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The Relationship Between Climate Change and The Incidence of Infectious Diseases

Ikechukwu Okoroafor
Evangel University Akaeze,Ebonyi State, Nigeria

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ABSTRACT: *Climate change, caused by anthropogenic activities and natural factors, refers to significant alterations in long-term weather patterns, including rainfall, temperature, and wind patterns. These changes result in rising temperatures, heat waves, and increased sea levels, leading to floods in countries like Pakistan and Brazil. Such climatic shifts affect the prevalence, distribution, and severity of infectious diseases, especially vector-borne diseases, by impacting hosts (vectors), pathogens, and transmission environments. The vulnerability of human populations to these diseases can exacerbate or mitigate the impact of climate change. Effective adaptation strategies, such as implementing advanced warning systems and strong disease surveillance using modern technologies, are crucial for reducing the adverse effects of climate change on public health.*

Keywords: Climate change, anthropogenic activities, Infectious diseases, Vector-borne diseases, Adaptation strategies

INTRODUCTION

Climate is defined as the prevailing weather conditions of a region such as temperature, air pressure, humidity, precipitation, sunshine, cloudiness, and winds throughout the year averaged over a series of years (Houghton, 2011). It can also be seen as the general or average weather conditions of a certain region at a given period of time including temperature, rainfall and wind (Houghton, 2011). Climate is mostly affected by latitude, the tilt of the Earth ‘s axis, the movement of the Earths wind belts, the differences in temperature of land and sea, topography and human activities especially relating to depletion of the ozone layer (Houghton, 2011). Climate is the statistics of weather over a period of time and it is determined by assessing the changes in the climatic components such as temperature, humidity, rainfall etc (Planton, 2013).

An obvious change in the patterns of the different components of the climate such as change in temperature, Rainfall, wind pattern, snow patterns that lasts for longer period is known as Climate change (USGCRP, 2015). This has been noted to be lethal to every biotic component of the earth's ecosystem ranging from microorganisms, crops, livestock, aquatic animals as well as human beings. A number of factors contribute to climate change but not limited to human and natural factors (EPA, 2010).

Human activities contribute to climate change by causing changes in Earth's atmosphere in the amounts of greenhouse gases, aerosols (small particles), and cloudiness. The largest known contribution comes from the burning of fossil fuels, which releases carbon dioxide gas to the atmosphere via industrial activities (IPCC, 2007). Greenhouse gases and aerosols affect climate by altering incoming solar radiation and outgoing infrared (thermal) radiation that are part of Earth's energy balance. Changing the atmospheric abundance or properties of these gases and particles can lead to a warming or cooling of the climate system. Since the start of the industrial era, the overall effect of human activities on climate has been a warming influence. The human impact on climate during this era greatly exceeds that of the contribution of known changes in natural processes, such as solar changes and volcanic eruptions.The climatic condition of a particular region the distribution of infectious diseases in that particular geographical area. This is so because most of infectious diseases are caused by microorganisms and transmitted through vectors. These vectors or microbes lack thermostatic mechanisms; therefore, they are greatly affected by climatic conditions prevalent in a geographical area at particular period of time. Changes in climatic conditions may affect the survival, reproduction or distribution of the disease, their means of transmission as well as the host susceptibility to the disease (Xiaoxu *et al.*, 2016). The effects of climate change on idisease distribution are characterized by shifts in the geographic and seasonal patterns of human infectious diseases, changes in their outbreak frequency and severity of the disease (Xiaoxu *et al.*,2016).

According to CDC (2021), if climate change remains unchecked it could lead to increased frequency of deaths and illness from frequent extreme weather events, such as heatwaves, storms and floods, the disruption of food systems, increases in zoonoses and food-, water- and vector- borne diseases, and mental health issues. Furthermore, climate change is undermining many of the social determinants for good health, such as livelihoods, equality and access to health care and social support structures. These climate-sensitive health risks are disproportionately felt by the most vulnerable and disadvantaged, including women, children, ethnic minorities, poor communities, migrants or displaced persons, older populations, and those with underlying health conditions (CDC, 2021)It is true that climate change affects infectious disease, however it is difficult to wholistically ascertain the extent of these impact on infectious diseases and the overall human health using the available models (WHO, 2021) Therefore, in the short- to medium-term, the health impacts of climate change will be determined mainly by the vulnerability of populations, their resilience to the current rate of climate change and the extent and pace of adaptation. In the longer-term, the effects will increasingly depend on the extent to which transformational action is taken now to reduce emissions and avoid the breaching of dangerous temperature thresholds and potential irreversible tipping points (Shunam, 2011, CDC, 2021).

In this review, the focus is to understand climate change and its various causes. It also examines the various mechanisms through which climate change affects infectious diseases and the accompanying effects on the health systems on various countries. The possible ways to ameliorate the effects of climate change on health systems is also considered.

What is Climate Change?

Climate is often defined loosely as the average weather at a particular place, incorporating such features as temperature, precipitation, humidity, and windiness. A more specific definition would state that climate is the mean state and variability of these features over some extended time period. Both definitions acknowledge that the weather is always changing, owing to instabilities in the atmosphere. And as weather varies from day to day, so too does climate vary, from daily day- and-night cycles up to periods of geologic time hundreds of millions of years long (Jackson, 2021).

Climate change is also defined as the periodic modification of Earth's climate brought about as a result of changes in the atmosphere as well as interactions between the atmosphere and various other geologic, chemical, biological, and geographic factors within the earth system. It also entails the changes in the mean state of the climate or its variability which keeps persisting for several decades (Ghil and Lucarini, 2019). Climate change can be explained by the changes in the weather conditions of the earth such as increases in the frequency of intense rainfall, decrease in snow cover and sea ice, more frequent and intense heat waves, rising sea levels, and wide spread ocean acidification (IPCC, 2021).

Climate change and climate variability are often used interchangeably but they are two different concepts. The major concept of climate change is time which could lapse for centuries. Climate change involves long-term continuous change (increase or decrease) to average weather conditions or the range of weather. This change is fuelled mainly by anthropogenic activities (Ghil and Lucarini, 2019). On the other hand, climate variability includes all the variations in the climate that last longer than individual weather events, such as for a month, season, or individual year. These variations in the mean parameters of climate just revolve around the average without any effect on the long-term average. The time period associated with climate variability ranges from as many as 30 years (Ghil, and Lucarini, 2019).

Causes of climate change

The EPA (2016) states that many factors, both natural and human, can cause changes in Earth's energy balance and climate change, including: variations in the sun's energy reaching Earth; changes in the reflectivity of Earth's atmosphere and surface; changes in the greenhouse effect, which affects the amount of heat retained by Earth's atmosphere.

Anthropogenic Causes

Human activities have changed and continue to change the Earth's surface and atmospheric composition (IPCC, 2021). Human-induced activities which cause climate change include burning fossil fuels, cutting down forests, and developing land for farms, cities, and roads. These activities all release greenhouse gases into the atmosphere (EPA, 2016).

Deforestation

Forests play a critical role in the Earth's climate system, in a number of different ways. Most importantly for global climate change, they capture carbon dioxide from the atmosphere and convert it, through photosynthesis, into living biomass (FAO, 2010). Forests act as natural filters for carbon dioxide absorption in the atmosphere. They store more carbon than they release and are termed as CO_2 sinks in their natural state (Negar and Jean 2014). Forest cover regulates the air and surface temperature by absorbing carbon dioxide, with a decrease in the forest cover there would a significant increase in the temperature (Yuksel, 2014). Increased evapotranspiration can result in cooler days during the growing season (high confidence) and can reduce the amplitude of heat related events (IPCC, 2018). When forests are burned or cleared for uses such as cropland, pasture, infrastructure or urbanization, the net flow of carbon from the atmosphere into the forest ends, both in the present and for the entire projected future lifetime of the trees (Fakana, 2020).

Deforestation also causes the release of the stock of carbon that has accumulated, both in the trees themselves and in the forest soil (David, 2018). Deforestation at the present rate has resulted in an unprecedented increase of CO_2 in the atmosphere for the past years. Changes in forest cover directly affect Earth's surface temperature through exchanges of water and energy (IPCC, 2020). Removal of forest cover alters global and regional climate patterns and results in catastrophic rainfall spells followed by prolonged dry periods (David, 2018).

Changes in Land-Use

Land-use change, land-use intensification and climate change have contributed to desertification and land degradation (IPCC, 2020). Changes in the way people use land-for example for forests, farms, cities, etc.-can led to both warming and cooling effects locally by changing the reflectivity of Earth's surfaces (affecting how much sunlight is sent back into space) and by changing how wet a region is (Adnan et al., 2011; David, 2018). Unsustainable land management and land use has led to negative economic impacts which are exacerbated by the Climate change (IPCC, 2020). Land use change – converting forests and peatlands to areas of agricultural production also releases carbon stored in the biomass and soil, which contributes a further 10 to 15 percent of total emissions as CO2 (Fakana, 2020)

Emissions of Greenhouse Gases

Greenhouse gases play a vital role in the earth's climate cycles. As the planet gets hit with the sun's rays, some of the energy is absorbed, and the rest of that energy and heat gets reflected into space. This is known as the Greenhouse effect, it exists to keep the earth warmer, without the temperature of the earth will very much lower. The emission of the green house gasses increases the concentration of the gases in the atmosphere increasing the green house effect, thus leading to an increase in the mean global temperature known as Global warming (Fakana, 2020).

These greenhouse gases are as follows

- ***Water vapor***: The most abundant greenhouse gas, but importantly, it acts as a feedback to the climate. Water vapor increases as the Earth's atmosphere warms, but so does the possibility of clouds and precipitation, making these some of the most important feedback mechanisms to the greenhouse effect (Fakana, 2020)
- ***Carbon dioxide (CO_2):*** A minor but very important component of the atmosphere, carbon dioxide is released through natural processes such as respiration and volcano eruptions and through human activities such as deforestation, land use changes, and burning fossil fuels.

Humans have increased atmospheric CO_2 concentration by 48% since the Industrial Revolution began. This is the most important long-lived "forcing" of climate change.

- ***Methane:*** A hydrocarbon gas produced both through natural sources and human activities, including the decomposition of wastes in landfills, agriculture, and especially rice cultivation, as well as ruminant digestion and manure management associated with domestic livestock. On a molecule-for-molecule basis, methane is a far more active greenhouse gas than carbon dioxide, but also one which is much less abundant in the atmosphere (NASA, 2019).
- ***Nitrous oxide:*** A powerful greenhouse gas produced by soil cultivation practices, especially the use of commercial and organic fertilizers, fossil fuel combustion, nitric acid production, and biomass burning (NASA, 2019)
- ***Chlorofluorocarbons (CFCs):*** Synthetic compounds entirely of industrial origin used in a number of applications, but now largely regulated in production and release to the atmosphere by international agreement for their ability to contribute to destruction of the ozone layer. They are also greenhouse gases (IPCC, 2020)

Burning Fossil Fuels

The global agricultural food sector uses more than 30 percent of global end-use energy demand, which is mostly met by fossil fuel sources, and emits around 22% of total anthropogenic greenhouse gases (FAO, 2015). According to NRC (2016) the Earth is getting warmer because humans are adding heattrapping greenhouse gases like CO_2, N_2O, CH_4, and water vapor to the atmosphere, mainly by burning fossil fuels. As fossil fuel usage increases, the amount of these gases in the atmosphere rises. Combustion of fossil fuels (burning of coal, oil and natural gas), cement production, etc., increases the level of CO_2 which reduces the CO_2 taken up by trees. Increase in CO_2concentration is the single largest contributor to global warming (IPCC, 2018).

Urbanization

Urbanization is believed to be a driving force of an economy which facilitates the transfer of surplus labor from the rural agricultural sector to the urban industrial sector and contributes to economic development (Muntasir and Syed, 2018). However, unplanned urbanization can result in negative impacts that adversely affect the economy, deforestation, environmental degradation as well as contribute to global warming and climate change (Zhang and Chen, 2017). Urban expansion can enhance warming in cities and their surroundings (heat island effect), especially during heat related events, including heat waves. Increased urbanization can also intensify extreme rainfall events over the city or downwind of urban areas. This can result in additional risks to the flood system (IPCC, 2020).

Emissions of Pollutants

Some industrial and agricultural processes emit pollutants (other than Greenhouse Gases)that produce aerosols (small droplets or particles suspended in the atmosphere) (IPCC, 2020). Some aerosols also affect the formation of clouds, which can have a warming or cooling effect depending on their type and location.

Black carbon particles or soot produced when fossil fuels or vegetation are burned, generally have a warming effect because they absorb incoming solar radiation (USGCRP, 2009).Chlorofluorocarbons(CFCs), hydrochlorofluorocarbons (HCFCs), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF6), together called F-gases, are often used in coolants, foaming agents, fire extinguishers, solvents, pesticides, and aerosol propellants (IPCC, 2013). Unlike water vapor and ozone, these F-gases have a long atmospheric lifetime, and some of these emissions will affect the climate for many decades or centuries (USGCRP, 2014). Black Carbon is a solid particle or aerosol, not a gas, but it also contributes to warming of the atmosphere. Unlike GHGs, Black Carbon can directly absorb incoming and reflected sunlight in addition to absorbing infrared radiation (IPCC, 2013; Sims *et al.*, 2017).

Agricultural Activities

Agricultural activities such as the use of nitrogen-based fertilizers increase the concentrations of Nitrous oxide (N_2O) in the air which causes climate change (MoA, 2011). In similar way human activities such as raising livestock, growing paddy rice, filling landfills, and using natural gas, etc. raise mostly Methane (CH_4) which is significant contributor to climate change. It is released by decomposition in swamps, from ruminants, especially cows, and leakage from fossil fuel extraction (Braman *et al.*, 2010). Due to human activities, CH_4 concentrations increased in the 20th century and are now more than twice than pre-industrial level (EPA, 2010). In addition, Halocarbons, including chlorofluorocarbons (CFCs), are chemicals used as refrigerants and fire retardants are potential contributors to climate change which can damage the ozone layer.

Natural Causes

Although anthropogenic activities are the root drivers of the climate change, there are some of major natural factors influencing climate system (IPCC, 2013).

Sun's Intensity

Climate is influenced by natural changes that affect how much solar energy reaches the Earth's surface (IPCC, 2018). Changes occurring in the sun itself can affect the intensity of the sunlight that reaches Earth's surface. The amount of heat energy received at any location on the globe is a direct effect of Sun angle on climate, as the angle at which sunlight strikes the Earth varies by location, time of day, and season due to the Earth's orbit around the Sun and the Earth's rotation around its tilted axis (Khavrus, and Shelevytsky, 2010). It has been suggested that changes in solar output might affect our climate—both directly, by changing the rate of solar heating of the Earth and atmosphere, and indirectly, by changing cloud forming processes. The intensity of the sunlight can cause either warming (during periods of stronger solar intensity) or cooling (during periods of weaker solar intensity) (IPCC, 2018).

Changes in the Earth's Orbit

According to Rutgers University (2018) Earth's climate is affected by a number of factors dealing with the Earth as a whole, in relation to its position in the space relative to the sun. These factors include the angle of Earth's axial tilt (also known as Earth's obliquity), the eccentricity of Earth's orbit (how circular/elliptical Earth's orbit is), and Earth's position in time in the precession of the solstices and equinoxes (with different Earth-Sun distances during any given season) which contributes to the climate change (William, 2007).

Changes in Ocean Current Circulation

Since the 1950s, geologists and oceanographers have been gathering convincing evidence that alteration in ocean current circulation is a key determinant of climate change (Cunningham, 2005; Tierney *et al.*, 2013). An ocean current is a continuous, directed movement of sea water generated by a number of forces acting upon the water, including wind, breaking waves, and temperature and salinity differences (England *et al.*, 2014). Ocean current circulation plays a central role in regulating global climate and maintains primary productivity and marine ecosystems (Duteil *et al.*, 2014).

Evidence of Climate Change

There are clear evidence that the climate is the recent mishaps ranging from over flooding, increase in temperature and the general shift in the earth's equilibrium. Some of the obvious signs include

Increase in CO_2 Concentrations in the Atmosphere

Prior to industrial revolution in the eighteenth century, the earth's CO_2content was about 280ppm and this has risen exponentially to about 400 ppm. CO_2 is a greenhouse gas and as such its increase in the atmosphere will surely lead to global warming. This is because greenhouse gases such as CO_2 have the ability to trap heat from the earth surface and this leads to global warming which in turn leads to climate change and invariably affect distribution of disease. Also, the greenhouse gas will increase water retention from vapour in the atmosphere which causes the glaciers to melt increasing the sea level and causing overflowing global climate change (Kieran, 2013).

Increasing Temperatures

The clearest evidence for surface warming comes from widespread thermometer record. Temperatures are monitored at many thousands of locations over both the land and ocean surface. Indirect estimates of temperature change from such sources as tree rings and ice cores help to place recent temperature changes in the context of the past. In terms of the average surface temperature of Earth, these indirect estimates show that 1983 to 2012 was probably the warmest a 30-year period in more than 800 years.Global surface temperatures have risen by 1.3 degrees Fahrenheit (ºF)over the last 100 years. Worldwide, the last decade has been the warmest on record.

Earth's average surface air temperature has increased by about 0.8 °C (1.4°F)since 1900. The rate of warming across the globe over the last 50 years (0.24ºF per decade) is almost double the rate of warming over the last 100 years (0.13ºF per decade) (Ralph and Paul, 2016).A wide range of other observations such as reduced, Arctic sea ice extent and increase ocean heat content and indications from the natural world such as poleward shifts of temperature sensitive species of fish, mammals, insects, etc all these together provides obvious evidence of planetary- scale warming. The evidence of climate change extends well beyond increases in global surface temperatures (Ralph and Paul, 2016). It also includes; changing precipitation patterns, melting ice in the Arctic, melting glaciers around the world increasing ocean temperatures, rising sea level around the world. acidification of the oceans due to elevated carbon dioxide in the atmosphere., Responses by plants and animals, such as shifting ranges (Ralph and Paul, 2016).

Infectious diseases

Infectious diseases are diseases/disorders caused by organisms — such as bacteria, viruses, fungi or parasites. Many organisms live in and on our bodies. They're normally harmless or even helpful. But under certain conditions, some organisms may cause disease. (Yu et al., 2015). Some infectious diseases can be passed from person to person. Some are transmitted by insects or other animals. And you may get others by consuming contaminated food or water or being exposed to organisms in the environment. Signs and symptoms vary depending on the organism causing the infection, but often include fever and fatigue. Mild infections may respond to rest and home remedies, while some life-threatening infections may need hospitalization. Many infectious diseases, such as measles and chickenpox, can be prevented by vaccines. Frequent and thorough hand-washing also helps protect you from most infectious diseases (Jameson, 2018).

Infectious disease classification based on climate relationship

Directly transmitted diseases

Anthroponoses

Directly transmitted anthroponoses include diseases in which the pathogen normally is transmitted directly between two human hosts through physical contact or droplet exposure. The transmission cycle of these diseases comprises two elements: pathogen and human host. Generally, these diseases are least likely to be influenced by climatic factors since the agent spends little to no time outside the human host. These diseases are susceptible to changes in human behavior, such as crowding and inadequate sanitation that may result from altered land-use caused by climatic changes. Examples of directly transmitted anthroponoses include measles, TB, and sexually transmitted infections such as HIV, herpes and syphilis (Altizer *et al*., 2013).

Zoonoses

Directly transmitted zoonoses are similar to directly transmitted anthroponoses in that the pathogen is transmitted though physical contact or droplet exposure between reservoirs. However, these agents are spread naturally among animal reservoirs and the infection of humans is considered to be a result of an accidental human encounter. The persistence of these pathogens in nature is largely dependent on the inter action of the animal reservoir and external environment which can impact the rate of transmission, host immunity, rate of reproduction, and species death, rendering these diseases more susceptible to effects of climate variability. Hanta viruses a directly transmitted zoonosis that is naturally maintained in rodent reservoirs and can be transmitted to humans at times of increased local abundance of the reservoir. Rabies is another directly transmitted zoonosis that naturally infects small mammals, although with very little opportunity for widespread transmission, being highly pathogenic to its vertebrate host.

Indirectly transmitted diseases (Anthroponoses & zoonoses)

Indirectly transmitted anthroponoses are a class of diseases defined by pathogen transmission between two human hosts by either a physical vehicle(soil) or a biological vector (tick). These diseases require three components for a complete transmission cycle: the pathogen, the physical vehicle or biological vector, and the human host. Most vectors require a blood meal from the vertebrate host in order to sustain life and reproduce. Indirectly transmitted anthroponoses include malaria and dengue fever, where by the respective malaria parasite and the dengue virus are transmitted between human hosts by mosquito vectors (vector-borne disease).

Malaria

Climate change may lead to an increase in malaria in certain spots of the world but in some other places it might have no effect on the mosquito. The climatic factors that influence malaria transmission include temperature and rainfall. These climatic factors affect their life cycle, transmission rates and the proliferation of the Plasmodium parasite in the mosquitoes. Some 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 (Franklin *et al.*, 2017). 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 (Lafferty, 2009, Shuman, 2011). For example, the two thresholds maximum temperature of 22–23 °C for mosquito development and minimum temperature of 25– 26°C for Japanese Encephalitis Virus (JEV) transmission, play key roles in the ecology of JEV(Xiaoxu *et al.,2016*). Excessive heat can increase the mortality rates for some pathogens. The development of malaria parasite (*Plasmodium falciparum* and *Plasmodium vivax*) ceases when temperature exceeds 33°–39 °C (Xiaoxu et *al.*,2016). The rising temperature can influence the reproduction and extrinsic incubation period (EIP) of pathogens. For example, the EIP for *P. falciparum* reduces from 26 days at 20 °C to13 days at 25 °C. On the contrary, lower ambient temperature is likely to lengthen EIP, which may in turn decrease the transmission of diseases such as dengue because fewer mosquitoes can live long enough (Xiaoxu *et al.*,2016). The extended periods of hot weather can raise the average temperature of water bodies and food environment, which may provide an agreeable environment for microorganism reproduction cycles and algal blooms (Xiaoxu *et al.*,2016).

Dengue Fever

Dengue fever is an important vector-borne viral infectious disease in the world. The abundance of vectors is directly dependent on the climatic conditions at a given time which in turn affects the distribution of the dengue fever disease, that is to say that the abundance of the mosquito vector increases the number of patients (Ichiro, 2010). The epidemics of malaria and dengue fever tend to occur annually during rainy seasons in the tropics and inter-annually after weather events. 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 (Shuman, 2011).

Water- Borne Diseases

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 (Gettleman, 2009). 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 (Mackenzie et al., 1994) . In this outbreak, there were over 403 000 reported cases, demonstrating how widespread diarrheal disease can be-come when community water sources become contaminated (Mackenzie et al., 1994).Salmonellosis Salmonellosis is a disease condition caused by *Salmonella* sp. The distribution and spread of this disease is strongly affected by climate change. This is because of the changes in seasonal patterns such as extreme rainfall, increased flooding, increased average temperatures, and extreme heat and all these affect the dynamics of the disease (Franklin, 2017).

Cholera

Cholera is a food borne infection or water borne infection caused by drinking water contaminated with the bacterium. High air temperatures and periods of excessive rainfall create environmental conditions that favor bacterial growth. In dry conditions, river levels decrease and bacterial accumulate in dangerously high concentration. During excessive rainfall, flooding can spread bacteria to regions that haven't previously been infected resulting in fast spreading epidemics (Laura, 2014). An increase in rainfall and stormy frequency leads to an increase in flooding and landslides. This can lead to an outbreak of cholera cases. Landslides are often accompanied by disabilities in the infrastructures in the environment (Franklin 2017).

Complex cycles of disease transmission also exist for several diseases which cannot be classified simply by method of transmission or natural reservoir. Such a disease is Rift Valley fever where the virus is primarily a zoonotic disease, spread among vertebrate hosts by the mosquito species Aedes. Primarily under flood conditions, Culex mosquitoes may feed up on infected ungulate hosts. This vector is referred to as a bridge species because it feeds on humans also, resulting in spread of the virus outside its normal zoonotic cycle (Janey, 2018).

Effects Of Climate Change on Infectious Diseases

Climate changes include alternations in one or more climate variables including temperature, precipitation, wind, and sunshine. These changes may impact the survival, reproduction, or distribution of disease pathogens and hosts, as well as the availability and means of their transmission environment. The health effects of such impacts tend to reveal as shifts in the geographic and seasonal patterns of human infectious diseases, and as changes in their outbreak frequency and severity.One of the major approaches of studying the effect of climate change on infectious diseases is to consider its impacts on the components of infectious diseases. These three components are the pathogen, host, and transmission environment.

Effect of climate change on host

Hosts in this context, refers to living animals or plants on or in which disease pathogens reside. Vectors are intermediate hosts and they carry and transmit pathogen to living organisms which become hosts. The focus here is on animal hosts or vectors, especially insects. The geographical locations and population changes of insect vectors are closely associated with the patterns and changes of climate. Thus, climate change may cause changes in range, period, and intensity of infectious diseases through its impacts on disease vectors.

Temperature affects the spatial–temporal distribution of disease vectors. As temperature continues to rise, the insects in low-latitude regions may find new habitats in mid- or high-latitude regions and in areas of high altitude, leading to geographical expansion or shift of diseases. Recent studies have found that some vector-borne human infectious diseases, including malaria, African trypanosomiasis, Lyme disease, tick-borne encephalitis, yellow fever, plague, and dengue have distributed to a wider range (Harvell *et al.,* 2002). Most of these diseases have extended into areas of higher latitude, following the habitat expansion of mosquitoes, ticks, and midge vectors. In China, as the winter temperature continues to rise, Oncomelania hupensis, the intermediate host of Schistosoma japonicum, extended its geographic distribution into new areas including northern China (Zhou *et al*., 2010).

However, temperature change may as well restrict the distribution of disease vectors. For example, *Aedes aegypti* is the mosquito host for yellow fever and dengue fever viruses (Epstein, 2001a). Laboratory experiments found that *A. aegypti* larvae perish when the water temperature surpasses 34 °C; the adults start to die when the air temperature is above 40 °C (Christophers, 1960). As global warming continues, the disease hosts such as A. aegypti may disappear from some regions where temperature rises beyond their thresholds. Similarly, since the Anopheles-borne falciparum malaria mostly exists when temperature is above 16 °C (Beck-Johnson *et al*., 2013, Martens *et al., 1997*), a temperature dropping to below this threshold will benefit malaria control.

Disease vectors/hosts may survive climate change by taking shield in small-scaled environment where ambient temperature change does not prevail. For example, A. aegypti mosquito was found to hide from the high summer temperature of 40 °C in Jalore Town of Rajasthan, India by using household pitchers or cement water tanks underground (Tyagi and Hiriyan, 2004). Similarly, field observations have recorded viable A. aegypti larvae in ice-encrusted water (Christophers, 1960). Historical record reported the presence of *A. aegypti* in Memphis, USA where the winter temperature normally falls below 0 °C (Reiter, 2001).

Changes in precipitation may impact disease vectors/hosts as well. Many vector-borne infectious diseases are found to be positively associated with rainfall. Larval development of some mosquito vectors accelerates with increased rain and rising temperature (Hoshen and Morse, 2004). Adult Anopheline, vector of malaria, reproduce in small natural ponds of clean water; droughts may limit the quantity and quality of breeding sites for these mosquitoes, resulting in reduction in vector population and disease transmission (Gage et al., 2008). The cocoliztli outbreaks in Mexico proved that rainfall can affect the outbreaks of rodent-borne diseases through its impact on rodent population (Zell, 2004).

However, rainfall is not always agreeable for vectors. Excessive precipitation may have catastrophic impacts on mosquito population because strong rain may sweep away their breeding sites (Kuhn *et al.,* 2005). On the contrary, drought in wet regions may decrease flow velocity in brooks and provide

mosquitoes with more pools of stagnant water as breeding places (Kovats *et al.,* 2003). The primary carrier of West Nile virus is a type of mosquito named Culex, which usually breeds underground in the nasty water pools in city drains and catch basins. Drought allows for rotten organic materials to accumulate in those pools, forming favorite condition for Culex; heavy precipitation would wash the drains and water down the pools (Epstein, 2001b), limiting the spread of West Nile virus.
Many disease hosts tend to respond strongly to humidity change. Relative humidity affects malaria transmission through impacting the activity and survival of mosquitoes. If the mean monthly relative humidity is under 60%, the lifespan of malaria vector mosquito becomes too short to incur malaria transmission (Wu *et al.,* 2016). When wet and warm weather is intersected by dry-spells, the mosquito vectors carrying West Nile virus and Lyme disease may move into non-traditional areas such as Canada and Scandinavia (Senior, 2008). Low humidity can negatively affect the adult survival of *A. aegypti,* therefore reduce dengue disease transmission (Wu et al, 2016). Generally speaking, low humidity, especially when coupled with high temperature, forms unfavorable condition for ticks and fleas (e.g. grasslands or forestlands), limiting the spread of the related infectious diseases (Gage and Kosoy, 2005).

Wind has dual effects on disease vectors/hosts. Wind may affect the malaria cycle both negatively and positively. Strong wind can reduce the biting opportunities for mosquitoes, but can extend their flight distance. During a monsoon season, wind is able to change the spatial distribution of mosquitoes (Reid, 2020).

Sunshine can affect a disease host through the synergistic function. A time series analysis of cholera cases in Matlab, Bangladesh suggested that increased temperature and prolonged sunshine are positively related to the monthly cholera occurrences (Islam *et al.,* 2009). Specifically, high temperature and medium sunshine hours together form the most agreeable condition for cholera outbreak. Relatively low temperature may still support cholera vector if long-hour sunshine is available.

Effect of climate change on pathogens
Pathogen refers to a wide range of disease agents, including virus, bacterium, parasite germ, and fungi. The impact of climate change on pathogens can be direct, through influencing the survival, reproduction, and life cycle of pathogens, or indirect, through influencing the habitat, environment, or competitors of pathogens. As a result, not only the quantity but also the geographic and seasonal distributions of pathogens may change.

Temperature may affect disease through impacting the life cycle of pathogens. First, a pathogen needs a certain temperature range to survive and develop. For example, the two thresholds, maximum temperature of 22–23 °C for mosquito development and minimum temperature of 25–26 °C for Japanese Encephalitis Virus (JEV) transmission, play key roles in the ecology of JEV (Mellor and Leake, 2000, Tian et al., 2015a). Excessive heat can increase the mortality rates for some pathogens (Gerba, 1999, Kuhn et al., 2005). The development of malaria parasite

(*Plasmodium falciparum* and *Plasmodium vivax)* ceases when temperature exceeds 33°–39 °C (Patz et al., 1996). Secondly, rising temperature can influence the reproduction and extrinsic incubation period (EIP) of pathogens (Harvell *et al.,* 2002). For example, the EIP for P. falciparum reduces from 26 days at 20 °C to 13 days at 25 °C (Bunyavanich *et al.,* 2003). On the contrary, lower ambient temperature is likely to lengthen EIP, which may in turn decrease the transmission of diseases such as dengue because fewer mosquitoes can live long enough. Third, extended periods of hot weather can raise the average temperature of water bodies and food environment, which may provide an agreeable environment for microorganism reproduction cycles and algal blooms. For example, Vibrio spp. bacteria, native to the Baltic and the North Sea, showed an increased growth rate during the hot summers in 2006 (Frank et al., 2006). Salmonellas is a food-borne disease; the reproduction of the bacteria increases as temperature rises in that range between 7 °C and 37 °C (IWGCCH, 2010). Lastly, rising temperature may limit the proliferation of a pathogen through favoring its competitors. For example, Campylobacter spp., the bacteria of food-borne disease Campylobacter, was found to be more concentrated in surface water at low temperature and during winter (Jones, 2001); it is believed that warmer temperature supports other bacteria to out-compete Campylobacter spp. and that ultraviolet light prohibits the survival of *Campylobacter* (Obiri-Danso et al., 2001).
Climate change may cause shifts in precipitation, which affects the dissemination of water-borne pathogens. Rainfall plays an important role in the development of water-borne disease pathogens. Rainy season is related to the increase of fecal pathogens as heavy rain may stir up sediments in water, leading to the accumulation of fecal microorganisms (Jofre *et al.,* 2010). However, unusual precipitation after a long drought can result in an increase of pathogens, causing a disease outbreak (Wilby *et al.,* 2005). Droughts/low rainfall lead to low river flows, causing the concentration of effluent water-borne pathogens (Hofstra, 2011, Semenza and Menne, 2009).

Humidity change also impacts the pathogens of infectious diseases. The pathogens of air-borne infectious disease such as influenza tend to be responsive to humidity condition. For example, absolute humidity and temperature were found to affect influenza virus transmission and survival (Shaman and Kohn, 2009, Xu *et al.,* 2014). Lowen *et al.* (2007) proposed that cold temperature and low relative humidity are favorable to the spread of influenza virus. Humidity change also affects the viruses of water-borne diseases. For example, the survival of water-borne viruses near water surface is limited due to the drying effect of surface water (Gerba, 1999). Lastly, virus of vector-borne diseases may be impacted by humidity change. Humidity was found to affect malarial parasite development in Anopheline mosquito (Patz et al., 2003). Thu. et al. (1998) found that the temperature and humidity during rainy season in Yangon and Singapore favor dengue virus propagation in mosquitos, contributing to the outbreaks of dengue hemorrhagic fever in these regions.

Sunshine is one more important climate variable that may affect the pathogens of infectious diseases. For example, sunshine hours and temperature act synergistically during cholera periods to create a favorable condition for the multiplication of *Vibrio cholerae* in aquatic environments (Islam *et al.,* 2009).

Wind is a key factor affecting the pathogens of air-borne diseases. Literature suggested a positive correlation between dust particle association/attachment and virus survival/transporting (Chen et al., 2010, Chung and Sobsey, 1993). It has been reported that the presence of desert dust in the atmosphere during Asian dust storms (ADSs) is associated with increased concentration of cultivable bacteria, cultivable fungi, and fungal spores (Griffin, 2007, Schlesinger et al., 2006). Chen et al. (2010) found that the concentration of influenza A virus was significantly higher during the ADS days than normal days. Studies further suggested that the viruses of infectious diseases be transported across ocean by dust particles (Chung and Sobsey, 1993, Cox, 1995, Griffin, 2007), which may facilitate the transmission of viruses between distant hosts The effect of Climate change on disease transmission

Depending on the transmission route, disease transmission can be direct or indirect. Direct transmission refers to the transmission of a disease from one person to another through droplet contact, direct pysical contact, indirect physical contact, air-borne transmission, or fecal–oral transmission. Indirect transmission refers to the transmission of a disease to humans via another organism, a vector, or an intermediate host.

Many studies have proved that climate variables and weather conditions may affect disease transmission, despite some uncertainty about the specific mechanisms. Rather than focusing on the disease transmission mechanisms, this section discusses the impacts that climate change may impose on the spreading of human infectious diseases. This impact can be direct as changes in climate condition may alter disease transmission by directly influencing the viability of pathogens. It can be indirect if a change in the transmission routes resulted from the responding behaviors of humans and vectors/hosts to climate change.

Temperature change alone, or together with other variable changes such as rainfall, may alter the transmission of diseases. Studies have reported an association between interannual variability in temperature and malaria transmission in the African highlands (Bouma, 2003). In the highlands of Kenya, hospital admissions for malaria have been associated with rainfall and high maximum temperature during the preceding 3–4 months (Githeko and Ndegwa, 2001). Hemorrhagic Fever with Renal Syndrome incidence closely correlates with meteorological factors that include temperature, rainfall, and humidity (Xiao et al., 2014).

Wind and dust storms affect the transmission of infectious diseases. Wind can act as a transportation means for pathogen and virus of air-borne diseases. Pathogens can spread from endemic regions to other regions through interregional dust storms. Human influenza virus could be transported from Asia to the Americas in winter months by prevailing wind over the Pacific (Hamnett et al., 1999). Chen et al. (2010) found that avian influenza outbreaks tend to occur in downwind regions of ADS (e.g. Japan and South Korean) during the dust storm season.

Climate change can affect the transmission of infectious diseases through altering the contact patterns of human–pathogen, human–vector, or human–host. An analysis of the de-trended time- series malaria data in Madagascar found that the cross-year variation in malaria prevalence can mostly be explained by the minimum temperature at the start of the transmission season, corresponding to the months when the human–vector contact is the greatest (Bouma, 2003). Evidences showed that diseases transmitted by rodents sometimes increase during heavy rainfall and flooding events because of altered patterns of human–pathogen–rodent contact. For example, during hazard periods deer mice may enter human dwellings searching for food and thereby transmit hantavirus to humans, leading to hantavirus pulmonary syndrome (HPS) cases (Engelthaler et al., 1999). There have been reports on flood-associated outbreaks of leptospirosis (Weil's diseases) in Central and South America and South Asia (Ahern et al., 2005, Confalonieri, 2003, Ko et al., 1999). The risk factors for leptospirosis for peri-urban population in low-income countries include flooding of open sewers and streets (Sarkar et al., 2002).

Climate variation plays an important role in shaping the patterns of human and other host activities and behaviors, such as seasonal occupation, migration, winter–summer lifestyles, and physical exercises (Viboud et al., 2004); these in turn can significantly influence the patterns of disease transmission (Kuhn et al., 2005). The seasonal prevalence patterns of influenza infection in Europe are believed to be related to people spending longer hours indoor during winter (Halstead, 1996, Lofgren et al., 2007). It was shown that within each wild fowl migratory flyway, the timing of H5N1 outbreaks and viral migrations is closely associated (Tian et al., 2015c). Live poultry markets particularly in the holiday season serve as sources of human infected avian

influenza and interacting with migratory birds may also contribute to the transmission of the virus (Zhang et al., 2014, Wang et al., 2014). The elevated morbidity of gastroenteritis in temperate developed countries during summer months could be related to increased picnics and other outside-cooked meals (Altekruse et al., 1998). The re-emergence of kala-azar (visceral leishmaniasis) in the cities of the semi-arid northeastern region in Brazil in the early 1980s and 1990s was caused by the rural–urban migration of the subsistence farmers (Kuhn et al., 2005). A global cross-sectional study of diarrhea incidences in children under 5 found a negative association between rainfall and diarrhea rates, pointing to increased using of unprotected water sources and reduced hygiene practices when water is scarce (Lloyd et al., 2007). With global warming, water scarcity will become a broader and more severe issue, which may lead to more diarrhea cases worldwide (Lloyd et al., 2007).

Climate change and Human's susceptibility to dieases

It is essential to recognize that social and economic factors play a significant role in predicting the changing risk for infectious diseases caused by climate change (Semenza and Menne, 2009, Wu et al., 2014, Xu et al., 2014). Some population and regions are more vulnerable to the elevated risks due to their lack of the ability to effectively respond to the stresses and challenges imposed by climate change (Li et al., 2014, Wang et al., 2013, Wei et al., 2012). Levels of vulnerability are partly a function of the programs and measures that are in place to reduce burdens of climate- sensitive health determinants and outcomes, and partly a result of the success of traditional public- health practices, including access to safe water and improved sanitation, and biosecurity and surveillance programs to identify and respond to infectious diseases outbreaks (Bai et al., 2014, Confalonieri et al., 2007, Jiang et al., 2014, Li et al., 2014). In India, unplanned urbanization has contributed to the spread of P. vivax malaria (Akhtar et al., 2002) and dengue (Shah et al., 2004). Since diarrhea morbidity increases as water becomes scarce, the segments of population who are projected to have restricted water access may be more vulnerable to diarrhea (Lloyd et al., 2007). Exceptions to this impact are those societies that can gather advanced technologies and abundant financial resources to eliminate or alleviate water shortage situation.

A society's vulnerability to climate change induced health risk of infectious diseases is related to its social development. Many infectious diseases often break out in developing countries after tropical cyclones, but they are rare in developed nations (Guill and Shandera, 2001). Examples include the outbreak of Balantidias on the Pacific Island of Turkey and typhoid fever in Mauritius (Toole, 1997), acute respiratory infection and leptospirosis in Puerto Rico (Sanders et al., 1999), acute respiratory infection and self-limiting gastrointestinal disease in Dominican Republic (CDC, 1999), cholera in Guatemala, Nicaragua, and Belize, leptospirosis in Nicaragua, and gastrointestinal disease in Honduras (PAHO, 1998). However, a surveillance report of the post- hurricane infectious diseases in developed nations found no increase (Toole, 1997). The inadequate financial and medical resources coupled with the less-effective communication and public health education in developing countries limit these societies' ability to prepare for and respond to climate change induced health issues.

A society's vulnerability to climate change induced health risk of infectious diseases is further related to its existing public health system and infrastructure. Developing countries tend to be more sensitive to an elevated health risk caused by climate change due to the lack of resources and capabilities for their public health system to effectively respond to the various challenges. The interference to public health service and anti-malaria spraying by Hurricane Flora of 1963 may have led to more than 75,000 cases of P. falciparum malaria in Haiti (Bissell, 1983). After Hurricane Mitch of 1998, morbidity of dengue fever amplified in Guatemala and Honduras; so did malaria morbidity in Guatemala and Nicaragua (PAHO, 1998).

Conclusions and Recommendations for future research

Climate change will continue to increase risk for human infectious diseases, limiting some disease transmission but creating opportunities for others. Reducing vulnerability through adopting adaptation measures is among the most effective approaches for the human society. The identification of most effective adaptive measure calls for scientific and social advances in several aspects. First, scientific advances are needed to go beyond empirical observations of the association between climate change and shifts in infectious diseases and to more explanatory conclusions. This advancement to explanatory approach depends on our knowledge about the net- outcome of health implications on all three aspects of infectious diseases; it also depends on our understanding of the net-health effects induced by changes in multiple climate variables. Second, there is a need for better understanding and modeling of the spatial–temporal process of climate change (including extreme weather events and meteorological hazards). Being able to map out this changing process through time and across space is the foundation for health impacts prediction and adoption of proper adaption measures. Therefore we need a comprehensive global map of changes in climate variables-not changes in sporadic and individual climate variables but the magnitude and sequence of all variable changes and the combined results. Lastly, on a practical level, effective early warning systems for health effects of climate change should be established broadly. Related to such early warning systems, protocols are needed for information sharing, public health awareness campaign, and resources sharing and relocation.

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