— Current Topics —

A Problem of Climate Change as Seen by a Pharmaceutical Researcher

Global Warming and the Water Crisis

Shinjiro Kanae*

Department of Mechanical and Environmental Informatics, Tokyo Institute of Technology, 2–12–1–W8–4 O-okayama, Meguro-ku, Tokyo 152–8552, Japan

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This paper overviews the latest information on the impact of global warming on water cycles and resources, with a focus on links to health science. Many people may think that water issues mainly involve securing safe drinking water for regions lacking this crucial resource. However, of world water withdrawals, 70% is for agricultural water. Therefore, issues of water scarcity are highly connected with agriculture and food production. Global warming is expected to result in decreased water availability in semi-arid regions where major crop regions are located. Crop production in semi-arid regions already requires more water inputs than does agriculture in regions of ample natural rainfall; with global warming, the water situation in semi-arid regions is expected to worsen. In addition to the decrease in water for agriculture, domestic and drinking water supplies will also be threatened in semi-arid areas. In contrast, other regions may face the problem of too much water and flood disasters. Currently, the flood-affected population worldwide ranges from an annual minimum of approximately 30 million to a maximum of 300 million people. Projections for the late 21st century, however, suggest that 300 million will be the minimum number affected by flooding each year. The consequences of water decreases in some areas and increases in others caused by global warming will likely have close links to health. Therefore, health scientists should pay close attention to issues of climate and water resource change.

Key words —— global warming, global water resources, climate change, water scarcity, flood

INTRODUCTION

The water crisis is recognized as one of the major environmental and social problems facing the world and regional societies. Anthropogenically induced climate change, or so-called global warming, is anticipated to worsen the global water crisis. This paper attempts to provide some clues to predicting future water issues under global warming.

First, it is useful to consider findings on the impacts of global warming on water cycles described in the Intergovernmental Panel on Climate Change's latest special report, the "IPCC Technical Paper on Climate Change and Water" (Bates *et al.*, 2008).[1] (1) Climate model simulations for the 21st century are consistent in projecting precipitation increases in high latitudes and parts of the tropics and decreases in some subtropical and lower mid-latitude regions. (2) By the mid-21st century, due to climate change, annual average river runoff and water availability are projected to increase at high latitudes and in some wet tropical areas but decrease over some dry regions of the mid-latitudes and in the dry tropics. (3) Increased precipitation intensity and variability are projected to increase the risks of flooding and drought in many areas. (4) Water supplies stored in glaciers and snowpack are projected to decline in the course of this century.

ISSUES OF "TOO LITTLE WATER"

The potential hydrological changes noted above may lead to various kinds of water-related crises.

*To whom correspondence should be addressed: Department of Mechanical and Environmental Informatics, Tokyo Institute of Technology, 2–12–1–W8–4 O-okayama, Meguro-ku, Tokyo 152–8552, Japan. Tel.: +81-3-5734-2190; E-mail: kanae@mei.titech.ac.jp

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This section describes problems of water scarcity at a global scale. First, the current global water status, without the influence of global warming, is introduced.

Water availability and withdrawal (or consumption) are the two main elements to consider. Although many water crises have been reported worldwide, humans currently use just 10% or less of the maximum available renewable freshwater resources (Oki and Kanae, 2006).[2)] Here, the maximum available renewable freshwater supply roughly corresponds to total terrestrial runoff or discharge. How, then, does 10% usage lead to so many water crises? The answer lies in the geographical and temporal imbalance between water availability and demand. Geographical imbalance is particularly important. Although a huge amount of water is available in humid regions, the distribution of human demand for water does not necessarily coincide with the distribution of available water. Figure 1 shows the geographical distribution of the ratio between water withdrawal and water availability. Red coloring indicates a high ratio (*i.e.*, water scarcity). The figure illustrates that much water is used in places where water is not naturally abundant. In particular, Fig. 1 shows high demand and use of water in semi-arid regions.

Why is water demand so high in these regions? As noted above, nearly 70% of water is withdrawn for agriculture, the main consumer of water. Although securing safe drinking water is an important issue, it is not the major element worldwide in terms of water quantity. In semi-arid regions, abundant sunshine and warm temperatures are favorable for agricultural productivity, if water is available. Major crop production regions worldwide are located in semi-arid regions, and people in those regions have exploited their water resources as much as possible. Engineering and technology have been employed to develop water resources and "solve" water problems. However, the use of such technologies tends to make water use unsustainable.

Unfortunately, projections of future global warming suggest that water availability will likely decrease in semi-arid regions, thereby strengthening droughts (Fig. 2). In contrast, it will likely increase in humid regions, where flooding hazards exist. Thus, global warming will bring changes contrary to the hopes of people in these respective regions. Although climate modeling contains uncertainty, and scientists and the public debate the reliability of climate projections, climate models have consistently and robustly predicted that global warming will lead to less water availability and therefore more droughts in semi-arid regions. Less future water is expected to result in part from less precipitation and in part from less snow and ice. One of the most apparent hydrological changes due to global warming is the change in natural water supplies from snow cover and glaciers, both of which are projected to decline. Because many human societies in semi-arid regions rely on snow and glacier meltwater, less water availability and more droughts are likely to occur in those regions, in

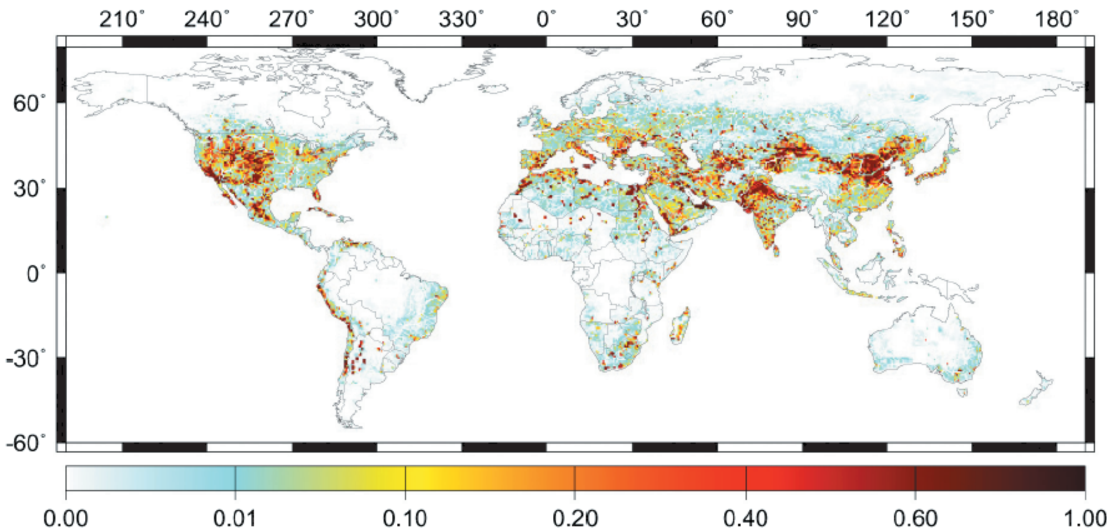

Fig. 1. Global Distribution of Water Scarcity (the Ratio between Water Withdrawal and Water Availability at Each Cell of the Map)
Water scarcity is higher for regions with redder colors. This figure is taken from Oki and Kanae (2006).[2)]

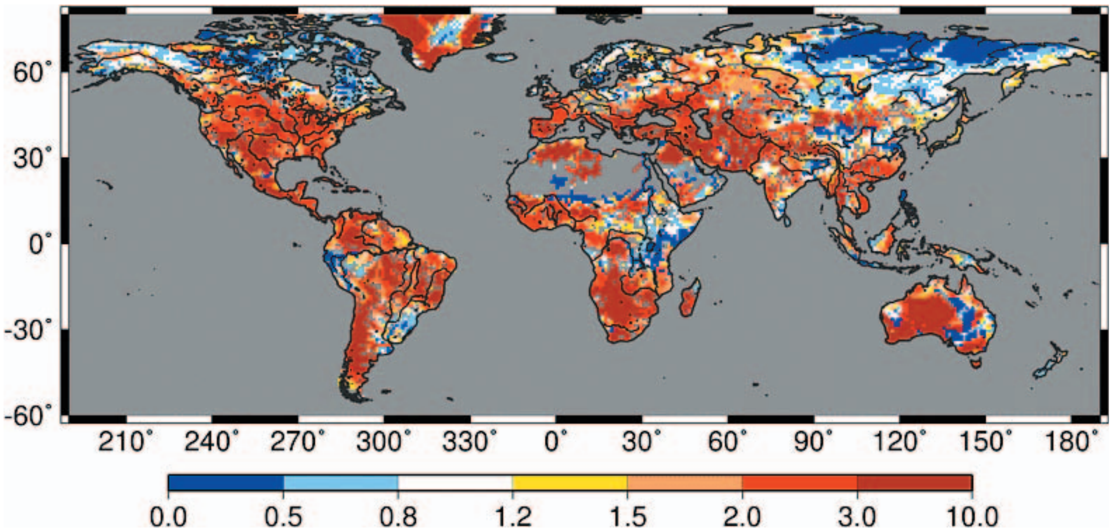

Fig. 2. Relative Change (Ratio) of Drought Frequency between the End of 21st Century and the Average of 20th Century
The details of the calculation is described in Hirabayashi *et al.* (2008).[5)]

part due to these snow and ice changes. Sea-level rise will also reduce the availability of freshwater in mega deltas and coastal zones where sea-level rise may lead to saline water intrusion into groundwater. Water scarcity and increased drought will also have social impacts (*e.g.*, damages, costs) in semi-arid regions, but these impacts have not yet been fully investigated, and they remain a major research challenge.

Less water availability and increased drought due to global warming cannot be fully mitigated by high-tech measures such as desalination, even if we neglect the fact that such measures consume much fossil fuel. Furthermore, we should remember that to be a useful resource, water should be inexpensive (Kanae, 2009).[3)] High-priced water, like commercial bottled mineral water, is only useful for very limited purposes. Water is only a resource if it is available where and when it is required, in sufficient and required amounts (usually vast amounts), and at sufficiently inexpensive cost. Therefore, change in water availability due to global warming may have large impacts on many agricultural communities in developing countries of semi-arid regions. Urban areas and/or developed countries, if located in semi-arid regions, may be also vulnerable to the change in water availability due to global warming. Furthermore, urban populations may be expected to expand in semi-arid regions, where favorable climates for various activities attract new residents.

Yet climate change may not be the primary driver of future water scarcity worldwide. The projected future change of water withdrawal is, in general, larger than the change in water availability. The change of water withdrawal is primarily driven by population and socio-economic conditions such as economic growth (Oki and Kanae, 2006).[2)] The change of food consumption patterns in conjunction with economic growth is an important factor. For example, the water necessary for a unit of beef production is approximately ten times larger than that needed for a unit of crop production. Partly because of this, the IPCC Technical Paper on Climate Change and Water (Bates *et al.*, 2008)[1)] argued that, for freshwater resources, “aside from major extreme events, climate change is seldom the main factor exerting stress on sustainability.” However, our imagination always has limitations, and we may be underestimating the impact of global warming on water availability. In any case, as described by Bates *et al.* (2008),[1)] “the negative impacts of future climate change on freshwater systems are expected to outweigh the benefits.”

ISSUES OF “TOO MUCH WATER”

Water scarcity is not the only aspect of the water crisis. “Too much water” can also cause problems such as flooding. However, even the latest report of the IPCC includes almost no description of future change in flood disasters at a global scale. Thus, the author and a colleague recently attempted to produce a first estimate of future change in flood disas-

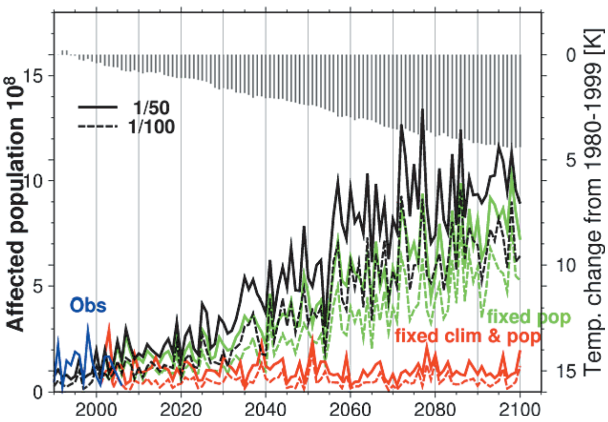

Fig. 3. Flood-Affected Population in the Past and Future

Actual flood-affected population in the past record (blue line), and flood-affected population derived from climate model outputs (black lines). Red lines show flood-affected population derived from climate model outputs in 1901–2000 (= 100-year difference in the horizontal axis) with the fixed population at 2000. Green lines show flood-affected population derived from climate model outputs in 2001–2100 with the fixed population at 2000. The change in global mean surface air temperature (from the average of 1980–1999 as like in the IPCC report) is also shown. This figure is taken from Hirabayashi and Kanae (2009).[4)]

ters due to global warming (Hirabayashi and Kanae, 2009).[4)] The result is outlined briefly below.

Figure 3 shows the time series of the actual past flood-affected population and the projected flood-affected population derived from climate model outputs from the 1990s to the end of the 21st century. The figure clearly shows that the future flood-affected population is likely to increase throughout the 21st century.

To calculate the estimates in Fig. 3, global-scale distributed river discharge and its change under global warming were first computed by a global river model using climate model outputs. Details on the calculation of river discharge have been described by Hirabayashi *et al.* (2008).[5)] Climate model outputs with high spatiotemporal resolution were available for flood calculation. Thus, for future climate, scenario A1B of the IPCC's Special Report on Emissions Scenarios (SRES) was adopted. This scenario projects moderate warming compared to other SRES scenarios. The occurrence of flooding in the simulated river discharge was superimposed on a global population map to estimate the flood-affected population. The flood-affected population, rather than the number of deaths or economic damage, was selected for evaluation and projection because of its robustness in changing social conditions. Note that many caveats exist in the current analysis method, and the result presented here contains uncertainty.

According to Fig. 3, after the mid-21st century, the affected population is likely to differ considerably from the flood-affected population at present. After the mid-21st century, the minimum flood-affected population in a year is likely to exceed 300 million, similar to the maximum worst-case number in the past actual record. The future projection shows that floods will mostly affect populations in warm humid Asia, including South Asia, Southeast Asia, and East Asia (Hirabayashi *et al.*, 2008).[5)]

The period after the mid-21st century in this projection roughly corresponds to the timing of a 2°C increase in global mean surface air temperature compared to the temperature at the end of the 20th century. This increased temperature is similar to the critical level of global warming proposed by EU nations. Note however, that the EU critical level is a 2°C increase from pre-industrial times, not from the end of the 20th century. By the multi-model projections in the latest IPCC report, the 2°C increase roughly corresponds to 2060–2070 in scenario A2, 2060–2080 in scenario A1b, and the end of the 21st century in scenario B1. 2°C warming does not mean that the world will suddenly become more dangerous. Gradual change is expected, and extremely severe flood years exceeding those in past records might also appear in the course of gradual temperature increase. Thus, adaptation measures can be instituted before reaching the level of 2°C warming.

DISCUSSION AND CONCLUSION

Water is already a major global concern even without anticipated warming. Population increase and socio-economic changes, particularly in developing countries, could be the major drivers of water scarcity in the next several decades and throughout the 21st century. Global warming may contribute to worsening water scarcity. Above all, semi-arid regions, which include major agricultural regions and many urban centers, are likely to suffer from decreased water availability caused by less precipitation and snow and glacier melt and more seawater intrusion into groundwater in coastal areas. Reduced water availability may lead to decreased food production and less water for safe drinking and domestic uses, creating health concerns. Scarcity, however, is not the only water concern. Many people in humid regions already suffer from flooding. Global warming is expected to cause more severe flooding in some regions, including warm humid Asia, and to affect more people in the 21st century. Although the flood-affected population includes all people affected, flooding will injure and/or sicken some portion of the population. Thus, greater flooding severity becomes a matter of health. This paper does not address waterborne diseases, but rises in water temperature accompanying global warming may also lead to increases in waterborne illnesses.

Scientists, researchers, and practitioners in health and pharmaceutical sciences should keep abreast of the latest information on changes in global climate and water issues, given the potentially close relationships to public health. Although much uncertainty still exists in projections of water issues under global warming, we must still determine the behavior of our societies based on these somewhat uncertain projections. Warming will not stop easily and suddenly, even if we could halt greenhouse gas emissions. We should not forget the fact that the impact of warming is likely to continue for hundreds and thousands of years, even after the termination of greenhouse gas emissions.

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