CLIMATE CHANGE AND THE EMERGENCE OF BACTERIAL ZOONOSES: A REVIEW

Sharvaree Ingle[1*], Santanu Pal[2], Tejpal C[3], Himani Ravi[4], Pokyem Ering[5], Sneha Naitam[6], Sumit Kamble[7], Gayatri Takekar[8]

[1]Indian Veterinary Research Institute, Division of Bacteriology and Mycology

[8]Mumbai Veterinary College, Department of Veterinary Public Health

Corresponding author email: ingle.sharvaree@gmail.com

DOI: https://doi.org/10.5281/zenodo.16356093

INTRODUCTION

Zoonotic diseases are at the nexus of climate change, alterations in ecosystems, and human and animal health. They have been emerging and re-emerging at an alarming rate due to unprecedented levels of warming instigated by deforestation, land shifts, habitat destruction, droughts, ocean acidification, and changes in the biological characteristics of pathogens and vectors, such as survival, virulence, and reproduction. Biodiversity decline from ecosystem destruction increases zoonotic spread.

Bacterial zoonoses seem to take a backseat to viral zoonoses at every aspect of research, social awareness, and policy formulation. It's about time that they be given equal, if not more, standing to avoid being blindsided and device timely interventions. The health of people living in low-income and middle-income countries (LMICs) will be disproportionately affected as they have vulnerable health-care systems with scant resources and a high burden of endemic infectious diseases. In the face of this grim picture, there are rays of hope, such as the increased individual commitment to mitigate climate change, increased media coverage, and the engagement of policy makers at high level meetings.

For the future, ecological knowledge will be a focal point in guiding both short-term and long-term health policy decisions. Models that can inform us of specific zoonotic hazards weeks or months in advance will be pivotal for supporting timely prevention strategies and health planning. In the short term, disease surveillance in areas with increased climate change will be crucial for launching an effective response to novel and emerging zoonoses ("Twin threats: Climate change and zoonoses," *The Lancet*, 2022).

Scientists have a huge part to play as their research efforts can guide policy makers to assist LMICs, not just in building capacity to lower risk and promoting health care, but by replenishing and innovating available drugs, vaccines, and technologies.

CLIMATE CHANGE

Climate change refers to long-term shifts in temperatures and weather patterns. Such shifts can be natural, due to changes in the sun's activity or large volcanic eruptions. But since the 1800s, human activities have been the main driver of climate change, primarily due to the burning of fossil fuels and intensification of animal agriculture. These activities generate greenhouse gas emissions (GHGs) that wrap the Earth like a blanket, trapping the sun's heat and raising temperatures.

"Climate change" and "global warming" are often used interchangeably but have distinct meanings. Global warming is the long-term heating of Earth's surface observed since the pre-industrial period (between 1850 and 1900) due to human activities (NASA, 2020).

The average temperature of the Earth's surface is now about 1.2°C warmer than it was in the late 1800s (before the industrial revolution) and warmer than at any time in the last 100,000 years.

In a series of UN reports, thousands of scientists and government reviewers agreed that limiting global temperature rise to no more than 1.5°C would help us avoid the worst climate impacts and maintain a liveable climate. Yet policies currently in place point to a 3°C temperature rise by the end of the century. The seven biggest emitters alone accounted for about half of all global greenhouse gas emissions in 2020. These are China, USA, India, the European Union, Indonesia, the Russian Federation, and Brazil (United Nations, 2020).

Effects of climate change are well documented and these changes include an overall warming trend, changes to precipitation patterns, and more extreme weather. Surface air temperatures over land have also increased at about twice the rate they do over the ocean, causing intense heat waves. These temperatures would stabilize if greenhouse gas emissions were brought under control. Ice sheets and oceans absorb the vast majority of excess heat in the atmosphere, delaying effects there but causing them to accelerate and then continue after surface temperatures stabilize. Sea level rise is a particular long-term concern as a result. The ocean is also acidifying as it absorbs carbon dioxide from the atmosphere (Doney *et al.*, 2020).

GREENHOUSE GAS EMISSIONS

GHGs mediate the balance between incoming solar radiation and outgoing infrared radiation; thus, their excess in the atmosphere causes warming.

Compounded with an increased capacity of the air to hold water, warming accelerates soil water evaporation, leading to drought in places that are commonly dry; excess drought can lead to heatwaves
when heat transfer from water evaporation ceases. Drought and heatwaves ripen the conditions for wildfires.

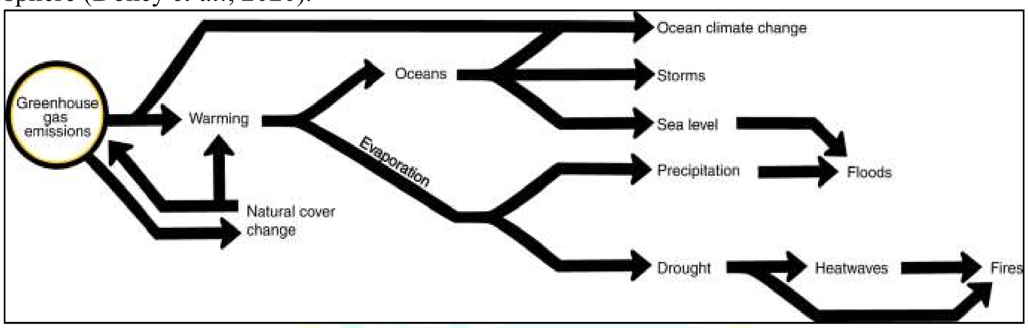

Fig.1 Consequences of greenhouse gas emissions (Mora *et al.*, 2021)

In moist places, the quick replenishment of evaporation strengthens precipitation, which is prone to cause floods as rain falls on saturated soils. Warming of the oceans enhances evaporation and wind speeds, intensifying downpours and the strength of storms, whose surges can be aggravated by sea level rise, which in turn can aggravate the impacts of floods.

Uptake of CO_2 in the oceans causes ocean acidification, whereas changes in ocean circulation and warming reduces oxygen concentration in seawater; these changes are referred to as ocean climate change.

LAND

Floods

Due to an increase in heavy rainfall events, floods are likely to become more severe when they do occur. Climate change leaves soils drier in some areas, so they may absorb rainfall more quickly. This leads to less flooding. Dry soils can also become harder. In this case heavy rainfall runs off into rivers and lakes. This increases risks of flooding (IPCC, 2021).

Droughts

Warming over land increases the severity and frequency of droughts around much of the world. Without climate change mitigation, around one third of land areas are likely to experience moderate or more severe drought by 2100 (IPCC, 2020). Several impacts make their impacts worse: these include increased water demand, population growth and urban expansion in many areas.

Wildfires

Climate change increases evapotranspiration. This can cause vegetation and soils to dry out. When a fire starts in an area with very dry vegetation, it can spread rapidly. Higher temperatures can also lengthen the fire season. This is the time of year in which severe wildfires are most likely, particularly in regions where snow is disappearing (Dunne, 2020). The carbon released from wildfires adds to carbon dioxide in Earth's atmosphere and therefore contributes to the greenhouse effect.

OCEAN

The rising temperature contributes to a rise in sea levels due to melting ice sheets. Other effects on oceans include sea ice decline, reducing pH values and oxygen levels, as well as increased ocean stratification. Oceans have taken up almost 90% of the excess heat accumulated on Earth due to global warming (von Schuckmann *et* *al.*, 2023). It also absorbs some of the extra carbon dioxide that is in the atmosphere. This causes the pH value of the seawater to drop. Scientists estimate that the ocean absorbs about 25% of all human-caused CO_2 emissions (Doney *et al.*, 2020).

The various layers of the oceans have different temperatures. For example, the water is colder towards the bottom of the ocean. This temperature stratification will increase as the ocean surface warms due to rising air temperatures (Bindoff *et al.*, 2019). Warmer water cannot contain the same amount of oxygen as cold water. This results in a decrease of nutrients for fish in the upper ocean layers. These changes also reduce the ocean's capacity to store carbon (Freedman, 2020).

Glaciers and ice sheets

Since the beginning of the twentieth century, there has been a widespread retreat of glaciers. Those glaciers that are not associated with the polar ice sheets lost around 8% of their mass between 1971 and 2019 (IPCC, 2021).

The melting of the Greenland and West Antarctic ice sheets will continue to contribute to sea level rise over long time-scales. Sustained warming between 1 °C (1.8 °F) (low confidence) and 4 °C (7.2 °F) (medium confidence) would lead to a complete loss of the ice sheet. This would contribute 7 m (23 ft) to sea levels globally. When ice melts on top of the ice sheet, the elevation drops. Air temperature is higher at lower altitudes, so this promotes further melting (IPCC, 2018). Thus, the ice loss could become irreversible.

Permafrost thawing

Permafrost thaw makes the ground weaker and unstable. The thaw can seriously damage human infrastructure in permafrost areas such as railways, settlements and pipelines (The global cryosphere past, present and future, second edition, 2021). Thawing soil can also release methane and CO_2 from decomposing microbes. This can generate a strong feedback loop to global warming (Koven *et al*., 2012) (Armstrong *et al*., 2022). Some scientists believe that carbon storage in permafrost globally is approximately 1600 gigatons. This is twice the atmospheric pool (United Nations Environment, 2008).

WILDLIFE AND NATURE

Climate change is a major driver of biodiversity loss in different land types. These include cool conifer forests, savannas, mediterranean-climate systems, tropical forests, and the Arctic tundra (IPCC, 2007). At 1.2 °C (2.2 °F) of warming, some ecosystems are threatened by mass die-offs of trees and from heatwaves. At 2 °C (3.6 °F) of warming, around 10% of species on land would become critically endangered (IPCC Sixth Assessment Report).

Rainfall on the Amazon rainforest is recycled when it evaporates back into the atmosphere instead of running off away from the rainforest. This water is essential for sustaining the rainforest. Due to deforestation the rainforest is losing this ability.

The higher frequency of droughts in the first two decades of the 21st century and other data signal that a tipping point from rainforest to savanna might be close. A 2019 study concluded that this ecosystem could begin a 50-year-long collapse to a savanna around 2021 (Lovejoy *et al.*, 2019) (Cooper *et al*., 2020).

HUMAN SETTLEMENT

Displacement and migration

Climate change affects displacement in several ways. More frequent and severe weather-related disasters may increase involuntary displacement. Slow-onset disasters such as droughts and heat are more likely to cause long-term migration than weather disasters like floods. Migration due to desertification and reduced soil fertility is typically from rural areas in developing countries to towns and cities (World Bank Publications, 2011).

According to the Internal Displacement Monitoring Centre, extreme weather events displaced approximately 30 million people in 2020. In 2018, the World Bank estimated that climate change will cause internal migration of between 31 and 143 million people by 2050. This would be as they escape crop failures, water scarcity, and sea level rise.

Social impact

Climate change disproportionally affects poor people in low-income communities and developing countries around the world. Those in poverty have a higher chance of experiencing the ill-effects of climate change, due to their increased exposure and vulnerability (Rayner *et al*., 2001). A 2020 World Bank paper estimated that between 32 million to 132 million additional people will be pushed into extreme poverty by 2030 due to climate change.

Indigenous communities tend to rely more on the environment for food and other necessities. This makes them more vulnerable to disturbances in ecosystems (IPCC, 2022). They generally have bigger economic disadvantages than non-indigenous communities across the globe due to inadequate access to education and jobs.

Climate change also increases gender inequality by reduces women's ability to be financially independent, and has an overall negative impact on the social and political rights of women (Goli *et al*., 2020). This is especially the case in economies that are heavily based on agriculture (Eastin, 2018).

Food & water security

Higher temperatures and altered precipitation and transpiration regimes are also factors. Increased frequency of extreme events. Droughts result in crop failures and the loss of pasture for livestock (Ding *et al*., 2011). Loss and poor growth of livestock cause milk yield and meat production to decrease. The rate of soil erosion is 10–20 times higher than the rate of soil accumulation in agricultural areas that use no-till farming.

Climate change is projected to negatively affect all four pillars of food security: It will affect how much food is available, how accessible it will be through prices, quality of food, and how stable the food system will be (IPCC, 2019). Droughts reduce the amount of freshwater available while heavy precipitation and flooding impact the quality of water. Higher temperatures also directly degrade water quality because warm water contains less oxygen (IPCC, 2022).

Between 1.5 and 2.5 billion people live in areas with regular water security issues. If global warming reaches 4 °C (7.2 °F), water insecurity would affect about twice as many people (IPCC, 2022). Water resources are likely to decrease in most dry subtropical regions and mid-latitudes. In the arid regions of India, China, the US and Africa dry spells and drought are already affecting water availability.

HOW DOES CLIMATE CHANGE AFFECT EMERGENCE OF BACTERIAL ZOONOSES?

An emerging disease is a disease that "has either appeared and affected a population for the first time, or has existed previously but is rapidly spreading, either in terms of morbidity or to new geographical areas." (Filho *et al*., 2022).

Approximately three-quarters of infectious diseases are expected to be impacted by climate change (Nel *et al*., 2022), and more than 60% of emerging infectious diseases (EIDs) will be zoonotic (Taylor *et al*., 2001). Vector-borne and water-borne diseases are the most likely to be affected, followed by illnesses spread by aerosol, fomites, and food.

Vector survival and geographical ranges

Warmer winters allow midges, ticks and some mosquito species to expand their geographical ranges northwards, and increased temperatures and high frequencies of droughts in the tropics are reducing the ranges of some vectors, like tsetse flies.

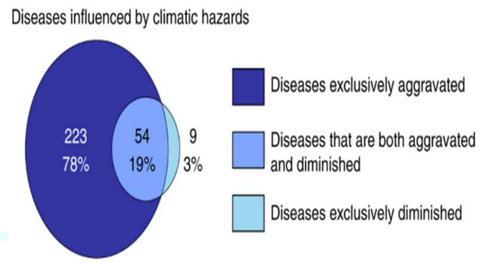

Fig.2. Diseases influenced by climatic hazards (Taylor *et al*., 2001).

Vectors whose geographical ranges have expanded northwards because of global warming include *Ixodes ricinus* which transmits tickborne encephalitis and Lyme disease (borreliosis) (Gray *et al*., 2009). The northern limit of *I. ricinus* has shifted northwards from about 61 to 66°N since temperature changes were noticed from the 1980s due to the shortening in the number of degree days required for the development of the vector. A further rise in temperature in areas that already experience high temperatures increases the likelihood of reduction in the vector geographical ranges due to desiccation.

LONGER AND MORE FREQUENT DROUGHTS

IPCC, 2007 estimates that 20-30% of the world's vertebrate species are likely to be at increasing risk of extinction from climate change impacts within this century if the change in global mean temperature exceeds 1.5 – 2.5° C.

Furthermore, extreme climate events, especially droughts, cause mass mortalities of a range of domestic and wild animals that are less resistant to these events, such as cattle and buffaloes. Following the 1984-1985 and 1994-1994 droughts in East Africa, for instance, the buffalo population declined by 48.6% and 76.1%, respectively, and it took 8-9 and 18 years for these populations to recover to pre-drought levels (Dublin and Ogutu, 2015). Droughts also lead to decreased water availability, resulting in increased pathogen concentrations in the water sources, making them more accessible to crops and animals (Yusa *et al*. 2015; Wang *et al*. 2022).

MELTING OF POLAR ICE CAPS AND GLACIERS

Increased temperature is also melting permafrost, leading to the concern that the permafrost degradation will expose ancient human burial sites and result in the revival of vectors and pathogens that spread deadly infections. Bacterial pathogens may be preserved in a quiescent state in permafrost and become activated when the permafrost thaws and conditions are favourable for growth. One of the best-known examples is that of *Bacillus anthracis*. Spores, such as those from *B. anthracis*, are notoriously robust during long-term storage under freezing conditions (Wu *et al*., 2022).

In 2016, an outbreak of anthrax was reported in Siberia as a result of exposure to infected carcasses that had previously been frozen in permafrost. As the permafrost thawed, the carcasses became exposed, and anthrax spores were released. As a result, one person and over 2,000 reindeer died after ingestion of the spores. Anthrax outbreaks have also occurred when infected cattle that were buried were re-exposed after permafrost thaw (Popova *et al.*, 2016).

RISING SEA LEVELS

Rising sea temperatures melt polar ice caps and glaciers, which will lead to an increase in sea levels, thereby coastal flooding, and changes in ocean currents, among many other consequences. On the global scale, the average sea level is projected to increase by 1 m with a rate of 8 to 16 mm/year by the 2100 (Church *et al*., 2013). Higher temperatures and changing precipitation patterns caused by climate change create ideal conditions for the proliferation of many foodborne pathogens. For example, *Salmonella*, *Escherichia coli*, and *Campylobacter jejuni* are the most common food-borne pathogens that thrive in warm and humid environments (Dietrich *et al.,* 2023).

As climate change leads to an increase in global temperatures, the distribution of *Salmonella* is expected to shift towards higher latitudes and altitudes, where cooler temperatures have previously limited its growth (Akil *et al*., 2014). This means that regions that were once too cold for *Salmonella* may now be suitable for its growth, leading to an increased exposure risk for humans and animals. Increases in waterborne and foodborne diarrheal diseases have also been reported in India, Brazil, Bangladesh, Mozambique, and the USA following flooding episodes (Tirado *et al*., 2010).

The encroachment of saltwater inland increases the distribution and prevalence of marine bacteria such as *V. cholerae*. Warm water of moderate salinity is ideal for this bacterium, and so are increased temperatures and precipitation, with a subsequent reduction in salinity, resulting in an accelerated growth rate (Nel *et al*., 2022).

Outbreaks of leptospirosis associated with rainfall and flooding have been reported in diverse areas including Brazil, India, Malaysia and the United States (Lau *et al*., 2010; Zavitsanou and Babatsikou, 2008). It has been shown to infect more than 180 species of animals including domestic and wild animals such as cattle, pigs, horses, dogs, rats and other rodents. The pathogen can survive in moist environments for many months and hence flood water provides an ideal condition for the survival of the pathogen. The disease is recognised as an emerging infectious disease that is climate-sensitive and hence climate change would influence its occurrence and transmission.

GLOBAL STATUS

Over 30 new infectious agents have been detected worldwide in the last three decades; 60 per cent of these are of zoonotic origin (Dikid *et al.*, 2013). The increasing number of interactions at the animal-human interface essentially is affecting the emergence and spread of zoonoses worldwide (Magouras *et al*., 2020). Many emerging infectious diseases (EIDs) have their origin in wildlife, and this is often due to dynamic interactions between human, wildlife, and livestock populations as well as due to rapidly changing environments.

A more proactive approach, with the identification and mitigation of the risk factors that have led to the disease emergence and spread of zoonoses, is crucial to better prevent and more rapidly respond to future epidemics and reduce the global burden of EIDs.

Table 1: Predicted trends of zoonosis due to climate change

Diseases	Predicted change	Region	Reference
Tick-borne			
Lyme disease	Expansion of vector *Ixodes scapularis* north into Canada with an upsurge of 213% suitable habitat by the 2080s Shift the vector from the Southern United States into the Central United States	North America	Brownstein *et al.*, 2005
	Northward shift of the habitats of the white-footed mouse (a reservoir host) by 3° latitude by 2050	Québec, Canada	Roy-Dufresne *et al.*, 2013
	Begin disease season 0.4–0.5 weeks earlier in 2025–2040 and 0.7–1.9 weeks earlier in 2065–2080	United States	Monaghan *et al.*, 2015
	Advance the peak activity of *Ixodes scapularis* nymph and larva by 8–11 and 10–14 days, respectively, by the 2050s.	Northeastern United States	Levi *et al.*, 2015
Water-borne			
Campylobacteriosis	Increase the annual rates of reported cases with children most at-risk and the highest expects in summer (e.g., an 8.4% increase in 2040 and a 19.5% increase in 2090 in children)	New Zealand	McBride *et al.*, 2014
Leptospirosis	Outbreaks associated with increased precipitation and subsequent flooding.	Worldwide	Lau *et al.*, 2010
Food-borne			
Campylobacteriosis	Doubling of *campylobacter* cases by the end of 2080s with an additional 6000 cases per year caused only by climate changes	Northern Europe (Denmark, Finland, Norway, and Sweden)	Kuhn *et al.*, 2020
Salmonellosis	Increase of the mean annual number of temperature-related cases by ~20,000 by the 2020s in addition to increases by population changes 50% more temperature-related cases than based on population change alone by 2071–2100	Europe (Higher in UK, France, Switzerland, and the Baltic countries)	Watkiss and Hunt, 2012
Rodent-borne			
Plague	1 °C degree increase in spring temperatures may result in *a* > 50% increase in *Y. pestis* prevalence in its reservoir host	Central Asia (Kazakhstan)	Stenseth *et al.*, 2006
	Increase risk along the northern coast while lower the risk in the southern regions by 2050	California, United States	Holt *et al.*, 2009
	Geographical shift of the disease with possible northward movement by 2055 (Increased potential for disease transmission)	North America	Nakazawa *et al.*, 2007

INDIAN STATUS

Zoonotic diseases are major public health issue in several countries of the world and India is among the top geographical hotspots for such diseases (Arun K *et al.*, 2014). Poor personal hygienic practices, improper farming practices, lack of awareness, poor diagnostic facilities, under reporting system, poverty and lack of medical facilities, all this causes high burden of morbidity and mortality, particularly in infants and children living in rural parts of developing countries (Dikid *et al.*, 2013).

Emergence of new zoonotic pathogens have caused heavy toll of life in the areas where locals doesn't have natural or artificial immune response for them. High priority zoonotic diseases like Brucellosis have emerged from Haryana to Goa; Leptospirosis from Maharashtra to Punjab; Listeriosis from Maharashtra to Delhi, Jammu and Kashmir, and Tamil Nadu, whereas neglected zoonotic diseases like Scrub typhus from Himachal Pradesh to Tamil (Dhiman *et al.*, 2018). Following bacterial zoonoses are reported via Integrated Disease Surveillance Program (IDSP) (Dikid *et al.*, 2013)

- Cholera (*Vibrio cholerae* serogroup O139)
- Scrub typhus
- Plague
- Leptospirosis
- Diphtheria
- Anthrax

Scrub typhus

This vector-borne zoonoses is caused by a gram-negative bacterium Orientia *tsutsugamushi* and transmitted via the bites of larvae (chiggers) of trombiculid mites, which also act as the infectious reservoirs. They're the most common ectoparasites of rats and shrews.

D'cruz *et al.*, 2024 analyzed the association of the meteorological factors like temperature, rainfall and humidity with Scrub typhus using the 15 years of data from a tertiary care hospital in Vellore, Tamil Nadu; from the period of May 2005 to April 2020. Meteorological data was correlated with the monthly Scrub typhus cases and a regression model was used to predict the relation between disease occurrence and climate factors. They found that for an increase of 1°C in mean temperature, the monthly cases reduced by 18.8%, and for 1% increase in relative humidity, monthly cases increased by 7.6%. They noted that the rise of Scrub typhus cases is maximal 2 months post rainfall.

Seroprevalence in the community is about 30% which is comparable to endemic infections like tuberculosis in India, which has an estimated prevalence (latent tuberculosis) of 40% (Devasagayam *et al.,* 2021). Majority cases were in rural areas close to shrubs and bushes and 53.3% of cases were agricultural labourers.

Leptospirosis

India is considered a Leptospirosis hotspot. Outbreaks have been increasingly noted in many states including Andaman and Nicobar Islands. It's noteworthy that this infection causes significant mortality and morbidity despite under-reporting and under-diagnosis. A comprehensive understanding of the extent of leptospirosis burden and the diverse clinical manifestations across different regions of India remains deficient, primarily attributed to the dearth of diagnostic modalities and a lack of awareness among clinicians.

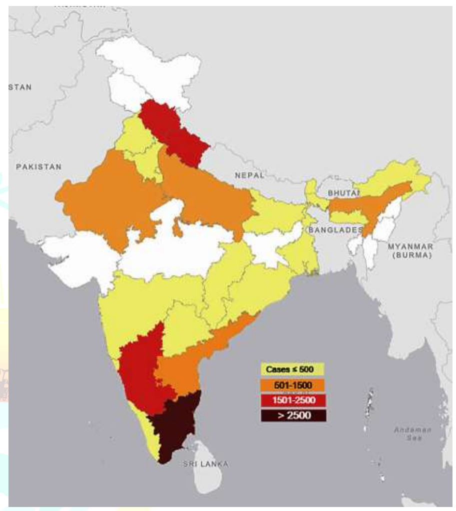

Fig. 3: Mapping the regional distribution of scrub typhus in India (Devasagayam *et al.,* 2021).

While Microscopic Agglutination Test (MAT) is deemed the gold standard, it demands substantial technical proficiency and thus, as an alternative diagnostic tool, the IgM ELISA is widely utilized for detecting antibodies against Leptospira spp. A retrospective study was planned in Madhya Pradesh, India by Manjunathachar *et al.*, 2024 to assess the prevalence of Leptospira. Between 2018 and 2019, 2617 samples from patients with hepatitis-related symptoms were collected. Of these, 518 samples tested negative for hepatitis and other tropical viral diseases, and were analyzed for Leptospira IgM using ELISA. Out of those, 68 (13.12%) tested positive for the disease, and were documented in 14 out of 24 districts in Madhya Pradesh post heavy rainfall and floods

Glanders

It is a highly contagious zoonotic illness that mostly affects horses, mules, and donkeys and is caused by the gram-negative bacillus *Burkholderia mallei.* Other animals such as dogs, cats, pigs, goats, and even humans, can contract it.

Though humans are considered unintentional hosts, the potential to be aerosolized, along with a low infectivity dosage, has rekindled interest in Glanders.
It has resurfaced as a significant health concern in Madhya Pradesh, India. A status report by Bijlwan *et al*., 2024 provides an overview of the current status and its socio-economic impact. The data available in Integrated Disease Surveillance Program (IDSP) cell of Directorate Health Services (Madhya Pradesh) was collected from the year 2017-2021 from 52 districts and 17 positive cases were reported in six districts in the year 2018.

BARRIERS TO CROSS-SECTORAL ACTION FOR ZOONOTIC DISEASE CONTROL

India provides an excellent case to examine the dynamics of One Health operationalisation for two main reasons. First, India ranks high globally in terms of the burden and diversity of endemic and emerging zoonotic diseases (Chatterjee *et al*., 2017). Secondly, there are ongoing efforts at the national and state levels towards advancing cross-sectoral action for zoonotic disease control (Abbas SS, 2018).
There is a strong policy impetus for the One Health cross-sectoral approach to address the complex challenge of zoonotic diseases, particularly in lower middle-income countries (LMICs). Yet the implementation of this approach in LMIC contexts such as India has proven challenging, due partly to the relatively limited practical guidance and understanding on how to foster and sustain cross-sector collaborations.
A study by Asaaga *et al*., 2021 aimed to identify barriers linked to the prevention and control of zoonoses:

- Disparate human and animal disease reporting/surveillance systems
- Differences in disciplinary training
- Knowledge deficits
- Inadequate infrastructure and funding allocation
- Competing department priorities
- Differences in regional capacities and working practices

National Centre for Disease Control (NCDC), Indian Council of Medical Research (ICMR) and Indian Council of Agricultural Research (ICAR): these three carry the overarching responsibility for zoonoses control and prevention within this hierarchical and sectorally defined structure.

The NCDC and ICMR are focal human health agencies under the Ministry of Health and Family Welfare (MoH&FW) promoting human well-being. By contrast, the Animal Science division of ICAR and the Department of Animal Husbandry and Dairying (AH&D) operate under the Ministries of Agriculture and Farmers Welfare (MoA&FW) and Fisheries, focussing on animal health to boost food production and safety. Likewise, the wildlife sector falls under the Ministry of Environment, Forests and Climate Change (MoEF&C) responsible for environment health and conservation-related concerns.
This fragmentation and disparate sectoral affiliations make cross-sectoral convergence difficult to achieve given the differing goals and power dynamics between ministries and departments.

As an example, the National Standing Committee on Zoonoses (NSCZ), a health-sponsored committee convened by the NCDC, is dominated by representatives from the human health and animal health sectors with little or no representation from the wildlife sector.

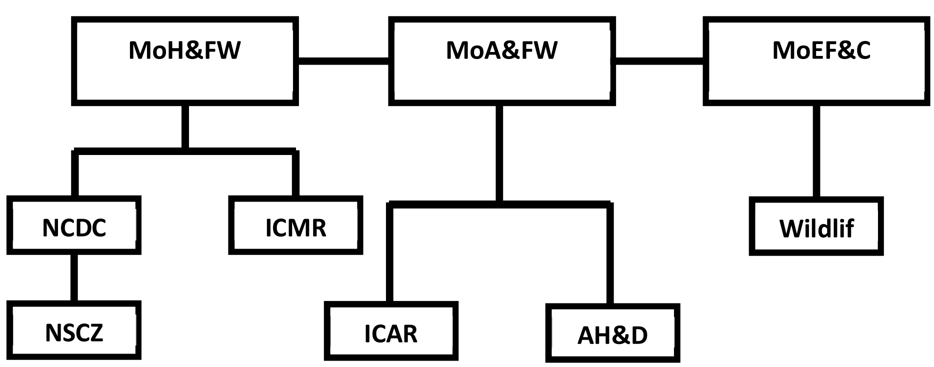

Fig. 4: Hierarchy and fragementation of governmental sectors

Low policy visibility of zoonotic diseases in India

Zoonotic diseases tend to have very limited visibility or expression in the existing policy agenda setting. Of the 29 policy documents reviewed, only 12 (41%) had a significant focus on any zoonotic diseases of relevance to India.

The National Livestock Policy (NLP) 2013 acknowledged the prevention, control and eradication of various disease conditions, including zoonoses, as critical to safeguarding livestock health but failed to spell out specific mechanisms or strategies on how this would be achieved.

National Health Policy (NHP) 2017, India's flagship health policy (which replaced the NHP 2002), despite its ambitious focus on adequate response to the changing health needs of India, the document fails to mention zoonoses as an important health concern and offers no guidelines on promoting cross-sectoral action; clarity on engagement with animal and/or forest sectors is conspicuously absent in the policy.

National Policy on Treatment of Rare Diseases (2018) underscores the importance of cross-sectoral approach to tackle rare diseases, including infectious diseases, but has not prioritised diseases and areas for research or how innovation will be supported.

National Wildlife Action Plan (2017–2031) includes wildlife health as one of its thematic areas of focus and seeks to build capacity of veterinarians in forest bearing districts to tackle zoonoses but lacks clarity on how key actions will be operationalised.

Table 2: Policy visibility of important bacterial zoonotic diseases in India:

Bacterial zoonoses	**Status**	**Hosts involved**	**Existence of national programmes**		**Notification status**	
			Human	Animal	Human	Animal
Anthrax	Endemic	Domesticated animals, humans and wildlife	×	×	×	√
Brucellosis	Endemic	Farm animals & humans	×	√	×	×
Tuberculosis	Endemic	Domesticated animals, wildlife, and humans	√	×	√	×
Leptospirosis	Re-emerging	Humans, domesticated animals, and rodents	√	×	√	×
Plague	Re-emerging	Rats, cats, and humans	√	√	√	×
Scrub typhus	Re-emerging	Rodents & humans	×	×	√	×
Salmonellosis	Re-emerging	Poultry, farm animals, and humans	×	×	×	×

√ Denotes presence of a specific (own) national programme
× Denotes absence of national programme

Different zoonotic diseases have different recognition (visibility) on the disease prioritisation scale. Inferring from this table, more policy attention seems to be on global zoonoses such as Plague, Leptospirosis, and Brucellosis, whose human and economic impacts have been well quantified. Less attention is given to endemic and re-emerging threats like Scrub typhus that affect rural marginalised populations and whose burdens and impacts are probably significantly under-estimated.

CONTROL AND MITIGATION STRATEGIES

Although low- and middle-income countries are responsible for only a small percentage of global greenhouse gas emissions, the adverse health effects associated with climate change will likely fall disproportionately on their populations. A greater understanding of the relationship between climate variability and human health in a country such as India could aid in the development of new prevention strategies and early warning systems, with implications throughout the developing world.

An integrated disease surveillance system already exists under the director general of health services; any new work on climate change and health should be linked to the already existing system. The Energy and Resources Institute (TERI) in Delhi, India, is one example of such a group linking research and action by increasing awareness within India and sharing the "developing country" perspective on climate change with the rest of the world (Bush *et al*., 2011).

Geospatial technology

Geographic information systems and spatial analysis must be further developed; this is a very effective tool when predicting prevalence, targeting resource distribution, and designing control programs for different infectious diseases. It is also useful when conducting vulnerability assessments and disseminating findings to decision makers and the public alike (Jerrett *et al*., 2010).

Environmental monitoring and surveillance

New research initiatives should focus on collecting high-quality, long-term data on climate-related health outcomes for the purpose of understanding current climate-health associations predicting future scenarios. Data on infectious zoonoses such as cholera, tuberculosis, typhoid, dysentery, and other vector-borne and water-borne diseases must be included. Surveillance of extreme weather conditions and risk indicators such as mosquito abundance or pathogen load is also necessary.

This data gathering should occur in conjunction with already existing public health programs and health centres. Such monitoring provides the information and feedback necessary to take action in response to the anticipated changes in climate and burden on the public health infrastructure.

Enhanced human and technical capacity

This is needed for new surveillance methods and analytical techniques to actually be effective for countries like India. It could take the form of public education on climate change and associated health impacts to enhance awareness and to influence lifestyle, behaviour, and individual choices. On the other end of the spectrum, developing capacity could take on a more holistic approach, such as region and city-specific climate action plans and early warning system for heat stress events, droughts, hurricanes, and floods.

Historical disease transmission and behavioural changes incorporated into future projections

Rather than focusing solely on historical data and incorporating these into mathematical models, additional emphasis is needed on how pathogens, vectors and people have behaved historically with climate change, even if these may contradict modelling predictions (Charnley *et al*., 2024). For instance, vectors require suitable habitats to increase their range with increasing temperatures.

CONCLUSION

The projected global increase in the distribution and prevalence of infectious diseases with climate change suggests a pending societal crisis. This not only threatens public health but also exacerbates existing inequalities and strains healthcare systems. Addressing this crisis requires a multifaceted approach, combining sustainable environmental practices, enhanced surveillance of zoonotic diseases, and international cooperation to mitigate climate change impacts.

More research is needed, particularly in developing countries, to accurately predict the anticipated impacts and inform effective interventions. Models that can inform us of specific zoonotic hazards months or weeks in advance will be pivotal for supporting timely prevention strategies. Along with this, investigating the impact of sustainable agriculture practices, renewable energy sources, and reduced meat & dairy consumption may contribute to a broader strategy for reducing the burden of emerging zoonoses in a changing climate.

REFERENCES

NASA, 2020. Global climate change: evidence. *NASA Global Climate Change and Global Warming: Vital Signs of the Planet*. Jet Propulsion Laboratory/National Aeronautics and Space Administration. Available at: https://climate.nasa.gov/evidence/

Mora, C., McKenzie, T., Gaw, I.M., Dean, J.M., von Hammerstein, H., Knudson, T.A., Setter, R.O., Smith, C.Z., Webster, K.M., Patz, J.A. and Franklin, E.C., 2022. Over half of known human pathogenic diseases can be aggravated by climate change. Nature Climate Change, 12(9), pp.869-875.

Leal Filho, W., Ternova, L., Parasnis, S.A., Kovaleva, M. and Nagy, G.J., 2022. Climate change and zoonoses: a review of concepts, definitions, and bibliometrics. International Journal of Environmental Research and Public Health, 19(2), p.893.

Nel, J. and Richards, L., 2022. Climate change and impact on infectious diseases. Wits Journal of Clinical Medicine, 4(3), pp.129-134.

Awad, D.A., Masoud, H.A. and Hamad, A., 2024. Climate changes and food-borne pathogens: the impact on human health and mitigation strategy. Climate Change, 177(6), pp.1-25.

Bett, B., Kiunga, P., Gachohi, J., Sindato, C., Mbotha, D., Robinson, T., Lindahl, J. and Grace, D., 2017. Effects of climate change on the occurrence and distribution of livestock diseases. Preventive Veterinary Medicine, 137, pp.119-129.

Brownstein, J.S., Holford, T.R. and Fish, D., 2005. Effect of climate change on Lyme disease risk in North America. EcoHealth, 2, pp.38-46.

Boeckmann, M. and Joyner, T.A., 2014. Old health risks in new places? An ecological niche model for *I. ricinus* tick distribution in Europe under a changing climate. Health Place, 30, pp.70-77.

Rupasinghe, R., Chomel, B.B. and Martínez-López, B., 2022. Climate change and zoonoses: A review of the current status, knowledge gaps, and future trends. Acta Tropica, 226, p.106225.

Stenseth, N.C., Samia, N.I., Viljugrein, H., Kausrud, K.L., Begon, M., Davis, S., Leirs, H., Dubyanskiy, V.M., Esper, J., Ageyev, V.S. and Klassovskiy, N.L., 2006. Plague dynamics are driven by climate variation. Proceedings of the National Academy of Sciences USA, 103(35), pp.13110-13115.

Dublin, H.T. and Ogutu, J.O., 2015. Population regulation of African buffalo in the Mara–Serengeti ecosystem. Wildlife Research, 42(5), pp.382-393.

Cite this article:

Sharvaree Ingle, Santanu Pal, Tejpal C, Himani Ravi, Pokyem Ering, Sneha Naitam, Sumit Kamble, Gayatri Takekar. (2025). Climate change and the emergence of bacterial zoonoses: a review. Vet Farm Frontier, 02(06), 36–46. https://doi.org/10.5281/zenodo.16356093