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THE IMPACTS OF CLIMATE CHANGE ON HUMAN HEALTH

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This paper addresses a number of factors relating to climate change and human health. Following an introduction outlining the overarching issues, a short summary is given on climatic change and its anthropogenic causes. The rest of the paper then focuses on the direct and indirect impacts of climatic change on health. Direct effects comprise changes in hygrothermal stress response of humans, atmospheric pollution, water quality and availability. Indirect effects include the potential for the spread of "vector-borne diseases" outside their current range. The paper concludes with some comments on possible response strategies aimed of alleviating the adverse effects of climatic change on human health.

INTRODUCTION

Human activities related primarily to the burning of fossil fuels and changes in land cover such as deforestation are changing the concentration of atmospheric constituents or properties of the earth's surface that help to absorb or scatter radiant energy (IPCC, 2001). Since the pre-industrial mid-1800s, increases in concentrations of three major greenhouse gases, carbon dioxide, methane, and nitrous oxide, have exceeded past changes that occurred over the last 10,000 years; carbon dioxide alone has increased by 30% since the late 1800s (Patz et al. 2000). 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. According to the United Nations Intergovernmental Panel on Climate Change (IPCC, 2001), "An increasing body of observations gives a collective picture of a warming world and other changes in the climate system" (McMichael, 2001). During the 20th century, global average surface temperature increased about 0.6°C, global average sea level rose 10 cm to 20 cm, and snow and ice cover decreased (IPCC, 2001) The latest IPCC report predicts that if current trends continue, sea level rise will reach 45 cm and global temperatures will increase by 3°C by the year 2100 (McMichael, 2001). The objective of this paper is to provide a brief overview of these interrelated factors and the manner in which they can impact human health.

TEMPERATURE RELATED MORTALITY

Small changes in global mean temperatures can produce relatively large changes in the frequency of extreme temperatures (IPCC, 2001). Mortality rates increase at both hot and cold extremes of temperature (Curriero et al. 2002). Increases in temperature have a direct and substantial impact on excess mortality for elderly individuals and individuals with preexisting illnesses. Much of the mortality attributable to heat waves is a result of cardiovascular, cerebrovascular, and respiratory disease (Kilbourne, 1997). A 1995 heat wave in Chicago that caused 514 heat-related deaths (12 per 100000 population) may be part of a recent trend of longer, more frequent heat waves and record-setting temperatures (Gaffen and Ross, 1998). Long-term global warming trends are further exacerbated by the "heat island" effect, whereby high concentrations of heat-retaining surfaces such as asphalt and tar roofs sustain higher temperatures through the night. Heat waves also have the secondary effect of worsening urban air pollution. Ozone, which forms chemically from precursor pollutants, is the most temperature-dependent air pollutant and may contribute to the development of asthma in children (McConnell et al. 2002).

It is often difficult to associate any particular change in the incidence of a particular disease with a given change in a single environmental factor. It is necessary to place the environment-related health hazards in a population context, such as age, hygiene practices, socioeconomic level, and medical and agricultural traditions (McMichael and Kovats, 2000). Forecasting the climate change impacts on health is complex, because populations have different vulnerabilities to change and susceptibility to disease.

There are numerous side effects of environmental change that can impact health and wellbeing, including hydrothermal stress and enhanced levels of air pollution and the modification of natural ecosystems which may have repercussions on such aspects as food production and water quality. These in turn may affect the geographical distribution and celerity of propagation of vector-borne diseases, as well as the equilibrium between a number of other infectious and noninfectious diseases (McMichael and Kovats, 2000). In addition, if climatic change were indeed to be

Table 1. Climate factors associated with water quality and quantity issues

Climate Factor	Effect on Water Resources and Water Quality
Rise in sea level	Saltwater intrusion, loss of beaches
Droughts of increased severity because of an increase in temperature and drier soils, with a prediction of less precipitation in some areas.	Greater use of polluted sources, changes in the sanitary situation of many populations as a result of the expansion of vector borne diseases.
Floods more likely with an increase in the frequency of intense rainfall	Changes in extreme events; natural hazards related to extreme weather events are those that inflict the greatest damage on the environment and infrastructure, and take the heaviest toll of life. Breaching of wastewater and drinking water systems

accompanied by an increase in the intensity of certain forms of natural hazards, such as cyclones, floods, or drought, these would compound the effects on human health (Table 1). Moreover, such catastrophes can generate large refugee and population movements, with a need for resettlement in what are often already densely populated areas (Pebley, 1998).

The impacts of climatic change on human health are likely to be twofold, namely direct effects related to the physiological effects of heat and cold, and indirect effects such as the spread of vector-borne pathogens into areas where a disease currently does not exist or was eradicated in the past (Table 2).

DIRECT EFFECTS OF CLIMATIC CHANGE ON HEALTH

Future increases in average seasonal temperatures entail an increase in the number of heat waves in summer and a decrease in the number of cold spells in winter, at any particular location. For example, it is anticipated that the equivalent of the UK heat wave in the summer of 1976, which occurs once every 300 years under the current climate, may occur every 5 to 6 years by 2050. Heat waves are associated with a short term increase in all causes of mortality. The heat wave in July-August 1995 in London was associated with a 16% increase in mortality (approximately 137 excess deaths compared with the seasonal average). In 1987, a major heat wave in Athens was associated with 2000 extra deaths.

Heat waves, particularly large in urban areas, are associated with episodes of strong pollution often linked to the formation of troposphere ozone, a gas that is formed by chemical transformation of nitrogen oxides and other "precursor" gases released during the combustion of fossil fuels. Ozone is a highly corrosive gas that can irritate or damage lung tissues in addition to provoking eye irritation. "Los Angeles smog" has long been a persistent feature of southern California, as a result of socioeconomic and meteorological conditions optimal for ozone formation, but today the very large cities in the south, such as Mexico City, New Delhi, or Cairo, are also severely affected by such pollution (Bobba and Bobba, 2003).

Water quality and quantity are also likely to change in the future, as precipitation patterns change and warmer conditions adversely affect the potential levels of aquatic-borne pathogens and water pollution (Table 1). The United Nations currently considers the availability of 1000 m^3 of water per capita per annum as a minimum for well-being; this includes the use of water for agriculture, industry, and domestic water supply. Currently, 50% of the world population does not reach this level, and close to 350 million people in 20 countries do not have access to potable water. In a changing climate and especially in a world whose population will continue to increase considerably in the developing countries, estimates point to reductions in water availability almost worldwide

Table 2. Mediating processes and direct and indirect potential effects on health of changes in temperature and weather.

Mediating Process	Health outcome
Direct effects	
Exposure to thermal extremes	Changed rates of illness and death related to heat and cold
Changed frequency or intensity of other extreme weather events	Deaths, injuries, psychological disorders; damage to public health infrastructure.
Indirect effects	
Disturbance of Ecological systems: Effect on range and activity of vectors and infective parasites	Changes in geographical ranges and incidence of vector-borne disease
Changed local ecology of water borne and food-borne infective agents	Changed incidence of diarrheal and other infectious diseases
Changed food productivity(especially crops) through changes in climate and associated pests and diseases	Malnutrition and hunger, and consequent impairment of child growth and development
Sea level rise with population displacement and damage to infrastructure	Increased risk of infectious disease, psychological disorders
Biological impact of air pollution changes (including pollens and spores)	Asthma and allergies; other acute and chronic respiratory disorders and deaths
Social, economic, and demographic dislocation through effects on economy, infrastructure, and resource supply	Wide range of public health consequences: mental health and nutritional impairment infectious diseases, civil strife

(Shiklomanov, 2001). In addition, water quality issues will become even more crucial than today, with possibly over one billion people in more than 30 countries without access to a clean water supply. The potential for disease is thus enhanced in the poorer nations of the world (Bobba and Bobba, 2006).

The combined effects of poorer water quality, increased air pollution, uncertain food security and hydrothermal stress will impact populations of the developing countries in particular, but also increasingly the countries of the North. Poor people are often exposed to greater health and environmental risks, and in countries with growing populations these risks will increase in the future.

VECTOR BORNE DISEASES

The occurrence of vector-borne diseases such as malaria and dengue is determined by the abundance of vectors and intermediate and reservoir hosts, the prevalence of disease-causing parasites and pathogens suitably adapted to the vectors, and the human or animal hosts and their resilience in the face of the disease (McMichael and Haines, 1997). Local climatic conditions, especially temperature and moisture, are also determinant factors for the establishment and reproduction of the Anopheles mosquito (Epstein et al., 1998). The possible development of the disease in mountain regions thus has relevance, because populations in uplands where the disease is currently not endemic may face a new threat to their health and well being as malaria progressively invades new regions under climatic conditions favorable to its development (Martens et al., 1999).

Vectors require specific ecosystems for survival and reproduction. These ecosystems are influenced by numerous factors, many of which are climatically controlled. Changes in any of these factors will affect the survival and hence the distribution of vectors (Kay, 1989). Global climatic change projected by the IPCC (1996, 1998, 2001) may have a considerable impact on the distribution of vector-borne diseases. A permanent change in one of the abiotic factors may lead to an alteration in the equilibrium of the ecosystem, resulting in the creation of either more or less favorable vector habitats. At the present limits of vector distribution, the projected increase in average temperature is likely to create more favorable conditions in terms of both latitude and altitude for the vectors, which may then breed in larger numbers and invade formerly inhospitable areas.

MALARIA

Malaria causes 300 million infections and 1 million deaths a year (WHO, 1999). Malaria is the second most fatal communicable disease and is a public health problem in 90 countries in the world, where 40% of the human population live (WHO, 1998). These diseases, because of the dependence of the vectors and pathogens on climatic factors, are expected to change in distribution and intensity. Malaria is one of the vector-borne diseases that are expected to be most sensitive to long-term environmental change (WHO, 1999).

Temperature, precipitation, relative humidity, and wind are the four main climatic factors that affect malaria transmission and upon which the predictions of the effects of climate change on malaria are based. These relationships can be best understood in relation to the malaria life cycle. Changes in temperature, rainfall, and relative humidity due to anthropogenic climate change are expected to influence malaria directly by modifying the behavior and geographical distribution of malaria vectors and by changing the length of the life cycle of the parasite (Martens et al., 1995). Climate change is also expected to affect malaria indirectly by changing ecological relationships that are important to the organisms involved in malaria transmission (the vector, parasite, and host). Examples of such indirect forces are deforestation and habitat changes due to climate change that may affect which species of Anophelines are able to survive (McMichael and Githeko, 1999). Recent evidence shows that changes in temperature and precipitation have already changed the distribution and behavior of malaria. Many time-series studies and studies of epidemics have been done to find explanatory variables for changes in malaria transmission, but many of them do not take into account climatic factors.

DENGUE FEVER

Dengue is a mosquito-borne virus with four serotypes (Dengue 1-4). It is classified as a Group B arbovirus and is antigenically related to St. Louis encephalitis, yellow fever, Japanese B encephalitis, and other viruses. Classic dengue fever, which usually is not fatal, is characterized by the abrupt onset of fever and generalized body aching as well as severe headache and retro-orbital pain. Dengue fever can be complicated by dengue hemorrhagic fever (DHF) and dengue shock syndrome (DSS), both of which can be fatal, particularly in young children.

Dengue is frequently introduced into North America by people who have traveled abroad, who return to areas containing a competent vector for dengue. Specific experiments have been conducted on the effect of temperature on the ability of Aedes aegypti to transmit DEN-2 virus. These experiments showed that the DEN-2 virus was transmitted by A. Aegypti only if the mosquitoes were kept at 30^o C. The required extrinsic incubation period was shortened if the temperature was increased to 32^o C and 35^o C (Gubler, 1998). This pattern of temperature and vector efficiency parallels the climatic pattern of DHF outbreaks in Bangkok, Thailand, where case rates rise during the hot season (with daily mean temperatures of 28-30^o C) and decrease during the cool season (with daily mean temperatures of 25-28^o C) (Gubler,1998).

WEST NILE VIRUS

West Nile virus was first identified in 1937 in the West Nile region of Uganda, in eastern Africa. It was first identified in the US in the summer of 1999 in the Queens borough of New York, NY. West Nile virus is a type of organism called a flavivirus and is similar to many other mosquito-borne viruses, including Japanese encephalitis (which is found in Asia). Researchers believe the virus is spread when a mosquito bites an infected bird and then bites a person.

West Nile virus is transmitted by mosquitoes and causes an illness that ranges from mild to severe. Mild, flu-like illness is often called West Nile fever. More severe forms of disease which can be life-threatening may be called West Nile encephalitis or West Nile meningitis, depending on where it spreads. Mosquitoes carry the highest amounts of virus in the early fall, thus there is a peak of disease in late August-early September. The risk of disease then decreases as the weather becomes colder and mosquitoes die off.

ENCEPHALITIS

Arthropod-borne viruses (arboviruses) are associated with several major clinical syndromes, including encephalitis. Arbovirus infections were responsible for 65% of diagnosed encephalitis cases reported to CDC between 1969 and 1979 (Shope, 1980), and Venezuelan equine encephalitis (VEE). The effects of infections with these viruses range from a mild influenza-like syndrome to central nervous system (CNS) disease, which can be fatal.

Outbreaks of encephalitis caused by the different viruses are normally limited to specific geographic locations and seasons, including seasons in which arthropod breeding and feeding occur. Most cases of encephalitis occur in late summer/early fall when mosquitoes, the primary vectors, are prevalent. In addition, infection depends on certain variables, including the species of mosquitoes that are susceptible to a specific virus, and the viral concentration in the susceptible vertebrate host's blood. More than 100,000 infectious units per milliliter are usually required in order for virulent strains to infect mosquitoes. An extrinsic incubation (EI) period, i.e., the interval between ingestion of the virus and subsequent transmission through biting, of 4 days to 2 weeks at summer temperatures is normally required, before the virus is fully multiplied and can be transmitted to a new host.

Many of these variables are affected by climatic change. For example, environmental temperature affects the EI (the species discussed here are active at temperatures of 13-35^{o}C). Increased temperature can decrease the EI, thereby quickening the transmission process and promoting epidemic disease. Moisture, present as rainfall or irrigation, affects the growth of plant life for feeding of host animals, and the presence of insect breeding sites. Changes in these environmental conditions affect the ability of the vectors to transmit the virus effectively. Finally, viruses carried by the same vectors appear to occur in the same climatic conditions and geographical distributions. It would follow, then, that the effective spread of the viruses, and usual subsequent epidemic disease, is dependent upon optimal environmental conditions in which the vectors may breed, feed, and transmit the viruses. Those conditions, wet or dry, mild or warm climates, vary with the particular species of mosquito vector.

Rainfall strongly affects the numbers of infected individuals, since C. Tarsalis breed mainly in ground pools and irrigated ponds. Environmental temperature also affects the activity of the arbovirus. The maximum temperature permissible for the WEE vector to transmit the virus effectively was $<= 25^{o}$ C. Above 32^{o} C, virus transmission rates rapidly decreased (Kramer 1993). A study of EI temperatures of C. Tarsalis showed decreased vector competence after two to three weeks of EI at 32^{o} C as compared with vector competence after EI at 18 or 25^{o}C. The high temperature did not, however, affect preexisting infection. Studies also demonstrate lower effectiveness in WEE virus transmission to humans at higher ambient temperatures (Kramer 1993). The cooler temperatures at which the WEE virus is better able to replicate allow for epidemic disease much earlier in the summer, and eventually much farther north in cooler climates later in the season (Shope, 1980).

High temperatures favor virus transmission for C. pipiens and C. tarsalis by decreasing the EI time, as well as the time required for larval maturation and development of viral infectivity. Studies of the relationships between incubation time of SLE virus in C. pipiens and mean temperature found that daily exposures to increased temperatures from a constant of 25^{o} C decreased incubation time, thereby increasing effectiveness of viral transmission. In addition, a review of all the arbovirus encephalitis cases found in the United States showed that most WEE outbreaks have occurred at or above the 70^{o} F June isotherm, whereas most SLE cases have occurred in warmer latitudes at or below the June isotherm.

SUMMARY

Four basic themes characterize the impacts of climate change upon human health.

1) Increases in temperature and changes in precipitation, as well as the possible increase in frequency and intensity of severe climate events will affect human health both directly and indirectly. A direct impact would be added deaths from heat stress for example, while and indirect impact would be an increase in famine resulting from changes in rainfall and drought in sub-Saharan Africa.

2) Most of these impacts will be negative. Any health benefits from less severe winters for example, will be offset by rapid changes to the environment to which human biology and culture have become accustomed. This could include changes in the distribution of disease, impacts on agriculture or changes to conditions in coastal areas which have large populations, especially in the developing world.

3) Direct impacts, such as heat stress or changes in patterns of air pollution, are likely to be less significant than indirect impacts, such as changes in the distribution of diseases like malaria.

4) The severity of the impacts will vary with location and impacts on human health are likely to be complex, based not just on changes to the physical environment, but also on the strength and nature of the social systems that will have to respond to those changes.

CONCLUSIONS

Human health impacts of climatic change will depend on many factors, including existing infrastructure, financial resources, technology access to adequate health care facilities and equity across different countries and regions. Climatic change will be one among many exacerbating factors, but possibilities do exist of adapting to global warming, through policy, economic, social and legislative action in the context of the United Nations Framework Convention on Climate

Change (UN-FCCC).

Climatic change presents the decision-maker with numerous sets of challenges, however. In a set of issues in which there are considerable uncertainties, the policymaker needs to take into account the potential for irreversible damages or costs and the long time frames involved, i.e., decades to centuries. He must also be aware of the long time lags between greenhouse-gas emissions and the response of the Earth system to higher levels of these gases in the atmosphere, and the fact that there will be substantial regional variations in impacts.

In order to come to terms with global warming, international cooperation is essential but this is far from a trifling matter in view of the wide range of conflicting interests and the extremely heterogeneous income levels in the nations of the world. Economic growth, social development and environmental protection are interdependent and mutually reinforcing components of sustainable development, which is the framework for international efforts to achieve a higher quality of life worldwide. Responses to environmental change should be coordinated with social and economic development in an integrated manner. Any policy decision should aim at averting the adverse impacts of change, taking fully into account the legitimate priority needs of developing countries for the achievement of sustainable development and the eradication of poverty.

The measures required to reduce the health-related impacts of climatic change are not necessarily of an advanced, "technological" nature but are more in the realm of common sense. Indeed, if advanced technologies were necessary to face up to health issues in a changing climate, then the majority of countries would not have the financial resources to implement such measures.

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