

Epidemics and climate change in India

Neethi V. Rao* and Harini Nagendra

Azim Premji University, PES Campus Pixel Park, B Block Electronics City, Hosur Road, Beside Nice Road, Bengaluru 560 100, India

As the world deals with COVID-19, there is increasing attention to the threat of emerging and re-emerging infectious diseases. India is especially vulnerable to climate-induced health risks and a hotspot for infectious diseases. In this study we use a scoping review to synthesize evidence on the impact of climate on infectious diseases. We use this to uncover gaps and understand the implications for policymaking and health system preparedness. There is a strong evidence base linking climate change to disease outbreaks, both directly and indirectly. Socio-economic factors are the modifiers that determine disease severity in different populations and locations.

Keywords: Climate change, epidemics, health systems, infectious diseases, public health.

THE world is in the midst of the COVID-19 pandemic, designated as a Public Health Emergency of International Concern by the World Health Organization on 30 January 2020. This brings back memories of SARS, Ebola, avian flu and Zika virus that similarly threatened global health security. The increasing burden of infectious diseases is among the major health risks of climate change, identified over a decade ago, viz. 2007 by the Intergovernmental Panel on Climate Change (IPCC). Recent epidemics seem to be reinforcing this assessment, increasing attention to the preparedness of health systems¹. Despite the rising number and frequency, countries across the world remain poorly prepared for epidemics of infectious diseases, as revealed by the Global Health Security Index of 2019 and evidenced by the performance of even developed countries in the face of the pandemic².

In recent years, India has witnessed an increasing number of outbreaks of infectious disease across the country. Diseases like malaria, dengue, chikungunya, filariasis, kala-azar and Japanese encephalitis have been endemic in India for a long time. In addition, in recent years we have witnessed epidemics of lesser known zoonotic diseases like the Nipah fever and Kysanur forest disease. Other infectious diseases like avian influenza, West Nile fever, Congo fever and acute encephalitis have been emerging and re-emerging in the country, raising fears that India is fast becoming a hotspot for infectious diseases^{3,4}. While not all epidemics are directly attributable to climate change, the re-emergence of diseases with

increased severity and frequency in recent years makes it very likely that climate variability has played a big role in turning these diseases into epidemics.

In this article, we analyse the recent literature on infectious diseases that are linked to climate variability in India, summarizing existing knowledge and identifying gaps. The results of this scoping literature review are further examined in the context of the existing public health programme for infectious diseases in India. We seek to understand the implications of available knowledge on climate-associated epidemic disease risk in the country for health policymaking and health system preparedness.

Methods

We conducted a scoping review of the published and grey literature using keywords on 'climate change', 'climate variability' AND 'epidemics', 'infectious disease', 'communicable disease', 'vector-borne disease' AND 'India' in various combinations. We limited our search to the literature in English, published in or after 2010. We included articles that provided information on how climatic parameters impact the risk of communicable diseases in India, as well as descriptions of the public health and/policy response to these risks. We excluded articles that described associations of climate with health risks other than infectious diseases, as well as those on countries other than India, although global studies that referred to India could remain. Articles that did not explicitly mention climate as a factor in prevalence or spread of infectious diseases were not considered.

Results

After removing duplicates, and screening titles and abstracts, the full text, of 84 articles was reviewed for inclusion. Among these, 30 articles were considered relevant using the criteria specified earlier in the text and included in this analysis (Table 1). The articles highlighted various aspects related to climate-associated risk of epidemics in India that are discussed below. Based on this analysis, it is difficult to distinguish the specific additional disease risk attributable to climate change versus risks associated with general climatic variability or changes in weather. Indeed, it has been argued that climate change may not be the principal determinant of increasing infectious disease risk⁵. This article also reflects the complexity by

*For correspondence. (e-mail: neethi.rao@apu.edu.in)

Table 1. List of selected references

Reference	Description	Disease/topic	Geography
<i>Quantitative projections/analyses</i>			
25	Adaptation of global climate models to arrive at dengue risk at 2030 and 2070.	Dengue	Global
23	Comparison of two forecasting models incorporating non-stationary data on climate and epidemiology.	Malaria	Northwest India – four districts
44	Transmission model based on temperature data from 1948 to 2016	Chikungunya	India
27	Using archival data Science 1896 from Indian Plague Commission to develop a mathematical model to analyse the relationship between flea population dynamics, climate and evolutionary resistance among rats (vector).	Plague	India
45	Correlation of surveillance data from 2010 to 2013 with temperature and relative humidity to show extension of transmission window.	Malaria	Uttarakhand
24	Impact of climatic variability on dengue risk using data from January 2008 to May 2013.	Dengue	Delhi
8	Demonstrating the extrinsic incubation period for vector to demonstrate spatio-temporal variability across climatic regions in India.	Dengue	Punjab, Haryana, Gujarat and Rajasthan
46	Geography and timeframes (July to November) for malaria, dengue, JE and Chikungunya across various districts.	Vector-borne diseases (VBDs)	Odisha
11	Association of temperature, relative humidity and rainfall with cases of JE.	Japanese encephalitis (JE)	Bihar
47	Using global climate models to analyse the impact of GDP (proxy for socio-economic status) on dengue risk in 2050.	Dengue	Global
18	Integrates spatial information with human activity through remote sensing and GIS to uncover risk factors for VBD.	VBDs	Uttarakhand
48	19-year retrospective analysis to estimate incidence based on climatic parameters.	Dengue	East Delhi
17	Mosquito collection combined with molecular tools to demonstrate replacement of malarial vector species.	Malaria	Assam, Manipur, Meghalaya and Sikkim
<i>Reviews</i>			
14	Cholera and its association with climate.	Cholera	Global
49	Review of eco-epidemiology to identify factors associated with re-emergence and strategies for control.	Kysanur forest disease (KFD)	India
22	Review on endemic VBDs of India, what has been done and what needs to be done.	VBDs	India
1	Global public health threats due to emerging or reemerging infectious diseases and strategies to reduce threats.	Infectious diseases	Global
50	Literature review from 1990 to 2009 on dengue.	Dengue	Asia-Pacific
13	Epidemiology and risk factors of VL, 2010–17	Visceral leishmaniasis (VL)	North India – Bihar, Uttar Pradesh, Jharkhand, Uttarakhand, West Bengal
10	Effect of climate change on zoonoses in India.	Zoonotic diseases	India
<i>Qualitative analyses</i>			
51	Narrative analysis of how climate change, deforestation and water pollution are interacting to increase mosquito-borne diseases.	Mosquito	Nanded, Maharashtra
52	Public knowledge/perceptions on causes of dengue and vector ecology based on observational study.	Dengue	Tamil Nadu
19	Qualitative assessment of community knowledge, perception and behaviour.	Dengue	Chennai, Tamil Nadu
16	Post-disaster disease outbreak among children.	Acute viral hepatitis	Uttarakhand
12	Descriptive analysis of how climate change impacts spread and transmission risk through sand-fly.	VL	Global
<i>Policy, planning and practice</i>			
35	Using climate vulnerability as indicator for health planning illustrated using Bihar flood mortality data of 2016.	Climate vulnerability indicator	Bihar
34	Public health research directions.	Public health research	India
9	Implications of climate change associated risks for health providers.	Health providers	India
39	Descriptive analysis of malaria control efforts in Odisha.	Malaria Programme	Odisha
53	Preparedness of health system to heat, floods and cyclones analysed using mixed methods.	Health system preparedness to climate risks	West Bengal

highlighting the role of socio-economic, ecological and health system factors that influence epidemic risk associated with climatic parameters.

We first examine the nature of the risks posed by climate change, and how climatic parameters and variability might lead to infectious disease outbreaks. As we next discuss, the literature clearly demonstrates that socio-economic factors are key modulators of climate-associated risks. We then summarize the available projections of infectious disease incidence and progression based on models of climatic variability in India, and reflect on their utility for health policymaking and health system preparedness.

Climate influences the spread of infectious diseases

Climate directly influences infectious diseases by affecting the geographic spread and transmission dynamics of disease vectors. Additionally, climate change can lead to epidemics indirectly, by increasing the frequency of extreme natural events or through interaction with other structural factors.

Temperature, rainfall and humidity are climatic factors known to considerably affect vector populations and associated disease transmission dynamics⁶. Temperature influences developmental rates, mortality and reproductive behaviour of mosquitoes. Precipitation provides the habitat for its larvae and pupae. Thus, all mosquito-borne diseases will be impacted by climate change. The 2007 assessment of IPCC cautioned that up to 1.5–2.5 billion additional people will be exposed to dengue infection worldwide during the 2080s, due to climate change⁷. Temperature is known to affect the survival of *Aedes* mosquitoes that transmit dengue and chikungunya. Epidemics of dengue have become increasingly more frequent in India. The number of dengue cases during 2010–14 was more than 2.5 times that reported during 1998–2009 (ref. 8).

Temperature and humidity also influence populations of rodents, fleas and ticks, which are involved in the transmission of diseases like plague, Lyme disease, Crimean–Congo haemorrhagic fever and typhus^{9,10}. Rainfall and relative humidity were found to be positively correlated with the incidence of Japanese encephalitis in Bihar¹¹. Temperature can influence the biting rate of sandflies affecting the spread of leishmaniasis, which is a protozoan disease transmitted by these insects^{10,12,13}. The causative agent of cholera – *Vibrio cholera* has been shown to be sensitive to fluctuations in rainfall and temperature, influencing the transmission of this disease in countries like India, where a large section of this population relies on untreated water¹⁴.

The probability of extreme weather events such as flash floods, extreme heat waves, cyclones, etc. is also greatly increased due to climate change. In addition to

causing deaths and diseases directly, these events are often followed by outbreaks of infectious diseases. The 26 July 2005 floods claimed over 1000 lives in Mumbai. In addition it triggered outbreaks of diseases like dengue, leptospirosis and cerebral malaria¹⁵. After the 2013 floods in Uttarakhand, high prevalence of hepatitis A among children due to contaminated water was reported¹⁶.

Climate change can also interact with other ecological or human factors to increase risk of epidemics. Indirect effects can include human migration and land-use changes that result in fragmentation or destruction of natural habitats. At least 60% of the emerging infectious diseases has been zoonotic; in other words, transferred from animals to humans³. As climate change and human activity interact to cause biodiversity loss, pathogens that are most resilient to ecosystem disturbances dominate. A study from four North East states of India demonstrated the replacement of one species of *Anopheles* as the predominant malarial vector with another due to deforestation and land-use change¹⁷. This vector replacement is likely influencing the success of the malaria control programme and further reduction in disease prevalence in these regions may depend on modified vector control strategies.

Socio-economic factors resulting in epidemics

In addition to climate-related factors, the distribution and severity of infectious diseases are influenced by social and demographic factors¹⁸. Population density, urbanization, housing type, water supply, sewage and waste management systems, land use and irrigation systems, access and utilization of public health services are all important factors in the spread and resurgence of infectious diseases⁹. For example, the *Aedes* mosquito which transmits dengue and chikungunya, breeds in stagnant water. Poor urban areas with lack of dependable piped water tend to store water in unprotected container that serves as a breeding grounds for mosquitoes.

Socio-economic factors can also lead to the dispersion or loss of local knowledge among indigenous communities, that helps prevent the escalation of outbreaks into epidemics. The recovery of communities from epidemics and disasters as well as preparedness for future outbreaks are greatly influenced by their socio-economic safety nets^{19,20}.

Internal migration of populations and urbanization may lead to movement of vector reservoirs from endemic to newer areas. Chikungunya had disappeared from India till it reappeared in 2005 and has spread to epidemic proportions due to the movement of people²¹. Similarly, kala azar which is transmitted by sandfly was largely restricted to Bihar and West Bengal, but has recently begun flaring up in Himachal Pradesh and Uttarakhand due to increased deforestation^{13,22}.

Using longitudinal data for projections of epidemic patterns

The move from drawing health linkages due to climate variability to being able to predict future scenarios requires high-quality data on health-related parameters, in addition to meteorological parameters⁶. Further, any forecasting models need to be specific to climatic zones within India instead of a standard country-wide model, since the incidence and severity of diseases may vary across states or regions⁸.

Long-term data on disease incidence have been combined with climate information to project changes in the patterns of infectious diseases such as malaria, dengue, chikungunya and plague^{6,23–27}.

Based on longitudinal data, malaria epidemics are predicted to shift from traditionally endemic regions of central India to the southwestern states. Transmission windows are also likely to expand in the northern states, making them more prone to malaria epidemics than before. Thus malaria will spread to new regions with increased virulence even as public health efforts to contain the disease have been successful in traditionally endemic states²².

Mean temperature data from 1948 to 2016 have been similarly used to show that the regions of environmental suitability for chikungunya have been expanding to parts of North and NE India, which typically have low temperatures²⁶.

Discussion

India's National Action Plan on Climate Change (NAPCC) recognizes the risk to human health due to climate change with a mission on health. Among the key interventions proposed under this mission is a disease-specific database to aid in the development of effective prevention strategies, improved epidemiological understanding and prediction. Proposed strategies include the creation of risk maps for climate-sensitive vector-borne diseases, and the use of technology to expand health access and disease surveillance. Synergies with other sectors of climate action, including water, agriculture and energy are especially emphasized with a view to addressing the ecological determinants of health.

An Environmental Health Cell within the Health Departments along with an Inter-Departmental Task Force are the institutional mechanisms to carry out the actions envisaged under the National Action Plan for Climate Change and Human Health (NAPCCH). However, the NAPCCH is yet to be formally adopted or supported with dedicated budgetary allocations, raising questions on its implementation. A new National Mission on Biodiversity and Human Health has been approved by the Prime Minister's Science, Technology and Innovation

Advisory Council, that aims to bring together experts in human health, animal health and the environment to prevent and manage zoonotic diseases²⁸. Successful implementation of such a programme will undoubtedly be critical in preventing the next COVID-like epidemic.

State governments have also drafted climate change adaptation plans for their health sector, either as separate documents (e.g. Chhattisgarh) or more commonly as a part of their overall climate change action plans (e.g. Bihar, Madhya Pradesh, Kerala, etc.). In the absence of climate-specific financial resources, most states have sought to leverage existing infrastructure and programmes of surveillance and research to manage climate-associated health risks.

Thus, the results of this scoping literature review need to be examined in the context of the existing public health programme for infectious diseases in India. This analysis has revealed significant gaps in research, policy and practice in the face of the climate challenge. Past epidemics may offer important lessons on improving our preparedness to the increased risk of epidemics.

Gaps in research on climate-associated epidemic risk

Research on understanding the role of climate variability in the prevalence and severity of infectious diseases is still at relatively early stages in India. Despite several methodological approaches used in analysing climatic associations with infectious diseases, the relative contribution of climate and therefore the centrality of climate change in increasing risk of epidemics in India are still unclear.

Despite repeated references to socio-economic factors influencing community behaviour and vulnerability¹, the literature is relatively sparse on research examining the effects of socio-economic parameters in climate resilience. There are no studies that empirically capture the feedback loops between climatic factors and the social, economic and political aspects associated with epidemics in India.

Progress has been made on developing early warning systems, but only for a few diseases such as malaria – even these are subject to updation based on availability of new data. This is not surprising, since modelling studies tend to require long temporal records of diseases, and therefore can only project changes in the burden of known diseases rather than predicting emergence of new ones.

The level of complexity arising out of population dynamics interacting with climate variations affects the accuracy and timeliness of any predictions. Regardless, there are important lessons to be drawn from the available projections of diseases like malaria, dengue and chikungunya^{26,29,30}. The most important lesson is clearly that

the range and severity of infectious diseases has already been affected by climate variability, to the extent that old assumptions about endemic regions within India no longer apply.

Policymakers need to account for the relatively short timescales and large magnitude of projected health impacts in their priority-setting processes. Long-term longitudinal surveillance of pathogens and hosts are required in conjunction, to mount an effective public health response. In addition, modifiable behaviours or risk factors in humans need to be identified to design risk reduction practices and behaviour change communication. Data and information should be made available in public registries of diseases for research and awareness.

In addition to surveillance of vector dynamics and transmission patterns, more qualitative and applied health systems research needs to be supported on the implementation of interventions, their cost-effectiveness, vulnerability assessments of communities, policy evaluations and decision-support systems, especially at sub-national levels. Expansion of the research base and institutionalizing mechanisms to incorporate evidence in policymaking is urgent, and essential to anticipate risks and proactively manage them.

Public health response and its lacunae

India's public health system has long emphasized surveillance and control of epidemic outbreaks. However, there are clear weaknesses in the public health system even under normal conditions that are especially egregious during epidemics.

The current programme for vector-borne diseases is the National Vector Borne Disease Control Programme (NVBDCP), which focuses on malaria, dengue, chikungunya, lymphatic leishmaniasis, Japanese encephalitis and kala azar. Surveillance data along with information of outbreaks in each district are collected and maintained under the Integrated Disease Surveillance Project (IDSP), which is coordinated with a rapid response team to manage these outbreaks. A network of epidemiologists, microbiologists and entomologists in referral laboratories has also been established up under the IDSP. The National Centre for Disease Control (NCDC) houses the IDSP, and is tasked with consistently enhancing the capabilities for surveillance and rapid response for communicable diseases. Further, the International Health Regulations (IHR) provide an instrument for the exchange of information and expertise on public health risks across international borders.

Research institutions led by the Indian Council of Medical Research (ICMR), Department of Biotechnology, Council of Scientific and Industrial Research and Department of Science and Technology assist in the development of protocols for surveillance, diagnostic

development and testing, drug development, clinical trials, etc. to augment our long-term capabilities in epidemic control. However, for a country the size of India, budgetary allocations for health research as well as health services remain inadequate.

Despite many successes, responses to communicable disease spread have traditionally been through vertical disease control efforts. Diseases that are not covered by control programmes are completely neglected. For example, while disease surveillance has improved for childhood diarrhoea, there is no systematic surveillance for water-borne diseases in general. Similarly, there are much less data and poor preparedness for emerging zoonotic diseases outside of traditionally endemic regions.

Even for diseases covered by vertical programmes, there are emerging barriers to continued success. The National Malaria Eradication Programme of the Government of India was launched in the 1950s, and has brought down disease incidence in large parts of the country through effective surveillance and improved access to artemisinin-based combination therapy³¹. However, the pest-control methods used to deal with vector, such as spraying of insecticides are themselves health risks by virtue of their toxicity and non-specificity of targets. In addition, long-term use of these pest-control strategies has led to the development of insecticide resistance, limiting their usefulness in the future. There is already a visible need for higher dosages and more frequent applications of insecticides, increasing the risk to human health from these synthetic chemicals. Current public health programmes thus face difficult challenges of drug resistance, financial sustainability and availability of trained human resources.

Further, India's health system is uneven, presenting weaknesses in dealing with climate-related public health challenges. Different states are highly varied in their health system capacity and effectiveness in the control of infectious diseases. While the National Rural Health Mission (now National Health Mission) made substantial progress in strengthening public health in rural areas, urban areas were relatively neglected, and depend more on private hospitals that are almost entirely focused on curative treatment. There is much less public health infrastructure and investment in surveillance and monitoring in urban areas that has proved to be a liability in the COVID-19 response as well. Despite existing evidence for the links between urbanization and zoonosis³², urban health policy and planning in India have not moved to mitigate the socio-environmental accumulation of health risks in urban areas.

Health policy and planning for climate adaptation

Roy *et al.*³³ recommend a National Preventive Health Care Mission (NPHCM) under the NAPCC, emphasizing

Table 2. Recommendations for health policy, practice and research to improve resilience to climate-associated risk of infectious diseases

	Actions
Policy	Intersectoral policymaking Preventive Healthcare Mission under National Action Plan on Climate Change Dedicated public health/environmental health cadre Use of climate vulnerability indices for health planning Sustained resource allocations
Practice	Multi-stakeholder partnerships at national, state and local levels Publicly accessible databases of health and socio-economic data Integration of climate risks in existing disease surveillance Prioritization of vulnerable populations and geographies Awareness and communication to facilitate behaviour change efforts
Research	Long-term multi-disciplinary analysis integrating climate, health and socio-economic parameters Operational research on governance, policy evaluations, implementation science, etc. Synthesis of local knowledge on climate adaptation and diseases

that prevention is the most cost-effective way to minimize climate vulnerability.

Research to create a baseline understanding of region-specific demographic, social, and ecological determinants of health is required to support policy development³⁴. Health sector planning has traditionally relied on disease prevalence to determine its priorities, whereas reporting by the public health system is highly uneven across the country. Using a vulnerability index can help get around this challenge while also incorporating parameters on climate adaptation encompassing socio-economic, health and disaster vulnerabilities³⁵. Additional sources of data such as emergency medical services are needed to augment disease surveillance³⁶.

An analysis of Odisha's malaria policy additionally reinforces the need for an intersectoral approach. The comprehensive case management programme initiated by ICMR along with the Health Department, specifically addressed issues of remoteness and shortage of health workers by involving non-health workers in malaria control. Intersectoral coordination at the community and block levels for active surveillance, diagnosis and treatment enabled significant decline in cases^{37–39}.

Conclusion

This analysis based on the existing literature on linkages between climate variability and infectious diseases in India provides specific lessons for health policy, research and practice (Table 2). The concept of health-system resilience is especially useful as a yardstick to ensure that the Indian health system can absorb shocks, respond to changing disease patterns and adapt to the instability brought about by climate change. Health system resilience is made up of the following components – the constant collection of data for surveillance and preparedness, effective financial allocation with protection of public health funding, availability of resources, including trained

workforce, medicines, vaccines and supplies, and most importantly, polycentric leadership and governance⁴⁰.

Existing resources are inadequate to meet the rising pressures of climate variability on India's public health infrastructure. Given the rising number and frequency of potential epidemic risks and the ultimate objective of epidemic response, undertaking disease-specific responses is neither cost-effective nor practical. Instead, scarce public resources should be directed towards systemic efforts to augment public health surveillance and response across the board.

Socio-economic factors also exacerbate the risk among vulnerable populations, with implications for equity and corresponding policy. For example, the acute encephalitis syndrome outbreak in 2019 which led to the deaths of over 160 children in Bihar was underpinned by undernutrition and poverty⁴¹. Over the long term action needs to be oriented towards sustained efforts for improving sanitation, public investments in innovations for sewage and waste management, improved urban planning and enhancing health equity.

Poor inter-departmental coordination can lead to policies of different departments working at cross-purposes with each other. For example, stubble burning in the neighbouring agricultural states that is blamed for high levels of air pollution in Delhi, is in fact the result of water policies that have minimized the gaps between farming seasons to manage the water table⁴². This also reinforces the need for inter-sectoral coordination across this Departments of Environment, Health, Disaster Management, Urban Development, etc. pointing to a health-in-all-policies approach to policymaking.

Beyond governmental policy, climate adaptation also requires multi-stakeholder partnerships at all levels³⁹. The private sector, philanthropists, researchers and activists all need to be engaged to improve knowledge and action on climate change and its associated risks for human health. Communities and civil society can be recruited to monitor outbreaks and facilitate behaviour change efforts

that minimize transmission of infectious diseases. Managing water use and lifestyles for example, could substantially reduce risks from dengue and chikungunya despite suitable climatic conditions by preventing man-mosquito contact.

The 2015 Lancet Commission on Health and Climate Change described tackling climate change as the greatest global health opportunity of the 21st century⁴³. Building climate resilience of health is really a subset of broader strengthening of the health system. Whether or not diseases are attributable to climate change, the ultimate objective must be sustained progress towards improving human health. The good news is that the same steps that need to be taken to improve climate resilience and public health preparedness will additionally further the country's economic and social goals. Thus, investments in health systems for climate resilience should go beyond health sector budgets and encompass all aspects of public policy and discourse.

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ACKNOWLEDGEMENT. We thank Azim Premji University, Bengaluru for research funding.

Received 13 August 2020; revised accepted 24 September 2020

doi: 10.18520/cs/v119/i12/1919-1926

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