REVIEW ARTICLE

Climate Change, Emerging Infections and One Health: A Review of Climate-Resilient Epidemiological Surveillance in India

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CITATION
Gopal KM, Garg S. Climate Change, Emerging Infections and One Health: A Review of Climate-Resilient Epidemiological Surveillance in India. Journal of the Epidemiology Foundation of India. 2026;4(2):175-183.
DOI: https://doi.org/10.56450/JEFI.2026.v4i02.006
ARTICLE CYCLE
Received: 04/05/2026; Accepted: 08/06/2026; Published: 30/06/2026

Abstract
Climate change is reshaping infectious disease risks through rising temperatures, extreme rainfall, flooding, drought, shifting vector ecology, water and food insecurity, ecosystem disruption and changing human-animal-environment interactions. These risks are highly relevant for India because of its climatic diversity, monsoon dependence, dense settlements, large livestock interface, forest-fringe populations, coastal vulnerability and uneven local health-system resilience. One Health provides an appropriate framework because climate-sensitive surveillance cannot depend only on human case reporting. It must integrate animal, environmental, entomological, laboratory and climate intelligence. India already has important institutional assets, including the National Programme on Climate Change and Human Health, IDSP/IHIP, zoonoses surveillance platforms, the National One Health Mission, the VRDL network and field epidemiology training systems. However, these platforms remain only partly linked for routine climate-informed surveillance and response. This review discusses major climate-infection pathways, examines India's current preparedness architecture, identifies implementation gaps, and proposes a practical agenda for building climate-resilient epidemiological surveillance through interoperable data systems, district risk profiling, joint risk assessment, sentinel surveillance, resilient laboratories and a climate-ready workforce.

Keywords
Climate change; emerging infections; One Health; surveillance; India; health systems resilience

Introduction
Climate change is no longer only an environmental concern. It is now a direct public health concern and an important driver of infectious disease risk. Temperature, humidity and rainfall influence vector survival, biting behaviour, pathogen replication within vectors, environmental persistence of microbes and seasonality of transmission. Climate change also acts indirectly through

flooding, drought, food insecurity, displacement, ecological degradation, wildlife movement, land-use change and damage to health infrastructure. The World Health Organisation describes climate change as a fundamental threat to health, and the Intergovernmental Panel on Climate Change has concluded that several climate-sensitive vector-, food- and water-borne disease burdens are likely to increase in the absence of additional adaptation (1,2).

The scale of the challenge is large. A major global synthesis reported that climatic hazards have aggravated more than half of known human pathogenic diseases (3). Another analysis has shown that climate and land-use change can increase opportunities for cross-species viral sharing among wildlife, thereby increasing the risk of future spillover events (4). These findings are important for India because the country has climatic diversity, monsoon dependence, dense settlements, large livestock populations, forest-fringe communities, long coastlines, Himalayan ecologies and marked subnational differences in water, sanitation and health-system capacity.

India's surveillance systems have improved over time, but climate-sensitive infectious disease risks require a further shift. Traditional outbreak surveillance is often strongest at detecting human illness after transmission has already started. Climate-resilient surveillance should provide earlier warning by combining disease data with meteorological anomalies, vector and reservoir intelligence, ecological signals, laboratory evidence and local vulnerability information. This is where One Health becomes essential. One Health links human, animal and ecosystem health and provides an operational frame for prevention, detection, preparedness and response (5,6).

MATERIAL & METHODS

This is a narrative review based on peer-reviewed literature and publicly available policy and programme documents. Literature was reviewed using combinations of the terms "climate change", "infectious diseases", "emerging infections", "One Health", "India", "surveillance", "vector-borne disease", "zoonoses", "climate-resilient health systems" and "epidemiological surveillance". Priority was given to recent global evidence, India-specific studies, official WHO and IPCC documents, and Government of India sources related to climate change and health, disease surveillance, zoonoses, laboratories and One Health.

Publicly available documents from the National Centre for Disease Control, Indian Council of Medical Research, Department of Health Research and the Office of the Principal Scientific Adviser were used to describe India's institutional architecture. Sources were selected for their relevance to climate-sensitive infectious diseases, One Health surveillance, public health preparedness and implementation in India. This article does not present a systematic review or meta-analysis. It synthesises available evidence and programme information to identify operational priorities for climate-resilient epidemiological surveillance.

Climate drivers and infectious disease pathways

Climate change affects infectious disease risk through several pathways. The first pathway is altered thermal and hydrometeorological suitability. Warmer temperatures can lengthen transmission seasons, expand or shift vector distributions, and change pathogen development rates within vectors. Changed rainfall and humidity also modify breeding habitats and environmental persistence. IPCC notes that climate-sensitive vector-borne diseases are already showing changes in distribution, with projected increases in some endemic areas and in new risk areas, including cities and mountains (2). In India, earlier review evidence linked climate variability with malaria, dengue and chikungunya, and recent modelling suggests that climate change may expand the future distribution of dengue vectors in parts of the country (15,16).

The second pathway is extreme rainfall, flooding and water-system disruption. Floods can contaminate drinking water, increase faeco-oral transmission, create mosquito breeding sites, increase rodent exposure and disrupt routine preventive and curative services. WHO identifies climate stressors as amplifiers of foodborne and waterborne disease risk, while IPCC highlights increasing risks for diarrhoeal disease and cholera under changing climatic conditions (1,2). In India, floods have been linked with diarrhoeal disease, cholera, leptospirosis and vector-borne disease risks, showing how one hazard can produce multiple infectious threats at the same time (15).

The third pathway is ecological disruption and spillover. Climate change acts with land-use change, biodiversity loss, wildlife range shifts, intensified human-animal contact and altered reservoir movement. These changes can bring vectors, reservoirs, livestock and people into new contact zones. This is important for India because many high-risk interfaces are located in peri-urban settlements, forest-fringe areas, wetlands, poultry and livestock belts, and rapidly changing rural-urban ecosystems. Surveillance that focuses only on confirmed human cases may miss early ecological signals.

The fourth pathway is disease-specific climate sensitivity and lag structure. Not all infections respond to climate in the same way or within the same time period. Some infections show seasonal signals, some respond after a lag period, and some are strongly mediated by urbanisation, immunity, housing, sanitation and poverty. Recent climate-smart public health literature argues that public health monitoring, environmental monitoring and climate analytics are still too siloed, even though early evidence already shows actionable climate sensitivity for diseases such as malaria and diarrhoea (17,18). Surveillance design must therefore be disease-specific, locally calibrated and linked to decision thresholds, rather than based only on general climate awareness.

The major climate-sensitive pathways and their corresponding surveillance and preparedness actions for India are summarised in Table 1.

Table 1. Climate-sensitive pathways and corresponding surveillance and preparedness actions for India

Climate-sensitive pathway	Likely infectious disease signal	Surveillance action	Preparedness action
Rising temperatures and longer warm seasons	Longer vector season; expansion of dengue, chikungunya and malaria suitability	Link district case trends with temperature anomalies, vector indices and seasonal forecasts; update risk maps before the season	Pre-position diagnostics, vector-control materials and facility surge plans in flagged districts
Heavy rainfall, urban flooding and riverine flooding	Diarrhoeal disease, cholera-like illness, leptospirosis, post-flood fever clusters and mosquito proliferation	Trigger event-based surveillance after flood alerts; intensify water-quality, syndromic and entomological surveillance	Rapid WASH restoration, chlorination, risk communication, rodent control and mobile outbreak teams
Drought and water scarcity	Unsafe water storage, concentrated contamination, altered vector habitats and migration-linked outbreak risk	Monitor water-stress districts for diarrhoeal clusters, water trucking points and informal settlement risks.	Contingency WASH planning, community messaging on safe storage and intensified primary care outreach
Ecological disruption and shifting human-animal interfaces	Unusual animal mortality, wildlife-human contact and zoonotic spillover signals	Integrate wildlife, livestock, wetland, bird sanctuary and human surveillance; activate joint risk assessment for unusual animal events.	Joint SOPs across health, veterinary and wildlife sectors; targeted field investigation teams

Extreme heat and degraded facility functioning	Increased care-seeking, surveillance blind spots due to service overload, and reduced cold-chain/logistics reliability	Monitor facility service disruption, absenteeism and heat-related syndromes alongside infectious disease alerts.	Heat action plans for facilities and ambulances, protected power and WASH systems, and staffing contingency plans.

Why One Health is essential for climate-resilient surveillance

One Health is an integrated approach that recognises the interdependence of human, animal and ecosystem health. It seeks to optimise prevention, detection, preparedness, response and management across these domains (5). The Quadripartite One Health Joint Plan of Action frames One Health as a way to build resilient systems that can better prevent, predict, detect and respond to multidimensional threats (6). This approach becomes even more important under climate change because the drivers of emerging infections increasingly sit at the boundaries between sectors: wildlife movement, land use, farming systems, vector habitats, water systems, biodiversity loss and human mobility.

One Health matters for surveillance for four practical reasons. First, animal, vector and environmental signals may precede confirmed human clusters. Second, climate shocks often create multisectoral consequences at the same time. A flood may affect water quality, rodent exposure, vector breeding, population displacement and hospital functioning together. Third, climate-sensitive risk is highly place-based, so district interpretation needs local intelligence from health, veterinary, wildlife, environment and disaster-management sectors. Fourth, climate-informed surveillance requires a shared analytic frame that can link climate data with ecosystem and disease data.

Therefore, climate-resilient surveillance should not be designed as another isolated dashboard. It should be designed as a One Health intelligence function. This function should integrate pre-outbreak ecological and climatic signals with human case-based surveillance, laboratory confirmation and joint field response. This shift moves surveillance from reactive counting to anticipatory risk management.

India's current architecture

India has already created several institutional platforms that can support climate-resilient surveillance. Under the National Centre for Disease Control, the National Programme on Climate Change and Human Health identifies adaptation priorities for heat-related illness, vector-borne disease, extreme weather, air pollution, and green and climate-resilient health systems. Publicly available NCDC information states that the National Action Plan on Climate Change and Human Health was developed in 2019 and revised in 2021. State and district climate-health planning, district risk assessments and capacity-building activities have also been developed as part of the programme architecture (8).

India also has a digital disease surveillance backbone. The Integrated Disease Surveillance Programme, through the Integrated Health Information Platform, supports near real-time reporting and monitoring of epidemic-prone diseases and conditions. NCDC has also reported heat-related illness and death surveillance on IHIP and app-based air-pollution-related disease surveillance with air-quality incorporation and district dissemination (8,9). These examples show that India has already started linking environmental triggers with digital health surveillance, although this linkage needs to become broader and more systematic.

India has a significant One Health and zoonoses platform. The National One Health Programme for Prevention and Control of Zoonoses aims to institutionalise One Health at national, state, district, block and village levels through integrated surveillance, sentinel surveillance sites, a digital portal, advocacy and operational research. NCDC has reported state and district zoonoses committees, strengthened sentinel surveillance institutes and annual human and animal sample testing across sectors (10). At the mission level, the National One Health Mission adds a broader whole-of-government framework for integrated disease control and pandemic preparedness at the human-animal-environment interface. It includes the National Institute for One Health and a geographically distributed network of high-containment laboratories (11,12).

Laboratory and workforce assets are also important. The Department of Health Research reported that the Viral Research and Diagnostic Laboratory network had expanded to 163 laboratories by 2024 (13). NCDC's India Epidemic Intelligence Service Programme and the wider field epidemiology training platforms provide applied epidemiology capacity. The SectorConnect Field Epidemiology Programme in One Health also creates an opportunity to train district-level multisectoral professionals in integrated outbreak analytics and response (14). These assets provide the institutional spine for climate-resilient surveillance, provided they are linked more systematically.

India also has guidance on climate-resilient health systems and facilities. WHO's operational framework for climate-resilient and low-carbon health systems and NCDC's model green and climate-resilient health facilities guidebook provide a basis for linking surveillance resilience with infrastructure, energy, water, waste management, service continuity and financing (19,20). This is important because surveillance cannot function during climate shocks if facilities lose power, water, cold chain, communications, transport and staff availability.

The key Indian platforms that can support climate-resilient One Health surveillance are summarised in Box 1.

Box 1. Indian platforms for climate-resilient One Health surveillance

- **NPCCHH under NCDC:** climate-health planning, district risk assessments, heat surveillance, air-pollution-linked health monitoring and state/district action planning.
- **IDSP/IHIP:** near real-time reporting of epidemic-prone diseases and opportunity for integrating climate-triggered alerts.
- **National One Health Programme for Prevention and Control of Zoonoses:** zoonoses committees, sentinel surveillance sites, integrated digital portal and operational research.
- **National One Health Mission:** whole-of-government framework for pandemic preparedness at the human-animal-environment interface.
- **VRDL network:** laboratory backbone for diagnostic confirmation and outbreak investigation.
- **Field epidemiology training platforms:** India EIS, FETP and One Health training for district-level outbreak analytics.
- **Climate-resilient health facility guidance:** support for continuity of surveillance, diagnostics and services during heat, floods and extreme weather.

Gaps and challenges

The first major gap is interoperability. Current public architecture shows important islands of integration, such as heat surveillance, air-pollution-linked surveillance, zoonoses sentinel systems, digital case-based surveillance and laboratory expansion. However, India still lacks a routinely interoperable national layer that combines human cases, meteorology, entomology, livestock and wildlife events, environmental sampling, water-system risk and locally interpreted vulnerability. Integration exists, but it remains selective rather than systematic across major climate-sensitive infectious disease pathways.

The second gap is uneven place-based risk intelligence. Climate-sensitive infections do not respond uniformly across districts. The same climate hazard may have different epidemiological consequences depending on water systems, housing, vector ecology, animal reservoirs, sanitation and care access. Risk management often remains programme-specific and hazard-specific. Surveillance systems, therefore, need district ecological profiling, disease-specific trigger thresholds and joint pre-season reviews to convert climate data into action.

The third gap is operational linkage among frontline response, laboratories and multisectoral teams. India has meaningful assets: the VRDL network, high-containment laboratories, zoonoses sentinel structures and field epidemiology platforms. However, a uniform national pathway is still needed for escalation from climate-triggered alerts to multisectoral investigation, joint sampling, laboratory confirmation, genomic analysis, where needed and shared after-action learning.

The fourth gap is resilience of service delivery and surveillance infrastructure under climate stress. Surveillance cannot function well if facilities lose electricity, water, cold chain, data connectivity, waste management capacity, staff availability or transport access during heatwaves, floods and storms. Climate-resilient surveillance is therefore inseparable from wider health-system resilience.

The fifth gap is workforce readiness. Climate-resilient surveillance requires epidemiologists and programme managers who understand climate data, GIS interpretation, vector ecology, lag structures, event-based surveillance and One Health investigation. Many public health teams are strong in routine outbreak response, but not all are trained to interpret climate-triggered signals before outbreaks become visible.

Way forward

India should build on current programmes rather than create a new vertical climate surveillance programme. The next step should be integration. First, India should create a climate-trigger layer within IHIP. This layer can link district disease surveillance with heat, heavy rainfall, flood, cyclone and air-quality alerts. Each trigger should be linked with disease-specific watch lists, standard operating procedures and clear action thresholds.

Second, India should prepare district climate-health risk profiles. These profiles should identify urban flood zones, coastal cyclone belts, forest-fringe interfaces, drought-stressed regions, high Aedes suitability districts, wetlands, peri-urban livestock belts and other high-risk ecological interfaces. Each priority district should have a tailored surveillance and preparedness package instead of a generic national template.

Third, seasonal joint risk assessment should become routine. Pre-summer and pre-monsoon reviews should bring together health, animal husbandry, wildlife, environment, disaster management, WASH, laboratory and meteorological inputs. These reviews should not remain ad hoc. They should be part of existing One Health and climate-health governance platforms at the state and district levels.

Fourth, ecological and interface sentinel surveillance should be expanded. Existing zoonoses surveillance structures can be widened to include vector surveillance, environmental sampling, wastewater and water-quality signals where feasible, unusual animal mortality or morbidity, and interface sites such as forest-fringe settlements, wetlands, bird sanctuaries, peri-urban farms and ports. This should be treated as a surveillance function, not only as a research activity.

Fifth, referral pathways across district laboratories, VRDLs and high-containment laboratories should be standardised. Climate-triggered outbreaks need rapid confirmatory testing, clear specimen routing and surge referral protocols. These pathways should be tested before monsoon and vector-borne disease seasons.

Sixth, field epidemiology training should become climate-ready. India EIS, FETP platforms and One Health field training should include modules on climate analytics, GIS interpretation, lag structure, event-based surveillance after extreme weather, integrated outbreak investigation and risk communication. District teams should be able to interpret climate-triggered anomalies, not merely count cases after an outbreak has occurred.

Seventh, surveillance continuity should be protected through resilient facilities. District hospitals, CHCs, PHCs and laboratories in high-risk areas should prioritise power continuity, water security, cold chain, biomedical waste management, drainage, heat protection, diagnostics, transport and data reporting. Climate-resilient facilities are not only environmental investments; they are also surveillance and epidemic preparedness investments.

Finally, India should track progress through a small national accountability set. This may include trigger-to-investigation time, proportion of flagged climate events receiving joint risk assessment, laboratory turnaround time, cross-sector notification completeness, district coverage of climate-health action plans, and annual multisectoral simulation exercises. Without measurable indicators, integration will remain a good intention rather than a functioning system.

Implementation can be phased. In the short term, India can add climate-triggered alerts to IHIP, prepare district climate-health risk profiles, institutionalise pre-summer and pre-monsoon joint risk assessments, and define disease-specific alert thresholds. In the medium term, it can expand ecological and interface surveillance, standardise referral pathways across district laboratories, VRDLs and high-containment laboratories, and make field epidemiology training explicitly climate-ready. In the long term, India should build an interoperable multisectoral data architecture, mainstream predictive analytics for climate-sensitive diseases, climate-proof surveillance facilities and logistics in high-risk districts, and embed One Health climate surveillance into routine state and district planning.

Conclusion

Climate change is changing not only the burden of infectious disease but also the logic of surveillance. A system designed mainly to count human cases after transmission has started is no longer sufficient when risk is shaped upstream by weather anomalies, ecological disturbance, vector shifts, animal reservoirs, water insecurity and service disruption. WHO, IPCC and current One Health thinking all point in the same direction: infectious disease preparedness must become anticipatory, multisectoral and climate-informed (1,2,4-7,17,18).

India has enough institutional substance to make that transition. The foundations already exist in NPCCHH, IDSP/IHIP, the zoonoses programme, the National One Health Mission, the VRDL network and expanding field epidemiology capacity. The strategic task now is integration. India must link climate triggers to epidemiological action, human surveillance with animal and environmental intelligence, district risk profiling with laboratory pathways, and surveillance with resilient facilities and financing. If India can do this, it will not merely adapt to climate-sensitive infections; it will move toward a stronger, more predictive and more resilient public health architecture.

Limitation of the Study

This review is based on publicly available evidence and programme information. It does not estimate the attributable burden of climate-sensitive infections in India and does not assess the cost-effectiveness of specific surveillance interventions. Publicly available programme data do not yet allow robust national comparison of climate-trigger thresholds, cross-sector data latency, district-level quality of joint investigations, or the impact of climate-linked surveillance on outbreak outcomes. The article, therefore, focuses on institutional architecture, operational functions and implementation priorities rather than formal burden estimation.

Authors Contribution

All authors have contributed equally.

Financial Support and Sponsorship

Nil

Conflict of Interest

There are no conflicts of interest.

Acknowledgement

The authors acknowledge the growing body of work by public health, climate, veterinary, environmental and laboratory professionals that has shaped India's climate-health and One Health agenda. No unpublished data were used in this review.

Declaration Of Generative AI And AI Assisted Technologies In The Writing Process

The authors confirm that artificial intelligence (AI)-assisted technology was used to support the drafting, language refinement and editing of this manuscript, and in the development of the graphical figure. The authors critically reviewed, revised and approved the final text and figure and take full responsibility for the accuracy, integrity and originality of the work.

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