WATER RESOURCES AND HUMAN HEALTH IN THE FRAMEWORK OF CLIMATE CHANGE

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ABSTRACT

Climate change profoundly affects some of the most fundamental determinants of health. The resulting increase in frequency and severity of extreme weather events such as intense storms, heat waves, droughts and floods, will lead to increases in food and water shortages, food and water-borne diseases, heat-related deaths and deaths and injuries from flooding. Such potentially severe human health impacts require a clear response that place health protection at the center of the climate mitigation and adaptation strategies. The aim of this paper is to provide an overview on the potential health effects related on water quality determined by climate change.

Keywords: climate change, health effects, waterborne diseases, water resources

INTRODUCTION

There is now scientific consensus that climate change affects health through changing weather patterns (for example, more intense and frequent extreme events) and indirectly through changes in water, air, food quality and quantity, ecosystems, agriculture, livelihoods and infrastructure. The effects will be unevenly distributed, and the people at greatest risk include the poor, very young, elderly and/or ill.

The problem of climate changes was first clearly recognized by the International Conference on Environment and Development in Rio de Janeiro in 1992 where the Framework Convention on Climate Change was signed. The most recent IPCC (Intergovernmental Panel on Climate Change) Assessment Report states that “most of the warming observed over the last 50 years is likely to be attributable to human activities” (IPCC, [1]). Climate change will affect the management of water resources in many ways, and wideranging impacts on socio-economic development might be the result.

Water resources in Europe

The total renewable freshwater resource in Europe is around 3500 km^3 per year. These water resources are unevenly distributed between regions and river basins in Europe. There are areas where water is abundant, while others are already facing water stress under present climatic conditions. Today, some 20 countries, mainly in central and northern Europe (50% of Europe's population), can be considered as non-water-stressed, 9 are considered as having low water stress (32% of population; including Romania, Belgium, Denmark, Greece, Turkey, and Portugal), and four countries (18% of population; Cyprus, Malta, Italy, and Spain) are considered waterstressed. Water abstraction in Europe amounts to about 353 km^3 water per year, i.e. 10% of the total freshwater resources. On average, 33% of water abstracted is used for agriculture (mainly irrigation), 16% for urban use, 11% for industry (excluding cooling), and 40% for energy production. The shares vary strongly between countries and regions. In the Mediterranean region, the share of water abstracted for irrigation is particularly high, while in the Western European Countries, the largest percentage of abstracted water is used for cooling in energy production.

Climate change impact on water resources

During the last century, temperatures in Europe have shown a relatively uniform increase of 0.95 °C across Europe (EEA [2]). Mean annual precipitation levels have exhibited distinct regional differences, however – increasing in northern Europe by 10-40%, and decreasing in some areas of central Europe and the Mediterranean region by up to 20%. According to most model predictions, countries in the Danube Basin will see more changes in the region's distribution of water in the future. Northern or upstream countries will experience more precipitation, with particular emphasis on winter precipitation. Southern or downstream countries would experience less precipitation, but more extreme events. During the last decades water resources are facing severe challenges all over the world and the trends of decreasing precipitations and increasing temperatures in the Mediterranean region intensify this situation. The large climate variability of the region □ makes drought events appear as a recurrent phenomenon in the area, causing important damages in both the economy and the environment.

With higher temperatures, the water-holding capacity of the atmosphere and evaporation in to the atmosphere increase and this favours increased climate variability, with more intense precipitation and more droughts (Trenberth et al., [3]). The hydrological cycle accelerates. While temperatures are expected to increase everywhere over land and during all seasons of the year, although by different increments, precipitation is expected to increase globally and in many river basins, but to decrease in many others. In addition, precipitation may increase in one season and decrease in another. These climatic changes lead to changes in all components of the global freshwater system.

Floods and droughts are a constant concern in water management (EEA [2]). During drought periods, the fair allocation of water and the sustainable management of the resource represents a great challenge.Water resources planning are part of complex, multi􀀐disciplinary processes overarching a wide range of stakeholders with different interests, technical expertise, and priorities. Successful planning requires effective Integrated Water Resource Management models that can solve these complex problems.

HEALTH EFFECTS OF CLIMATE CHANGE

Global climate change would affect human health via pathways of varying complexity, scale and directness and with different timing. Similarly, impacts would vary geographically as a function both of environment and topography and of the vulnerability of the local population. Impacts would be both positive and negative (although expert scientific reviews anticipate predominantly negative). The main pathways and categories of health impact of climate change are shown in Figure 1.

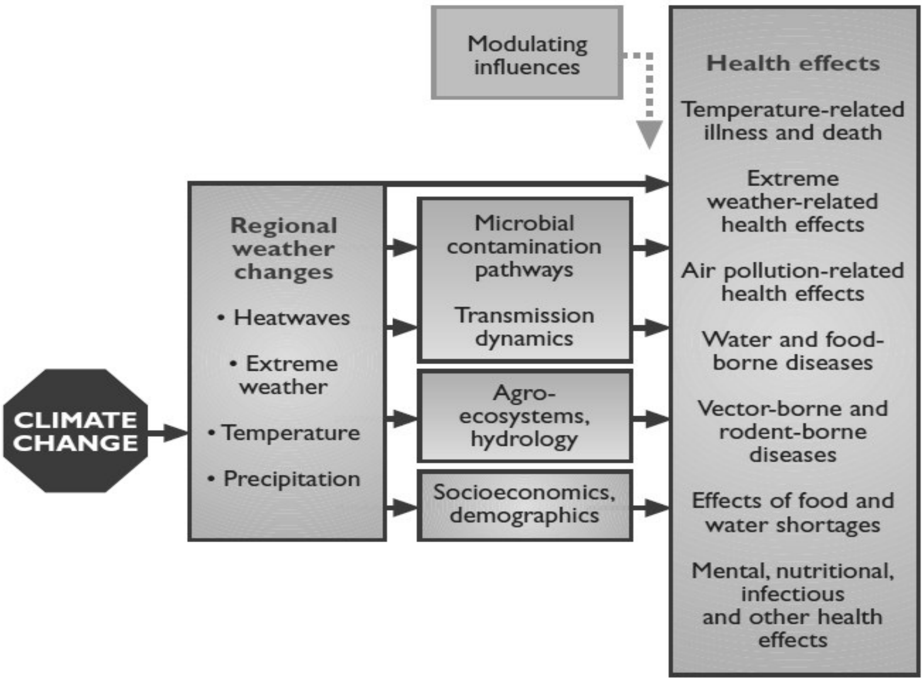

Figure 1. Pathways by which climate change affects human health, including local modulating influences and the feedback influence of adaptation measures (Patz et al.[4])

Direct effects

Climate change may directly affect human health through increases in average temperature. The more direct impacts on health include those due to changes in exposure to weather extremes (heatwaves, winter cold); increases in other extreme weather events (floods, cyclones, storm-surges, droughts); and increased production of certain air pollutants and aeroallergens (spores and moulds). Decreases in winter mortality due to milder winters may compensate for increases in summer mortality due to the increased frequency of heatwaves.

Rising temperatures have two opposing direct effects on mortality: higher temperatures in winter reduce deaths from cold; higher temperatures in summer increase heat-related deaths. The net local impact of these two direct effects depends on the current climate in a particular area. The European heat wave of 2003 killed 22000–35000 people, based on normal mortality rates.

Indirect effects

Climate change, acting via less direct mechanisms, would affect the transmission of many infectious diseases (especially water, food and vector-borne diseases) and regional food productivity (especially cereal grains). In the longer term and with considerable variation between populations as a function of geography and vulnerability, these indirect impacts are likely to have greater magnitude than the more direct.

For vector-borne infections, the distribution and abundance of vector organisms and intermediate hosts are affected by various physical (temperature, precipitation, humidity, surface water and wind) and biotic factors (vegetation, host species, predators, competitors, parasites and human interventions). Various integrated modelling studies have forecast that an increase in ambient temperature would cause, worldwide, net increases in the geographical distribution of particular vector organisms (e.g. malarial mosquitoes) although some localised decreases also might occur. Further, temperature related changes in the life-cycle dynamics of both the vector species and the pathogenic organisms (flukes, protozoa, bacteria and viruses) would increase the potential transmission of many vector-borne diseases such as malaria (mosquito), dengue fever (mosquito) and leishmaniasis (sand-fly)—although schistosomiasis (water-snail) may undergo a net decrease in response to climate change(EPA [5], WHO [6]).

Trends in climate change - related health effects

From several studies and assessments we can expect that projected trends in climate-change-related exposures of importance to human health are likely to: increase heat-wave-related health impacts; continue cold-related health effects in particular in populations with lack of access to continuous energy; increase flood-related health impacts; increase malnutrition in areas already affected; change foodborne disease patterns; change the distribution of infectious diseases and potentially contribute to the establishment of tropical and subtropical species; increase the burden of waterborne diseases, in populations where water, sanitation and personal hygiene standards are already low; and increase the frequency of respiratory diseases due to higher concentrations of ground-level ozone concentrations in urban areas and changes in pollen distribution related to climate change (Table 1).

Table 1. Global direction and trends in extreme weather events and health

Phenomenon and trend	Benefits or risks to human health
Over most land areas, warmer days and nights, more hot days and nights and fewer cold days and nights	Reduced mortality from decreased cold exposure
Increase in frequency of warm spells/heat-waves over most land areas	Increased risk of heat-related mortality, especially forthe elderly, chronically ill, very young and socially isolated
Increase in frequency of heavy precipitation events over most areas	Increased risk of deaths, injuries, infectious, respiratory and skin diseases, and mental health problems
Increase in drought areas	Increased risk of food and water shortages, malnutrition and water- and foodborne diseases
Increased incidence of extreme high sea levels (excluding tsunamis)	Increased risk of deaths and injuries from drowning and of negative migration-related health effects

POPULATIONS AT RISK

Climate change will affect everybody, but everyone in the European Region will not be equally vulnerable. Vulnerability to weather and climate change depends on people’s personal characteristics (e.g. age, income, education, health status), their broader social and environmental contexts, their access to resources (e.g. health services) and their level of exposure to climate change. Geographically, the populations considered to be at greatest risk are those living in large cities or areas that are mountainous, water-stressed or near a coast. Children are particularly vulnerable because of their physiological and cognitive immaturity and their greater potential for long-term exposure (Table 2).

Table 2. How the differences between children and adults make children more susceptible to the effects of climate change

Type of difference	Internal sources of difference	External sources of greater sensitivity
Metabolic	Greater respiratory rate Greater metabolic rate Greater water demand per unit of body mass	Air pollution, allergens Malnutrition, thermal extremes Gastrointestinal illnesses, dehydration
Behavioural	Greater outdoor time Greater vigorous activity Less ability to avoid unhealthy situations Less ability to swim	Infectious diseases, air pollution, ultraviolet (UV) radiation, thermal extremes, allergens UV radiation, thermal extremes Drowning
Physiological	Greater surface areas Less detoxifying capacity Less skin development Reduced immunity	Air pollution, UV radiation Infectious diseases, Air pollution, UV radiation UV radiation thermal extremes Infectious diseases, allergens, mycotoxins
Temporal	Greater latency for genetic/long-term effects	UV radiation, malnutrition, allergens
Developmental	Undergoing development	Malnutrition, psychosocial trauma, morbidity and quality of life compromised

CLIMATE CHANGE AND WATER-BORNE DISEASES

Climate-change-related alterations in rainfall, surface water availability and water quality could affect the burden of water related diseases. Water-related diseases can be classified by route of transmission, thus distinguishing between water-borne (ingested) and water-washed diseases (caused by lack of hygiene). There are four main considerations to take into account when evaluating the relationship between health outcomes and exposure to changes in rainfall, water availability and quality:

- linkages between water availability, household access to improved water, and the health burden due to diarrhoeal diseases;
- the role of extreme rainfall (intense rainfall or drought) in facilitating water-borne outbreaks of diseases through piped water supplies or surface water;
- effects of temperature and runoff on microbiological and chemical contamination of coastal, recreational and surface waters;
- direct effects of temperature on the incidence of diarrhoeal disease (Confalonieri [7]).

Access to safe water remains an extremely important global health issue. More than 2 billion people live in the dry regions of the world and suffer disproportionately from malnutrition, infant mortality and diseases related to contaminated or insufficient water. A small and unquantified proportion of this burden can be attributed to climate variability or climate extremes.

There is mounting evidence that weather is often a factor in triggering waterborne disease outbreaks. Climate change may affect the growth, survival, transmission, and virulence of the disease-causing organisms related to water-borne illness. Storms and flooding may result in drinking water contamination that leads to illness. Vector-borne infections are also affected by climate change as the hosts (rodents, etc) and pathogens (bacteria, viruses, parasites) are sensitive to the climate variables, including temperature, humidity, and rainfall. Water-borne illnesses increase when outdoor temperature increases.

Higher temperature was found to be strongly associated with increased episodes of diarrhoeal disease in adults and children in many studies. Gastroenteritis is the primary disease associated with exposure to contaminated water. While gastroenteritis may be uncomfortable for a healthy adult, it can be debilitating and even fatal for young children. Globally, infectious diarrhea is the second-leading cause of death in young children, with 1.62 million under age 5 dying annually, mostly due to contaminated water exposure. In many countries, death from water-borne infections is unlikely, but an increase in the number of children who get sick is possible.

Globally the largest burden of disease from climate change is set to be associated with water shortage. In many regions if climate change warming is higher than 2°C then acute water shortages are predicted to put billions at risk of water stress death.

Several studies have shown that transmission of enteric pathogens is higher during the rainy season. Drainage and stormwater management is important in low-income urban communities, as blocked drains are one of the causes of increased disease transmission (Parkinson and Butler [8]).

Climate extremes cause both physical and managerial stresses on water supply systems. Reductions in rainfall lead to low river flows, reducing effluent dilution and leading to increased pathogen loading. This could represent an increased challenge to water-treatment plants. During the dry summer of 2003, low flows of rivers in the Netherlands resulted in apparent changes in water quality (Senhorst et al. [9]).

Extreme rainfall and runoff events may increase the total microbial load in watercourses and drinking-water reservoirs, although the linkage to cases of human disease is less certain. A study in the USA found an association between extreme rainfall events and monthly reports of outbreaks of water-borne disease (Curriero et al. [10]). The seasonal contamination of surface water in early spring in North America and Europe may explain some of the seasonality in sporadic cases of water-borne diseases such as cryptosporidiosis and campylobacteriosis (Clark et al. [11], Lake et al. [12]). The marked seasonality of cholera outbreaks in the Amazon is associated with low river flow in the dry season, probably due to pathogen concentrations in pools.

Climate influences the spatial distribution, intensity of transmission, and seasonality of diseases transmitted by vectors (e.g., malaria) and diseases that have water snails as an intermediate host (e.g., schistosomiasis). During droughts, mosquito activity is reduced but, if transmission drops significantly, the population of non-immune individuals may increase. In the long term, the incidence of mosquito-borne diseases such as malaria decreases because mosquito abundance is reduced, although epidemics may still occur when suitable climate conditions occur.

Malaria causes 500 million illnesses annually and more than 1 million deaths, mostly among children and pregnant women in Africa, Central Asia and Latin America. Around 40% of the world's population currently lives in malaria-endemic areas. Climate change may expand the range, and warmer temperatures will cause greater exposure. An increase in malaria-carrying mosquitoes will affect young children more than adults because children lack immunity to malaria and because they play outside, where mosquitoes are found.

The distribution of schistosomiasis, a water-related parasitic disease with aquatic snails as intermediate hosts, is influenced by climate factors in some locations, For example, the observed change in the distribution of schistosomiasis in China over the past decade may in part reflect the recent warming trend. Irrigation schemes have also been shown to increase the incidence of schistosomiasis, when appropriate control measures are not implemented.

Climate change will increase the geographical distribution of Lyme disease, which is spread by ticks. Children are especially vulnerable to tick bites because they tend to play outside and they play close to the ground. Children that are five to ten years old get Lyme disease more often than older children and adults. Lyme disease is rarely fatal, but it does have the potential to cause long-term illness.

Increased precipitation caused by global warming may increase flooding in some areas, which could lead to drinking water contamination. Cryptosporidiosis is one of many waterborne diseases whose prevalence could increase with increased precipitation and flooding triggered by climate change. Cryptosporidium parvum, a protozoan parasite, was first recognized in 1976 as producing illness in humans. Causing a diarrheal disease that lasts for one to two weeks in healthy individuals, Cryptosporidium can be fatal among immunocompromised persons. One problem assessing the impact of this disease in an altered climate regime is the prevalence of very tiny Cryptosporidium oocysts - the protozoan equivalent of a fertilized chicken egg. Reservoirs for Cryptosporidium exist in livestock, such as cattle and dairy cows and wildlife such as deer. Runoff from agricultural areas can release the Cryptosporidium oocysts into the drinking water supply. Another problem is that the standard purification approach for drinking water, chlorination, has little effect on the organism. Filtration can remove the oocysts, but because of their small size, filters must be properly monitored and managed.

In many countries cholera transmission is primarily associated with poor sanitation. The effect of sea-surface temperatures in cholera transmission has been most studied in the Bay of Bengal (Koelle et al. [13]). In sub-Saharan Africa, cholera outbreaks are often associated with flood events and faecal contamination of the water supplies.

Freshwater harmful algal blooms (HABs) produce toxins that can cause human diseases. The occurrence of such blooms in surface waters (rives and lakes) may increase due to higher temperatures. However, the threat to human health is very low, as direct contact with blooms is generally restricted. There is a low risk of contamination of water supplies with algal toxins but the implications for human health are uncertain.

The risk of outbreaks of waterborne diseases increases where water, sanitation and personal hygiene standards are low. Climate change is likely to increase heavy precipitation events, reduce the amount of fresh water in parts of the European Region and reduce water quality. Water stress is expected to increase across central and southern Europe and central Asia. It has been estimated that the percentage of the EU's area under high water stress is likely to increase from 19% today to 35% by the 2070s, and the number of additional people affected by the 2070s is expected to be 16–44 million. Freshwater availability in central Asia is likely to decrease, while summer water flows in southern Europe and some parts of central and eastern Europe may be reduced by up to 80%. Loss of fresh water could have serious implications for health, if not managed appropriately and equitably.

Access to safe water in Europe is unequally distributed. For example in central Asia, total access to water supply is around 70%, but only 25% of the rural population has access to water supply. Even where high access to water is available, in many cases, the supply is not continuous and does not meet the microbial and/or chemical standards set by WHO. The risk of outbreaks of waterborne diseases increases where water, sanitation and personal hygiene standards are low. The burden of disease attributable to poor-quality water, sanitation and hygiene is estimated to be 5.3% of all deaths in children aged 0–14 years in the Region.

Reductions in rainfall lead to low river flows, reducing effluent dilution and leading to increased pathogen loading. Extreme rainfall and runoff events may increase the total microbial load in watercourses and drinkingwater reservoirs. The seasonal contamination of surface water in early spring in Europe may explain some of the seasonality in sporadic cases of waterborne diseases such as cryptosporidiosis and campylobacteriosis.

Further, increasing temperatures and changing water composition create new ecological niches that allow pathogens to invade new areas. Reduced dilution, increased pathogen load and the presence of opportunistic pathogenic invader organisms and their toxins will all present new and increasing challenges to watertreatment plants.

Climate change is also likely to affect the quality of coastal waters, by changing either natural ecosystems or the quality of the waters draining into coastal zones. Recreational users of bathing waters, including tourists, may face poorer water quality and higher risk of infection. An additional area of concern is the production of seafood in aquaculture, which takes place in coastal zones.

Disasters, including wind storms and floods have a considerable impact on health both in terms of number of deaths and disease burden, and also in terms of damage to the health infrastructure. While the risk of infectious disease following flooding is generally low in high-income countries, populations with poor infrastructure and high burdens of infectious disease often experience increased rates of diarrhoeal diseases after flood events. There is increasing evidence of the impact that climate-related disasters have on mental health, with people who have suffered the effects of floods experiencing long-term anxiety and depression. Flooding and heavy rainfall may lead to contamination of water with chemicals, heavy metals or other hazardous substances, either from storage or from chemicals already in the environment (e.g., pesticides). Increases in both population density and industrial development in areas subject to natural disasters increase both the probability of future disasters and the potential for mass human exposure to hazardous materials during these events (Parkinson and Butler [8]).

For a few infectious diseases, there is an established rainfall association that is not related to the consumption of drinkingwater (quality or quantity) or arthropod vectors. The spatial distribution, intensity and seasonality of meningococcal (epidemic) *meningitis* in the Sahelian region of Africa is related to climatic and environmental factors, particularly drought, although the causal mechanism is not well understood. The geographical distribution of *meningitis* has expanded in West Africa in recent years, which may be attributable to environmental change driven both by land-use changes and by regional climate change.

CONCLUSION

Changes in climate will occur, even if climate protection measures are effectively implemented today. Although the magnitude and shape of climate change impacts on the water cycle and water resources cannot be predicted exactly, scientific evidence is sufficient to urge immediate action.

There is a wide range of driving forces that can affect and modify the impact of climate change on human health outcomes. Because of the complexity of the association between climate factors and disease, it is often not possible to attribute changes in specific disease patterns to observed climate changes. Furthermore, health data series of sufficient quality and length are rarely available for such studies. There are no published studies of water-related impacts on health that describe patterns of disease that are robustly attributed to observed climate change. However, there are several reports of adaptive responses in the water sector designed to reduce the impacts of climate change.

Climate-change-induced effects on water pose a threat to human health through changes in water quality and availability. Although access to water supplies and sanitation is determined primarily by non-climate factors, in some populations climate change is expected to exacerbate problems of access at the household level. Appropriate disaster planning and preparedness need to be developed in order to address the increased risk of flooding due to climate change and to reduce impacts on health and health systems.

Health must be at the centre of all climate change action. Health-system leaders can use their knowledge and authority to inform and influence action in key national and international processes that guide policy and allocate resources for work on climate change, for instance in preparing national communications, national action programmes on adaptation and international agreements.

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