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Climate Changes and Human Infectious Diseases

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Abstract

Because of being partially attributable to the varying effects of climate change, spatio-temporal scale, and different types of host-pathogen systems, the debate on the potential human health impacts remains polarizing, in spite of a growing progress in determining climate change effects on human infectious diseases. While regions geographically experiencing higher temperature anomalies have been provided more study attention, the Earth' s most vulnerable regions to climate variability and extreme events unfortunately have been less studied. Agreements on the response of human infectious diseases to climate change tend to converge from local to global scales. Then the number of mechanistic studies are slowly growing, with abundance of findings of rapidly growing of statistical methods, for examples, using seasonal auto-regressive integrated moving average (SARIMA) model with local weather conditions in forecasting hand-foot-mouth disease, using generalized estimating equation models/multivariate random-effects meta-regression analyses in quantifying the city-specific climate change-malaria associations, etc. The authors extracted the published evidence and demonstrated that over the past three years (2016 to early 2018), the negative or uncertain reports on responses of human infectious diseases to climate change has been increasing. Research gaps and trends found in this study should be addressed in the near future, including impact of climate change on respiratory infectious diseases and human infectious diseases other than vector-borne diseases.

Keywords: *Human Health; Climate Change; Impact; Infectious Diseases*

Abbreviations

oC: Degree Celsius; CI: Confidential Interval; DF: Dengue Fever; DLNM: Distributed Lag Non-linear Model; DOM: Dissolved Organic Matter; DTR: Diurnal Temperature Ranges; ENM: Ecological Niche Model; ENSO: El Niño Southern Oscillation; GAM: Generalized Additive Models; GP: Genetic Programming; HadGEM2-ES: Hadley Global Environment Model 2-Earth System; HFMD: Hand; Foot and Mouth Disease; IRR: Incidence Risk Ratio; NA: Not Available; NAPAs: National Adaptation Programs of Action; OECD: Organization for Economic Cooperation and Development; PROMETHEE: Preference Ranking Organization Method for Enrichment Evaluations; SARIMA: Seasonal Auto-regressive Integrated Moving Average; SARS: Severe Acute Respiratory Syndrome; TBEV: Tick-borne Encephalitis Virus; UK: United Kingdom; UN: United Nations; USA: United States of America; UV: Ultraviolet; VBDs: Vector-borne Diseases; WHO: World Health Organization

Introduction

Climate change, the long-term shifts in weather conditions and patterns of extreme weather events may contribute to changes in human health threats and multiplying existing health problems [1] whose occurrence and geographic range is affected by climate and weather variables [2] (Figure 1, 2). Increasing severity and frequency of flooding, which is the most frequent and deadly disaster, globally

[3]. Morbidity and mortality from climate events, extreme weather can be affected by changing weather pattern and changing concentration of ground-level ozone, aeroallergens, and particulate matter [2] and changing weather pattern can create environmental conditions that facilitate alterations in seasonality, geographic range, and climate-susceptible infectious diseases in some areas, as well as mental health, migration, and other factors affecting well-being [2]. Changes in water availability and agricultural productivity associated with a changing climate can affect the burden of undernutrition that is especially true in some regions of Asia [2]. Overall health balance will be detrimental, especially in low- and middle income countries that experience higher burdens of climate-sensitive health outcomes while climate change will probably benefit some short-term health outcomes in some locations [2]. A recent study on host-parasite systems under the thermal ecology in the United States demonstrated that in warming scenarios within the coastal southern United States, the model predicts sharp declines in parasite prevalence, with local parasite extinction occurring with as little as 2oC warming [4]. Local increasing transmission was found considering the northern portion of the parasite's current range [4]. There was no evidence that the parasite will expand its range northward in a warming condition [4]. This study indicates that host populations may experience decreased parasitism in a warming condition and highlights the further measuring host and parasite thermal performance for predicting infection responses to climate change [4].

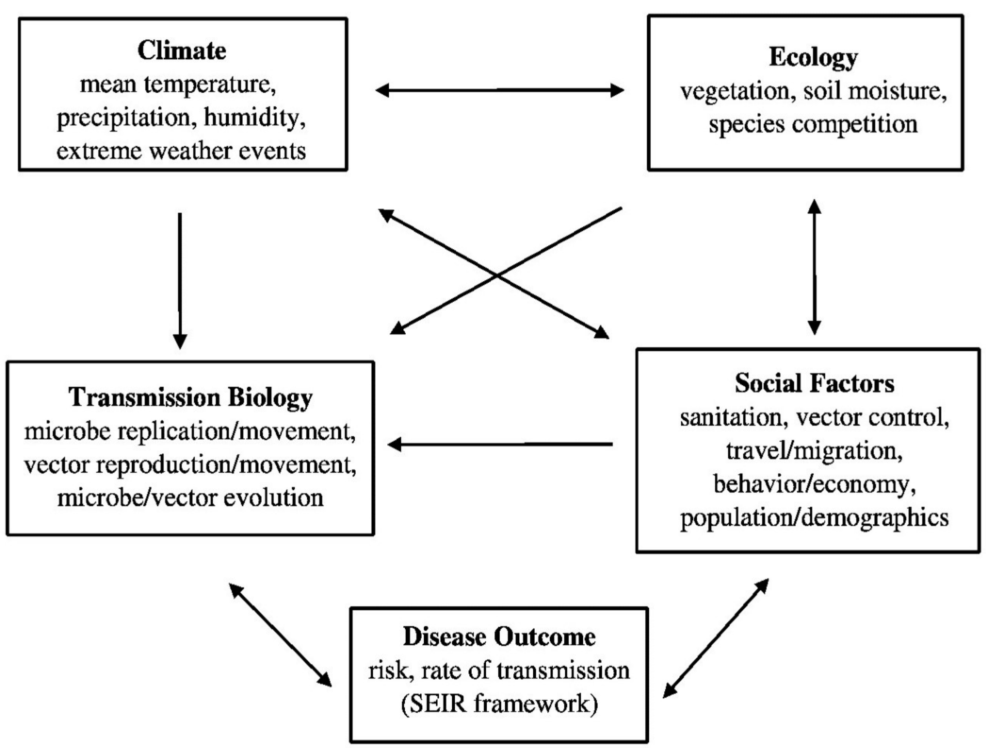

Figure 1: *The " web " of factors that influence transmission of infectious disease agents. (Source: Linkages Between Climate, Ecosystems, and Infectious Diseases. National Research Council. 2001. Under the Weather: Climate, Ecosystems, and Infectious Disease. Washington, DC: The National Academies Press. doi: 10.17226/10025).*

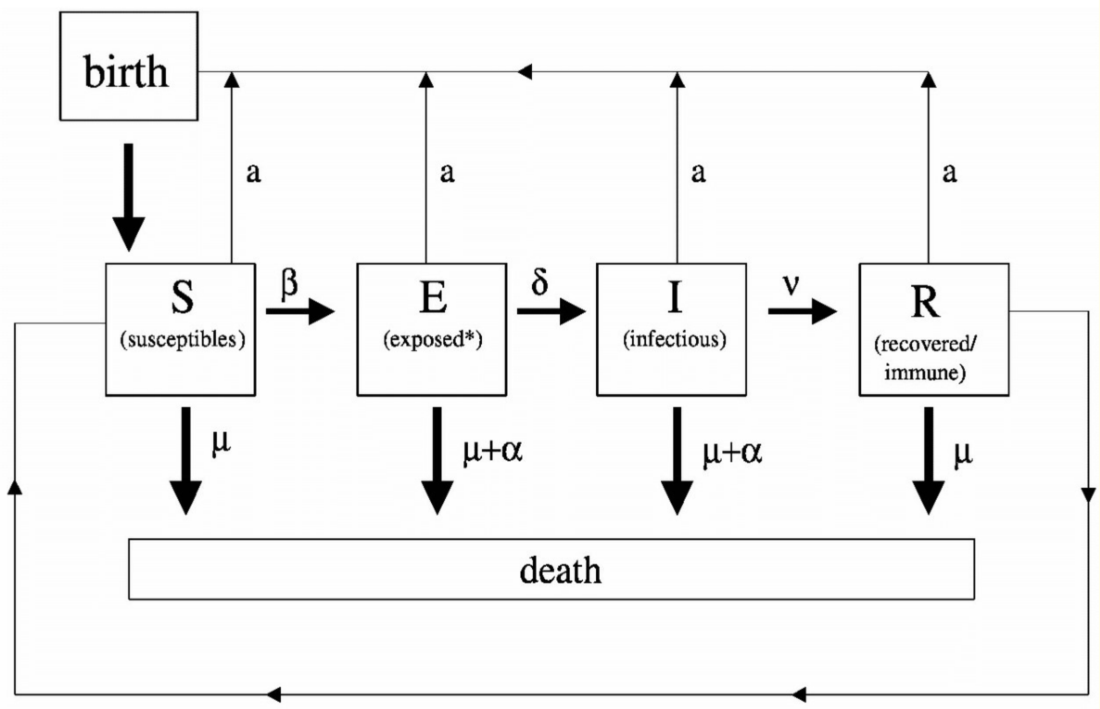

Figure 2: *Diagram of the SEIR (S: Susceptibles; E: Exposed; I: Infectious; R: Recovered/Immune) framework used in modeling the transmission of disease agents. Definition of parameters: a = host per capital reproductive rate; μ = host per capita death rate; α, β, δ, ν = various factors affected by climate and ecological changes that influence on disease dynamics.*
(Source: Linkages Between Climate, Ecosystems, and Infectious Diseases. National Research Council. 2001. Under the Weather: Climate, Ecosystems, and Infectious Disease. Washington, DC: The National Academies Press. doi: 10.17226/10025).

The World Health Organization (WHO) has been supporting, advocating, and guiding Member States to manage and address the impacts of climate change on human health, particularly, in the WHO South-East Asia Region that national meetings, regional meetings, and high-level conferences have been continuously conducted [2]. Indonesia, India, Nepal, Bhutan, and Bangladesh have carried out the assessment programs of human health and adaptation, accompanying the national and regional training on climate-related subjects [2]. In 2013, Nepal and Bangladesh have been started new projects adapting to climate change, focusing on sanitation and resilient water services [2], whereas Bhutan implemented a human health adaptation to climate change project that resulted in a permanent focus on climate change and human health outcomes between 2010 and 2015 [2]. The National Adaptation Programs of Action (NAPAs) have been prepared by Nepal, Bhutan, Timor-Leste, Maldives, and Bangladesh and were submitted to the secretariat of the United Nations (UN) Framework Convention on Climate Change [2]. Those countries delay submitting the NAPAs would increase their vulnerability and/or costs at a later stage compared to those submit earlier [2]. Nevertheless, all countries have developed some sort of strategy and national plan for addressing the human health risks of climate change in their countries [2].

Objectives of the Study

The objectives of this study are to identify the better understanding on the mechanisms of interaction between climate change and human infectious diseases, the scientific opinions change towards the climate change-human infectious disease associations over time and space, and the changing of the direction and shifting of certainty of research findings as the temporal and spatial scales of climate change-human infectious disease studies change.

Methods of the Study

Search Strategy and Inclusion Criteria

A comprehensive search was carried out in mainstream bibliographic databases or Medical Subject Headings, including ScienceDirect, PubMed, Scopus, and ISI Web of Science. The search was applied to the articles that were published between 2016 and 2018. Our first involved performing searches of article abstract/keywords/title using strings of ["Climate change" or "climate" and "infectious disease"]. After a first approach of search, published articles focusing on human infectious disease were retained and the information on disease type and climate change was extracted for having a crude knowledge involving their themes. Another round of publication search was conducted for adding the missing published articles that were not identified by the first round.

All keywords combinations from one disease type and climatic variable to bind the population of cases under consideration. Search string for disease groups include ["infectious disease" or "communicable disease" or "airborne" or "food borne" or "Fecal oral" or "water contact" or "zoonoses" or "vector" or "insect borne"]. The initial literature databases were further manually screened with the following rules: 1) non-human infectious disease-related articles were excluded; 2) articles that did not report a human health outcome related to climate change were not considered, such as commentary articles, or editorial; 3) non-peer reviewed articles were not considered to be of a scholarly trustworthy validity; and 4) duplicated and non-English articles were removed. The articles were carefully selected to guarantee the literature quality, which is a trade-off for quantity.

With strict literature search and screening processes, it yielded 36 articles from 253 articles of initial literature database. Needed article information was extracted from each article by: 1) direct information including journal, title, authors, abstract, full text documents of candidate studies, publishing year; 2) spatial scale and place name of the study area; 3) study period; 4) research method used; 5) type of climatic variables studied; 6) types of infectious disease studied; and 7) the conclusions made about the impacts of climate change on human infectious disease. An overview of the information required for the present analysis that was captured by those themes was shown in the figure 3.

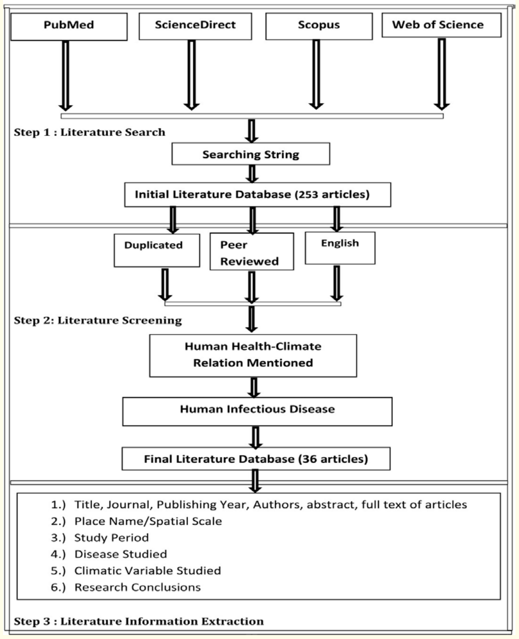

Figure 3: *Literature Search and Screening Flow.*
Y: Yes, N: No

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Hierarchical classification system for infectious diseases and climatic variables

Climatic terms and wide range of infectious disease can cause potential statistical bias due to insufficient cases for a certain infectious disease and climate type accompanying the difficulties in result interpretation. Thus, broad categories in the database should be merged into several concise classes based on their similar functional characteristics. Nevertheless, no perfect method can build either climate classification system or an infectious disease. Because of the influencing on the contact patterns of human-pathogen, human-host, or human-vector, climate change can affect infectious diseases via the pathogen, host, and transmission environment, whereas transmission is likely the most sensitive component to variations of the external environment [1]. For the best categorization of the different response of infectious disease to climate change, the authors modified the Webber's infectious disease classification system (2005), that is built upon the means of transmission. Inclusion of the five broad classes were: 1) airborne (transmitted by airborne routes); 2) insect-borne (transmitted by flying vectors); 3) ectoparasite zoonoses (diseases with both humans and animals involved and transmitted by non-flying vectors, such as lice and fleas); 4) fecal-oral (transmitted by person-to-person contact via water, food or directly to the mouth); and 5) domestic and synanthropic zoonoses (infections caused by the association of humans with domestic or other animals). Due to small number of cases with several dermatological infections and diseases transmitted via body fluids found in the database, the authors excluded them from the analysis. Seven groups of the climatic variables were categorized including air temperature, humidity, precipitation, climate variability, ocean, extreme events, and other.

Results

The number of climate change-human infectious disease related research articles has increased steadily after a clear detection of the influence of climate variation on marine and terrestrial pathogens [5]. The articles were examined according to different directions of climate change-human infectious disease relations to reflex how scientific opinions change overtime. Articles rated as uncertain do not allow any constant causal inference, and the outcome can be unrelated or non-linear. A positive relation implies a higher probability of disease outbreak with the increased magnitude of climate variables. The authors separated the articles by time. More diverse disease types have been investigated in recent years, compared to insect-borne diseases in more earlier years. The climate change-human infectious disease research trends express different patterns in each relation category as the following: a gradual shift from insect-borne diseases to a mixture of disease groups occurred in the positive category; the change of research foci in uncertain category was less distinct, in which airborne, insect-borne, and fecal-oral diseases were all found with high weight in some years; and an abrupt transition from airborne to insect-borne diseases was clear in the negative category.

The authors finally summarized the scientific opinions on climate change-human infectious disease relation according to disease group by examining the counts of 253 records for each disease-response pair over the past three years, 2016-2018 (Table 1). A decrease for airborne diseases was demonstrated in a number of articles with positive responses to climate change. An increase in negative responses for airborne diseases was observed. The opinions reflecting positive effects have become weaker overtime. Regarding to domestic zoonoses, few uncertain or negative relations have been discussed. An increasing trend in both positive and uncertain responses to climate change was demonstrated in fecal-oral diseases and ectoparasite zoonoses, with a few negative relations. The number of articles reporting positive responses, negative responses, and uncertain responses of insect-borne diseases to climate change has all increased, whereas the positive responses have increased the fastest.

Disease	Positive	Negative	Uncertain
Insect-borne	Increased	Increased	Increased
Fecal-oral diseases	Increased	None	Increased
Ectoparasite zoonoses	Increased	None	Increased
Airborne	Decreased	Increased	Increased
Domestic and synanthropic zoonoses	Decreased	None	None

Table 1: *Trend of disease responses to climate change over the past three years (2016-2018).*

The climate change-human infectious disease relationship is well described by the "climate-human infectious disease-method-scale" thematic network and ecological niche modeling illustrated in a web-like model, including climate variables, human disease type, methodology, and spatial-temporal scales (Figure 4 and 5). The complex interactions of climate change-human infectious disease relation with a heterogeneous level of connectivity among thematic terms are demonstrated. Both climate change and human infectious diseases outbreaks can occur at multiple temporal and spatial scales with unknown relationship regarding time and space. Insect-borne infections-related climate change studies are much faster rising compared to fecal-oral diseases in both mechanistic model-based and statistical analysis-based climate change-human infectious disease studies. Both statistical analyses and regressions are the two most commonly applied tools. Most study activities are locally and nationally conducted with study duration from inter-annual to decadal. These researches are rarely conducted beyond trans-boundary scales. Global, domestic, intra-annual, synanthropic zoonoses, and extreme events are relatively isolated compared to other terms. The tendency of generalized schematic representation of the climate-human infectious disease relationship indicates that the reliability of positive relationship is higher for most climatic variables, as the spatial extent increases, except for climate variability. At smaller scales, the negative relationships are conversely more robust and are less evident beyond the national scale. At large spatial scales, more uncertain relationships are demonstrated. While uncertain responses decreases other than humidity, the percentage of positive relationships from the intra-annual to decadal scale increases for most climatic type except for precipitation. Regarding the category of negative relationships, the tendency differs among the climatic types, with a decreasing trend in extreme events, an increasing trend in humidity, and relatively constant in the remaining variables.

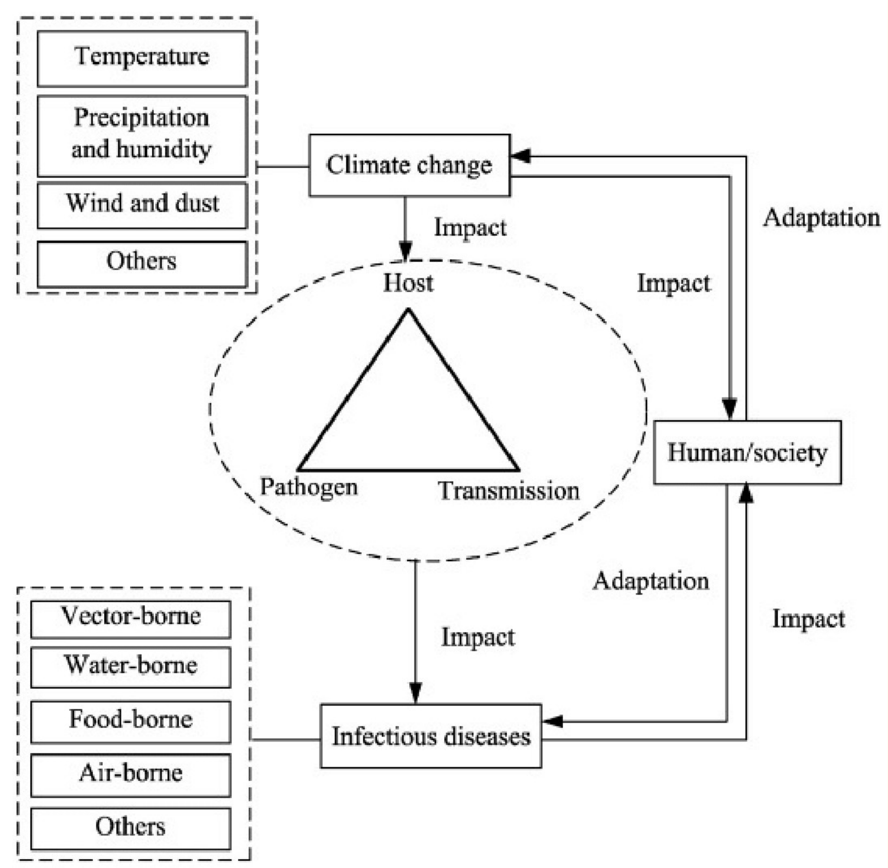

Figure 4: *Ecological Niche Modeling in Climate-Disease Network.*
Source: Wu., et al. Environmental International 86 (2016): 14-23 (Providing the Permission by the ELSEVIER/ScienceDirect).

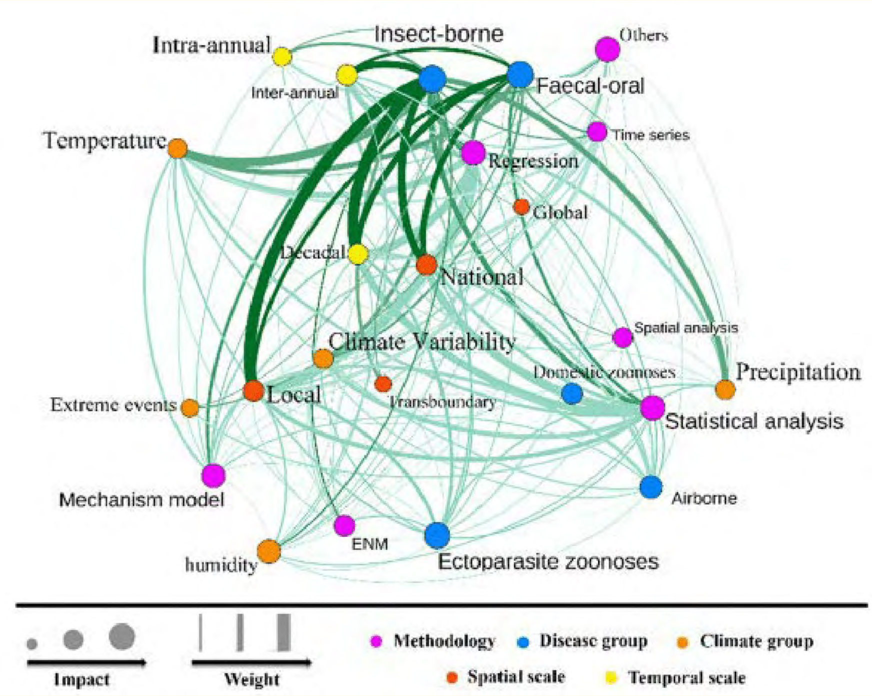

Figure 5: *Climate-Human Infectious Disease-Method-Scale Thematic Network.*
(Source: Liang., et al. Environmental International 103 (2017): 99-108 (Providing the Permission by the ELSEVIER/ScienceDirect)

Discussion

The studies by regression models in three different areas of Gansu Province, China revealed different seasonal patterns of hand, foot and mouth disease (HFMD) [6]. HFMD responded differently on different factors, and the effect was a non-linear interacted association [6]. Tianshui had no secondary peaks in seasonal components time series, other than Lanzhou and Jiuquan [6]. The primary peaks in Lanzhou and Jiuquan came 2 weeks later than those occurred in Tianshui. The secondary peaks occurred mainly in October and November, which was consistent with the studies in Hong Kong (from 2001 - 2009) [6]. They hypothesized that substantial asymptomatic infected children transmitted HFMD to their neighbors or younger siblings during summer holiday, which contributed to the second rise in September and peaked in November [6]. The difference of primary weather drivers of HFMD of two peaks is another potential reason and causes of this phenomenon [6]. By using seasonal auto-regressive integrated moving average (SARIMA) model (with local weather conditions in forecasting HFMD) and Poisson regression model combining with a distributed lag non-linear model (DLNM) (applying to examine the association between weather factors and HFMD) for studying on weather conditions and HFMD between 2009 and 2014 in Huainan, China demonstrated that temperature rise was significantly correlated to an elevated risk of HFMD [7]. A previous systematic review of literature between 1980 and 2017 on the impact of climate change on dengue fever (DF) in China by Li., et al. demonstrated that dengue fever was impacted by climate change via affecting three essential biological aspects: DF virus, vector (mosquito), and DF transmission environment [8]. The prediction of DF distribution is based on climate model, weather-based DF model, and mosquito model [8]. There is a lack of knowledge in China regarding how the spatiotemporal distribution of DF will respond to climate change comparing with some well-known research projects in the western world [8]. Two main areas for China to respond the impacts of climate change on DF distribution are promoting more advanced research on the association between extreme weather events and DF distribution and developing regional specific models for the high risk regions of DF in south China [8]. Increasing risk of DF was found in Southeast Asia and North-East Brazil due to El Niño causing drought and heat waves [9]. The El Niño Southern Oscillation (ENSO), a major, irregular, periodic global climatic phenomenon resulting from thermal inversion in the Pacific Ocean is associated with anomalous precipitation (both unusual dry and unusual wet) and temperatures (in the USA, cooler than usual in the southern states, warmer than usual in the northern states) across the continental USA [10,11]. A recent study on the effects of climate change on Hawaii state, USA revealed that Hawaii's communicable disease surveillance and response system can counteract rapidly to increases in any disease above baseline, particularly outbreaks due to exotic pathogenic organisms with rapidly redirecting resources to deal with changes [12]. Very low climate-sensitive infectious and mosquito-borne diseases were revealed in Hawaii [12]. The investigators recommend a community resilience model to increase adaptive capacity for all possible climate change impacts rather than an approach specifically focusing on communicable diseases [12]. Although ENSO effects are global, some regions considered "teleconnected" to ENSO (for example, they experience climatic anomalies linked to ENSO anomalies despite being many thousands of kilometers away), while other regions are non-teleconnected [10]. ENSO represents a useful natural experiment that may be used to infer effects of changed climatic patterns on a variety of phenomenon, such as infectious diseases, health of fisheries, agricultural productivity, vegetation abundance, and conflict [10]. Evaluation of the potential impact of ENSO on changing infectious disease dynamics across multiple regions in high-income countries is mostly focused on viral respiratory disease risk in California, plaque occurrence in New Mexico, arboviral disease risk in Australia, but remain limited [10,13]. Nevertheless, there were many attempts to evaluate ENSO effects on infectious disease occurrence in relatively small geographic areas [10]. About 75% of all recently emerging human infectious diseases, such as SARS and avian influenza originated in animals with emergence, West Nile Virus infection, and Lyme disease often associated with ecological change [13]. In California, flu transmission is lower during mild El Niño winters than in normal cold winters [14]. Plaque transmission in the Southwest and Rocky Mountain region of the USA has been related to rainfall and temperature patterns contributing to increases in wild rodent populations [13]. Rif Valley Fever outbreaks in East Africa have been associated with ENSO phenomenon [13]. West Nile Virus transmission intensity has been linked to warmer than normal summer temperatures [13]. Weather patterns, heat waves, and severe storms have been related to outbreaks of several environmentally-sensitive infectious diseases. Climate disruption, as a driver changes in the ecology of these diseases will influence both disease incidence and disruption in the future years [13]. It is so much challenging to correlate climate change directly to changes in transmission patterns of infectious diseases for several reasons. First, climate change requires disease surveillance data to be collected consistently and systematically over many years, whereas climate change takes place very slowly. Second, meaningful associations rely on multifactorial datasets composing of both weather data, collected over comparable temporal and spatial scales and disease surveillance (i.e. exposure to precipitation, soil moisture, and humidity could impact on infectious disease research, especially for respiratory and vector-borne diseases). Third, climate is the only one of a multitude of possible ecological and epidemiological factors that mediate disease risk in humans. Nevertheless, attribution is particularly challenging without knowing the relative contribution of several other factors, including the frequency of movement of infected humans, limited public health resources in some affected areas, poverty and overcrowding, and introduction of the disease into an immunologically naive human population. Research progression is being performed in understanding how weather patterns and trends related to climate change interact and work together with multiple drivers of disease emergence. Validating change in disease occurrence patterns overtime, tracking climate-sensitive disease trends, and strengthening health surveillance for the purpose of establishing baselines are the research priorities. Exposure scientists can work across disciplines to assist improve surveillance system that is needed to defined the critical correlations between climate change, weather, environmental change, and disease emergence for development of the predictive models [13].

Climate change might affect disease transmission via host susceptibility, which partly depends on defensing investment by commonly assuming that warming will decrease immune function due to expensive maintenance of cellular and humoral immune defenses and being able to collapse under thermal stress [14]. According to diverse immune responses to climate change, the immune response should follow a hump-shaped temperature response curve with decreased function at higher or lower than optimal temperatures, although too few data available for explanation [14]. Host susceptibility can respond to climate change if there are shifts in pathogenic organism distributions that expose naive host populations to new diseases [14]. Pathogenic organisms tend to be locally and temporally adapted to their co-occurring hosts, but when pathogenic organisms from a different time or different environment enter the host community, the degree to which a new host-pathogen interaction is a threat will depend on the specific genotypic relationships, the interactions with native or recent host and pathogen species, and the time lag between the host and the pathogenic organism [15]. For a key example in the Ethiopian highlands, where recent malaria epidemics have caused increased disease in previously unexposed populations [14]. Several previous studies indicated the potential for climate change to increase malaria incidence in cooler, marginal transmission environments [16]. The effects of diurnal temperature ranges (DTR; +/- 0°C, 3°C, and 4.5°C) and increasing temperature on parasite (*Plasmodium falciparum*) prevalence and intensity, and mosquito (*Anopheles stephensi* and *Anopheles gambiae*) mortality decreased overall vectorial capacity for both mosquito species [16]. Reduction of vectorial capacity by 51% to 89% can be achieved by increases of 3°C from 27°C, depending on DTR and mosquito species [16]. With increases in DTR alone had potentially malaria transmission [16]. These findings indicate that small shifts in temperature could play a significant role in malaria transmission dynamics and future warming could reduce transmission potential in existing high transmission settings [16], whereas several studies have demonstrated that rising global temperatures may result in a resurgence of malaria [17-22]. A recent study in China suggested that genetic programming (GP) method can increase the more accuracy of predicting the spatial distribution of malaria incidence, compared to those study results by generalized additive models (GAM) and linear regressions [23]. The associations between malaria incidence and the varied variables demonstrates nonlinearity and spatially differentiation [23]. A recent study in five regions of Papua New Guinea showed that malaria incidence was associated with local weather factors in most regions, but at the different lag times and in directions, whereas there were trends in relationships with global climate factors by geographical locations of the study sites [24]. A recent study on criteria for pilot prioritization of five potentially climate-sensitive vector-borne diseases (VBDs), malaria, dengue, chikungunya, West Nile virus, and Lyme was conducted in Quebec, Canada by using the PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluations) method in visual PROMETHEE software (version 1.4.0.0) (VP Solutions software, Brussels, Belgium, http://www.promethee-gaia.net) for analysis of disease performance and criteria weight of disease prioritization demonstrated that West Nile virus and Lyme were ranked 1st and 2nd respectively in the research and prevention and control domains, with this order reversed in the surveillance domain. Dengue, malaria, and chikungunya virus were ranked 3rd, 4th and 5th in the research and surveillance domains, whereas malaria in 3rd and dengue in 4th in prevention and control domains. Nevertheless, additional data as well as further discussion with stakeholders and experts is required to validate these findings [25]. Environment-transmission associations are probable to be a result of a host-parasite range shift due to climate warming and can change the distribution of VBDs, including malaria, tick-borne encephalitis virus (TBEV), and Rift Valley fever [18]. For instance, TBEV transmission is continued only when the temperatures result in synchronous feeding of larvae and nymphs [18]. Nevertheless, in TBEV transmission, projected temperature rises might desynchronized feeding and shrink the area within which TBEV persists [18]. Increasing temperature or climate warming facilitate the development of arthropod vectors that carry various parasitic organisms and parasites themselves and increasing the biting rates, range of reservoir hosts, overall survival, and parasitic transmission rates of vectors, such as mosquitoes, ticks, and tsetse flies [21]. In malaria transmission, short-term climate variations (for examples, temperature, precipitation, and humidity) or irregular climate phenomena (for example, ENSO) may also be significant factors in malaria transmission because climate conditions drive mosquito and parasite development, feeding frequency, and disease transmission [19]. A study conducted in Swaziland by using the random forest regression tree approach to generate malaria risk maps of Swaziland in 2011 based on various variables demonstrated that warmer temperatures, lower rainfall, lower elevation, and close proximity to water lead to a higher risk of malaria during low- and high-transmission seasons [19]. Regional climate indices, such as the Indian Ocean Dipole (IOD) or the ENSO have been associated with malaria transmission in Ethiopia, Kenya, and South Africa [19]. A previous study conducted in Ontario, Canada demonstrated that *Cryptosporidium* seasonality, collected from three surface water surveillance programs in surface water from two river basins (South Nation River and Grand River) demonstrates matching seasonality of human infections from *Cryptosporidium* in the study sites [26]. This study indicates significance of *Cryptosporidium* species or genotype data to determine surface water pollution sources and seasonality, including assisting more accurately quantifying human parasitic infection risks [26]. A recent study conducted in Thailand by using the Hadley Global Environment Model 2-Earth System (HadGEM2-ES) climate change model the IPCC scenarios A2a for 20150 and 2070 revealed a surprising decrease in the presence of *Opisthorchis viverrini* in the northeast region of Thailand [27]. This study model should be a useful reference to implement long-term prevention and control strategies for this parasite in Thailand [27]. A recent study on solar ultraviolet (UV) radiation in inactivation of surface water pathogens in Lake Michigan, USA suggests that widespread increases in dissolved organic matter (DOM) and consequent browning of surface waters reduce the potential for solar UV inactivation of pathogenic organisms and increase exposure to infectious diseases in humans and wildlife [28]. Climate change is accelerating the release of DOM to inland and coastal waters via increases in thawing of permafrost, precipitation, and changes in vegetation [28]. Extreme weather events are a significant factor in the spread of water-borne diseases, such as leptospirosis, cholera, and gastrointestinal infections [29]. Heavy rainfall and flooding frequently precede water-borne disease outbreaks, whereas drought can contribute to the concentration of water-borne pathogenic organisms in water bodies and rivers [29]. Climate change mostly affects diseases caused by pathogenic organisms that spend part of their lifecycle outside of the host [29]. Arthropod (insect and tick), in water and in food are the most significant routes of transmission of climate-sensitive diseases [29]. The disappearance of malaria in the UK and mainland Europe is attributed mainly to changes to the environment (drainage of marshes) and farming and currently, no areas are endemic for the disease [29]. Vector-borne diseases frequently have geographically-restricted distributions due to the effects of climate of the insects or ticks [29]. These diseases are especially likely, therefore, to spread to new areas with climate change [29]. Temperature also affects transmission of parasites via infective stage and vector production and longevity [14]. High temperatures contribute to increase use of bathing waters by the public and faster growth rates of disease-causing pathogenic organisms [29].

A recent study conducted in Cape Town, South Africa revealed that a cluster adjusted effect of an increase of 5oC in minimum and maximum temperatures result in a 40% (Incidence Risk Ratio (IRR): 1.39, 95% CI: 1.31-1.48) and 32% (IRR: 1.32, 95% CI: 1.22 - 1.41) increase in incident cases of diarrhea in children under five years old [30]. This study used a mixed effects over-dispersed Poisson regression model to evaluate possible association between temperature variability and pediatric diarrheal disease occurrences. Some study limitations exist, such as age-specific characteristics, vaccination coverage, behavior patterns, different immune system and dietary practices in children [30]. Climatic factors alone cannot explain the increases occurrence of pediatric diarrhea, provided that the diarrhea epidemic involves complex and critical interactions between extrinsic environmental factors and intrinsic dynamic [30].

Significantly, the interaction between environmental forcing and socioeconomic heterogeneity at local scales remains an open area in infectious disease dynamics, particularly for urban landscapes of the developing globe [31]. Integrating aspects of climate forcing, population density, urbanization, eating behaviors, trade, deforestation, developments in agriculture and food production, changes in medicine, the use of antimicrobials, changes in how people live, the occurrence of “shocks”, such as migration, famine and war, and level of wealth would provide benefit for establishing a quantitative and conceptual framework on urban health focusing on infectious diseases [29,31,32]. Nevertheless, an analysis of more than 300 human disease outbreaks indicated that climate and weather were infrequent causes (3%) [29]. Other drivers, such as agriculture and changes to land use (11%) are themselves affected by climate change [29]. Thus, indirect effects of climate change on disease emergence (through effects on other drivers) may also be significant [29]. Therefore, there are strong arguments to expect climate change to impact on human disease outbreaks, particularly those transmitted by vectors or in water/food, but there are practically relatively few examples for which there are documented evidences [29]. The ecological backdrop of infectious disease events is a common theme, regardless of whether the focus is human, animal, or plant health [33]. Climate change, travel, globalization, chemical pollution, and deforestation are catalysts after ecological simplification increase exposures of pathogenic organisms in certain circumstances [29,33]. An Arctic Council survey on water and sanitation services in the Arctic revealed that two main health threats were unsafe water/water-borne infections and water-washed infections [34]. For unsafe water/water-borne infections, heath threats are easily eliminated via water treatment, whereas eliminating water-washed infections requires behavior change, such as hand and body washing [34]. Few studies have empirically tracked national-level public health adaptation to climate change across multiple countries [35,36]. Following the adoption the Paris Agreement, research tracking adaptation is urgently needed to define what health adaptation looks like in practice, can be taken up across states and sectors, including ensuring policy orientated learning [35].

Conclusion

The selected literatures in this study should have an appropriate representation of the research trends although the search can difficultly be exhaustive. Due to inherently independent cases in terms of variable selection, temporal extent, and geographic coverage that contribute to difficult knowledge generalization on climate change-human infectious disease studies. With rising anxiety about human infectious diseases and growing concern about climate change, this study contributed to an attempt in identifying the existing evidence on climate change-human infectious disease relationships. Delay or failure in the adaptation human health or the alleviation of climate change may lead to poorly preparation of the communities and nations. The meta-analysis of data used in this study contributed to generating a number of relevant identifications. Several water-borne and food-borne diseases are climate-sensitive, there is a relative scarcity of published research studies on impacts of climate change upon them. Because respiratory infectious diseases can spread rapidly and cause significant health impact, the impact of climate change on them urgently required further studies. Detailed studies of the impacts of climate change on them have drawn little attention. The impact of human infectious diseases, especially emerging infectious diseases, is context-dependent. Targeted disease monitoring and surveillance at suitable spatio-temporal resolution are still essential due to changing of the significance of particular parasite species and strains. The key research gap is evaluation of the impact of climate change on human infectious diseases that are not vector-borne, including respiratory infectious diseases.

Author's Contributions

Dr. Attapon Cheepsattayakorn conducted the study framework and wrote the manuscript. Associate Professor Dr. Ruangrong Cheepsattayakorn contributed to scientific content and assistance in manuscript writing. Both authors read and approved the final version of the manuscript.

Competing Interests

The authors declare that they have no actual or potential competing financial interests.

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