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Global Climate Change and Child Health: A review of pathways, impacts and measures to improve the evidence base*

Yoko Akachi, Donna Goodman, David Parker

DISCUSSION PAPER

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Abstract

This paper reviews the published evidence of pathways and impacts of global climate change on child health. The review was occasioned by the recognition that most of the work to date on climate change and health lacks clear focus on the children's dimension, while the climate change and children literature tends to be brief or imprecise on the complex health aspects.

Studies were identified by searching the PubMed database for articles published before April 2009. Publications by agencies (e.g., UNICEF, WHO, IPPC) were also included based upon review. A list of references was developed that provide evidence to the linkages between climate change and health outcomes, and on specific health outcomes for children. The analysis explores the hypothesis of disproportionate vulnerability of children's health to environmental factors, specifically those most closely related to climate change.

Based upon scientific and policy research conducted to date there is found to be substantial evidence of disproportionate vulnerability of children in response to climate change. The diseases likely to be potentiated by climate change are already the primary causes of child morbidity and mortality, including vector-borne diseases, water-borne diseases and air-borne diseases. For this reason further research, assessment and monitoring of child health in respect to climate change is critical. Proposals are made for governments to integrate environmental health indicators into data collection in order to accurately assess the state of child health in relation to other age groups and its sensitivity to climate change.

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The findings, interpretations and conclusions expressed in this paper are entirely those of the author(s) and do not necessarily reflect the policies or the views of the United Nations Children's Fund (UNICEF).

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Correspondence should be addressed to:

UNICEF Innocenti Research Centre, Piazza SS. Annunziata 12, 50122 Florence, Italy
Tel: (+39) 055 20 330, Fax: (+39) 055 2033 220, Email: florence@unicef.org

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The Centre's publications contribute to the global debate on children's issues and include a wide range of opinions. As a centre for excellence, Innocenti also collaborates with external partners and often seeks contributions and inputs from children's rights specialists from a range of disciplines

The Centre collaborates with its host institution in Florence, the Istituto degli Innocenti, in selected areas of work. Core funding for the Centre is provided by the Government of Italy, while financial support for specific projects is also provided by other governments, international institutions and private sources, including UNICEF National Committees

GLOBAL CLIMATE CHANGE AND CHILD HEALTH: A REVIEW OF PATHWAYS, IMPACTS AND MEASURES TO IMPROVE THE EVIDENCE BASE

Yoko Akachi, Donna Goodman, David Parker

Keywords: climate change, child health, natural disaster, malnutrition

1. Introduction

There is wide scientific consensus that the global climate is changing in ways that have major implications for human life. More research is needed, however, to make accurate predictions of the overall effects on humans and on the earth. It is critical to identify the populations most at risk of adverse effects from climate change. Available evidence indicates that children are a particular population whose vulnerability must be reduced with priority. WHO estimates, for example, that a third of the global burden of disease for children is due to modifiable factors in air, water, soil and food (McMichael et al 2008, Prüss-Ustün and Corvalan 2006 and 2007). Analysis of geophysical systems identifies several 'tipping points' in the earth's environment where the effects of climate change would play decisive roles – such as changes in the Gulf Stream circulation, the Asian Monsoon, the Sahara Desert and the Antarctic ice-sheets (McMichael and Butler 2004). In contrast, less progress has been made to identify the most vulnerable human communities and the main health risks they face as a result of changes in the environment. Further systematic evidence on health vulnerability and specific impacts according to social grouping and life course stage must be collected. This paper attempts to make a contribution to this effort.

Four of the eight Millennium Development Goals are closely linked to health: eradicating extreme poverty and hunger, reducing child mortality, improving maternal health, and combating HIV/AIDS, malaria and other diseases. Only one of the goals is regarded to be directly relevant to global climate change, namely, ensuring environmental sustainability. It is widely understood, however, that without environmental sustainability, including appropriate measures to mitigate the impacts of climate change and adapt strategies and behaviours appropriately, significant challenges will remain in achieving health improvements (IPCC, UNDP 2007-2008).

The Convention on the Rights of the Child (CRC), signed in 1989 and ratified by 192 countries, protects and preserves the basic human rights held by children everywhere, including: the right to survival; to develop to the fullest; to be protected from harmful influences, abuse and exploitation; and to participate fully in family, cultural and social life. [1] Children's environmental health is associated with all of these rights from the health perspective. Children's right to health is amplified well within the broader human right to health, on which a substantial literature and discussion has emerged in recent years (WHO 2005b; OHCHR and WHO 2008.) Environment surrounds the child, and children's health is sensitive to the environment (Neira et al. 2008). Climate change and its effects on child health threaten realization of children's basic rights.

Yet children must not be viewed purely as passive victims of environmental degradation and the increasing threat of climate change. Educational practices and methodologies which build knowledge and understanding while encouraging empowered participation of children and young people can significantly decrease severity of impacts, most notably in cases related to environmental health threats (Penrose and Takaki 2006).

Needs for increased knowledge as a guide to action

The effects of climate change are predicted to be heavily concentrated in poorer populations at low latitudes, where the most major climate-sensitive health outcomes (malnutrition, diarrhoea and malaria) are already common (WHO 2008a), and where the vulnerability to climate effect is the greatest (WHO 2002). These diseases mainly affect younger age groups; hence the total burden of disease due to climate change appears to be borne mainly by children in developing countries (Haines et al 2006). The broader-themed research on climate change and human health has a tendency to focus on cases from the developed countries and on the adult population, such as the European heat waves of 2003, in discussing the impact of climate change on health owing partially to the availability of data (Haines et al. 2006). We argue that existing evidence collectively point to the vulnerability of children, especially those residing in developing countries that are geographically predicted to be most affected by climate change and have fewer resources to cope and to adapt.

Review of recent research on children and climate change shows that attention to monitoring and analysis through the use of indicators has been relatively limited.[2] Focusing on the impact of climate change on child health reinforced this finding; many publications call for the investigation of specific health risks and health outcomes of children in response to climate change over longer periods of time with reliable data.

The particular vulnerability of children calls for concerted action; within this the development of relevant indicators is an essential step. Indicators play an important role in assessing the state of child health in relation to changing environmental factors at community, national and international levels. Currently many countries lack ways and means to collect verifiable data, which makes it difficult to assess the current state and future trends in environmental changes and their effects on child health. For example, without accurate statistics on health outcomes such as childhood respiratory diseases in relation to outdoor air pollution caused by burning of inefficient and unclean bio-fuels, diarrhoeal diseases caused by lack of access to water and inadequate sanitation, and physical injuries associated with natural disasters, we cannot grasp how changes in the environment affect children in either the short or the long term. This greatly limits the ability to specify optimal policies and interventions to improve the health and well-being of children. Much of the relevant data from developing countries in particular currently leaves room for quality improvement; data on key issues related to climate change are frequently missing, so values are often interpolated or extrapolated over time. Development of environmental health indicators that are disaggregated by age group, including children, together with effective means of data collection, is essential to ensuring the availability of needed evidence.

This paper first attempts to summarize what is known about global climate change and its link to child health through a review of the literature. Studies were identified by searching the PubMed database for articles published before April 2009. Most articles referenced are from peer-reviewed journals, the full-text accessed on-line through the Harvard Countway Medical Library. Publications by agencies (UNICEF, WHO UNEP, IPPC, etc) were also included, upon review. On this basis a list was developed of references providing evidence on the linkages between climate change and health outcomes, and specifically on outcomes for children. The paper identifies evidence at varying levels of impact and in relation to different health outcomes. It documents the disproportionate vulnerability children's health to environmental factors, specifically those most closely related to climate change. It then describes initiatives to develop environmental health indicators for children, and outlines actions including measures to integrate indicators of children's environmental health into existing data collection systems.

2. Global Climate Change and Impacts on Child Health

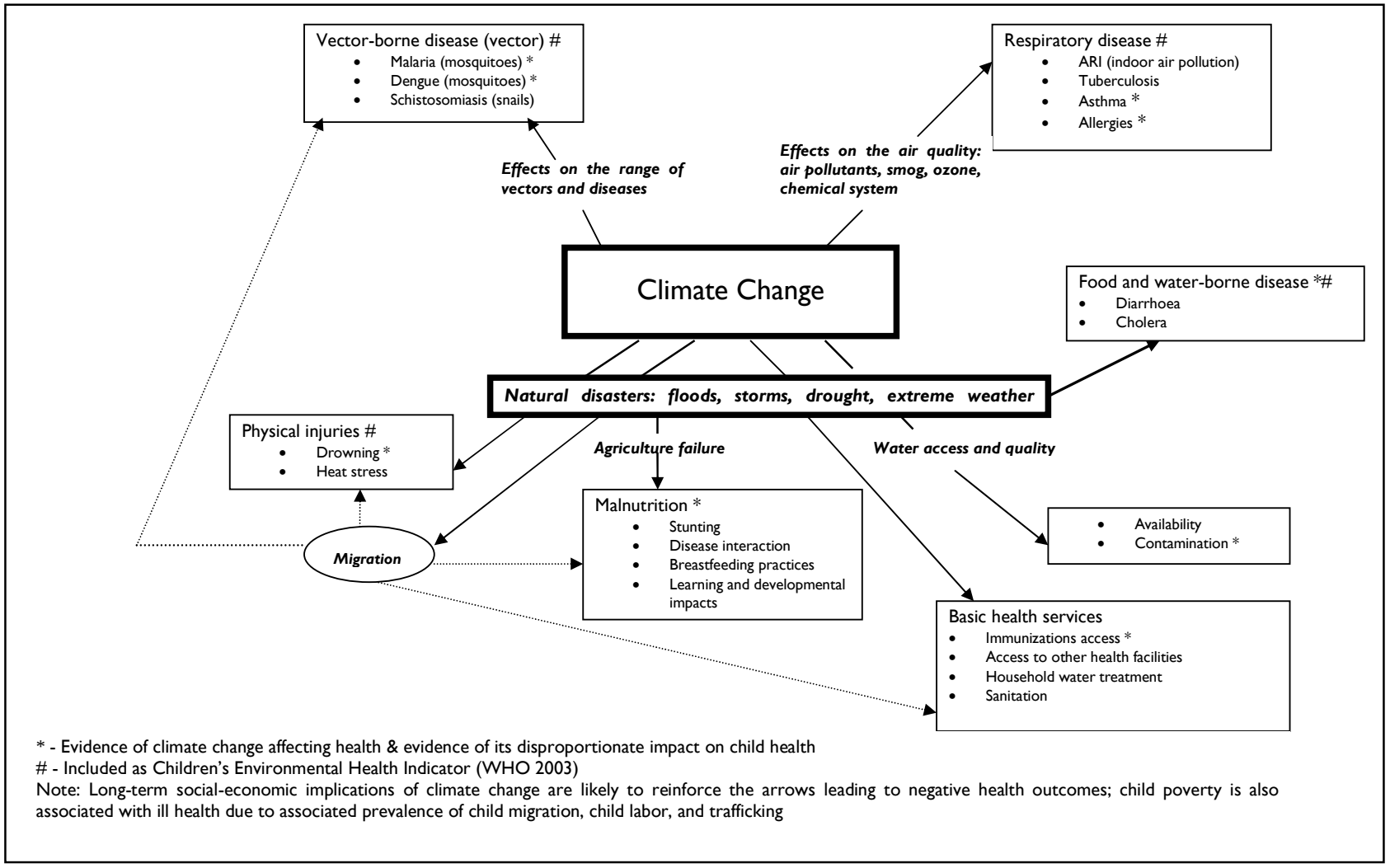
Exposure to the effects of climate change during childhood can cause immediate harm or cause damage that becomes evident much later in life, resulting in lasting imprints over lifetime and over generations (Neira et al. 2008, Berkman et al. 2002)

The direct impacts (WHO 2008a) of natural disasters associated with climate change include extreme weather events such as floods, storms, droughts and heat waves (Figure 1). They can lead to adverse health outcomes, ranging from physical injuries such as drowning and accidents to heat stress, respiratory diseases and trauma. Access and quality of drinking water is threatened by environmental changes. Climate change affects crop yields, which is associated with food production and risk of malnutrition. Malnutrition interacts with and aggravates diseases, hindering child development. Children are also susceptible to food and water-borne diseases that are sensitive to temporal changes such as diarrhoea. Air pollutants can lead to respiratory diseases which children are especially vulnerable to, such as asthma. Climate change can also affect the geographic distribution of vector-borne diseases (Anderson et al. 2006) such as malaria, dengue and schistosomiasis. Within each of these health outcomes, children have increased vulnerability compared with the rest of the population, and they are one of the groups most likely to experience adverse health caused by environmental change (Neira et al. 2008). Due to children's rapid growth and physiological and cognitive development, they are exposed and more vulnerable to biological, chemical and physical environmental hazards compared to adults (Shea 2003). Specific health outcomes of climate change impacts and how it is related to child health is explored in subsequent sections.

Climate change is a long-term phenomenon with potentially unpredictable, significant and lasting effects on the environment and on humans (IPCC, UNDP 2007-2008, WHO 2008a). The long-term socio-economic implications of climate change are foreseen to be negative in many respects. As is the case for all forms of natural disaster, the poor are among the most vulnerable, and their poverty is likely to be exacerbated by the need to respond to the disaster. Poverty is in turn both directly and indirectly associated with ill health, denying children their basic rights to health by limiting access to safe water, sanitation, nutrition and health care (WHO 2008 b). A major driver in this result of climate change is environmentally induced migration, which is projected to generate substantial additional impacts on children and on their health, as illustrated in Figure 1.

In the overall context of climate change and health there are particular reasons why we need to understand the impacts on child health and to invest in actions to address them. A growing body of findings points to the critical imprints that childhood health and nutrition leave on adult morbidity and mortality (e.g. Barker 1997, Crimmins and Finch 2006, Victora et al. 2008). Children are not only susceptible to current environmental risks, but these early effects of the climate change on their health could leave lasting impacts on their potential human capital as they move

Figure 1: Pathways of impact of climate change on child health



* - Evidence of climate change affecting health & evidence of its disproportionate impact on child health
# - Included as Children's Environmental Health Indicator (WHO 2003)
Note: Long-term social-economic implications of climate change are likely to reinforce the arrows leading to negative health outcomes; child poverty is also associated with ill health due to associated prevalence of child migration, child labor, and trafficking

into their adult life, and eventually on the subsequent generations. Investment in child health thus means investing for the future generations and for the future environment.

The sections that follow examine the implications of climate change in relation to specific health outcomes. A framework is offered to facilitate the understanding of these pathways and impacts, presented as Figure 1.[3] The discussion in this paper attempts to follow the main lines of the pathways indicated, although due to the complexity of climate change impacts this cannot be done fully.

2.1 Health effects related to natural disasters

Global climate change scenarios consistently forecast increases in the intensity and frequency of extreme climatic events, as have been witnessed the recent years (Easterling et al. 2000, Thibault and Brown 2008). Globally, 66.5 million children annually were affected by disasters between 1990 and 2000 (Penrose and Takaki 2006). Children are at risk of injury and death from storms and floods. Warmer air, such as that resulting from the greenhouse effect, can hold more moisture and more quickly evaporate surface water, thereby increasing the frequency of severe storms, floods and droughts (Patz et al. 2000). A significantly high mortality was observed in children and women among the displaced population in the eastern coastal district of Sri Lanka as a result of tsunami (Nishikiori et al. 2006).

The risk factors for infectious disease outbreaks after disasters are associated primarily with population displacement. Interactions with the availability of safe water and sanitation facilities, the degree of crowding, the underlying health status of the population, and the availability of health care services within the context of the local disease ecology influence the risk for infectious diseases in the affected population (Watson et al. 2007). Children suffer from lack of access to basic health practices such as immunization and breast feeding practices at the time of natural disasters (Mohan et al 2006, Adhisivam et al 2006).

Flood. The number of people at risk from flooding by coastal storms is projected to increase by two to three-folds (IPCC 2001). Immediate health impacts of flood include drowning, injuries, and physical and mental trauma. Severe flooding in the Sarlahi district of Nepal shows that the flood-related fatality rates for children were 6 times higher than mortality rates in the same villages a year before the flood. Flood-related fatality rates in the recorded population were 13.3 per 1,000 for girls and 9.4 per 1,000 for boys, 6.1 per 1,000 for women and 4.1 per 1,000 for men. Children, particularly girls, were at highest risk of flood-related fatality; in this population, children aged between 2 and 9 years were twice as likely to die as their same sex parent (Pradhan et al. 2007). The study does not explore the rationale for these statistics; the risk difference may be related to the children's physical size and strength compared to adults, as well as acquirement of survival skills. Longer-term effects of flood include increases in communicable diseases such as those caused by ingestion of contaminated water (e.g., cholera and hepatitis A) or contact with contaminated water (e.g., leptospirosis) (Patz and Khaliq 2002).

Drought. Droughts have their largest impact on population health by threatening food supplies and nutrition. In addition, diarrhoeal diseases, scabies, conjunctivitis and trachoma are associated with poor hygiene and may result from inadequate sanitation as water resources become depleted (Patz and Khaliq 2002 Prüss et al. 2008). Among children, pneumonia, and to a lesser extent, diarrhoeal diseases showed highest incidence rates during the main dry season in southern Ethiopia (Lindtjorn et al. 1992). The highest incidence of pneumonia coincided with an outbreak of measles, whose interaction is life-threatening. During droughts, water availability is diminished forcing people to access poorer quality water supply sources, and water quality is often degraded. An example is when people share water with livestock. A long drought followed by an intense rainfall generates multiple disease outbreaks. This includes rodent-borne disease outbreaks as rodent population booms in the wake of replenished water supplies (IPCC Working Group II report, Tibbetts 2007).

Extreme heat and extreme cold. Mortality rates increase at both high and low extremes of temperature (Curriero et al. 2002). A study from the United States showed that place of death, race and educational attainment indicate vulnerability to temperature-related mortality, reflecting inequities in health impacts related to climate change (O'Neill et al. 2003). The impact of heat waves and cold spells on mortality in Netherlands during 1979-1997 support earlier findings that temperature has a relatively small influence on mortality among those less than 65 years of age (Huynen et al. 2001), and it appears that it is the elderly population that are most affected by weather extremes. The infants and young children may represent a second, high-risk group (Wyndham and Fellingham 1978), and this was the case from the heat waves in Brazil (Gouveia 2003). Lam (2007) shows a link between hot days and child hospital admissions in Sydney. Young children under age six appeared to become overheated on the hot days and developed fever, and the author also found that children's hospitalisation for gastroenteritis increased on extremely hot days. Effects on children have not been studied sufficiently, especially in the developing nations. Children in general spend more time outside, which puts them at increased risk of heat stroke and heat exhaustion. There is little evidence on the effects of extreme heat and cold in developing countries, however the availability of suitable

infrastructure to provide protection suggests the impact would be considerably higher than that experienced in developed countries as described here.

Mental health. Children are also subject to adverse psychological suffering from natural disasters and other outcomes of climate change. Even though mental health is difficult to measure as an impact of climate change alone, there is some evidence that natural disasters associated with climate change has impact on child mental health and should not be neglected as part of the environmental effect on child health. A majority of children had post-traumatic symptoms, which was clinically evaluated after a super-cyclone in Orissa, India. Post-traumatic stress disorder (PTSD) was present in 30 per cent of the children (Kar et al. 2007). A tsunami in Thailand left nearly 60 per cent of the children with PSTD at six weeks after the incident (Piyasil et al. 2007). The mental health impacts on children of the 2003 Canberra bushfires have been linked to the prolonged period of drying in this region , this being an example of impacts on children even in the developed world (McDermott 2005). Younger children and individuals with greater exposure to and perception of threat experienced higher levels of PTSD and general psychopathology.

2.2 Health effects related to water

Natural disasters such as floods and droughts affect human interactions with water resources and therefore exposure to the pathogen, and in addition, sanitary conditions and susceptibility to disease (Boxall et al. 2009). The pathways and potential extent of impacts of climate change due to changes in the availability and quality of water for children may be inferred from a range of existing evidence.

Water access and quality. Access to clean, safe water is still unavailable to more than 1 billion people worldwide. Climate change further threatens to severely impact the water quality and quantity particularly in arid regions, small island states, and in regions hit by natural disasters where conditions of living are compounded by weakened infrastructure (Anderson et al. 2006). Limited access and poor quality of water affect child health through both chronic (e.g. arsenic) and acute (i.e. biological) exposures.

A large-scale (n=25500 children) prospective cohort study in Sudan showed that those with access to adequate household water and sanitation were independently associated with physical growth in children, controlled for the following variables: age, religion, gender, mother's literacy, family wealth, breastfeeding, cleanliness, intervention group (vitamin A vs. placebo). Among children stunted at baseline, those coming from homes with water and sanitation had a 17 per cent greater chance of reversing stunting than those coming from homes without either facility (Merchant et al. 2003).

Contaminated water hinders children's ability to learn, in addition to its impacts on physical growth. Poor water and sanitation has been associated with increased risk of infections in children (Daniels et al. 1990; Huttly et al. 1990; Mertens et al. 1990) and increased malnutrition (Adair and Guilkey 1997); improved water and sanitation was related to lower risk of malnutrition (Huttly et al. 1990; Daniels et al. 1991; Ricci and Becker 1996). Stunting in children is associated with increased risk of morbidity (el Samani et al. 1988; Kossmann et al. 2000), mortality (Bhutta et al. 1997; Fawzi et al. 1997; Yoon et al. 1997) and cognitive impairment (Berkman et al. 2002).

A recent review by experts assessed the implications of climate change on human exposures to pathogens and chemicals in agricultural systems and the subsequent effects on health. Even though the context was focused on the U.K., much of the finding is applicable to other countries and regions. The overall conclusion was that climate change will result in an increase in risks of pathogens and chemicals from agriculture to human health (Boxall et al. 2009). The development and growth in foetus, infant, child and adolescent life can define periods of great vulnerability to environmental toxicants due to the rapid tissues and organs growth, development and differentiation until maturity. Exposure to a wide range of chemicals and environmental toxicants during this period has the potential to significantly affect the development, maturation, growth and function of organ systems well into adulthood (Gavidia et al. 2009)

Water- and food-borne diseases. Diarrhoeal disease is a major cause of child deaths, with data suggesting that it accounts for over 15 per cent of cause-specific proportional mortality in children younger than five years worldwide. [4] Climate change is predicted to increase the incidence and severity of diarrhoeal disease. For example, during the period before the EI Niño episode in Peru, admissions for childhood diarrhoea increased by 8 per cent per 1°C increase in mean temperature. Diarrhoeal diseases may increase by millions of cases worldwide with each degree of increase in ambient temperature above normal (Checkley et al. 2000).

Lack of safe water is a major factor in diarrhoeal disease. Water shortage is a serious problem in many of the small island states. A study on the relationship between climate variability and diarrhoea in the Pacific region found that higher temperature and extreme rainfall, phenomenon associated with climate change, are likely to exacerbate diarrhoeal diseases in these island countries. They found that infants and children were particularly vulnerable to diarrhoeal disease, and suggest that global climate change is likely to

exacerbate diarrhoeal illness in many Pacific Island countries (Singh et al. 2001).

Rotavirus remains the leading cause of childhood diarrhoea. About 40 per cent of the hospitalizations for childhood diarrhoea worldwide are attributable to rotavirus and more than 0.6 million children under age five die every year from rotavirus infection, mainly in developing countries (Parashar 2003). Factors associated with high temperature, low humidity and high river-level increased the incidence of rotavirus diarrhoea in Dhaka, Bangladesh (Hashizume et al. 2007).

Regional correlation maps have shown a significant association of temperature with the recent cholera data for Dhaka, Bangladesh (Pascual et al 2000). There are other quantitative evidences for an increased role of climate variability over the last decades on the temporal patterns of cholera in Bangladesh (Rodo et al. 2002). The study conducted time-series analysis of monthly 18-year cholera time series from Bangladesh and controlled for other factors to the extent possible with their data. It shows that climate phenomena (El Niño/Southern Oscillation or ENSO) account for over 70 per cent of disease variance. The ENSO system is the primary driver of inter-annual variability in global climate, but its long-term behaviour is poorly understood. A shift has been observed in the 1970s, unique in this past century, towards an intensified cycle under doubled CO_2 scenarios and warmer and wetter conditions in the tropical Pacific, with widespread climatic and ecological consequences (Rodo et al. 2002).

The association between climate variability and cholera incidence is expected to have particular impacts on children as a highly vulnerable age group. A recent review of population-based estimates of cholera incidence in Indonesia, India and Mozambique confirmed that young children bear the greatest burden of cholera, and this was the case in all regions (Deen et al. 2008). The study also found that the cholera burden is particularly high in Africa, consistent with findings of other studies, which call for particular attention to this region (WHO 2007a, Griffith et al. 2006).

2.3 Health effects related to air pollution

Climate change is linked to air pollution both by its cause (greenhouse gas emissions) and by its effect (climate variability such as heat waves in urban areas leads to higher concentration of air pollutants).

The world faces increasing levels of air pollution as a result of economic and industrial growth. The air pollution is manifesting increasingly in the urban centres of developing countries. Ambient air pollutants such as nitrogen dioxide (NO_2), ozone, particulate matter (PM), and components of PM including organic carbon and volatile organic compounds (VOCs) have been linked with increased allergic disease and asthma (McConnell et al. 2002, McConnell et al. 1999).The recorded cases of asthma have been increasing all over the world, including developed countries like the United States, especially among children (Anderson et al. 2006). An extensive review of studies demonstrate that exposure to increased levels of ambient air pollutants and pollens exacerbate asthma and respiratory allergic responses, and some may be factors in developing disease (Shea et al. 2008).

Climate change–related increased burden of disease, specifically from allergy and asthma, is anticipated because of changes in the distribution, quantity and quality of pollens, and changes in the timing and duration (lengthening) of pollen season. Asthma and allergic disease will also likely be worsened because of interaction between heavier pollen loads and increased air pollution; thunderstorms and extreme precipitation events; worsening heat-related ground-level ozone pollution; increased ambient air pollution from natural and anthropogenic sources; and air pollution related to wildfires (Shea et al. 2008).

It is important to focus on children with respect to air pollution because their lungs are not completely developed, they can have greater exposure than adults, and those exposures can deliver higher doses of different composition that may remain in the lungs for greater duration (Bateson and Schwartz 2008). Additionally, the undeveloped lung is more vulnerable and less able to fully repair itself from injury. Children spend more time outside, where concentrations of air pollution are generally higher. Children have higher baseline ventilation rates and are more physically active than adults, thus exposing their lungs to more air pollution. Higher ventilation rates and mouth-breathing may pull air pollutants deeper into children's lungs. Children also have immature immune systems, which plays a significant role in asthma. The observed consequences of early life exposure to adverse levels of air pollutants include diminished lung function and increased susceptibility to acute respiratory illness and asthma (Bateson and Schwartz 2008).

Outdoor air pollution. Linked with climate change is the compounding effect of increased temperature and increased levels of contamination in urban areas leading to increased risk by outdoor air pollution. Although air pollution has long been thought to exacerbate minor acute illnesses, recent studies have suggested that air pollution is associated with infant mortality and the development of asthma and atopy. A 5-year follow-up study of young children in Australia showed that there was an association between air pollution and respiratory systems (Rodriguez et al. 2007). There are limited studies from developing countries on the effects of air pollution on children, which could offer more specific indications of climate change impacts. However, there

is growing evidence that industrial development in urban areas and increased traffic raise the level of exposure to air pollutants in developing countries. In a coal-burning city in northern China, the associations between school children's asthmatic symptoms and indoor and outdoor air pollution in schools were observed (Zhao et al. 2008). Nearly 30 per cent of the total pupils had daytime attacks of breathlessness. Other studies have associated particulate air pollution with acute bronchitis in children and demonstrated that rates of bronchitis and chronic cough declined in areas where particle concentrations have fallen. Overall, evidence for effects of air pollution on children have been growing, and effects are seen at concentrations that are common today (Schwartz 2004).

Greater concentrations of carbon dioxide and higher temperatures may increase pollen quantity and induce longer pollen seasons. Some investigators have argued that part of the current global increase in childhood asthma can be explained by increased exposure to aeroallergens driven by climate change (Beggs et al. 2005).

Indoor air pollution. Indoor air pollution – generated largely by inefficient and poorly ventilated stoves burning biomass fuels such as wood, crop waste and dung, or coal – is responsible for the deaths of an estimated 1.6 million people annually. More than half of these deaths occur among children under age five. In developing countries with high mortality rates overall, indoor air pollution ranks fourth in terms of the risk factors that contribute to disease and death (WHO 2002).

Solid fuel dependency exacerbates deforestation, a process that contributes to the build-up of greenhouse gasses, particularly carbon dioxide, in the earth's atmosphere, and thus to global climate change (UNEP 2005). The activities that lead to indoor-air pollution are contributors to climate change as well as negative effects on child health. Even though indoor air pollution is not the expected effect of climate change per se, it is important to be considered in the context of climate change and child health as part of mitigation policy. By reducing indoor air pollution, better outcome on the environment as well as on child health could be expected. About half of the world's households use unprocessed solid fuels for cooking, and the estimates range up to 80 per cent for China, India and Sub-Saharan Africa (Rehfuess et al. 2006 Holdren et al. 2000). Much of the health impacts from air pollution worldwide seem to occur among the poorest and most vulnerable populations, largely women and young children who are most exposed to the indoor pollution sources in developing countries (Smith 2002). Children and adult women jointly receive the highest exposures due to their household roles.

A study on biomass fuels used in Indian households shows association with acute respiratory infections (ARI), lung cancer, tuberculosis, asthma and blindness (Smith 2000). Their resulting conservative estimates indicate that some 400,000-550,000 premature deaths can be attributed annually to the use of biomass fuels in these population groups. Using a disability-adjusted life-year approach, the total is 4-6 per cent of the Indian national burden of disease, placing indoor air pollution as a major risk factor in the country (Smith 2000). Another study investigated the association between household use of biomass fuels for cooking and ARI in preschool age children (under age five) in Zimbabwe. After adjusting for child's age, sex, birth order, nutritional status, mother's age at childbirth, education, religion, household living standard and region of residence, children in households using wood, dung, or straw for cooking were more than twice as likely to have suffered from ARI as children from households using LPG/natural gas or electricity (Mishra 2003). The relationship needs to be further investigated using more direct measures of smoke exposure and clinical measures of ARI; however, there appears to be strong association between household use of biomass fuels and ARI in children.

Overall, while there is little direct evidence of the impacts of climate change on child health due to air pollution, the studies discussed above suggest that this is an issue meriting specific attention.

2.4 Vector- and rodent-borne diseases

Vector-borne infections are affected by climate change (Epstein 2000). Climate and its variability alter the range of the vectors, and extreme weather events such as heavy rainfall precipitate large outbreaks. Increasing number of research are conducted on infectious diseases and climate change, including empirical analysis, computer simulation models and global change scenarios (Sutherst 2004), implicating the geographical expansion and increased intensity of these diseases. There is already evidence of vector species responding to recent climate change in Europe (Purse et al. 2005, Skarphedinsson et al. 2005) although alternative explanations, such as changes in socioeconomic, demographic and other environmental factors remain plausible.

Malaria is a climate-sensitive vector-borne illness to which children are particularly vulnerable. According to the WHO, malaria currently causes 350 million to 500 million illnesses annually and more than 1 million deaths (WHO 2005a). Because they lack specific immunity, children experience high levels of both morbidity and mortality from malaria; 75 per cent of malaria deaths occur in children younger than 5 years (WHO 2005a). There are various studies that model and estimate the impact of climate change on future transmissions of malaria (Rogers 2000, Lieshout 2004,

Sutherst 2004). These forecasting researches have been supplemented by studies using community data. There was a high spatial variation in the sensitivity of malaria patients to climate fluctuations in the highlands, and climate variability played an important role in initiating malaria epidemics in the East African highlands (Zhou et al. 2004). For the clinical malaria among children under five in Kenya, the temperature was found to be the best predictor (Ye et al. 2007). Studies of the association of malaria and past climate in Africa remain controversial due to the varying quality of long-term data and the difficulty in controlling for demographic and drug resistance variables (Patz et al. 2005). For example, some areas may be becoming too dry for mosquitoes to breed.

Predictions of impact of climate change on malaria are contradictory. Evidence so far suggests, however, that negative effects could outweigh the overall benefits. In one of the most recent studies, using historical climate data and annual malaria case number data from 1960 to 2006, statistical models were developed to isolate the effects of climate in each of Colombia's five contrasting geographical regions. A one degree Celsius change in sea surface temperature, indicating a weak to moderate ENSO (see previous section on "Water- and food-borne diseases"), is seen to translate to an approximate 20% increase in malaria cases, holding other variables constant. The authors conclude that ENSO may be a significant predictor of the malaria cases in Colombia (Mantilla et al. 2009). Such studies and emerging scientific evidence give rise to concern regarding impacts on children and pregnant mothers, who are most vulnerable to malaria.

Assessment of changes in the geographical limits of dengue fever transmission in respect to climate changes and population shows that a larger proportion of the human population would be affected, estimating that about 5–6 billion people (50–60 per cent of the projected global population) would be at risk of dengue transmission by later this century (Hales et al. 2002). Although there is controversy, the recent expansion of dengue in the Americas is partially attributed to incremental changes in climate by environmental scientists (Barclay 2008). Dengue affects all ages, but the burden of disease and the majority of deaths caused by dengue are highest among children. In several Asian countries, it is a leading cause of paediatric hospitalization and death.

Schistosomiasis is a parasitic disease where infected snails release parasite into water, leading to infections in human. Children are especially vulnerable to infection, which develops into chronic disease if not treated.[5] Climate change could affect schistosomiasis because changes in rainfall will have an impact on flow of rivers and levels of lakes in addition to the temperature, factors which impact the snail population. A model assessing the potential impact of rising temperature on the transmission of schistosomiasis in China forecasts an expansion of schistosomiasis transmission into currently non-endemic areas in the north (Zhou et al 2008).

Other vector-borne diseases that are affected my climate change and variability include (vector in parentheses) West Nile virus (mosquitoes), Lyme disease (ticks), Yellow fever (mosquitoes) and Leishmaniasis (sand flies).

2.5 Nutrition-related impacts

The total population of the over 80 poor food-insecure countries currently amounts to some 4.2 billion, more than 70 per cent of current world population (FAO 2001); about 20 per cent of this population is considered undernourished. An assessment of the impacts of climate change on agro-ecosystems projects that by the end of the century the total population of food-insecure countries may increase to 6.8 billion, or about 80 per cent of the world population (Fischer et al. 2005). The study suggests that socio-economic development over this century will greatly alter production, trade, distribution and consumption of food products worldwide, as a consequence of population growth, economic growth and diet changes in developing countries. Climate change is foreseen additionally to modify agricultural activities, probably increasing gaps between developing and developed countries (Fischer et al 2005).

Undernutrition, which includes stunting, poor foetal growth and micro-nutrient deficiencies, is the underlying cause of at least 3.5 million deaths, and 35 per cent of the disease burden in children younger than 5 years of age (Black et al. 2008). Malnutrition is a major risk factor for disease (Lopez 2006), and the effects of many diseases are mediated by nutrition.

The correlations between nutrition and diseases are bi-directional: not only does disease negatively impact on nutritional status, but undernutrition predisposes to different diseases including through lowering of resistance (Scrimshaw 2003, Walter 1997, Victora 1990). The effects of climate change on water availability and quality have implications for nutritional status (Prüss et al 2008, Fewtrell et al. 2007). The effects of diarrhoea, malaria and respiratory diseases on children are further confounded by undernutrition (Friedman et al. 2005, Mihrshahi et al. 2007). Disease may restrict food intake, impair nutrient absorption, cause direct nutrient losses, increase metabolic requirements or catabolic losses and impair transport to target tissues (Stephensen 1999). For all of these reasons nutrition must not be overlooked as part of the health agenda in protecting children from the adverse effects of climate change. A study of growth patterns in Papua New Guinea indicates that in populations where malnutrition is still common, infection has become

more important than primary malnutrition as the initiator of growth faltering due to malnutrition-infection interactions (Ulijaszek 2000).

There is some specific evidence that climate change and its accompanying phenomena have aggravating impacts on child nutrition. For example, a study undertaken in the desert area of India investigated the impact of drought on the nutritional status of children aged 0-5 years. Although the presence of drought alone is not indicative of climate change, climate change is associated with the increase in frequency and intensity of drought over time. Nutritional status was assessed by anthropometry, dietary intake and clinical signs of nutritional deficiency and the results revealed both stunting and wasting, signs of malnutrition of both long and short durations (Singj et al 2006). Further data for additional regions and settings is required for a full assessment of the links between climate change and childhood nutrition, including to take into account likely confounding factors such as population growth and food prices.

2.6 Health effects related to migration

There is increasing attention to the evidence and expectation of human migration driven by climate change (Warner et al 2008). Health effects of this phenomenon may be considered in the light of known impacts of induced migration from other causes.

Natural disasters such as flooding, drought and environmental degradation can lead to population displacement. Conflict, political instability and war, whose causes may in some cases be a response to environmental changes such as water scarcity, also indirectly lead to migration (Homer-Dixon 1994) and to temporary dislocation. Women and children account for a large proportion of displaced persons following natural disasters and are the most susceptible to adverse health effects such as malnutrition and outbreaks of diseases (Sapir 1993, Chew and Ramdas 2005).

The significance of interactions between disease and population mobility has been demonstrated for malaria, cholera and schistosomaiasis, among others (Prothero 1994). People forced to move for resettlement are most exposed to diseases associated with ecological conditions which differ from those in which they have lived previously. The consequences are not immediately apparent, and since many environmental pressures are cumulative over time they may engender health hazards which develop more insidiously (Prothero 1994). Overall changes in the morbidity and mortality patterns are likely from forced movements associated with resettlement and environmental pressures, though data is limited. A study in Timbuktu in Mali in the mid 1980s during the drought and the consecutive migration, calculated a crude mortality rate nearly twice the national rate. This was attributed to famine conditions at the time and measles outbreak (Carnell and Guyon 1990). Peak periods of migration coincided with times of food scarcity in southern Ethiopia among the agricultural community (Lindtjorn et al. 1993).

Medical interventions such as immunization and vaccination (particularly against measles) have critical impact on child survival and yet are difficult to be carried out among elusive populations. For example, those treated for tuberculosis in Somali refugee camps were lost in the follow-up phase, some having moved to other camps, and children were found to be particularly elusive (Shears 1983). Transient population are also subject to poor vector control, particularly against malaria. Malnourished children and pregnant women are high-risk groups when they move into areas where malaria is endemic. Through movements existing pathologies may be exacerbated and new pathologies acquired. For example, the spread of falciparum malaria resistant to chloroquine has been facilitated by movements of people, particularly of refugees in South East and South Asia (Verdrager 1986, Payne 1987) (Figure 1).

The particular vulnerability of children in small island developing states

In areas such as the Pacific Ocean and the Caribbean Sea, the rise in surface air temperatures has been more rapid than the global rates of warming. Many small island states are particularly vulnerable to tropical cyclones, storm surges, flooding and drought (Ebi et al. 2006b). Damages to the land precipitate dislocation of populations, and the residents of small island states are particularly susceptible to situations that force them to migrate. Small island states share many features that constrain their ability to adapt to current climate variability and future climate change, including their small physical size, remoteness from major land masses, limited natural resources, vulnerability to natural disasters and extreme weather events, economies sensitive to external shocks, populations with high growth rates and densities, poorly developed infrastructure, and limited financial and human resources (Nurse 2001, Ebi et al. 2006b). High-priority diseases of concern for small island states include malaria, dengue, diarrhoeal disease/typhoid, heat stress, skin diseases and acute respiratory infections and asthma. Decreases in water availability and agricultural production are also main causes of adverse health outcomes in these regions (Hamnett et al 1998). Studies however were not found that address child health outcomes of climate change in the specific context of small island developing states.

3. Monitoring and Addressing Health Impacts on Children

The measurable effects of climate change on children have been identified in the previous section at multiple levels in relation to specific health outcomes. Increased severity and prevalence of climate change impacts are predicted to be concentrated in tropical regions which are largely comprised of developing countries, and where the majority of climate-sensitive health conditions (e.g. malnutrition, diarrhoea and malaria) are already prevalent and which would be most affected by climate change and its variability. Within this population of least resilience, children are particularly likely to suffer increased vulnerability and risks due to climate change.

However, the health-outcome-specific approach can lead to underestimates of the overall impact of climate change on health. Climate has been seen to influence a wide range of diseases through complex pathways, many of which may not be fully known or predictable at this time (see e.g. Gommes et al. 2004). A disease-by-disease approach misses the compounding effects and interactions between pathways, as illustrated in Figure 1. For example, as referred to above, undernutrition is considered to be the underlying cause of the majority of child deaths as it leaves children susceptible to and aggravates diseases.

Similarly, the natural disasters that lead to agricultural failure and lack of access to food contribute to the exacerbation of diseases such as malaria and diarrhoea. Climate is a major influence on all eco-system functions, and climate change and the sudden "threshold" shifts may lead to the emergence of new disease or health threats that are currently not foreseeable (Campbell-Lendrum and Woodruff 2006). Climate change and variability also affect health indirectly through the ecological system, causing irreversible damage to arable land and water resources in some regions, with serious local consequences for food production. These losses will be felt most profoundly in developing countries with a low capacity to cope and adapt (Fischer et al. 2005).

Study of the overall impact of climate change on human health remains limited, and future policies need to reflect the findings of recent and ongoing research.

3.1 Action framework

In parallel to the mitigation advocating emissions reductions, adaptation is regarded as an integral part of climate policy. The Stern Review on the Economics of Climate Change (Stern 2006) and the Intergovernmental Panel on Climate Change both have strongly confirmed this view. The emphasis on adaptation is partially due to the fact that there is a time-lag between the present emissions and the projection of increased greenhouse-gas concentrations (Pielke et al. 2007).[6] It is also because adaptation is the most tangible and feasible focus for intervention by many actors, such as the operational agencies of the UN system, to help to alleviate climate change impacts.

Many of the health risks and outcomes associated with climate change are already being addressed to some degree through existing health programmes and interventions. The health concern that climate change poses is not only a question of new diseases (although these may contribute to emergence of new strains of viruses and other microbes that cause human infection) but the alternation of incidence, range, intensity and seasonality of many of the existing health disorders (McMichael et al. 2008). Concerted action to strengthen

health systems adapting to environmental risks and to promote sustainable and healthy development choices can enhance current health conditions as well as reduce vulnerability to future climate change.[7]

An immediate basis for intensified adaptation measures is the recognition that developing country populations, most notably those in small island states, arid and high mountain zones, and densely populated coastal areas, are particularly vulnerable to the health impacts of climate change.[8] The above review has underscored that children in developing countries are especially vulnerable. The importance of adaptation is further supported by the fact that vulnerabilities to climate-related impacts are influenced by additional factors such as rapid population growth, unsustainable development and growing socio-economic inequality, threatening the most exposed groups within society (Pielke et al. 2007). There is urgent need to make the more vulnerable sectors of the population, especially children, more resilient and better prepared for the environmental risks by climate change by improving their adaptive capacity.

The evidence outlined above regarding the impacts on child health provides a strong basis for concerted efforts by policy makers to promote measures for adaptation as well as mitigation, and in this context to reorient and strengthen existing health and development initiatives to ensure that they incorporate and address the vulnerability of children to effects of climate change.

3.2 Knowledge gaps and needs for additional information

Existing research provides strong evidence that climate change is occurring (IPCC) and that it has adverse effects on human health, especially on child health, as outlined above. Nevertheless, significant uncertainties are noted regarding estimates made (WHO 2002), and the completeness of the range of impacts being considered (McMichael et al. 2006). There is uncertainty over the future drivers of climate change, particularly future greenhouse gas emissions; about the nature and complexity of relationship between climate, environment, natural resources and health; and, most importantly, about the degree to which current climate-health relationship will be modified by socioeconomic adaptation in the future (Haines et al. 2006). This last statement holds equally for the impact of climate change on child health. Confounding factors complicate the analysis of long-term effect of climate change on health, including trends in travel, trade and migration, erratic disease control efforts, emerging drug or pesticide resistance, human population growth, urbanization, agricultural development and variable reporting biases (Patz 2002). Scarcity or inconsistent quality of health databases makes trend analysis of this type challenging; datasets from the developing countries are particularly lacking, especially those related to children.

A number of substantial studies link the effect of climate change to specific health outcomes. In addition there is a literature linking these specific health outcomes to the vulnerability of children. Very little evidence has been found, however, that links climate change to child health, particularly to illuminate the suspected disproportionate impacts on child health. For this reason this review paper has taken a two-step approach to examining evidence on the susceptibility of child health to climate change, even though this is not the ideal strategy.

Gaps are also seen between micro analysis (epidemiological studies linking disease to climate change in specific contexts), macro studies (global modelling and projections of climate change and trajectories) and policy analysis (recommendations for mitigation and adaptation). Bringing these types of work together systematically in a way that addresses the relevant health outcomes and regional and population specificities will be crucial to more clearly identify the vulnerability of children and prepare for future responses. There are major needs for further research on the above dimensions. Within this there is a strong requirement for better availability of longitudinal data and of reliable indicators of children's environmental health.

In addition, as introduced above, alternative modelling methods are needed in order to address the likely underestimation of impacts using the health-outcome-specific approach.

It should be noted that several studies were identified that specifically focus on climate change and children's health (Bunyavanich et al. 2003, Ebi and Paulson 2007, Shea 2007, Waterson 2007). These tend to focus on children in industrialized countries (although most of them acknowledge the increased susceptibility of children in developing countries). However, details of the children's susceptibility are generally omitted, and the content is particularly targeted for paediatricians and what they should know and do. Another recent literature review on the links between climate change and population health (Ebi et al. 2006a) focuses solely on the US population. It points to the vulnerability of children and of the poor, but the literature under focus and the discussion apply specifically to a particular population from a wealthier country.

Similar reviews, covering wider population groups, will be critical for the international community to be better prepared for the human security risk created by climate change. The present initial review, however, underscores the key need for additional research evidence on the health risks associated with climate change and the identification of vulnerable populations and life stages. An important support for this effort is strengthened health information systems to obtain and organize the necessary data.

3.3 Children's environmental health indicators

Substantial efforts have been made towards the development of environmental health indicators covering children, most notably through the global initiative on Children's Environmental Health Indicators (CEHI) launched at the World Summit on Sustainable Development in 2002.[9] Working together with governments, NGOs and UNICEF and other international organizations, WHO has coordinated several pilot indicator projects around the world. The results, outcomes and lessons learned were reviewed at an international workshop held in Tunisia in 2008.[10]

Five principal categories of children's environmental health indicators have been identified based on the burden of disease, including mortality impacts: physical injuries, diarrhoeal diseases, respiratory diseases, insect-borne diseases and perinatal diseases (Briggs 2003). Four of these categories are included in Figure 1 of this review as effects of climate change: physical injuries, food and water-borne diseases (diarrhoea), respiratory diseases and vector-borne diseases. Each is associated with disproportionate vulnerability to child health, as illustrated in the previous section:

The remaining CEH indicator, that of perinatal deaths, is not specifically identified in this review as a health impact of climate change. However, a number of the anticipated consequences of climate change including natural disasters, agricultural failures, malnutrition and induced migration are expected to have particular negative impacts on pregnant women. Thus, although studies could not be identified that directly link perinatal conditions and climate change, an indirect effect in this regard may be predicted.

The review above has highlighted the role of malnutrition as a key underlying factor in morbidity and mortality among children under age 5, and the likely sensitivity of children's nutritional status to effects of climate change. Malnutrition is currently classified as a CEH indicator under the heading of perinatal diseases. On the evidence from this review, it may be suggested that malnutrition merits greater emphasis as a core CEH indicator category, and that countries develop further indicators of nutrition status within the CEH framework according to their situations.

Improving child health and ensuring environmental sustainability are two of the Millennium Development Goals (MDGs). Strong health information systems that include environmental indicators are thus essential to effective monitoring of efforts to achieve the MDGs and other agreed global targets.

Environmental threats differ significantly among regions of the world, among countries within a given region and even among communities within a given country. Environmental health indicators must therefore be sensitive to the varying needs; however, the aim should be for an eventually integrated, standardized approach that reflects global standards. On the basis of strengthened environmental health indicators and health information systems, within and across country-comparisons are possible to understand what is happening. This will in turn provide a framework of international priorities for research and for effective and efficient policy responses with the limited resources available (WHO, 2009a).

Within this overall framework, children's environmental health indicators provide:

- a basis for assessing environmental risks to children's health, in order to help prioritize policy at national and global level
- a basis for monitoring and evaluating the effectiveness of national and international initiatives to reduce environmental health risks to children, and
- a template for developing additional indicators to address issues of specific local or national concern.

Through the process of developing environmental health indicators and health information systems, countries accumulate knowledge and capacity to assist them in addressing climate change and related priorities. In this context, for example, WHO and other partners are developing a programme of support applied research on such issues as the assessment of climatic risks to health, estimation of the health benefits of mitigation measures and the costs of adaptation (WHO, 2009). Toward such an objective, the present paper offers an initial review of the impacts of climate change and its disproportionate risks to child health. This review has highlighted the limitations of available data to provide a sound scientific evidence base for environmental policies for children, within the broader context of strengthened health information systems for decision-making.

Several key actions may be identified to support the strengthening of health information systems and child health indicators. First, national governments and their partners should assess the existing health information system including routine data, service records, censuses, civil registrations and surveys such as Demographic and Health Surveys (DHS) and MICS, to determine the already available information on children's environmental health. On this basis gaps can be identified in knowledge, and steps taken towards filling these to support improved interventions and policies. As a contribution to this process the Health Metrics Network assists in coordinating and aligning partners around an agreed framework for development and strengthening of health information systems, and provides guidance and tools for the countries.[11]

Secondly, assessment and monitoring tools that are found to be effective in the CEHI pilot projects could be offered and applied to the other regions and countries.

On the basis of the accumulated experience the set of core CEH indicators can be increasingly refined, and the global database expanded in partnership with governments and other stakeholders. Finally, a long-term commitment of technical and financial assistance is required for effective information system strengthening. Beginning with baseline assessment and proceeding to action studies and evaluations, operational research using environmental health indicators must be supported as an integral component of the global response to climate change. This effort will require time to be established, and constant upgrading with new knowledge and resources.

Finally, children themselves should be seen as key partners in the collection and use of environmental health information. Integration of children's environmental health indicators into primary school life skills and environmental education initiatives, which engage children through participatory approaches in relevant local action, can become an important element of national programmes addressing the impacts of climate change (UNICEF 2008).

4. Conclusion

Climate change is predicted to have substantial effect on human health. As outlined in this review, children are among the most vulnerable population groups and they are likely to disproportionately suffer negative health outcomes. The diseases seen to be aggravated by climate change, including vector-borne diseases, water-borne diseases and air-borne diseases, are already the primary causes of child morbidity and mortality. For this reason further research, assessment and monitoring of child health in respect to climate change is critical.

The development of children's environmental health indicators has been presented as a key step in moving forward to fill evidence gaps. Within the currently evolving frameworks of CEH indicators, it is particularly important that nutrition-related indicators be given increased attention in the light of the impacts of environmental changes on nutrition. Governments should be encouraged and supported to integrate environmental health indicators within national health information systems, covering the entire population but including specific focus on children.

In order to tackle the challenge of global climate change and child health a concerted effort is required by all partners. A cross-sectoral and interdisciplinary approach is key. At national level this must involve all the relevant ministries and offices concerned with environment, water, sanitation, health, education, statistics and social policy. At the international level, organizations and partnerships concerned in this area should establish this issue as a priority and take actions accordingly. On this basis, a contribution can be made to addressing the overall health impacts of climate change, and to the promotion of children's needs and rights at both the national and global levels.

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[3] A number of different efforts have been made to capture the key pathways of causality and impacts of climate change. Among those focusing specifically on children see UNICEF (2008) and UNICEF UK (2007). The framework presented here draws from those efforts and a wide range of common reference materials, but it is intended to focus specifically on child health impacts.
[4] From the 2008 update of the WHO Global Burden of Disease estimates, Global causes of under 5 mortality http://www.who.int/entity/child_adolescent_health/media/causes_death_u5_neonates_2004.pdf: Accessed 2 June 2009.
[5] http://www.who.int/tdr/diseases/schisto/diseaseinfo.htm
[6] UNFCCC http://unfccc.int/national_reports/napa/items/2719.php ; http://unfccc.int/cooperation_and_support/education_and_outreach/items/2529.php
[7] http://www.who.int/globalchange/climate/en/ Accessed 7 March 2009.
[8] Ibid.
[9] An important on-going indicator initiative at the regional level is the European Environment and Health Information System (ENHIS) project (www.enhis.org). The ENHIS project has contributed to the overall objectives of the Global Initiative and developed a core set of indicators for the European Region.
[10] http://www.who.int/ceh/cehi_workshop_tunisia2008/en/index.html. The workshop report is currently under preparation (WHO 2009b).
[11] http://www.who.int/healthmetrics/documents/hmn_framework200803.pdf; http://www.who.int/healthmetrics/en/