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Review Article

Effect of Global Warming on Human Health: The Past, the Present and the Future

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Abstract

The aim of the present study was to review the possible impact of global warming on human health. We have also discussed the substantial contribution of human activity on the concentration of greenhouse gases in the atmosphere. CO_2, which accounts for 81% of greenhouse gas emissions, is produced from combustion of petroleum products, natural gas, and coal. Several vector borne diseases such as malaria are also considered to be water-borne, as the transmission of the disease is associated with factors such as rainfall. This aspect has also been explicitly discussed in this article. Heat shock is a health problem that is most directly affected by the ambient temperature hence heat-related diseases caused by heat waves, injuries, and deaths caused by extreme geological events have also been explored. To conclude, global warming is a very real phenomenon which has already impacted the global distribution of infectious diseases. If climate change continues unabated, it is likely that the range of deadly diseases such as malaria will expand or shift, resulting in sickness and death as populations without pre-existing immunity are increasingly affected.

Keywords: Heat; disease; climate; population; warming.

Introduction

Global warming in an unequivocal phenomenon in today's world. Global warming is the underlying cause for climate change, which in turn greatly impacts human health. Sharp increase in greenhouse gases including but not limited to carbon dioxide, nitrous oxide and methane have been witnessed. This has led to unprecedented changes in the earth's climate [1]. The basic causes of global warming have been listed in **Figure 1**.

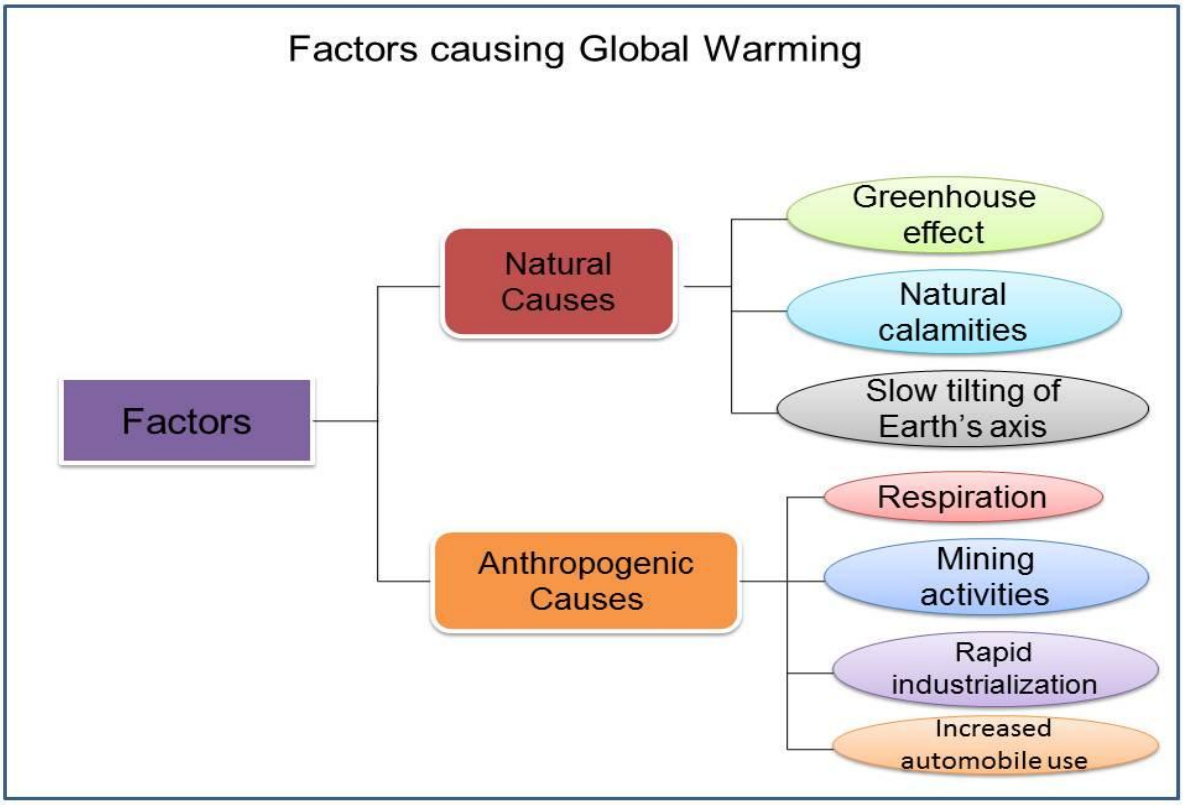

Figure 1: Factors causing global warming.

The emerging evidence of the effect of global warming on human health has been summarized by Intergovernmental Panel on Climate Change (IPCC) [2].Some of the health effects attributable to climate change are directly related to changing environmental conditions [3]. The Public Health Agency of Canada anticipates increased burden of disease as a result of thermal stress and more frequent extreme weather events, and some projected direct effects of climate change on human health, such as heat-related morbidity and injuries, have been previously reviewed. However, climate and weather patterns are important physical components of complex ecosystems and any major change in the non-living component of an ecosystem will affect living components, including microbes, insect vectors, animal reservoirs and susceptible humans, and change the incidence and distribution of infectious diseases [4]. The close relation between climate, environment and infectious disease in the developing world are well recognized. For example, the importance of rainfall and drought in the occurrence of malaria, the influence of the dry season on epidemic meningococcal disease in the sub-Saharan African "meningitis belt" and the importance of warm ocean waters in driving cholera occurrence in the Ganges River delta and elsewhere in Asia are well described [5, 6]. Indeed, there is widespread concern about the potential impact of global climate change on the distribution and burden of these and other infectious threats in the developing world. The effect of global warming on human health is divided into two categories includes direct effect on the illness such as heat shock and increased mortality in population with other diseases and indirect effect on diseases such as infectious diseases and allergy. The IPCC report states that climate change has altered the distribution of some infectious disease vectors, the seasonal distribution of some allergenic pollen species, and increased heat wave-related deaths. In the present review, the effect of global warming on infectious diseases is addressed. Furthermore, current

research on the effect of global warming on infectious diseases is introduced.

The Effects of Global Warming on Human Health: The Past

In general, global warming occurs as a result of imbalance between incoming and outgoing radiation in the earth's atmosphere. Solar radiation enters the atmosphere, some of which is absorbed by the earth's surface and re-emitted as infrared radiation. Greenhouse gases, primarily carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) in the atmosphere from both naturally-occurring and human sources, absorb infrared radiation, generating heat and therefore warming the earth's troposphere (the lower portion of the atmosphere). Fluctuations in the temperature of the troposphere have occurred over time due to variations in concentrations of the naturally-occurring greenhouse gases in the earth's atmosphere. However, emissions from human activity now contribute substantially to the concentration of greenhouse gases in the atmosphere. CO_2, which accounts for 81% of greenhouse gas emissions, is produced from combustion of petroleum products, natural gas, and coal (the fossil fuels). The other primary greenhouse gases include CH_4 (10% of emissions), which comes from landfills, coal mines, oil and natural gas operations, and agriculture; and N_2O (5% of emissions), which results from use of nitrogen fertilizers, burning of fossil fuels, and industrial and waste management processes. In addition to emissions, deforestation has contributed about 15%–20% of greenhouse gas concentrations in the atmosphere, as plants are the primary storers of CO_2 [7].

There is now convincing evidence that human activity has indeed led to warming of the earth's troposphere with resulting global climate change. Based on studies of trapped air bubbles in Antarctic ice, we know that atmospheric levels of greenhouse gases have increased more rapidly since the mid-1800s (corresponding with the beginning of the human industrial age) than at any point in the preceding 10 000 years. Since the pre-industrial era, mean CO_2 concentration in the atmosphere has increased from 280 to over 380 parts per million Parallel to record level increase in greenhouse gas concentration in the atmosphere, global temperature has risen at a faster rate than at any time before ever since records were maintained from 1850s. An increase of 0.6°C has been observed since the 1950s. If CO_2 emissions remain at current or projected levels, global temperatures are expected to rise on average an additional 1.8–5.8 °C by the end of the 21st century. As a result, ocean temperatures will increase as well, and sea levels will rise by 9–88 cm as sea ice melts. The hydrologic cycle will be disrupted due to the ability of warmer air to retain more moisture. Some areas will see more rainfall and some drought, and severe weather events including heat waves and storms are expected to become more common. Between 1951 and 2000, about 3.3% of the earth's surface changed from one climate category to another, with an overall loss of polar and boreal (northern coniferous forest) climates and an increase in arid (dry) climates, and this trend is largely expected to continue. Because of the potential for changing rainfall patterns and severe weather events, climate change is expected to have a significant impact on human health, particularly with regard to certain infectious diseases [8].

Effect of Global Warming on Vector-borne and Water-borne Infectious Diseases on Human Health:

Many infectious diseases of humans are transmitted by insect vectors. These infections typically cannot be transmitted directly from person to person and result in a wide range of clinical illness [9]. Many vector-borne diseases such as malaria are also considered to be water-borne since transmission is associated with factors such as rainfall which will be discussed further later in this article. Important examples of vector-borne infectious diseases are outlined in **Table 1**.

Table 1: Important examples of infectious diseases transmitted by insect vectors

Infectious disease	Causative microorganism	Insect vector	Geographic distribution	% of world population currently at risk	Nature of illness	Ref
Malaria	Plasmodium species	Mosquito (Anopheles species)	Sub-Saharan Africa, Southeast Asia, Central and South America	45%	Destruction of red blood cells, severe illness or death in those with limited immunity (e.g., young children)	[5, 6]
Dengue fever	Dengue fever virus	Mosquito (Aedes species)	Tropical areas worldwide	40%	Fever, rash, joint pain, can lead to severe bleeding and death	[25, 33]
West Nile virus infection	West Nile virus	Mosquito (Culex species)	Essentially worldwide	N/A	Often asymptomatic but can cause encephalitis	[34]

The global health impact of vector-borne diseases, particularly malaria and dengue fever, is tremendous. Currently, 300–500 million people worldwide develop malaria annually, of which one million die. Ninety percent of the deaths occur in Sub-Saharan Africa and malaria causes one out of every five childhood deaths in Africa [10]. While malaria is an ancient human disease, dengue fever became widespread only in the middle of the last century [9]. This disease now affects 50–100 million people annually, with 500 000 developing the most severe form of the disease dengue haemorrhagic fever. There are 22 000 deaths annually due to dengue fever, most of which occur in children [11].

Many infectious diseases are transmitted by ingestion of, inhalation of, or contact with contaminated water. These infections can also lead to a wide range of clinical illness, but herein we will only focus on infections causing diarrheal disease since this is currently the second leading cause of death among children under the age of five worldwide. Important examples of water-borne infectious causes of diarrheal disease are outlined in **Table 2.**

Table 2: Important waterborne infectious causes of diarrheal disease

Type of Microorganism	Examples
Bacteria	*Escherichia coli, Vibrio species* (including *V. cholerae*, which causes cholera), *Campylobacter, Salmonella, Shigella*
Viruses	Norovirus
Parasites	*Cryptosporidium, Giardia, Entamoeba histolytica*

Direct Effect of Global Warming on Human Health Other Than Infectious Diseases:

It has been reported that global warming has direct effects on various aspects of human health including infectious diseases. They include heat-related diseases caused by heat waves, injuries, and deaths caused by extreme geological events. Heat shock is a health problem that is most directly affected by the ambient temperature. In the studies in Japan, there has been a positive relationship between the temperature and the number of heat shock cases in most of the major cities in Japan [7]. The number of heat shock cases increases sharply when the temperature becomes 32^0C and higher. Based on these observations, it is assumed that global warming will increase the number of heat shock patients. However, adaptation measures such as introduction of air-conditioning system are expected to ease the effect. It has also been reported that global warming increases the mortality rate, especially among those with cardiovascular and/or respiratory diseases. Many studies have demonstrated that there is a temperature at which the mortality rate is at the lowest level. This temperature is called the optimum temperature. The mortality rate is higher at both extremes of temperature, that is, high and low sides. Thus, the temperature-mortality relation is usually "V" shaped. The 80 - 85 percentile value of the daily maximum temperature is the best index of the optimum temperature [12-14].

Climate Change and Infectious Diseases:

General impact of climatic conditions on infectious diseases:

Before humans understood that microorganisms caused epidemic diseases, they knew that these diseases were intimately related to climate. For example, ancient Romans retreated to cooler hillside resorts in the summer to avoid malaria. We now have an understanding as to why epidemics of infectious diseases are strongly tied to climate. For those infectious diseases transmitted by insect vectors, we know that vectors are more active at higher temperatures. Tropical species of mosquitoes such as Anopheles require temperatures above 16 °C to complete their life cycles, and malaria parasites are able to develop more rapidly within mosquitoes at higher temperatures (>20 °C). In the case of malaria due to Plasmodium falciparum, one mosquito can infect 200 individuals if temperature conditions are ideal, allowing for rapid spread of the disease [15]. Vector-borne diseases such as malaria are also thought of as water-borne diseases, since mosquitoes typically thrive in aquatic habitats, where they lay their eggs in water-filled containers. Thus, epidemics of malaria and dengue fever tend to occur annually during rainy seasons in the tropics and inter-annually after weather events such as those associated with El Niño-Southern Oscillation (the warm phase in the atmospheric temperature oscillation over the tropical Pacific Ocean) [16, 17]. On the other hand, epidemics of the mosquito-borne West Nile virus infection can occur during times of drought. This happens because mosquitoes and birds the primary hosts of the virus are brought into close proximity at scarce water sources, enhancing transmission of the disease between mosquitoes and birds (and thus to humans). In addition, natural predators of mosquitoes are greatly reduced during times of drought as wetlands dry up [18, 19]. The relationship between climate change, human disease and human society has shown in **Figure 2** [20].

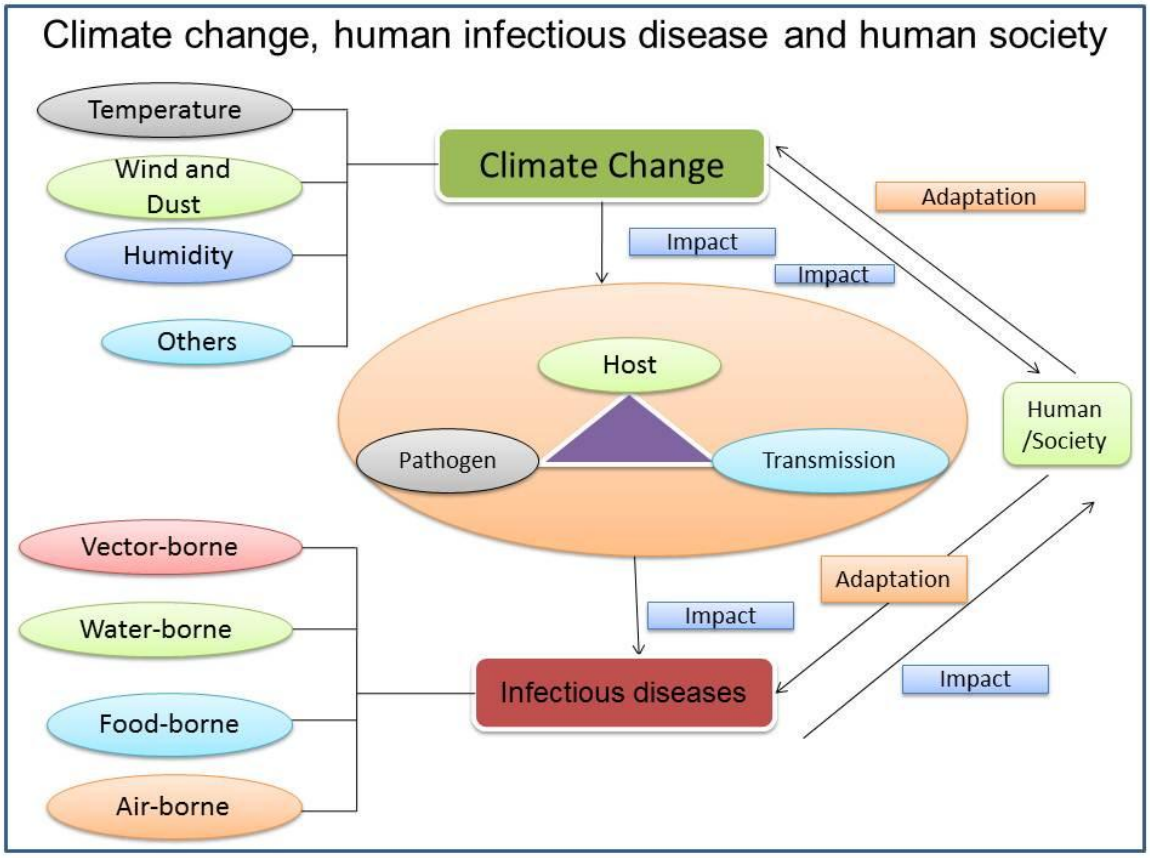

Figure 2: Relationship between climate change, human infectious disease and human society.

Like vector-borne diseases, water-borne diseases are also strongly impacted by climate, particularly the effect of climate on the hydrologic cycle. During times of drought, water scarcity results in poor sanitation and exposure of much of the population to potentially contaminated water. For example, an epidemic of cholera occurred in late 2009 in northern Kenya after a severe drought, with over 4700 cases reported in one month, including 119 deaths. The mainstay of treatment for diarrheal disease such as cholera is rehydration, which further exacerbates the situation due to the lack of adequate potable water available for this purpose. Excess rainfall and flooding, like drought, can also contribute to epidemics of water-borne infectious diseases, in this case due to poor sanitation resulting from run-off from overwhelmed sewage lines or contamination of water by livestock. An example is the 1993 outbreak of diarrheal disease due to Cryptosporidium in Milwaukee, Wisconsin after heavy spring rains. In this outbreak, there were over 403 000 reported cases, demonstrating how widespread diarrheal disease can become when community water sources become contaminated.

Impact of Global Warming on Infectious Diseases: The Present

We currently know more about the effect of climate change on the distribution of animals and plants than on infectious diseases. In general, species ranges have shifted away from the poles and the equator and toward higher altitudes. However, these changes cannot be attributed entirely to climate change, as habitat destruction played an important role as well. At the same time, it is difficult to determine what impact climate change has had thus far on the distribution of infectious diseases, as many other factors play a role as well. Important examples of such factors include extensive travel and migration of human populations, drug and pesticide resistance,

urbanization and increased population density, and availability of health services. In particular, health services tend to break down in the setting of natural disasters, making it more difficult to determine if epidemics following such disasters are related to the event itself or to poor delivery of health care [21].

Despite our fairly limited knowledge, there are some widely cited examples demonstrating that climate change has indeed resulted in the introduction of certain infectious diseases into previously unaffected areas. One such example is the spread of malaria beginning in the 1950s into highland regions of East Africa where this disease previously did not exist. This occurred in the setting of a comparatively warmer and damper weather than usual. Parallel occurrence of deforestation may have been an important contributor in the increasing warming trend.

During the same time as the expansion of malaria into the African highlands, there was a sharp reduction in the prevalence of malaria in the Sahel, an arid region of West Africa which was experiencing a particularly severe drought. Thus, climate change may not always result in overall expansion of tropical infectious diseases, but rather may be followed by shifts in geographic ranges. In the case of malaria in the highlands of Africa, this geographic range shift resulted in high morbidity and mortality due to introduction of the disease into a largely non-immune population.

While it is helpful to examine specific case studies such as those detailed above, it is also useful to look at the effect of climate change on human health thus far on a more global scale. In 2002, the World Health Organization (WHO) released data from a statistical model regarding the impact of climate change on human health as of the year 2009. The aspects of climate change considered in the model included direct effects of heat and cold, drought and famine, population displacement due to natural disasters or resource shortages, breakdown of health infrastructure in natural disasters, and conflict over scarce resources [22]. The health outcomes examined were diarrheal disease, vector-borne disease (specifically malaria), malnutrition, and injury due to natural disasters [23]. Outcomes were measured in disability-adjusted life years (DALY) a commonly used measure which includes years of life lost and years of life lived with disability. The outcomes are summarized in **Table 3.**

Table 3: Global health outcomes due to climate change, expressed in disability-adjusted life years (DALYs)

Region	Total DALYs (1000s)	DALYs/million population	Ref
Africa	1894	3071.5	[35]
Southeast Asia	2572	1703.5	
Eastern Mediterranean	768	1586.5	
Latin America and Caribbean	121	188.5	
Western Pacific	169	111.4	
Developed countries	8	8.9	

What is readily apparent from these data is that developing regions of the world have been dramatically affected by climate change in comparison with developed countries. This stands in stark contrast with CO_2 emissions, which are accounted for almost entirely by developed countries such as the US and countries with rapidly

developing economies such as China and India. According to the most recent data from the United Nations (UN) the Millennium Development Goals in 2006, just about 6.2 billion tons (about 22%) of the global total of 28.7 billion tons of CO_2emissions was produced by the developing regions (excluding China and India).

Impact of Global Warming on Infectious Diseases: The future

The 2002 WHO report also used a statistical model to estimate the global burden of disease that will occur in the future as a result of climate change. According to this model, by 2030, there will be 10% more diarrheal disease than if climate change did not occur, which will primarily impact the health of young children [24]. It is estimated that the population at risk for malaria will increase by 3%-5%, if the increase in global temperature is by an already expected 2-3°C. This is a clear indication of an incremental growth pattern of an additional population of 3%-5% contracting malaria each year Other models predicting the future impact of infectious diseases have been developed Hales, et al, estimated that 5-6 billion people (about 50% of the population) would be at risk for contracting dengue fever by 2085, an estimation drawn on the projections based on the expected effect of climate change on humidity [25]. However, the authors were careful to state that being at risk for getting a disease does not necessarily translate into getting the disease, and that further modelling studies are needed to estimate what the actual impact on human health will be [26].

Others have focused on predicting the impact of climate change on local epidemics of infectious diseases, with an emphasis on developing early warning systems that may allow populations to prepare for such epidemics in advance. For any disease, early warning systems are developed based on models derived from disease surveillance data in combination with climate data. Cholera has served as popular disease for such studies since cases must be reported to the WHO within 24 hours as part of a large-scale surveillance system [27]. For example, elaborate modelling studies have been performed in Bangladesh in order to predict cholera outbreaks on the basis of weather patterns. Developing early warning systems for vector-borne diseases is more difficult because accounting for the unique biology of the vector adds another layer of complexity [28-30]. However, there is significant interest in developing such early warning system. For example, models for early warning systems for dengue fever have now been developed in Thailand and Puerto Rico, where robust surveillance data is available. While many models for early warning systems have been developed, the systems themselves are not widely used at this point [31]. As noted previously regarding the impact of climate change on infectious diseases, the development of truly useful early warning systems is affected by difficulty measuring the impact of non-climatic factors (e.g., migration, population immunity) on susceptibilities of different populations to disease**(Table 4)** [32].

Table 4: Effects of weather and climate on infectious diseases and possible impact of climate change on disease incidence and burden

S. No	Infectious Disease	Examples	Known effects of weather and climate	Possible impact of climate change
1.	Zoonotic and vector-borne diseases	Lyme disease, West Nile virus, dengue, malaria, chikungunya, tularemia, rabies	➢ Increased temperature shortens pathogen development time in vectors. This increases the duration of infectiousness, allowing for prolonged periods of transmission to humans. ➢ Changes in climate may expand the geographic range and abundance in both vectors and reservoir hosts. ➢ Warming and altered rainfall patterns may increase populations of reservoir animals and their predators (e.g., rabbits and foxes). ➢ Early onset of favorable transmission conditions may prolong transmission cycles. ➢ Increased risk of travel-associated illnesses	➢ Increased temperature, rainfall Variability and altered dynamics of reservoir populations are predicted to increase the transmission of some zoonotic diseases. ➢ Changes may permit establishment of novel imported infectious diseases in regions that were previously unable to support endemic transmission. ➢ Changes likely to vary geographically
2.	Water- and food-borne diseases	Verotoxigenic *Escherichia coli, Campylobacter, Salmonella, Shigella, Vibrio, Legionella, Clostridium botulinum, Giardia, Cryptosporidium*	➢ Survival and persistence of disease-causing organisms directly influenced by temperature. ➢ Increased air and water temperatures improve the survival and proliferation of some pathogens (e.g., *Vibrio).* ➢ Climate conditions affect water availability and quality. ➢ Heavy rainfall and flooding facilitates rapid transportation of disease-causing pathogens into water supplies	➢ Increased temperature and rainfall is predicted to increase the intensity and frequency of water- and food-borne diseases. Risks are particularly elevated in the far North
3.	Communicable respiratory diseases	influenza, respiratory syncytial virus, *Streptococcus pneumoniae*	➢ Occurrence of respiratory illnesses may decrease as winter temperatures increase. ➢ Changes in climate may increase the concentration of harmful air pollutants, which might enhance invasiveness due to damage of host mucus membranes	➢ A shorter, warmer and wetter winter season may reduce the number of respiratory diseases observed. Such effects may be counterbalanced by changes in air quality and mass movements of people
4.	Invasive fungal diseases	*Blastomyces dermatitidis, Cryptococcusgattii*	➢ Ecological and meteorological changes may affect local soil ecology, hydrology and climate, resulting in the persistence of invasive fungal pathogens in the environment	➢ Warm, dry summers in combination with heavy wintertime precipitation provide optimal conditions

Projected Trends in the Effect of Global Warming on Human Health in the World:

The projected trends of the effect of global warming on human health have also been summarized in the fourth report of IPCC. The projected trends in climate change related effects include (1) increase in malnutrition and consequent disorders; (2) increase in the number of people suffering from death, disease, and injury from heat waves, floods, storms, fires, and droughts; (3) change of habitants of some infectious disease vectors; (4) mixed effects on malaria (the geographical range will contract in some areas, whereas it will expand and the transmission season may be changed); (5) increase in the burden of diarrhoeal diseases; (6) increase in cardio respiratory morbidity and mortality associated with ground-level ozone; and (7) increase in the number of population at risk of dengue. On the other hand, there will be some benefits to health, including fewer deaths from cold. The benefits will be, however, outweighed by the negative effects of rising

temperatures worldwide in developing countries [3].

The projected trends in the global warming effect in the East Asian countries may be different from those in other regions of the world. There will be increase in the number of heat shock cases and in mortality rate amongst those who have cardiovascular and respiratory disorders, unless appropriate adaptation measures are taken. As stated above, there has not been apparent profound effect on infectious diseases in East Asia yet. It is predicted that the impacts will appear in one form or another if global warming continues to progress in future. It seems unlikely that, global warming will induce an upward trend in the number of patients with diarrhoeal diseases in the East Asian countries. This is primarily due to a well-established social infrastructure in these countries. Furthermore, it is possible that activity of vector mosquitoes will become constantly high even in Northeast Asia. These trends are however not indicative of an increase in the number of patients with vector borne infectious diseases, particularly if appropriate counter measures are considered.

Conclusion

In summary, global warming is a very real phenomenon which has already impacted the global distribution of infectious diseases. If climate change continues unabated, it is likely that the range of deadly diseases such as malaria will expand or shift, resulting in sickness and death as populations without pre-existing immunity are increasingly affected. It is our responsibility to take action now to prevent this from occurring. We must reduce greenhouse gas emissions by developing an international treaty, enacting legislation locally, and acting responsibly as individual citizens of the world. Finally, we must continue to seek answers to how the climate change will have an effect on the most vulnerable population and what can be done to protect them.

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