about child deaths that occurred at any time and sampling was limited to parents < 40 years old with at least one surviving child.

Overall, the reported death rate in the sample was 20.5 and 27.0 per 1,000 male and female children, respectively. The cause of 48 per cent of deaths was unknown or not reported. Of the remaining deaths, diarrhoea and tetanus were the most frequent causes across the total population, but causes varied somewhat by age and sex (Table 4). There were significantly more deaths in girls, which may be partially explained by the finding that in infancy, sick boys were more likely to receive treatment. Child mortality was higher in lower income households. However, all results should be interpreted with extreme caution due to the sampling strategy and high rate of unknown causes of death.

Figure 6: Top causes of premature mortality (YLL) in children under five and in those five and older in a slum population in Nairobi[a]



[a] The total YLL was 15,192 and 22,535 in the two groups, respectively (Kyobutungi *et al.*, 2008).

Table 4: Deaths by age and cause (n is total deaths)

CAUSE	<12 MONTHS		12–59 MONTHS		60–107 MONTHS	
	Boys (n = 109)	Girls (n = 156)	Boys (n = 47)	Girls (n = 67)	Boys (n = 8)	Girls (n = 15)
Unknown	59	156	14	31	2	4
Diarrhoea	12	17	13	10	3	3
Tetanus	13	27	0	2	2	1
Respiratory	8	13	2	0	1	2
Measles	6	4	4	8	0	3
TB	1	2	0	1	0	0
Fever	6	11	6	8	0	1
Accidents	4	1	8	7	0	1

Source: Adapted from Hussain *et al.* (1999).

Newer data from the 2010 Sample Vital Registration Survey list the Dhaka division's crude death rate as 5.5 per 1,000 population, the lowest of the six administrative divisions (Bangladesh Bureau of Statistics, 2011). Within the Dhaka division, urban areas had a lower crude death rate than rural areas (4.7 vs 6.0). The 2010 infant mortality rate per 1,000 live births in the urban Dhaka division was 38 and 36 for males and females, respectively. The overall (boys and girls) infant mortality rate decreased by about 15 per cent from 2001 to 2010. The report also provides data on death rates at different age-sex combinations and cause of death estimates for the whole country and for urban and rural areas. In 2010, the top five causes of death in urban Bangladesh (Dhaka and elsewhere) were:

1) Heart disease/stroke/brain hemorrhage (123 per 100,000 population)
2) `Old age' (88 per 100,000)
3) Tumour/Cancer (47 per 100,000)
4) Asthma/respiratory diseases (36 per 100,000)
5) Accidents (31 per 100,000).

In a recent study, Molla *et al.* (2014) compared disease burdens from diarrhoea and asthma in `climate refugees' and `non-climate refugees', finding much higher burdens for both diseases in the former (Molla *et al.*, 2014). However, sampling and assessment methods were crude and it is not clear if the migration in the population defined as `climate refugees' was induced by climate change or non-climate change related environmental conditions.

4

Health data

Health data drawn from various sources are used to generate information that answers specific questions about population health. That is, the potential utility of a type of health data is not just a property of the data themselves; it also depends on factors associated with the question of interest (e.g. assessment of average population health versus impact of an event), the source of the data (e.g. surveillance versus a survey), and the technical method by which the raw data will be transformed into information about population health (e.g. cross-sectional versus time-series studies). We give a short overview of analysis methods below in `Epidemiological studies of climate and health'. In this section, we focus on general types and sources of health data, and highlight some means of evaluating the quality of the data in light of the question of interest.

Types of data and questions of interest

The data commonly used in health assessments may be split into two general types: determinants of health and measures of health (health status)[3]. There are a wide range of determinants of health (Table 5) and they tend to interact to shape population and individual health. For example, a population living in improvised structures in an informal settlement (i.e. physical environment) without formal waste collection (i.e. service) may be more likely to be flooded (i.e. physical environment) if waterways are blocked by rubbish, and are thus more likely to be disabled through injury (i.e. health outcome), which may in turn reduce employment opportunities (i.e. personal

Table 5: Determinants and measures of health

DETERMINANTS OF HEALTH	MEASURES OF HEALTH
Personal and family environment (e.g. family structure, income, employment)	Self-assessed health status (and experience of this)
Social environment (e.g. social support, discrimination)	Symptoms (e.g. difficulty breathing, chest pain)
Physical environment (e.g. housing, air quality, waste accumulation, climate and weather)	Morbidity (e.g. asthma, angina)
Services (e.g. health care, public transport, water provision, waste collection)	Disability
	Mortality (and cause of death)

Source: Adapted from Gentle (2003, p30) and Scott Samuel *et al.* (2003, p55).

[3] Other types of data, such as control variables, are commonly used, but we do not discuss these here.

and family environment) and compromise future health. Thus, for example, when assessing the potential health impacts of climate change on a population, it is critical to consider the determinants of health as far as possible. Consideration of data sources for the determinants of health in the sites of interest is beyond the scope of this report, although we include a general discussion on the social determinants of health in relation to disasters below.

Health data may capture a range of measures of health (Table 5), which are often roughly considered as being `harder' or `softer'. Hard data may be characterised as precise, numerical (or coded by protocol), and reproducible (i.e. different recorders would record the same event in the same way), whereas soft data tends to be qualitative and subjective (Tennison, 2003). Mortality data are the `hardest' data (i.e. a person is either dead or alive), but recording may be incomplete and the recorded cause of death may be incorrect. Disability and morbidity need to have an agreed definition in advance of data collection (e.g. when blood pressure exceeds a certain threshold a person is diagnosed with hypertension). The case definition for some outcomes is easier to define and standardise than others. Data on symptoms are sometimes difficult to quantify, in that they are partly subjective and may arise due to a range of underlying pathologies and data on self-assessed health status is usually considered less robust than objectively determined health outcomes (e.g. through a visit to a health clinic, or laboratory based detection of a specific pathogen).

The relative suitability of the type of data depends on the question of interest and their intended use: for instance, hard data may be preferable when comparing cause-specific mortality rates in different populations using statistical methods and soft data may be preferred when personal health experiences of a disaster are of interest, such as when seeking local input to health-related policy.

This means that to provide a lens through which to search for and select health data, the question of interest and the intended use of the data must first be clearly defined. This involves, amongst other things, specifying the purpose of the assessment (which will often imply a broad means of analysis (e.g. statistical; textual), the focal population(s), and the health impact(s) of interest. Three main considerations are outlined in the upper half of Table 6.

It is also necessary to consider the quality of the data themselves (lower half of Table 6), and this is partially shaped by the source of the data. We discuss general type of data sources in the next section.

Table 6: Assessing the available health data relative to the intended purpose and in terms of data quality

VALIDITY OF DATA RELATIVE TO INTENDED PURPOSE	
Definition	Are the data items usefully defined for the question of interest? For example, is the definition of `being affected by a disaster' sufficiently precise to estimate morbidity rates? Or, if comparing a mental health across space of time, are the definitions consistent?
Timeliness	Are the data sufficiently up to date? For example, if interested in current health of a population in an informal settlement, is data from five years ago likely to provide a reasonable picture?
Generalisability	Are the data relevant to the population of interest? For example, are hospital admissions data for injuries likely to be representative of injuries occurring in an informal settlement? Or, in the absence of local health data, can national level data or data from a similar city be used to make inferences about the location of interest?
TECHNICAL QUALITY OF THE DATA	
Completeness	Have all the instances of interest been recorded? Has this changed over time?
Selection bias	Are the data collected for the entire target population, or does it systemically exclude certain groups?
Classification bias	Have the data been entered correctly according to the definitions?

Adapted from Gentle (2003, p33).

Sources of data

Sources of health data may be broadly classified as routine or specially collected (Table 7). Routine data are usually collected through vital registration or the health system (e.g. hospital admissions data). They are available at regular intervals, are intended to allow tracking over time, and are coded using an agreed standard (e.g. International Classification of Diseases) (Tennison, 2003).

Specially collected (or non-routine) data are usually collected on a one-off basis for a particular study or task, and coded according to the specific requirements of the study (Tennison, 2003). A third type of data is demographic and health surveillance sites are set up in areas where routine data are of poor quality or not available. These are intended to provide long term data of high quality, though cause of death is reported using verbal autopsy rather than through medical confirmation.

Table 7 provides some examples. Note that cohort studies (also known as longitudinal or panel studies) refer to studies established to collect health data over time (the length of the time period depends on the purpose of the study). As discussed in the previous section, different data types have different strengths and weaknesses.

Below we define a broad typology of health data sources and then briefly discuss availability in each of the four study cities. We have summarised the available data sources in table format, but details for each city are provided inAppendix 1. We stress however that it is not possible to identify every data source in each location and therefore recommend that any researcher considering initiating a study should liaise with a local partner with detailed knowledge of the site and population.

Vital registration (vital statistics): Vital registration refers to government records of births and deaths in a population under a defined jurisdiction. Death certificates normally include a cause and date of death, as well as age at death and gender, making them an invaluable source of information for epidemiological and burden of disease studies. Cause of death is normally determined by a coroner or by a health professional (doctor).

Surveillance data: The World Health Organization defines surveillance as "the systematic on-going collection, collation, and analysis of data and the timely dissemination of information to those who need to know so that action can be taken". At its best, surveillance is active and systematic, recording long-term data on populations residing in established surveillance sites. The population is in regular contact with the surveillance professionals, allowing for estimates of cause-specific disease incidence and prevalence as well as data on important individual, household and community-level characteristics. Other forms of surveillance, such as through hospital reports, are more passive but allow detection of important public health deviations, such as disease outbreaks. See Box 2 for a summary of surveillance activities in each city.

Survey data: Surveys focus on individual units within a population and are done in response to a particular need (e.g. government needs assessment or research project). Sampling may be representative of the whole population, such as Demographic and Health Surveys (DHS) which are conducted in some countries at regular intervals (e.g. every few years), or may focus on specific sub-populations, for example HIV patients or sex workers. Non-health surveys, such as household budget surveys, may provide important information on potential confounders that can be included in

Table 7: Examples of routine and non-routine (survey) health outcome data

MEASURE OF INTEREST	ROUTINE	SPECIALLY COLLECTED
Demography	Census; birth registration	Surveys to assess slum population
Mortality	Death registration, cause of deaths recorded on death certificate	Surveys of deaths in a defined population, using verbal autopsy to describe cause of deaths
Morbidity	National health surveys; hospital records	Surveys associated with a particular study.

Source: Adapted from Tennison (2003, p9).

epidemiological studies, or exposures such as food purchasing patterns.

Hospital data: Hospitals provide important data on disease incidence. Monitoring hospital records is one form of surveillance, as mentioned above, but hospital patients generally do not represent a full cross-section of society: not everyone goes to hospital (only those who are the most ill, or those who can afford it), and people also do not necessarily go their nearest hospital. Therefore, hospital data usually does not provide a reliable denominator to determine disease prevalence and can introduce bias into epidemiological studies. Nevertheless, hospital data are sometimes the only source of data in certain areas or for some diseases and can be used successfully in health studies, particularly when the catchment area is well known.

Censuses: Population censuses do not necessarily include data on health status but, at the least, can provide important demographic information on potential confounders (age, sex, income), as well as the distribution of certain environmental risk factors, such as housing type.

Table 8 summarises data availability from key sources in each of the four cities based on literature reviews of published epidemiological and burden of disease studies. The table is non-comprehensive, and therefore more details of data sources in each city are available in Appendix 1.

BOX 2: SUMMARY OF KEY SURVEILLANCE SITES IN THE STUDY CITIES.

In areas where routine data collection is minimal, surveillance systems that monitor select households provide a rich information source for understanding population health. Much of the published literature on health in the four study cities have relied on data from these surveillance systems, the most important of which are described below.

Nairobi

The Nairobi Urban Health and Demographic Surveillance System (NUHDSS) is a health surveillance project that has been running since 2002. The project was established by the African Population and Health Research Center and is a member of the INDEPTH network, a coordinated network of surveillance systems running in 42 centres in 20 countries in Africa, Asia and Oceania.

The NUHDSS conducts surveillance in two slum communities (Korogocho and Viwandani) in Nairobi, following about 66,000 individuals of over 28,000 households by 2013. All households are visited three times each year, providing long-term data on various aspects of mortality and morbidity as well as other information such as migration, education and livelihood strategies. Data from the project has been used in many research publications and provides a wealth of knowledge about urban slum living in Nairobi.

Dhaka

The International Centre for Diarrhoeal Disease Research, Bangladesh (ICDDR,B) is a long running health surveillance organisation that has collected data in multiple sites in Bangladesh, in some cases for many decades. The Dhaka surveillance programme, established in 1979, enrols two per cent of patients presenting at Dhaka hospital. The system uses structured questionnaires to collect a wide array of information including clinical, demographic and anthropometric characteristics as well as data on housing and environmental exposures. Diarrhoea is a focus of the project and there is extensive testing of faecal samples.

Dar es Salaam

During the late 1990s and early 2000s, a large multi-institutional collaboration called the Adult Mortality and Morbidity Project (AMMP) ran a national surveillance system in multiple sites across Tanzania. The Dar es Salaam site was located in the Temeke and Ilala municipalities, representing aboout 14,000 households, and covered a range of living conditions and included variation in socioeconomic conditions and population density. At the time, the site was assumed to represent 8.6 per cent of Tanzania's population.

Unfortunately, surveillance at many of the AMMP sites, including the Dar es Salaam site, has been discontinued. There is currently no comparable site in the city, but surveillance continues in other (mostly more rural) areas of Tanzania.

Ibadan

There are no established demographic surveillance sites yet established in Ibadan.

Table 8: Data availability by source for the sites of interest

	VITAL REGISTRATION	DEMOGRAPHIC AND/OR HEALTH SURVEILLANCE SITES[a]	LATEST CENSUS DATA[b]	DHS SURVEYS[c]
Nairobi	Partial	Yes	2009	2014
Dar es Salaam	Partial	None after ~2007	2012	2010
Ibadan	Partial	No	2006	2013
Dhaka	Partial	Yes	2011	2011

[a] Refers to the existence of current and systematic surveillance sites (rather than just routine hospital surveillance).

[b] Data is at the country level, but with city components.

[c] These are nationally-representative household surveys that collect a wide range of data on demographics, health and nutrition. Data is at the country level, but with city components. Dates refer to most recent DHS survey, but some countries will have more recent surveys on specific aspects of health, such as Malaria Indicator Surveys (MIS) or AIDS Indicator Surveys (AIS).

5

Epidemiological studies of climate and health

Research on the potential health impacts of climate change needs to be informed by the observed effects of weather and climate on human disease outcomes, primarily using epidemiological methods (Kovats and McMichael, 2010).

There are three main types of observational studies relevant for climate and health:

- Health impacts of individual extreme events (heat waves, floods, storms, droughts).
- Spatial studies, where climate is an explanatory variable in the distribution of the health outcome (or related outcome such as disease vector).
- Temporal studies of changes in climate-related health outcomes:
  - short term (daily, weekly) changes in meteorological parameters
  - inter-annual climate variability
  - longer term (decadal) changes.

As with all epidemiological studies, it is important that information on potential confounders is included in the analysis. Cross-sectional studies are particularly subject to confounding, as non-climate determinants are significant when comparing between populations with different climate exposures, and there are few robust studies of this type. Three key epidemiological study designs are briefly summarised below and some example studies on the relation between weather and human health for the sites of interest are shown in Table 9.

Table 9: The potential impacts of weather on human health

TYPE OF HEALTH OUTCOME	KNOWN EFFECTS OF WEATHER AND CLIMATE VARIABILITY	EXAMPLE STUDIES
Heat stress	Deaths from cardio-respiratory disease increase with high temperatures. Heat-related illness and death due to heat waves.	Egondi *et al.* (2012b) (Nairobi)
Cold	Deaths from cardio-respiratory disease increase with low temperatures. Low temperature associated with increase in some diseases (morbidity) e.g. respiratory diseases. Neonatal effects.	Egondi *et al.* (2012b) (Nairobi)
Air pollution-related mortality and morbidity	Weather affects air pollutant concentrations. Weather affects distribution, seasonality and production of aeroallergens.	Jonsson *et al.* (2004)[a] (Dar es Salaam)
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).	Bich *et al.* (Bich *et al.*, 2011) (Hanoi[b])
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.	Banu *et al.* (2014) (Dhaka)
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.	Dewan *et al.* (2013) (Dhaka) Hashizume *et al*. (2007) (Dhaka)

[a] Note that this paper considers the relation between air pollution and weather but does not quantify health impacts. However, to our knowledge, no study in the sites of interest has considered air pollution, weather, and health together. For an example of such a paper for Canadian cities, see Vanos *et al.* (2014) .

[b] Note that this paper focuses on Hanoi. However, to our knowledge, there have been no epidemiological studies of a weather-related disaster in the sites of interest (we summarise published studies for the sites of interest in *Disasters in target sites: data and the literature*). For an example of a study looking at the health impacts of a non-weather related disaster see Pfefferbaum *et al.* (2003) , which looks at post-traumatic stress disorder in children following the bombing of the American embassy in Nairobi in 1998.

Source: Adapted Kovats and McMichael (2010)

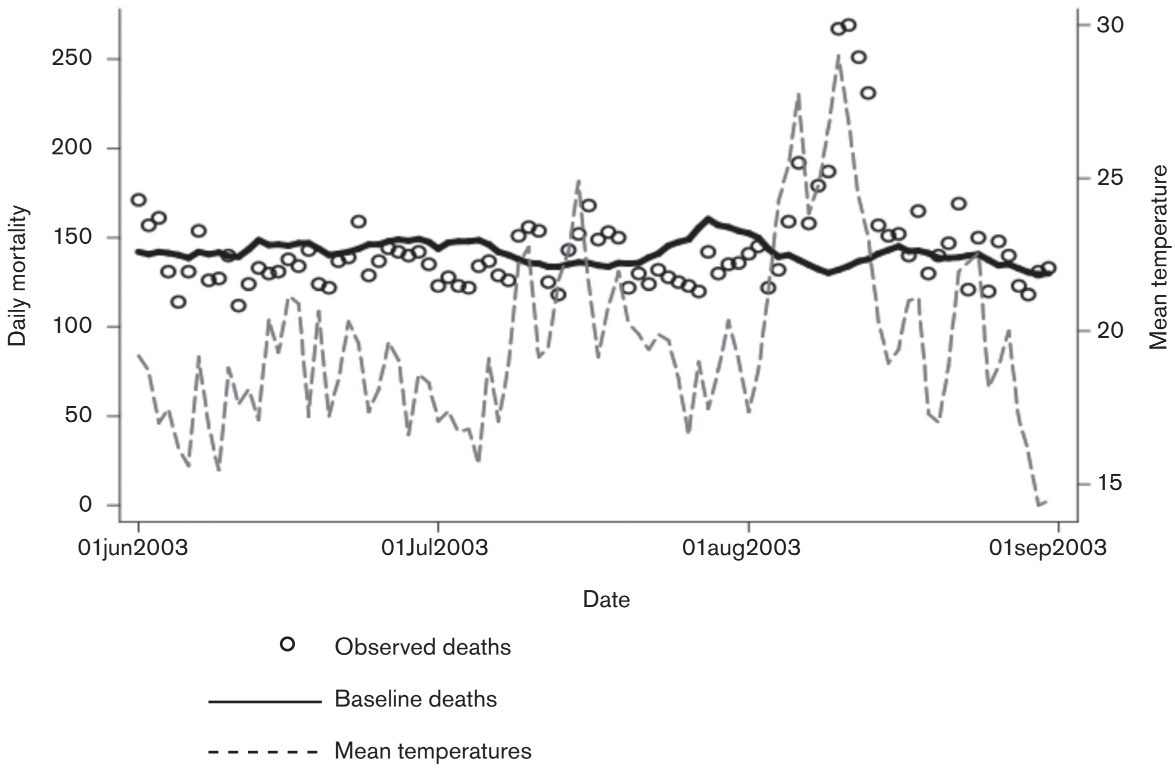
Episode analysis

An episode analysis refers to the investigation of how a discrete event, such as a flood or a heat wave, impacts health. It is generally considered one of the simpler epidemiological study designs, but as with any design, episode analyses have their challenges and can provide misleading results if not used appropriately.

Although an episode analysis can be conducted for many different types of events, the exact approach of the study may differ somewhat. Investigating the (direct) effects of a natural disaster is sometimes relatively straightforward, as deaths may be clearly attributable, for example from drowning during a flood. However, this relies on some form of data collection, which does not always occur. Furthermore, even if routinely collected, the data may not be available in the immediate aftermath of a disaster. In areas without vital registration, survey methods may be required to ascertain the number of fatalities, while the use of hospital records is another option. Even where reasonable data does exist, it is always a challenge to estimate the more indirect health effects of disasters, such as influences on morbidity and, in particular, on mental health.

The investigation of heatwaves requires estimates of daily counts of mortality (or morbidity, e.g. hospital admissions). The health impact is explored by comparing the number of total deaths during an event with the average number of deaths over some baseline, often the same time period in a previous year or in

Figure 7: Daily mortality and mean temperature in London during the summer of 2003. Figure courtesy of Shakoor Hajat.



the weeks before and/or after the event. The episode analysis requires an *a priori* definition of the timing of the episode, which should be based on the observed temperatures and not the mortality response. In an episode analysis, one does not control for potential confounders because the population is essentially the same before, during and after the episode. Although air pollution is often high during a heat wave, it is considered as part of the exposure (the episode).

Example of an episode analysis

Figure 7 presents a typical graphical representation of an episode analysis. In this case, the study analysed daily mortality in London during the summer of 2003. Daily deaths were compared against expected values and, as the figure shows, a period of substantially elevated mortality closely corresponded to the August heatwave.

Time-series regression

Time-series regression analysis is a commonly used method in environmental epidemiology to study associations between short-term environmental exposures (particularly weather variables and air pollution) and health (often mortality or hospital admissions). Compared to many study designs, the data needs are fairly minimal: high-quality meteorological observations tend to be readily available (although it is important to use the appropriate observed meteorological data for the population of interest), while health data may come from vital registration or hospitals.

Most often, time-series studies explore how day-to-day variations in exposure affect day-to-day changes in health. Studies may use shorter (e.g. hourly) or longer (e.g. weekly or monthly) time periods, but in all time-series analyses, the main unit of analysis is time. Therefore, over these relatively short time scales, it is not necessary to control for typical confounders such as age, sex, etc. because the population under study will not change meaningfully from day to day.

It is however important to control for potential time-varying confounders. Raw time-series data, for example mortality counts, typically show strong temporal trends such as seasonality or long-term trends. These trends need to be removed in order to then assess if remaining short-term variations in mortality are associated with the exposure of interest. It is also necessary to control for potential confounders that change day-to-day that are associated with both the exposure and the outcome. In studies of temperature, certain air pollutants are an important example.

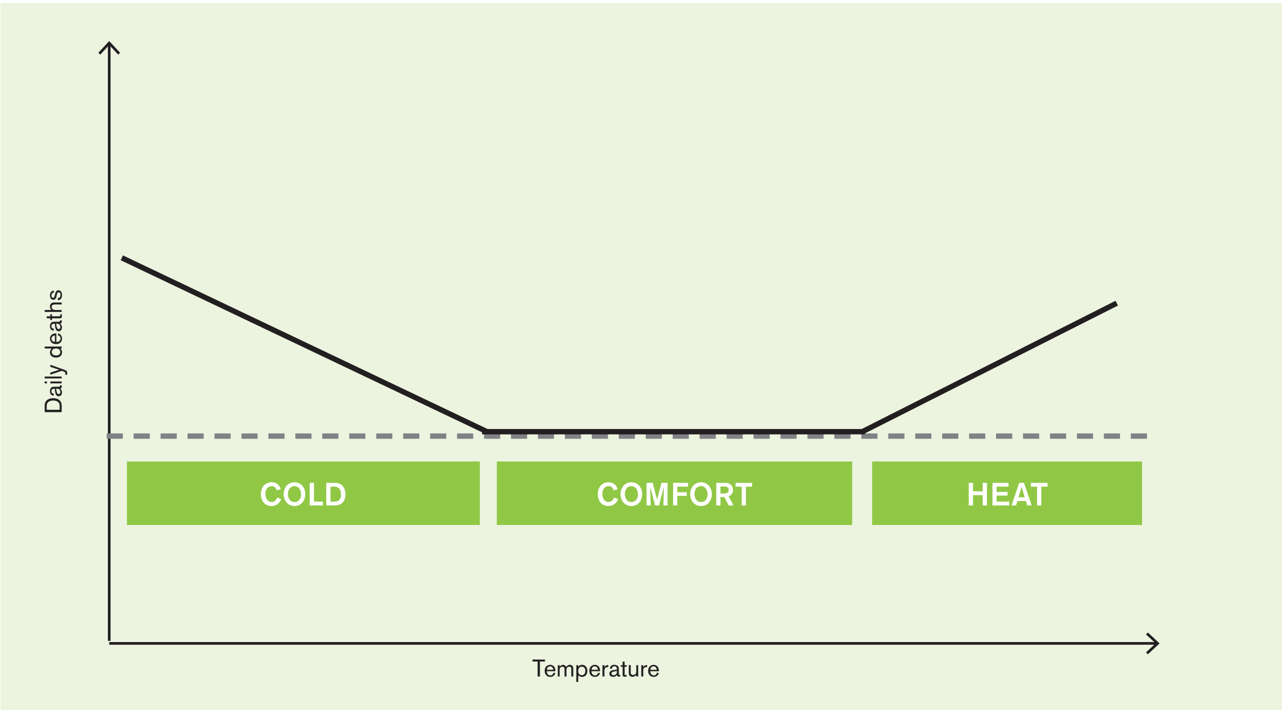
There are many specific methodological issues that have been discussed in more detail elsewhere (Bhaskaran *et al.*, 2013, Gasparrini and Armstrong, 2010). One issue worth mentioning is the importance of `time lags'. It is not a given that exposure on one day is necessarily associated with the outcome on the same day. Exposure to excessive heat on day 1, for example, may affect mortality the following day (day 2) or the day after (day 3). Similarly, it may be a period of sustained exposure over a few days that affects health. Hypotheses should consider different time lags between exposure and outcome before the analysis.

There are a few other important points to bear in mind with regard to time-series studies. First, the excess risks estimated by time-series studies are often relatively small. However, because, typically, the whole population is exposed to the environmental factor (ambient temperature or outdoor air pollution), the total impact at the population level can still be large. Second, time-series studies only look at the effect of short-term (daily or weekly) changes in *temperature (or rainfall)* and therefore should not be equated to the effects of a changing *climate*. Climate is a longer-term measure (decadal or longer) and if climate changes over time, so might the population's response to weather, for example through adaptation.

Third, some time-series studies report that the initial increase in deaths after exposure is followed by a period of lower than expected daily counts. This pattern suggests some level of mortality displacement (or `harvesting') whereby a proportion of the excess deaths occurred in vulnerable people who may have died anyway soon afterwards (Bhaskaran *et al.*, 2013). If mortality displacement comprises a large proportion of the excess deaths, total disease burdens (in terms of years of life lost) would be much lower than if the deaths were in otherwise healthy individuals. This is particularly true where temperature effects are largest in the older age groups.

Although studies in different populations vary, most time-series studies exploring the association of temperature and health report a roughly U-shaped relationship, where there is a minimum mortality temperature range beyond which increasing mortality risks are experienced as temperatures get lower (cold) and higher (hotter weather) (Figure 8). However, the exact shape of the relationship and the minimum mortality range is known to differ by location which is likely due in part to adaptation, which may be physiological, behavioural or related to infrastructure.

Figure 8: Schematic example of the results of a time-series study. The minimum mortality temperature range (the `comfort' range), thresholds and slope of the heat/cold effects may differ somewhat by location but in most cities the `U' shape is evident.



Example of time-series study

Egondi *et al.* (2012a) used time-series analysis to examine the relation between weather and mortality in informal settlements in Nairobi for the period 2003–2008. The study used routinely collected daily mortality data from the Nairobi Urban Health and Demographic Surveillance System (NUHDSS) (see Box 2 above). The analysis was stratified by age and sex, and cause of death was classified into five broad categories (HIV/AIDS-related, non-communicable diseases, pneumonia, acute infections, and other natural causes of death). The delayed effect (i.e. lag) of weather on mortality was also investigated. It was not possible to adjust for other time-varying confounders such as air pollution because such data were not available.

Days with high temperatures (above the 75^{th} percentile) were significantly associated with mortality in children and deaths from non-communicable diseases while mortality in older people aged 50+ and children aged below five years were most susceptible to cold compared to other age groups. Low temperatures were associated with deaths due to acute infections. Rainfall was also shown to have an effect on all-cause mortality, as well as pneumonia and NCDs deaths.

Cross-sectional studies

A cross-sectional study is an observational study that involves collecting data on a population or representative sample of a population at a single point in time. Questionnaires are a common tool in cross-sectional studies, but measurements may also be taken, for example of blood pressure or body mass index. Cross-sectional studies are often used to estimate the prevalence of a disease, but their relatively high susceptibility to bias and confounding makes them less ideal to investigate causality: problems associated with cross-sectional studies include non-response and recall bias, where responders may (accidentally) struggle to answer questions accurately. Furthermore, as information on both exposure and outcome variables (and confounders) is collected simultaneously, it can be difficult to ascertain the direction of causality (i.e. whether the exposure preceded or followed the disease). Nevertheless, cross-sectional studies may be used to generate hypotheses and/or to support inferences of cause and effect. The main strengths of cross-sectional studies are that they are relatively quick, easy and cheap to conduct.

Example of a cross-sectional study

Tran *et al*. investigated the association between self-reported heat-related illness and a range of household vulnerability factors amongst slum residents in Ahmedabad, India (Tran *et al*., 2013). Households were selected using randomised, multi-stage cluster sampling. 300 households were included in the study, representing 1,650 individuals. Data was collected from a senior household member via questionnaire.

Nearly 30 per cent of the sample reported experiencing either heat-related symptoms or heat-related illness. In multivariate analyses, factors increasing vulnerability to heat included: older age, pre-existing medical conditions (including infectious disease), not accessing information about heat-related illness and working in the sun. Younger age (< five years) and using a public tap for drinking water were protective. No specific occupations showed significant associations, although statistical power may have been insufficient. Social connectedness did not show a consistent association.

6

Health impacts of disasters

Disasters are often perceived as sudden departures from `normal' existence caused by high intensity `natural' trigger events such as a major tropical cyclones (Wisner *et al*., 2004). Indeed it is a handful of infrequent, big events that are associated with the majority of loss of life and assets. For instance, between 1975 and 2008, 23 mega-disasters caused 1.8 million deaths and 25 events were associated with about US$600 billion in economic losses (UN Office for Disaster Risk Reduction, 2009b).

Over the same time period, almost *9000 disaster events* were reported. The death toll associated with each of these smaller events was considerably less, in total accounting for around 500,000 deaths (22 per cent of all disaster deaths). However, the disasters cost more in economic terms, with estimated losses of US$900 billion (60 per cent of all disaster-related losses) (UN Office for Disaster Risk Reduction, 2009b). These events predominately affect the poor and cause low-intensity damage to housing, infrastructure and livelihoods (UN Office for Disaster Risk Reduction, 2009b), each of which in turn may shape patterns of health and vulnerability to future disasters .

The above suggests that – while the poor may of course be disproportionately affected by `big' events – for people living in urban slums, `small' events are likely to be of particular importance. Further, rather than being abnormal disruptions, these events and their impacts may be considered part of `everyday existence' (Wisner *et al*., 2004). This is so in two senses: firstly, small events occur extensively and frequently; secondly, it is everyday existence *itself* that conditions vulnerability to hazards (as well as modifying hazards) and it is this interaction that generates disaster risk and disasters.

This section focuses on the evidence for health effects of weather-related disasters in urban slum populations, in particular in the target sites: Dar es Salaam, Ibadan, Nairobi and Dhaka. The overall aim is to highlight the types of disasters and risks that affect the areas of interest, and in particular to describe the sources of health data that may be used to characterise disaster impacts and risks.

Hazard, vulnerability, exposure

The United Nations International Strategy for Disaster Reduction (UNISDR) defines a disaster as: “A serious disruption of the functioning of a community or a society involving widespread human, material, economic or environmental losses and impacts, which exceeds the ability of the affected community or society to cope using its own resources” (UNISDR, 2007).

Expanding on this, they add: “Disasters are often described as a result of the combination of: the exposure to a hazard; the conditions of vulnerability that are present; and insufficient capacity or measures to reduce or cope with the potential negative consequences. Disaster impacts may include loss of life, injury, disease and other negative effects on human physical, mental and social well-being, together with damage to property, destruction of assets, loss

Table 10: Definitions of hazard, vulnerability, and exposure, with examples of possible data types to operationalise each concept

CONCEPT	DEFINITION	EXAMPLES OF TYPES OF DATA
Hazard	A dangerous phenomenon, substance, human activity or condition that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage. Hazards may be of natural and/or human created environmental and technological origins. Such hazards arise from a variety of geological, meteorological, hydrological, oceanic, biological, and technological sources, sometimes acting in combination.	Climate/weather extremes Average climate/weather deviation from long term averages (e.g. for droughts; here, may need to be coupled with data on, for example, change in soil moisture) Sea level Flood frequency curves
Vulnerability	The characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard. There are many aspects of vulnerability, arising from various physical, social, economic, and environmental factors. Examples may include poor design and construction of buildings, inadequate protection of assets, lack of public information and awareness, limited official recognition of risks and preparedness measures, and disregard for wise environmental management. Vulnerability varies significantly within a community and over time.	Climate/weather patterns and averages Social (e.g. income distribution, patterns of information access, education distribution) Economic (e.g. livelihood, poverty) Physical (e.g. assets) Health patterns Demographic (e.g. women, children and elderly often more vulnerable)
Exposure	People, property, systems, or other elements present in hazard zones that are thereby subject to potential losses.	Population grids Spatial distribution of poverty Maps of the built environment maps, including asset value

Source: Definitions are from UNISDR (2007).

of services, social and economic disruption and environmental degradation" (UNISDR, 2007).

Three key factors that condition disaster risk are hazard, vulnerability, and exposure. These are defined in Table 10, along with examples of data types that may be used to operationalise them.[4]

There is a large conceptual and empirical literature on disasters, but here we raise a few general issues. Firstly, it has been argued that there are no natural disasters, only natural hazards; a disaster is a combination of natural and social factors (Wisner *et al.*, 2004). Secondly, it may be argued that the 'natural hazard' component is increasingly shaped by social influences; for instance, via the impacts of climate change on, say, tropical cyclone patterns, or via loss of soil permeability in urban areas which reduces the intensity of rainfall required to generate a flood. Thirdly, while disasters are events at particular moments that are temporally bounded, vulnerability is ever present and changes gradually (usually) over time (Wisner *et al.*, 2004). Given the rapidity of growth and change in urban slums, it is plausible – perhaps likely – that vulnerability to disasters is changing at a 'faster rate' than climate change is or will changing vulnerability to hazards. That is, to assess future disaster-associated health risks, at least as much attention should be given to vulnerability as to climate-related hazard changes.

[4] It is beyond the scope of this report to outline specific data sources other than those for health data.

Global disaster data

EM-DAT

The only open access[5] global disaster dataset that includes health impact data is EM-DAT (The Emergency Events Database) (Centre for Research on the Epidemiology of Disasters, 2014). Disasters are reported at country level, although an increasing number of entries include more detailed information on location (e.g. georeferencing). For each disaster, the total number of people killed is reported, but this does not include any information on mortality by age or by cause of death. Data for the number of people injured are also available, but due to incomplete reporting these are not considered to be very reliable. Additionally, data on number of people affected[6] or made homeless are reported, but again this data have poor reliability. (See EM-DAT website for details on other data fields). Completeness of the database (i.e. the proportion of all eligible disasters recorded) has increased in recent decades, being reasonably complete for around the previous two decades or so (If using EM-DAT, we suggest discussing this issue with the data holders in terms of the specific use to which the data will be put).

For a disaster to be included in EM-DAT, one of the following criterion must be met: 10 or more people are reported killed; 100 or more people or reported affected; a state of emergency is declared; or, there is a call for international assistance.[7] This means many `small' disasters, particularly those affecting the urban poor, remain unrecorded by intent.[8] Further, it is possible that in marginalised slum populations, the killed or affected thresholds are exceeded but not reported.

Despite reporting being primarily at the national-level, some insight into disasters affecting a city of interest may be gained from EM-DAT. Data holdings for the relevant country could be investigated and an attempt could be made to link entries that appear to be for the city of interest to available literature and reports. However, at best it is unlikely that EM-DAT can provide more than a very general and incomplete picture of disasters in urban slums.

The UNISDR and the HFA

The International Strategy for Disaster Risk Reduction was adopted by the United Nations General Assembly in 1999, and the UNISDR secretariat was established to ensure its implementation (UNISDR, 2014b). The UNISDR also oversees the implementation of the Hyogo Framework for Action (HFA) (UNISDR, 2005), which is the blueprint for international disaster reduction. The overall aim of the HFA is "the substantial reduction of disaster losses, in lives and in the social, economic, and environmental assets of communities and countries" (UNISDR, 2005). It has five priorities for action (UNISDR, 2005):

(i) Ensure that disaster risk reduction is a national and local priority with a strong institutional basis for implementation

(ii) Identify, assess and monitor disaster risks and enhance early warning

(iii) Use knowledge, innovation and education to build a culture of safety and resilience at all levels

(iv) Reduce the underlying risk factors

(v) Strengthen disaster preparedness for effective response at all levels.

HFA progress implementation reports are available at regional, national and local levels (UNISDR, 2013b). While these reports do not contain health data or information, they are of course useful for developing an understanding of the risks that disasters potentially pose to health. At the time of writing, local level reports are not available for the sites of interest, however national level reports are available for Kenya (for 2013), Nigeria (for 2010), Tanzania (for 2012), and Bangladesh (for 2012).

The UNISDR also hold a range of disaster statistics in different formats, such as maps (UNISDR, 2014a). In general the data relate to hazard, exposure, and event-type; health data, when available, are limited to deaths, and generally draw on EM-DAT[9] or are modelled. As for EM-DAT, the global focus limits the utility of the data holdings for local-level assessments; however some useful insights may be gained. At the time of

[5] Detailed disaster data is also recorded by private organisations, such as re-insurance companies, but the data are not publically available.

[6] 'Affected' refers to people requiring immediate assistance during a period of emergency; it can also include displaced or evacuated people CENTRE FOR RESEARCH ON THE EPIDEMIOLOGY OF DISASTERS. 2014. *EM-DAT: The International Disaster Database* [Online]. Louvain. Available: http://www.emdat.be/ [Accessed 25 February 2014].

[7] Compare with the above UNISDR definition.

[8] Of course it could be argued that below-threshold events are not disasters; regardless of definition, these events may have significant impacts on people's lives.

[9] Other health data such as injuries may be listed but draw on EM-DAT and are subject to the limitations noted above.

writing, three databases were available via the UNISDR (UNISDR, 2014a):

- **GAR Risk Data Viewer**
  The global risk analysis presented in the Global Assessment Reports is based on a joint effort by leading scientific institutions, governments, UN agencies and development banks, the private sector and non-governmental organisations. This interactive Risk Viewer provides the global risk data from the Global Assessment Reports, presented in an easily accessible manner.
- **DesInventar**
  DesInventar is a tool for generating National Disaster Inventories and constructing databases that capture information on damage, loss and general effects of disasters. With increased understanding of disaster trends and their impacts, better prevention, mitigation and preparedness measures can be planned to reduce the impact of disasters on the communities.
- **PREVIEW Global Risk Data Platform**
  The PREVIEW Global Risk Data Platform is an effort by multiple agencies to share spatial data information on global risk from natural hazards. Users can visualise, download or extract data on past hazardous events, human and economic hazard exposure and risk from natural hazards. It covers tropical cyclones and related storm surges, drought, earthquakes, biomass fires, floods, landslides, tsunamis and volcanic eruptions.

In addition, the UNISDR produce biennial Global Assessment Reports, which provide a review and analysis of disasters and their impacts. The 2013 report looks at `how public regulation and private investment shapes disaster risk' (UNISDR, 2013a).

Consulting the above data sources and reports is likely to be a useful first step before seeking local disaster data and reports.

Morbidity data

While the above data sources contain information on disaster deaths, no (good quality) routinely collected information on morbidity is available. Disasters, however, may have major and long-lasting impacts on survivors. Given that disasters are always a combination of a hazard and social factors, the morbidity impacts of a given hazard of a given magnitude can vary enormously across space and time. However, reviews have assessed the types of morbidity impacts that may be expected.

Table 11 outlines the general morbidity impacts that have been associated with tropical cyclones, floods[10] and droughts. The table is based on systematic literature reviews of papers from across the globe for each of these disaster types (Ahern *et al*., 2005, Stanke *et al*., 2013, Shultz *et al*., 2005). Of note, while some of the papers included in the reviews were based on surveillance data, most drew on data collected as part of a specific epidemiological study. That is, morbidity is often not routinely reported, and where it is, is often not explicitly linked to a disaster (this may be particularly difficult for droughts; even the beginning and end of the event may be difficult to define, and health impacts may be via very indirect routes).

While the majority (but by no means all) of disaster mortality occurs during the event phase, disaster-associated morbidity may also occur in the pre-disaster phase (for example while reinforcing structures or during evacuation) and after the event (for example, while living in crowded shelters). Note that the absence of an association between a type of event and a health impact in Table 11 means that no papers were found.

[10] Note `floods' may be associated with various hazards. For instance, they may be associated with a heavy rainfall event. Or they may be caused by a storm surge associated with a tropical cyclone. Thus there is some crossover between the events categorised as `floods' and `tropical cyclones'.

Table 11: Morbidity impacts reported in the literature for tropical cyclones, floods, and droughts[a]

HEALTH OUTCOME	TROPICAL CYCLONES[b]	FLOODS[c]	DROUGHT[d]
Injuries	Primary cause of morbidity. Most common are lacerations, blunt trauma, and puncture wounds. ~80% affect feet and lower extremities. Timing in relation to the event may be: before (e.g. during preparation), during (e.g. due to collapsing structures or directly due to rain or flood waters), and after (e.g. burns, falls from roofs).	May occur before, during, or after event. Examples include contusions, sprains, strains, lacerations.	No studies found.
Infectious disease	Associated with disruption of health services, infrastructure damage, density of displaced population (crowded conditions may result in delayed onset outbreaks). Risk increases with prior: high rates of disease, low immunisation, inadequate water and sanitation, crowding, poor nutrition. Outbreaks have included: typhoid, acute respiratory infections, leptospirosis, cholera.	Faecal-oral diseases, especially when water and sanitation is poor; e.g. cholera, cryptosporidiosis, rotavirus, typhoid, paratyphoid, diarrhoea of unspecified cause.	Associated with water scarcity (reduced dilution or necessitate use of contaminated sources), or with intense rains following a drought (i.e. accumulated contaminates wash into supplies). Evidence in scarce, but impacts may include: amoebiasis, hepatitis A, salmonellosis, schistosomiasis, shigellosis, typhoid and paratyphoid.
Vector-borne disease (VBD)	Malaria, dengue. For example, malaria spraying may be disrupted or mosquito populations may increase (e.g. due to changed habitat).	Floods may wash away breeding sites and decrease VBD. Alternatively, may result in stagnant water due to, for example, blocked drains: possible increases in malaria, lymphatic filariasis, arbovirus.	Dengue; malaria (malaria may occur with droughts associated with El Niño Southern Oscillation (ENSO). May be associated with increased water domestic storage during droughts (effects depend on type of vector).
Undernutrition	[The review did not include this impact. However, tropical cyclones may impact on population nutritional status via crop loss and the resulting decrease in food access and availability (e.g. (Paul *et al.*, 2012))]	[The review did not included this impact. However flooding may impact on nutritional status via crop loss. Floods have also been found to impact on nutrition via increases in diarrhoeal disease and changes in mother's feeding practices of infants and young children (e.g. (Goudet *et al.*, 2011a).	Decreased food availability may result in undernutrition (although relation may be complex).
Mental health	May be among the most long-term and debilitating effects of cyclones. May cause anxiety, major depression, post-traumatic stress disorder. Some reports of increased suicide and child abuse.	Impacts include anxiety, major depression, and post-traumatic stress disorder.	Farmers (including subsistence farmers) may be at particular risk. Anxiety, depression, post-traumatic stress disorder, and suicide have been linked to droughts.

[a] Note that this table only includes the major health impacts reported in each review. For a full list of impacts reported in the literature, see the original paper.
[b] Based on Schultz *et al.* (2005).
[c] Based on Ahern *et al.* (2005). Note that the definition of `floods' includes floods associated with tropical cyclones (i.e. storm surge); hence there is some crossover with impacts of tropical cyclones.
[d] Based on Stanke *et al.* (2013).

Disasters by region

Africa

In Africa[11] between 2002 and 2011, an average of 72 disasters killed or affected[12] 26 million people per year and caused ~$1 billion (USD 2011) in damages per year (Guha-Sapir *et al*., 2012). Globally, this accounts for about 18 per cent of disaster events and about 10 per cent of people killed or affected. Due to the nature of disasters, however, actual impacts in any year are volatile. In 2012, for example, there were 57 reported disasters (i.e. below average) but 38 million people were killed or affected (i.e. above average), and this accounted for 30 per cent of people killed or affected globally. This volatility, along with changes in reporting patterns, makes trends in impacts difficult to interpret, but overall disaster frequency, severity and impacts are thought to be increasing in Sub-Saharan Africa (UN ISDR Regional Office for Africa, 2014).

The general types of hazard associated with the disasters affecting Africa (based on the 2002–2011 decadal average) are: ~64 per cent hydrological, ~19 per cent climatological, and ~13 per cent meteorological.[13] That is, these hazard types account for almost all disasters affecting Africa, and each may be influenced by future climate change. For example, of the 12 disasters that accounted for 85 per cent of all people killed or affected by disasters in 2012, 11 were associated with drought and food crises, and one was associated with flooding (Guha-Sapir *et al*., 2012); climate change is expected to affect all these factors (Parry *et al*., 2007).

That a small number of disasters generally account for the majority of human impacts should not obscure the fact that disasters are `common' rather than unusual occurrences in Africa. Since the year 2000, an average of 1.5 to 2 disasters have been reported per week (Morinière, 2013). Further, as noted above, `small' disasters affecting informal settlements may go unrecorded. In these locations, even minor hazards may be associated with disasters as human vulnerability – associated with, for example, poverty, undernourishment and general poor health – is often high (Morinière, 2013).

Disaster summary data, assembled by the UNISDR based on EM-DAT data (UNISDR, 2013c), for the period 1980–2008[14] for the countries containing the four sites of interest in this report are shown in Table 12.

Asia

In Asia between 2002 and 2011, an average of 156 disasters killed or affected (as per the EM-DAT definition above) 232 million people per year and caused ~$62 billion (USD 2012) in damages per year (Guha-Sapir *et al*., 2012). Globally, this accounts for about 40 per cent of disaster events and about 87 per cent of people killed or affected. As for Africa, impacts in any year are volatile. In 2012, for example, there were 145 reported disasters (i.e. close to average) but 80 million people were killed or affected (i.e. well below average), and this accounted for 65 per cent of people killed or affected globally (also below average).

The general types of hazard associated with the disasters affecting Asia (based on the 2002–2011 decadal average) are: ~53 per cent hydrological, ~8 per cent climatological, and ~25 per cent meteorological[15] (The remaining 15 per cent were geophysical). As for Africa, the hazard types associate with the majority of disasters may be influenced by future climate change (Parry *et al*., 2007).

For summary disaster data for Bangladesh, see Table 12, above.

[11] The figures relate to the African continent rather than just Sub-Saharan Africa.

[12] As per the EM-DAT definition above.

[13] Definitions are, Hydrological: events caused by deviations in the normal water cycle and/or overflow of bodies of water caused by wind set-up (e.g. floods, (wet) landslides); Climatological: events caused by long-lived meso to macro scale processes (in the spectrum from intra-seasonal to multi-decadal climate variability) (e.g. extreme temperature, drought); Meteorological: events caused by short lived/micro- to meso-scale atmospheric processes (in the spectrum of minutes to days (e.g. storms). CENTRE FOR RESEARCH ON THE EPIDEMIOLOGY OF DISASTERS. 2014. *EM-DAT: The International Disaster Database* [Online]. Louvain. Available: http://www.emdat.be/ [Accessed 25 February 2014].

[14] As noted above, the quality of disaster data (particularly in terms of completeness) has improved significantly over the time period covered by these data.

[15] Definitions are, Hydrological: events caused by deviations in the normal water cycle and/or overflow of bodies of water caused by wind set-up; Climatological: events caused by long-lived meso to macro scale processes (in the spectrum from intra-seasonal to multi-decadal climate variability); Meteorological: events caused by short lived/micro- to meso-scale atmospheric processes (in the spectrum of minutes to days CENTRE FOR RESEARCH ON THE EPIDEMIOLOGY OF DISASTERS. 2014. *EM-DAT: The International Disaster Database* [Online]. Louvain. Available: http://www.emdat.be/ [Accessed 25 February 2014].

Table 12: Disaster summary data[a] for the countries containing the sites of interest for the period 1980–2008[b]

DISASTER TYPE	TANZANIA	NIGERIA	KENYA	BANGLADESH
All disasters:				
Number of events	73	94	79	234
Number killed	6798	21,002	6066	191,836
Economic damage[c]	3790	188,025	112,338	17,072,500
Droughts:				
Number of events	7	1	8	3
Number killed	–	–	196	–
Economic damage	–	71,103	–	–
Floods:				
Number of events	26	35	34	68
Number killed	593	840	990	12,437
Economic damage	3790	116,900	12,338	11,228,800
Storms:				
Number of events	4	2	1	108
Number killed	4	100	50	167,189
Economic damage	–	–	–	5,343,700

Source: Adapted from data held at UNISDR (2013c).
[a] 'All disasters' includes any type of disaster reported in EM-DAT, i.e. not only droughts, floods and storms.
[b] '-' indicates no deaths or economic losses recorded in the database.
[c] All figures for economic damage in 1000s of US dollars (reference year not specified in source).

Disasters in urban areas

As discussed above, urban and urban slum populations are growing, mostly in low nad middle income countries. In the absence of alternatives (but at times because of livelihood opportunities), people in urban areas are increasingly settling in risky areas such as flood plains and unstable hillsides (UN Office for Disaster Risk Reduction, 2009a). Further, slums are potentially vulnerable to disasters by definition: that is, the living conditions that define a slum – for example, lack of basic services such as water and sanitation, inadequate building structures, and overcrowding (UN Centre for Human Settlements, 1996) – also shape disaster vulnerability.

Climate-related hazards that affect urban areas include floods, flash floods, tropical cyclones, drought, fires and heatwaves (UN Office for Disaster Risk Reduction, 2009a), and these are expected to increase in frequency and/or intensity with climate change and sea level rise (IPCC, 2012) (see also Table 1).

Further, evidence from cities in Africa, Asia and Latin America suggests that the expansion of informal settlements is associated with increases in reports of weather-related disasters (UN Office for Disaster Risk Reduction, 2009b).[16] Thus, it may be anticipated that urban hazards and urban vulnerability to disasters will increase in future years.

In order to reduce disaster health impacts, it is necessary to understand the processes that shape risk. The UNISDR have identified the following factors as drivers of urban disaster risk:

- Weak governance (which limits institutions, infrastructure, services, and regulation)
- Unplanned urban development (rapid growth, lack of land for low-income citizens, inappropriate construction)

[16] For an overview of the evidence the UNISDR use to support this statement see Chapter 3 and Appendix 2, Note 2.4 of UNISDR UNISDR 2009. Global Assessment Report on Disaster Risk Reduction. Geneva: United Nations.

- Concentration of economic assets (growth fastest in coastal regions and near large navigable rivers)
- Ecosystem decline (squatter encroachment on waterways; deforestation).

In addition, the ways in which urban poverty may manifest as particular vulnerabilities to disaster were outlined in the World Disasters Report 2010 (International Federation of Red Cross and Red Crescent Societies, 2010); Table 13.

While far from simple, it has been shown that the processes driving disaster risk can be addressed. Settlement upgrading, land access, provision of infrastructure, strengthened livelihoods, ecosystem protection and micro-finance and insurance have all been shown to be effective in a variety of settings. The UNISDR has provided a `check-list' of 10 essentials that will enable disaster risk reduction (UN Office for Disaster Risk Reduction, 2009a).

Table 13: Urban poverty and disaster risk

ASPECT OF URBAN POVERTY	IMPLICATIONS FOR DISASTER RISK
Inadequate and often unstable income and thus inadequate consumption of necessities, including food and, often, safe and sufficient water. Often, problems of indebtedness, with debt repayments significantly reducing income available for necessities. Inability to pay for insurance.	In most cities and many urban centres in low- and middle-income nations, most low-cost housing is on dangerous sites, e.g., at high risk from flooding or landslides. The lack of public provision for infrastructure and services adds to such risks, particularly for flooding.
Inadequate, unstable or risky asset base (e.g., property, skills, savings, social networks) for individuals, households or communities.	Very limited capacity to cope with disaster events when they occur including lacking assets that are not damaged or destroyed by the disaster and having no insurance.
Poor-quality and often insecure, hazardous and overcrowded housing (often rented) located on dangerous sites such as flood plains, steep slopes and soft or unstable ground.	Housing is often of poor quality so at risk from storms/ high winds, earthquakes, landslides, floods, fires and disease transmission which may cause epidemics.
Inadequate provision of `public' infrastructure (piped water, sanitation, drainage, roads, footpaths, etc.), which increases the health burden and often the work burden.	Lack of protective infrastructure against flooding. Lack of roads, footpaths and drains inhibiting evacuation when disaster threatens or happens.
Inadequate provision of basic services – day care, schools, vocational training, healthcare, emergency services, public transport, communications, policing and good information on safe building practices.	Lack of healthcare and emergency services that should provide rapid response to disaster (and should have a role in reducing disaster risk and in disaster preparedness).
Limited or no safety net to ensure basic consumption can be maintained when income falls; also to ensure access to housing, healthcare and other necessities when these can no longer be paid for (or fully paid for).	Very limited capacity to recover from disaster, for instance to afford food and water, rebuild homes and livelihoods. Lack of documentation often means not getting post-disaster support.
Lack of influence over what government does, including what it does in post-disaster responses.	Little external support for low-income groups and their organisations to rebuild in ways that reduce disaster risk.
Limited influence over external civil society actors such as international aid agencies during disaster risk reduction and response.	International humanitarian actors can overwhelm local government and civil society organisations alike. Lack of partnership inhibits good governance.

Source: Based on Table 1.2 in World Disasters Report 2010 (International Federation of Red Cross and Red Crescent Societies, 2010).

These are:

1. Put in place organisation and coordination to understand and reduce disaster risk, based on participation of citizen groups and civil society. Build local alliances. Ensure that all departments understand their role to disaster risk reduction and preparedness.
2. Assign a budget for disaster risk reduction and provide incentives for homeowners, low-income families, communities, businesses and public sector to invest in reducing the risks they face.
3. Maintain up-to-date data on hazards and vulnerabilities, prepare risk assessments and use these as the basis for urban development plans and decisions. Ensure that this information and the plans for your city's resilience are readily available to the public and fully discussed with them.
4. Invest in and maintain critical infrastructure that reduces risk, such as flood drainage, adjusted where needed to cope with climate change.
5. Assess the safety of all schools and health facilities and upgrade these as necessary.
6. Apply and enforce realistic, risk compliant building regulations and land use planning principles. Identify safe land for low-income citizens and develop upgrading of informal settlements, wherever feasible.
7. Ensure education programmes and training on disaster risk reduction are in place in schools and local communities.
8. Protect ecosystems and natural buffers to mitigate floods, storm surges and other hazards to which your city may be vulnerable. Adapt to climate change by building on good risk reduction practices.
9. Install early warning systems and emergency management capacities in your city and hold regular public preparedness drills.
10. After any disaster, ensure that the needs of the survivors are placed at the centre of reconstruction with support for them and their community organisations to design and help implement responses, including rebuilding homes and livelihoods

More generally, the experience of Bangladesh, where disaster risk has declined markedly over the last 40 years, has suggested four key insights that may inform a framework with application globally (Cash *et al*., 2013). These are:

(i) The identification and focus on the greatest drivers of morbidity and mortality.

(ii) Use of experience in disaster management to inform and improve strategies for future events.

(iii) Designing of interventions that draw on existing social capital and self-sufficiency of the community.

(iv) Viewing poverty as a key source of vulnerability (as well as disasters potentially being a key driver poverty).

In terms of health data for urban areas, the above and other issues raised in the report suggest it may serve three distinct functions. Firstly and most obviously, health surveillance may guide rapid and ongoing health responses. Secondly, routine health data may be used to quantify some forms of vulnerability. Finally, event-associated health data can be used to plan responses to future disasters.

The health impacts of weather disasters in selected sites: data and published literature

A review of the peer reviewed literature was undertaken to inform the following discussion of disasters in the target sites. Searches covering the year 2000 to the present were carried out in Medline, EMBASE, Global Health, and Scopus using search terms for the areas of interest and various types of disaster.[17] Few papers that considered actual or modelled disasters were found. An outline of these papers and the relevant data sources are outlined in tables by site.[18]

Due to the scarcity of papers and data, when assessing morbidity impacts of disasters locally, Table 11 (and the reviews on which it is based) may act a useful initial guide on the types of data likely to be required.

[17] For each city of interest, the event search terms used were: disaster* or `natural hazard*' or `extreme weather' or `extreme event*' or flood* or storm* or `storm surge' or `coastal flood* tropical cyclone*'or hurricane* or cyclone* or typhoon* or drought* or rain* or `heavy rain*' or `extreme precipitation' or earthquake* or fire*. Note that although these search terms capture a broader range of disasters, we included only papers on weather and climate related disasters in this report.

[18] As there were very few relevant papers, and because the types of papers dominant in each site differed, the format of the table differs for each site.

Dar es Salaam

Only two relevant papers were identified for Dar es Salaam (Table 14). Both model floods rather than assess the impacts of particular real events. The first considers floods associated with rainfall and uses detailed built environment mapping; the second assesses the risks of a hypothetical high impact coastal flood (storm surge) in the present and future. Both papers utilised spatially explicit data for population and the urban area.

Table 14: Papers assessing the risk of flooding in Dar es Salaam.

FLOOD RISK ASSESSMENT AND MODELLING		
PAPER	**OVERVIEW AND FINDINGS**	**HEALTH DATA SOURCES**
de Risi *et al.* (2013)	Develops a method for flood risk assessment in slums based on flood hazard, building fragility, and potential people exposed to floods. The method is applied to Suna (a sub-ward of Dar es Salaam with a high concentration of informal settlements). It was estimated that ~35% of the population would be affected by flooding per year.	Model driven by assumed population density (per house, or per unit area) in affected area. It is unclear how this was estimated.
Kebede and Nicholls (2012)	Scenario-based assessment of potential number of people and value of assets exposed to coastal flooding in Dar es Salaam. Focused on a worst-case scenario assuming a 100-year flood with defence failure. Findings suggest ~8% of population live within the low elevation coastal zone (within 10m of sea level). An estimated 30,000 people would be exposed to a 100-year flood in 2005; this may increase to 210,000 by 2070. The corresponding figures for asset exposure are US$35 million. and US$10 billion. Rapid population growth, urbanisation and economic growth influence future exposure estimates more than the effects of climate change.	Potential human exposure using downscaled city level population projections assuming rapid urbanisation (see paper for details).

Ibadan

Three papers were identified for Ibadan which considered heat extremes, high speed winds, and floods (Table 15). The main data source for each was original data questionnaire, survey and/or interview data collected specifically for the study.

Nairobi

No papers related to natural disasters were found for Nairobi in the review.

Table 15: Papers focused on natural hazards and health impacts in Ibadan.

HAZARDS AND HEALTH		
HAZARD TYPE	**OVERVIEW AND FINDINGS**	**HEALTH-RELATED DATA SOURCES**
Heat extremes		
Taiwo *et al.* (2012)	Examined the perceived causes, exposures and adjustments to heat events, and investigated the relationship between heat exposure, built environment, socio-economic and cultural factors. Perceived causes were: intense heat from the sun, climate change, and absence of rains. Exposure was linked to the number of electricity hours, the distance from water supply points, and the number of neighbourhood trees. There was considerable variation in perceived causes, exposures and in adjustment by residential area: i.e. local knowledge may be useful for vulnerability and adaptation assessments.	Primary data: structured questionnaires.
High speed winds		
Adelekan (2012)	Mean maximum wind gusts and frequency of wind storms increased in 1998–2008 compared to 1989–1997. Following a major windstorm in 2008, an assessment of damage and vulnerability-characteristics of residents was undertaken. (See paper for details on vulnerability; factors assessed included: age, education, occupation, house ownership status and characteristics).	Primary data: questionnaires and in-depth interviews. Secondary data: local newspaper reports and other publications.
Floods		
Adetunji & Oyeleye (2013)	Investigates causes and effects of flooding. About 90% of questionnaire respondents suggested that flooding was caused by poor waste management, building construction along waterways, and poor planning and about 40% linked them to climate change. In terms of effects, about 90% indicated property and economic losses and about 25% suggested lives were lost. Around 30% suggested floods caused injuries and disease outbreaks.	Primary data: questionnaires. Secondary data: 2012 report of the National Emergency Management Agency in Nigeria.

Dhaka

Ten papers on the health effects of disasters in the population of Dhaka were identified (Table 16). Six of these focused on diarrhoeal disease using surveillance data from the International Centre for Diarrhoeal Research, Bangladesh (see Box 2 above for more about this surveillance programme). The remaining papers looked at malnutrition, dengue, and general health outcomes associated with floods and stagnant water; these drew primarily on qualitative data collected specifically for the study, with the exception of the dengue paper which used routine hospital admission data.

Table 16: Papers considering the impacts of flooding in Dhaka

FLOOD IMPACTS		
OUTCOME	**OVERVIEW AND FINDINGS**	**HEALTH DATA SOURCES**
DIARRHOEAL DISEASE		
Qadri *et al.* (2005)	Flooding in 2004 led to a diarrhoea epidemic. ICDDR,B's[19] hospital saw >17,000 cases, peaking at 700/day. *Cholera and enterotoxigenic Escherichia coli (ETEC) were each estimated to account for about 20% of cases.*	ICDDR,B.
ICDDR,B (2007)	During flooding in 2007, 401 patients with diarrhoeal disease were admitted to ICDDR,B's hospital in a single day. 70% were dehydrated but there were no deaths. Based on a 2% sample, 35% of patients had cholera and 12% rotavirus. It was estimated that during August, 6000 lives were saved by free rehydration treatment provided.	ICDDR,B.
Harris *et al.* (2008)	Assessed changes in prevalence of major diarrhoeal disease pathogens seen in floods in 2007 compared to floods in 2004 and 1996. Shifts of phenotype were seen for cholera and enterotoxigenic *Escherichia coli, and a greater proportion of cases exhibited severe dehydration in 2007 than in past floods.*	ICDDR,B.
Hashizume *et al.* (2008)	Assessed observed versus expected weekly cases of cholera and non-cholera diarrhoea during a flood in 1998, and identified vulnerable groups. During the flood, cholera cases increased six times, and non-cholera diarrhoea two times. For non-cholera diarrhoea, people with less education, living in a house without a concrete roof, drinking tube-well water (versus tap water) or with unsanitary toilets were at greater risk. The latter two factors increased the risk for cholera.	ICDDR,B (including data for age, sex, socioeconomic status, hygiene and sanitation practices).
Sirajul Islam *et al.* (2007)	Examined water samples from 20 sources (e.g. taps, hand pumps, tanks) for faecal contamination and pathogens during and after a flood in 2004. Waters were heavily contaminated as a result of the flood, peaking in the early stages then declining. The authors assessed various water treatments and concluded that point-of-use water treatment could reduce diarrhoeal disease during and after a flood.	Water samples collected for study and analysed at the Environmental Microbiology Lab at ICDDR,B.

[19] International Centre for Diarrhoeal Disease Research, Bangladesh.

FLOOD IMPACTS		
OUTCOME	**OVERVIEW AND FINDINGS**	**HEALTH DATA SOURCES**
Schwartz *et al.* (2006)	Examined the pattern of diarrhoeal disease presenting at ICDDR,B hospital during flood-associated epidemics in 1988, 1998, and 2004 compared to non-flood periods. In terms of proportion of cases, cholera increased during flood periods, rotavirus decreased, and proportions were unchanged for other pathogens. During flood-associated epidemics, dehydration was more severe, and people of lower socioeconomic status were more likely to present.	ICDDR,B
MALNUTRITION		
Goudet *et al.* (2011c)	Investigated how floods impact on feeding practices of infants and young children in slums, and coping strategies. Feeding practice were found to be generally poor (due to lack of knowledge, time, and resources) but worse during floods. As a coping strategy, some mothers decreased their own food intake. Mothers were aware of the negative impacts of floods but lacked means to address it.	Primary data collected for the study: participant observation, semi-structured interviews, household survey, anthropometric measurements.
Goudet *et al.* (2011b)	Assessed perceptions of pregnant women and health workers of the causes of malnutrition in infants and young children in slums. Along with inappropriate care, feeding, and environment, recurrent flooding was identified as a perceived cause.	Focus groups
DENGUE		
Hashizume *et al.* (2012)	Analysed the association between weekly dengue admissions, river levels and rainfall (which may be associated with flooding). Both high (over lags of 0 to 5 weeks) and low (over lags of 0 to 19 weeks) river levels (relative to an average threshold) were associated with increased admissions. This suggests water-related disasters such as floods and hurricanes may be associated with increased dengue cases.	Data on dengue admissions from 11 hospitals in Dhaka (see Figure 1 of original paper for details)
GENERAL		
Khan *et al.* (2014)	Assessed the health impacts of flood and stagnant water (FSW). Findings suggested that: people living in slums were more affected by FSW than people in adjacent rural areas, and, people (whether in a slum or rural area) affected by FSW were more at risk of diarrhoeal disease and poor mental health compared to non-affected people. Differences in vulnerability were evident at the individual-, household-, and area-level.	Primary data based on a survey and face-to-face interviews.

7 Conclusions

Increasing concerns about climate change have spurred a broad and urgent research agenda which includes developing an evidence base that will help prevent future health burdens through informed adaptation. Priorities for adaptation investment include populations situated in locations where adverse climate events are likely to be most frequent or extreme as well as those populations with the least resilience. In some cases the two overlap.

Urban populations living in informal settlements are inherently vulnerable to climate change, as informal settlements are characterised by overcrowding, poor infrastructure and poverty. They are also disproportionately found in low- and middle-income countries where resources (economic and otherwise) are relatively scarce. As a result, there is a substantial need to guide adaptation policies in these areas in order to minimise the negative impacts of climate change.

A first step in estimating the potential impacts of climate change on urban populations is to understand the current health burden and how this is associated with environmental and social factors. Burden of disease studies range from simple estimates of the number of deaths attributable to certain diseases to more complex analyses that look at specific risk factors and include estimates of morbidity. Although methods for quantifying disease burdens are well-established and have relatively minimal data requirements, in many urban populations in low- and middle-income countries, and in informal settlements in particular, high-quality vital registration may not exist. Therefore, burden of disease studies may have to rely on data from surveillance sites, hospital data or ad hoc surveys. Based on data from the Global Burden of Disease study and a literature search for studies in four cities (Nairobi, Dar es Salaam, Ibadan and Dhaka) it is clear that environmental risk factors contribute an important proportion of disease burdens in many urban populations. These include air pollution (household and outdoor) and inadequate water supply. Other environmental risk factors that are less frequently assessed, but also likely to contribute meaningful burdens include poor housing and unsafe roads, as well as general vulnerability to natural hazards (discussed more below).

Separate from burden of disease studies, there are a number of study designs available to specifically explore the influence of weather/climate on health outcomes. Three of the more commonly used designs include episode analyses, time-series regression and cross-sectional studies. Of the three, only the third generally involves primary data collection: the former two designs often require only daily (or sometimes weekly or monthly) death counts and data on the environmental exposure of interest (e.g. temperature). There have been a few of these types of studies conducted in the four example cities listed above.

This report also looked specifically at natural hazards and how they interact with social and environmental risk factors to produce disaster events. While a small number of large disasters cause the majority of disaster mortality, small disasters occur frequently and may have significant health and economic impacts on people living in informal settlements. Global disaster mortality data is routinely collected by EM-DAT, but the lack of morbidity data and the likely exclusion of many small disasters means the data is a limited use for assessing local-level vulnerability. Observations suggest that Africa and South Asia experience around 72 and 156 disasters per year respectively but data and studies on the sites of interest are extremely limited. However, as is the case in Bangladesh, actions can be taken to significantly reduce population vulnerability – access to good quality health, environmental and social data is necessary to enable and enhance these efforts.

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Related reading

Environment & Urbanization 23:1 Health and the City – http://eau.sagepub.com/content/23/1.toc

Environment & Urbanization Brief 22 'Why is urban health so poor even in many successful cities?' http://pubs.iied.org/10595IIED.html

Urban Poverty in the Global South – book by Diana Mitlin and David Satterthwaite http://pubs.iied.org/X00098.html

Reconfiguring Urban Adaptation Finance – working paper available at http://pubs.iied.org/10651IIED.html

Understanding children's risk and agency in urban areas and their implications for child-centred urban disaster risk reduction in Asia – working paper available at http://pubs.iied.org/10652IIED.html

Heat stress and adaptive capacity of low-income outdoor workers and their families in the city of Da Nang, Vietnam – working paper available at http://pubs.iied.org/10051IIED.html

Appendix 1: Health data availability in the sites of interest

Dar es Salaam

Vital statistics and other government data

The National Bureau of Statistics (www.nbs.go.tz/) reports results from numerous surveys and censuses in the country. According to their website, recent health-related surveys include:

- 2012 Population and Housing Census
- 2011/12 HIV and Malaria Survey
- 2011/12 Household Budget Survey

Over the past decade, Tanzania has implemented vital registration. It is a decentralised, bottom-up system that registers births, deaths and marriages, with registration offices at various administrative levels. The WHO provides a summary of this system as well as links to the appropriate government agencies that handle the process: www.aho.afro.who.int/profiles_information/index.php/Tanzania:Civil_registration_and_vital_statistics_systems

Demographic and health surveys

There have been a number of DHS surveys conducted in Tanzania. The most recent standard DHS was completed in 2010, while others were conducted previously (2010, 2004/05, 1999, 1996, 1991/92). There is also an ongoing HIV/MCH survey and a recent AIS survey. The Tanzania DHS web portal can be found at: https://dhsprogram.com/Where-We-Work/Country-main.cfm?ctry_id=39&c=Tanzania&Country=Tanzania&cn=&r=1

Surveillance

Although there was previously a major surveillance site in Dar es Salaam (see `Sources of data' section), to our knowledge this is no longer functioning. The WHO does support a Communicable Disease Surveillance program that focuses on disease outbreaks: www.afro.who.int/en/tanzania/country-programmes/3104-communicable-disease-surveillance-and-response-csr.html

Government data archives

Initiatives to make data publicly available have resulted in the Tanzania National Data Archive (www.nbs.go.tz/nbs/index.php?option=com_content&view=article&id=98&Itemid=89) and the Tanzania Socioeconomic Database (www.nbs.go.tz/nbs/index.php?option=com_content&view=article&id=96&Itemid=87)

Meteorological data

Data can be obtained through the Tanzania Meteorological Agency: www.meteo.go.tz/

Other resources:

Key government departments/ministries

Ministry of Health and Social Welfare: www.moh.go.tz/

Ministry of Lands, Housing and Human Settlements Developments: www.ardhi.go.tz/

Ministry of Water: www.maji.go.tz/

A full list of ministries can be found at: www.tanzania.go.tz//directoryrecords/sub_dir/26

World Health Organization sites

Country profile: www.who.int/countries/tza/en/

Country office for Tanzania: www.afro.who.int/en/tanzania/who-country-office-tanzania.html

African Health Observatory country site: www.aho.afro.who.int/profiles_information/index.php/Tanzania:Index

Ibadan

Vital statistics and other government data

The National Bureau of Statistics (www.nigerianstat.gov.ng/) reports results from numerous surveys and censuses in the country. According to their website, recent health-related surveys include:

- 2012 National Baseline Youth Survey
- 2011 Multiple Indicator Cluster Survey
- 2010/11 General Household Survey
- 2009 Harmonised Nigeria Living Standards Survey
- 2006 Population Census

Data for many of the surveys can be found on the Bureau's data portal: www.nigerianstat.gov.ng/nada/index.php/catalog

According to the government's website, Nigeria has not yet implemented compulsory vital registration of births and deaths. There is an existing vital registration system, but coverage in the country is low (National Population Commission, 2008).

Nigeria has recently launched an Open Data initiative for open access to government data, but it was not yet functioning at the time of writing.

Demographic and health surveys

There have been a number of DHS surveys conducted in Nigeria. The most recent standard DHS was completed in 2013, while others were conducted previously (2008, 2003, 1999, 1990). There was also a Malaria Indicator Survey conducted in 2010. The Nigeria DHS web portal can be found at: http://dhsprogram.com/Where-We-Work/Country-Main.cfm?ctry_id=30&c=Nigeria&Country=Nigeria&cn=&r=1

Surveillance

To our knowledge, there is no systematic surveillance in Ibadan. There is some reporting of notifiable diseases in Nigeria.

Meteorological data

Data can be obtained through the Nigerian Meteorological Agency: http://nimet.gov.ng/

Other resources:

Key government departments/ministries

Federal Ministry of Health: www.health.gov.ng/

Federal Ministry of Environment: http://environment.gov.ng/

Federal Ministry of Water Resources: www.nigeria.gov.ng/2012-10-29-11-06-51/executive-branch/110-federal-ministry-of-water-resources/129-federal-ministry-of-water-resources

Federal Ministry of Women's Affairs and Social Development: www.nigeria.gov.ng/2012-10-29-11-06-51/executive-branch/111-federal-ministry-of-women-affairs-and-social-development

Federal Ministry of Lands, Housing and Urban Development: www.nigeria.gov.ng/2012-10-29-11-06-51/executive-branch/113-federal-ministry-of-lands-housing-and-urban-development

A full list of ministries can be found at: www.nigeria.gov.ng/2012-10-29-11-06-51/executive-branch

World Health Organization sites

Country profile: www.who.int/countries/nga/en/

Country office for Nigeria: www.afro.who.int/en/nigeria/who-country-office-nigeria.html

African Health Observatory country site: www.aho.afro.who.int/profiles_information/index.php/Nigeria:Index

The Ibadan Study of Ageing has contributed to many research projects in the city. The Principal Investigator is Oye Gureje at the University of Ibadan.

Oyo State government website: www.oyostate.gov.ng/

Nairobi

Vital statistics and other government data

The Kenya National Bureau of Statistics (www.knbs.or.ke/) conducts numerous surveys and censuses in the country. According to their website, recent and ongoing health-related surveys include:

- 2012 Kenya Urban Reproductive Health Initiative
- 2012 National Housing Survey
- 2011 Multiple Indicator Cluster Survey
- 2009 Population and Housing Census

However, note that the website is not always easy to navigate and it may be easier to access data through Kenya's Open Data initiative (see below).

In terms of vital statistics, there is a system of reporting for births and deaths in the country, but coverage rates are often low, ~50 per cent nationally (Kenya National Bureau of Statistics, 2012). The figure is much higher in Nairobi, with 2011 data reported as 93 per cent for births and 70 per cent for deaths. There are also statistics on outpatient morbidity by disease type, although reporting completeness is also low.

Demographic and health surveys

There have been a number of DHS surveys conducted in Kenya over the past three decades. There is a standard DHS ongoing at the moment, while others have been completed in the past (2008/09, 2003, 1998, 1993, 1989). In the last five years there has also been a DHS survey on HIV and Maternal and Child Health (HIV/MCH) as well as a Malaria Indicator Survey (MIS). The Kenya DHS web portal can be found at: http://dhsprogram.com/Where-We-Work/Country-Main.cfm?ctry_id=20&c=Kenya&r=1

Surveillance

NUHDSS

As highlighted in Box 2 of the main text, there is a successful health surveillance program running in two of Nariobi's slums, called the Nairobi Urban Health and Demographic Surveillance System (NUHDSS). This is the main source of data for the major studies on Nairobi's burden of disease and epidemiological studies linking temperature and health. See: http://aphrc.org/projects/nairobi-urban-health-and-demographic-surveillance-system-nuhdss/

Integrated Disease Surveillance and Response

Kenya also has an integrated disease surveillance and response (IDSR) strategy, which is a surveillance program for collecting data on communicable diseases in the country. The program links health data at many administrative levels and focuses on ~35 different conditions. An IDSR has been adopted by many African countries and is a joint effort between the adopting countries, the WHO and the US Centres for Disease Control. See: http://41.57.109.244/idsr/

Population Based Infectious Disease Surveillance (PBIDS)

For the past decade, there has been a collaboration between the US Centers for Disease Control and the Kenya Medical Research Institute that has conducted infectious disease surveillance in two villages in Nairobi's Kibera slum (Gatwikira and Soweto West). The site is 0.42 km^2 and has approximately 28,000 participants enrolled. Data is collected by community interviewers. See: http://ije.oxfordjournals.org/content/39/2/450.full

Meteorological Data

Data can be obtained through the Kenya Meteorological Service: www.meteo.go.ke/

Kenya Open Data

Kenya has been a leader in making government datasets available through their Open Data website (https://opendata.go.ke/). The website provides a range of data on health, poverty, migration, education and others. Many datasets are disaggregated to the district level or focus on Nairobi specifically.

Other resources:

Specific government departments/ministries:

Ministry of Public Health and Sanitation (including the Division of Disease Surveillance and Response) – http://ddsr.or.ke/idsr/index.php

Ministry of Environment, Water and Natural Resources – www.environment.go.ke/

Ministry of Land, Housing and Urban Development: www.ardhi.go.ke/default/index.php

World Health Organization sites:

Country profile: www.who.int/countries/ken/en/

Country office for Kenya: http://www.afro.who.int/en/kenya/who-country-office-kenya.html

African Health Observatory country site: www.aho.afro.who.int/profiles_information/index.php/Kenya:Index

Population Council – www.popcouncil.org/countries/kenya.asp

Dhaka

Vital statistics and other government data

The Bangladesh Bureau of Statistics (www.bbs.gov.bd/home.aspx# or http://203.112.218.66/Home.aspx) conducts numerous surveys and censuses in the country. According to their websites, recent health-related surveys include:

- 2011 Population and Housing Census
- 2010 Sample Vital Registration System (SVRS) survey
- 2010 Household Income and Expenditure Survey
- 2009 Multiple Indicator Cluster Survey

However, note that the Bureau websites are not always easy to navigate and have many broken links.

In terms of vital statistics, the government of Bangladesh periodically conducts SVRS surveys to estimate births, deaths (by cause) and life expectancy (including life tables) as well as to collect other information including on demographic characteristics, housing, migration and disability. Data can be found at http://203.112.218.66/PageReportLists.aspx?PARENTKEY=51 This survey supplements vital registration data, as coverage in Dhaka (and elsewhere) is low (Bangladesh Bureau of Statistics, 2010).

An additional data source is the Directorate of General Health Services, which collates data on notifiable disease cases (e.g. Dengue) reported by hospitals. This data has been used in epidemiological studies to investigate weather/climate-health associations (Banu *et al.*, 2014).

Demographic and health surveys

There have been a number of DHS surveys conducted in Bangladesh over the past three decades. The most recent standard DHS was completed in 2011, while others were conducted previously (2007, 2004, 1999/2000, 1996/97, 1993/94). There is also a DHS HIV/MCH survey scheduled to commence fieldwork in June 2014. The Bangladesh DHS web portal can be found at: http://www.dhsprogram.com/Where-We-Work/Country-Main.cfm?ctry_id=1&c=Bangladesh

Surveillance

ICDDR, B

As highlighted in Box 2 of the main text, there is a successful health surveillance program running for the Dhaka population by the International Centre for Diarrhoeal Disease Research, Bangladesh (ICDDR,B) which is the main source of data for many epidemiological studies in Dhaka, including those linking temperature and health (e.g. Hashizume *et al.*, 2007). See: www.icddrb.org/

WHO surveillance

The WHO supports a Communicable Disease Surveillance program in Bangladesh that aims to ensure that there is the capacity to identify and appropriately respond to epidemics and pandemics of emerging and re-emerging diseases. There are also disease-specific surveillance programmes in the country. See: www.searo.who.int/bangladesh/areas/communicable_disease/en/

Meteorological data

Data can be obtained through the Bangladesh Meteorological Department: www.bmd.gov.bd/

Other resources:

Key government departments/ministries

Ministry of Health and Family Welfare: www.mohfw.gov.bd/

Ministry of Disaster Management and Relief: www.dmrd.gov.bd/

Ministry of Environment and Forests: www.moef.gov.bd/index.php

A complete list of ministries can be found at www.bangladesh.gov.bd/?q=en

World Health Organization sites

Country profile: www.who.int/countries/bgd/en/

Country office for Bangladesh: www.searo.who.int/bangladesh/en/

This paper guides those who are interested in the current and potential health impact of climate change on urban populations in low- and middle-income countries. It describes the sources and types of health data available to assess current disease burdens and the relative importance of environmental risk factors. This includes how to identify sources of mortality and morbidity data in cities. It also shows how health data are incorporated into survey designs with examples of how this can assess weather and climate related disaster impacts on health in particular cities. Such work is challenging when routine health data (including the recording of causes of death) are not available.

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