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CRITICAL PERSPECTIVES ON EXTREME HEAT IN INDIA

THE SALATA INSTITUTE
FOR CLIMATE AND SUSTAINABILITY
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Glossary of Abbreviations

AIDMI	All India Disaster Mitigation Institute
CMIP3	Coupled Model Intercomparison Project Phase 3
CMIP6	Coupled Model Intercomparison Project Phase 6
COP	Conference of the Parties
CSS	Centrally Sponsored Scheme(s)
DPI	Digital Public Infrastructure
ENSO	El Niño–Southern Oscillation
G20	Group of Twenty
GEF	Global Environment Facility
GCF	Green Climate Fund
GDP	Gross Domestic Product
HAP(s)	Heat Action Plan(s)
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
ILO	International Labour Organization
IMD	India Meteorological Department
IPCC	Intergovernmental Panel on Climate Change
IRDAI	Insurance Regulatory and Development Authority of India
IOD	Indian Ocean Dipole
LST	Land Surface Temperature
NABARD	National Bank for Agriculture and Rural Development
NCDC	National Centre for Disease Control
NDMA	National Disaster Management Authority
NPCCHH	National Programme on Climate Change and Human Health
OSHA	Occupational Safety and Health Administration
SDG(s)	Sustainable Development Goal(s)
SDMA	State Disaster Management Authority
SDRF	State Disaster Response Fund
SDMF	State Disaster Mitigation Fund
SEWA	Self-Employed Women's Association
Twb	Wet-Bulb Temperature
UHIE	Urban Heat Island Effect
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
WASH	Water, Sanitation, and Hygiene

Glossary of Definitions

Climate & Meteorology

Wet bulb temperature (Twb) — A measure of heat that accounts for both air temperature and humidity, reflecting the lowest temperature a surface can reach through evaporative cooling. It is a closer proxy for physiological heat stress than air temperature alone.

Sub-seasonal — A forecasting timescale between roughly two weeks and two months, bridging the gap between short-range weather forecasts and seasonal outlooks.

Synoptic — Large-scale atmospheric conditions, typically spanning hundreds to thousands of kilometers, that drive regional weather patterns such as heat waves and monsoon behavior.

Physiology & Health

Thermoregulation — The body's ability to maintain a stable internal temperature, primarily through sweating and increased blood flow to the skin. When environmental heat overwhelms these mechanisms, core body temperature rises, leading to heat exhaustion or heatstroke.

Heat stress — The combined burden of environmental heat, humidity, physical activity, and clothing on the body. Distinct from thermal comfort, heat stress refers to conditions where the body is gaining heat faster than it can dissipate it.

Thermal comfort — A subjective condition in which an individual is satisfied with the surrounding thermal environment, determined by air temperature, humidity, radiant heat from surrounding surfaces, air movement, clothing, and activity level.

Mean radiant temperature — The average temperature of all surfaces surrounding a person (walls, floors, ceilings, ground), weighted by how much of each surface the person "sees." It has a greater influence on how hot an occupant feels than air temperature alone.

Glossary of Definitions

Morbidity — The incidence of illness or disease in a population, as distinct from mortality (death). In this paper, used to capture non-fatal health impacts of heat exposure that are often under-recorded.

Alma-Ata Declaration — A 1978 declaration by 134 member states of the World Health Organization committing to “Health for All” through universal primary health care. Referenced in this paper as a benchmark for unfulfilled global health commitments.

Building & Design

Passive design — Building strategies that reduce indoor heat without mechanical cooling by managing how heat enters, moves through, and leaves a building. Includes orientation, material selection, ventilation, shading, and spatial configuration.

Cool roof — A roofing surface engineered to reflect more sunlight and absorb less heat than conventional materials, lowering roof surface temperature and reducing cooling loads in the building below.

Thermal retrofit — Modifications to existing buildings to improve thermal performance, such as adding insulation, reflective surfaces, improved ventilation, or shading to reduce heat gain.

Finance & Insurance

Parametric insurance — Insurance that triggers automatic payouts when a predefined measurable threshold is crossed (e.g., temperature exceeding a set level for a set duration), rather than requiring a claims process to assess actual losses.

Anticipatory finance / forecast-based financing — Financial mechanisms that release pre-authorized funds based on climate forecasts before a hazard event occurs, enabling early action such as water distribution or cooling-center activation ahead of a heat wave.

Blended finance — An approach that combines public or philanthropic capital with private investment, typically using guarantees, concessional terms, or first-loss positions to lower risk and attract commercial participation in projects that would otherwise lack a market-rate return.

BACKGROUND AND CONTEXT

Satchit Balsari

Extreme heat is the deadliest climate hazard globally, yet it remains among the least resourced in adaptation planning. The effects of extreme heat are diffuse, cumulative, and invisible in the ways that governments and financial systems currently measure damage. Nowhere is this tension more acute than in India, where over 1.4 billion people contend with exposure that extends far beyond outdoor work to include dense urban settlements, heat-retaining built environments, limited access to cooling, and uneven health system capacity. These intersecting forms of exposure—across workplaces, homes, and public infrastructure—mean that rising temperatures affect not only labor productivity but also health, habitability, and economic stability, making India a critical frontier for climate adaptation.

An estimated three-fourths of the country's workforce, roughly 380 million people, are engaged in heat-exposed labor, spanning agriculture, construction, and a wide range of informal occupations underpinning about half of India's GDP (World Bank, 2022). In the near future, the scale of exposure is set to intensify: Up to 200 million people in the country could face lethal heat conditions as early as 2030, while rising heat stress is projected to account for tens of millions of lost jobs globally (ILO, 2024). The capacity to adapt remains deeply unequal: For instance, only about 8 percent of households currently have access to air conditioning, leaving the majority of the population to cope with rising temperatures through limited or ineffective means. This raises a more fundamental set of questions about how heat is understood, measured, and acted upon across science, policy, and planning.

This white paper encompasses a range of conversations that began at a unique interdisciplinary workshop hosted in New Delhi in March 2025, *India 2047: Building a Climate-Resilient Future*, organized by Harvard's Salata Institute for Climate and Sustainability, the Lakshmi Mittal and Family South Asia Institute, and India's Ministry of Environment, Forest and Climate Change. Leading experts in climate science, public health, medicine, labor, business, agriculture, and urban planning met over three days to examine the most pressing climate-related challenges facing the subcontinent, with an emphasis on the short- and long-term impact of heat on the region's agricultural landscape, population health, habitat, and labor. The workshop's unique composition—comprising some of the world's leading climate scientists sharing space with trade-union and gig-worker organizers, or urban planners in dialogue with physicians and thermal physiologists, for example—allowed an in-depth interdisciplinary examination of questions fundamental to heat adaptation: What should India expect in the coming decades, who is most at risk, what adaptation measures are the most effective and scalable, and what should financing look like?

This white paper is not a summary of the conference proceedings. It draws instead from key questions that emerged at the conference. The white paper builds on the deliberations that began at the conference but continued amongst colleagues through ongoing collaborations, including the Climate Adaptation in South Asia research cluster at the Mittal and Salata institutes, the Scholarly Working Group on Heat and Worker Protections at the Harvard Global Health Institute, the India Climate and Health Coalition, the Community Heat Adaptation and Treatment Strategies Project, and others. The authors of this white paper contributed to shaping the agenda of the workshop but present here learnings not only from workshop participants, but colleagues across disciplines and institutions, to whom we are indebted for their time and expertise.

Perhaps most importantly, this white paper underscores the need for mainstreaming multidisciplinary teams and approaches to understanding and addressing the climate crisis. As each chapter demonstrates, both problem identification and solution design are better off when multiple stakeholders can inform each other, question disciplinary orthodoxies, and contribute to new and durable solutions. The conference and this paper include expertise from climate science, medicine, public health, urban planning, architecture, engineering, government, law, labor, and business.

In this collection, Peter Huybers first examines India's observed warming trends since 1980, explaining why northern India has warmed less than expected due to aerosol loading and irrigation—mechanisms that may weaken in the coming decades—and why historical temperature records cannot be taken at face value as a planning baseline. Next, Lucas Vargas Zeppetello considers climate implications for agriculture and cautions that despite advances in rainfall forecasting, significant limitations hinder its applicability and usability, especially over longer timescales. These challenges are further compounded while attempting to predict extreme heat spells that, like the monsoons, have the potential to disrupt crop cycles, labor productivity, and wages across large swaths of South Asia.

Robert D. Meade, Aditya Valiathan Pillai, and I posit a seemingly innocuous question—how hot is too hot? The answer is a prerequisite for planning adaptation and protection measures for human health and necessary systems, for setting thresholds for activating heat action plans (HAPs) or designing new financial instruments like parametric heat insurance. We submit that the answer is relative, varies widely, and depends on the impact and timescales of interest. While a short, intense heatwave may be detrimental to the health of the elderly who cannot get out of harm's way, sustained months-long extreme heat would impact the ability of outdoor workers to maintain usual productivity or, on longer timescales, be detrimental to aging infrastructure.

We then examine three distinct but popular adaptation strategies: cool roofs, heat action plans, and parametric heat insurance products (i.e. financial instruments that trigger wage payouts when specific temperature thresholds are crossed). These case discussions rely on experts from across urban planning, architecture, engineering, government, labor, law, medicine, and public health. They underscore how cross-disciplinary expertise can contribute to new and durable alternatives in policymaking, technology, and financing.

Rajan Rawal and Radhika Khosla urge policymakers and planners to look beyond cool roof solutions as the sole adaptation strategy for buildings, arguing instead for pervasive adoption of passive design strategies to reduce urban-scale cooling demand. They call for at-scale adoption of building materials and designs that target all three modes of heat transfer—conduction, convection, and radiation—through heat protection, modulation, and dissipation techniques. To drive adoption at scale, they call for targeted policies, market incentives, and strategies to shift societal preferences.

Millions of dollars are being invested by international institutions to support the development of heat action plans—roadmaps for cities to prepare for and respond to extreme heat events. Pillai contends that these efforts, albeit well-intentioned, remain misguided without the regulatory and financial teeth needed to enforce them. Pillai argues that HAPs are not the ultimate solution as often touted, but instead should serve as guideposts to begin the painstaking embedding of climate-responsive actions across multiple agencies and budgets.

Caroline Buckee and Owen Gow critically examine parametric heat insurance, the latest in the armamentarium of adaptation tools in which funding agencies are showing growing interest. Workers who purchase the product for heat protection are expected to receive cash payouts on extremely hot days to compensate for lost wages. In reality, given their inability to predict if payout conditions will be met on a given day, workers will not risk not working; the payout functions as hazard pay and does not protect the health of workers, as is often the articulated intent. The authors also examine the parameters used to design the product and their disconnect from the lived micro-environments of the homes and workplaces of the poor.

Rajesh Nayak and Sharon Block argue that current workforce protections fail to accommodate the actual lived experiences of workers globally. The vast majority of the Indian labor force works in the informal sector, falling outside the purview of traditionally recognized "worker protections," rendering employer-based protection measures inapplicable to nearly 90 percent of the workforce. On the other hand, part-time and gig work weaken formal protection mechanisms in industries and trades where enforcement was already challenging. In the absence of enforceability or accountability, workers end up bearing both the highest risk, through impacts on health and wages, as well as the cost of adaptation. The authors argue that protections for workers in the informal sector cannot be abandoned. Where regulation is lacking, there have been successful attempts at societal, financial, and technical innovations that have not been allowed or incentivized to scale. Ignoring the protection of these workers imperils not only their health but economic output, as growing evidence has shown.

Nitya Mohan Khemka and Bhargav Krishna ask what the health agenda for climate change should be, given that the primary-care promises of the World Health Organization's 1978 "Health for All" Alma-Ata Declaration remain unfulfilled for most of the planet. They draw attention to the foundational challenge of weak, incomplete, or inaccessible data on which the planning and preparation of health systems rely. Both meteorological and population health data are not easily accessible to the local or international research community, precluding the kind of context-aware preparedness that India's socially and spatially heterogeneous society warrants. The authors call for a three-pronged approach to bolstering the health system—expanding and strengthening human capacity; embedding climate resilience into existing programs; and improving infrastructure.

In the final chapter, Kartikeya Bhatotia, Mihir Bhatt, and Jorge Gastelumendi make a case for revamping local and global adaptation financing. They examine the limits of current international adaptation financing that fails to percolate to the communities most at risk, leaving them no choice but to adapt and bear the costs themselves. They draw attention to successful decentralized models like anticipatory financing that have vested choice in the hands of the poorest. In India, they call for integrating adaptation finance into local, state, and national fiscal frameworks, noting that heat resilience is best positioned not only as a public health concern but also as a significant macroeconomic and fiscal risk.

Extreme heat adaptation presents a frontier for innovation across policy, technology, and finance. Social protection systems can deliver direct cash transfers before or after heat events, while research and development in passive cooling, building materials, and early warning systems can position India as a global leader in exporting adaptation solutions. There is also a growing market opportunity for technology and financial innovation around heat risk—from sensor-based forecasting tools to mobile-enabled insurance platforms—creating prospects for both public welfare and private enterprise. Over the next decade, aligning this innovation with India's green industrial strategy could anchor a new "cool economy," blending adaptation goals with growth.

This collection concludes with an endnote by Tarun Khanna reflecting on the challenges of translating knowledge across domains, institutions, and society—a theme that frequently punctuated the workshop.

On behalf of my colleagues at Harvard's Mittal and Salata institutes, I would like to thank the over-180 participants who contributed to our interdisciplinary experiment in New Delhi and have continued to challenge and shape our thinking and research. In turn, I would like to thank both institutes for their support to students, faculty, and collaborators, catalyzing critical dialogues and meaningful partnerships across the proverbial academic silos. The administrative staff at the Salata and Mittal institutes have been particularly generous with their time and support to our motley crew, despite ever-shifting goalposts and timelines. Our team of rapporteurs—Neil Singh Bedi, Monica Robles Fontan, Owen Gow, Klara Kuemmerle, Yuvika Pharaswal, and Amanda Thounaojam—succinctly captured the essence of complex deliberations across six plenaries and 14 parallel sessions.

Finally, I would like to extend our gratitude to Prof. Ann-Christine Duhaime for her careful and incisive review of the manuscript, and Kartikeya Bhatotia, for his editorial and deft managerial contribution, without which neither the workshop nor this paper would have seen the light of day.

Sincerely,

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India 2047: Building a Climate-Resilient Future

1. INDIA'S HEAT CHALLENGE IS HERE AND ALREADY EVOLVING

Peter Huybers

Source: David Trilling

India is already living through substantial climate warming. Area-averaged annual anomalies in monthly maximum temperature rose by approximately 0.28°C per decade since 1980, and the mean anomaly for 2015–2024 reached 0.88°C relative to a 1980–1990 baseline—with 2025 the warmest year on record. India's average temperature rise, however, is muted compared to global land warming of approximately 1.4°C over the same period (Dhara et al., 2025). Understanding this warming gap matters for adaptation planning because the processes that have partially suppressed warming in parts of India are not guaranteed to persist.

This trend matters not just because averages are rising, but because heat extremes are increasing in frequency and becoming more consequential for health, labor, infrastructure, and food systems. The IPCC finds with high confidence that rising temperatures and more frequent hot days and heatwaves will increase heat-related mortality and put growing pressure on human well-being across Asia (Shaw et al., 2022). In India, those risks are intensified by dense urbanization, widespread outdoor labor, unequal access to cooling, and already-fragile health and water systems. While this national warming trend is clear, its spatial and seasonal expression is not uniform. Warming differs across regions, months, and times of day. In particular, winter daytime temperatures in northern India show weaker warming than the national average, and in some areas a distinct cooling trend. This heterogeneity is important because observed temperature trends over India reflect not only large-scale greenhouse forcing, but also regional aerosol loading, land-use change, and internal climate variability. As such, we cannot interpret local historical trends as direct measures of background warming alone.

The warming hole

The Indo-Gangetic Plain is among the most densely populated and agriculturally critical regions on Earth and, therefore, a particularly important case. According to temperature data from Berkeley Earth (BEST), average maximum January temperatures across northern Indian districts (north of 22°N) cooled by −0.53°C (95% CI: −1.5 to 0.33°C) since 1980 (Kuemmerle and Huybers, in review). A second independent product, DCENT, shows a similar January cooling signal of −0.39°C (95% CI: −0.59 to −0.24°C) over the same period (Chan et al., 2024). October, November, and December also show less warming over northern India than the national average.

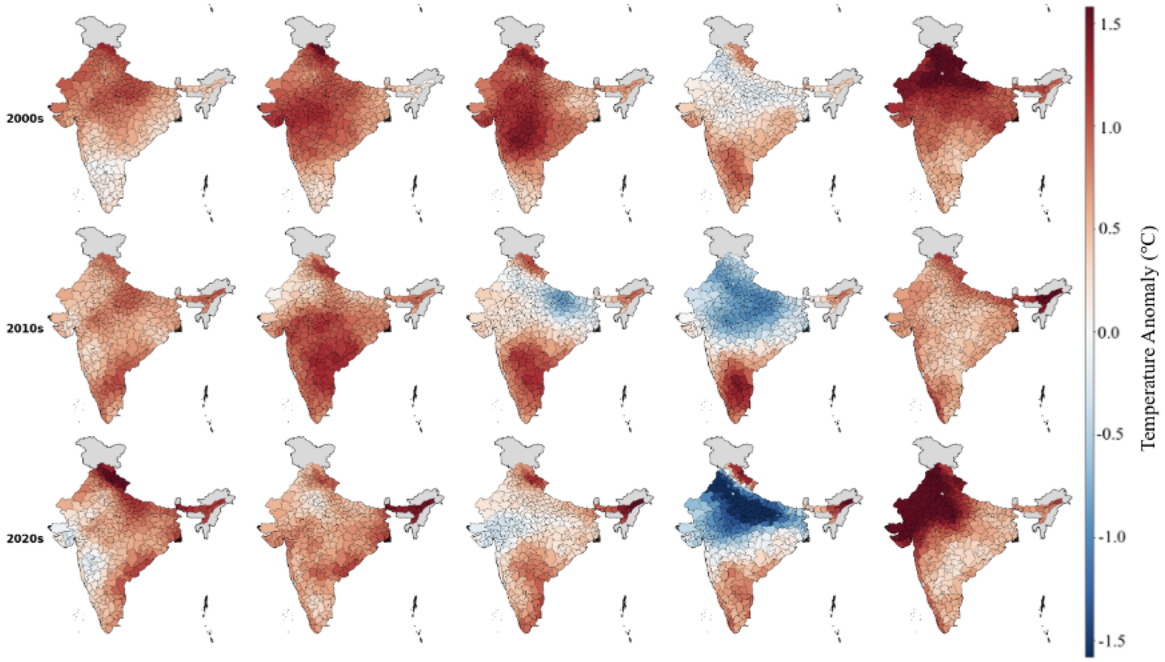

Fig. 1. Decadal maximum temperature anomalies across India by month, 2000s–2020s. District-mean daily maximum temperature (Tmax) anomalies (°C) aggregated to ICRISAT districts and averaged within decades, shown for each month of the rabi growing season (October through February, left to right) across three decades (2000s, 2010s, 2020s, top to bottom). Anomalies are computed relative to the district-level monthly climatology over 1980–1990. Warming (red) is widespread across most of India in October, November, and February, while a pronounced cooling signal (blue) emerges in December and January over the Indo-Gangetic Plain, intensifying from the 2000s through the 2020s. The spatial pattern of winter daytime cooling is concentrated in northern districts and coincides with regions of intensified irrigation and elevated aerosol loading. Source: Berkeley Earth Surface Temperature (BEST) data; district aggregation follows Kuemmerle and Huybers (in review).

At least three classes of explanation have been proposed for this pattern. Internal climate variability—related to Indian Ocean modes, Pacific variability, or multi-year La Niña states—can generate regional cooling on multi-year timescales, but is generally considered insufficient to sustain the spatial coherence and magnitude of the observed winter daytime cooling across Northern India (Sanjay et al., 2020). Two more deterministic mechanisms have received more attention: aerosol forcing and irrigation-driven latent cooling.

Aerosols that are emitted from crop-residue burning, industry, traffic, and cooking can cool the daytime surface by scattering or absorbing incoming shortwave radiation, while warming nights through increased downwelling longwave radiation and a shallower nocturnal boundary layer (Ramanathan and Carmichael, 2008; Krishnan and Ramanathan, 2002). Irrigation cools the near-surface air primarily by promoting evapotranspiration and shifting surface energy partitioning from sensible to latent heat—a mechanism already documented over the U.S. Midwest (Mueller et al., 2016) and observed in other heavily irrigated regions.

Kuemmerle and Huybers (in review) evaluate both mechanisms jointly using a new district-level reconstruction of monthly irrigation intensity, combined with MERRA-2 aerosol optical depth, across 1980–2022. Their district fixed-effects regressions find that a one standard deviation increase in January irrigation (17 mm) is associated with -0.60°C cooling of daytime daily maximum temperature (Tmax, 95% CI: -0.72 to -0.48°C), with the effect strongest in mid-winter and weaker or reversed at the seasonal margins. Aerosol optical depth is associated with an additional −0.25°C per standard deviation in January Tmax (95% CI: -0.33 to -0.18°C). The two effects interact: Contemporaneous increases in both aerosols and irrigation are associated with greater daytime cooling than the sum of their separate contributions, with a January interaction term of -0.13°C per (1δ × 1δ). Aerosols also warm nighttime Tmin, consistent with longwave trapping, while irrigation effects on Tmin are smaller and less systematic.

Irrigation intensification is most pronounced across northwestern India, while aerosol increases are strongest in the northeast, and both regions coincide with the band of observed January Tmax cooling. The results are robust across three alternative irrigation reconstructions—a fixed crop water requirement allocation, an ERA5-driven Penman-Monteith approach, and an AQUASTAT-based estimate—which increases confidence in the qualitative finding while leaving magnitudes subject to the usual uncertainties of a non-experimental design.

It is worth noting that not all researchers are convinced that these mechanisms fully account for the warming deficit. Others have pointed to India's location in the humid tropics, multi-decadal ocean variability, and potential model artifacts as contributing factors, and debate continues (Hari et al., 2022; Kim et al., 2024). The irrigation finding also requires careful seasonal qualification. Jha et al. (2022) show that irrigation has limited influence on pre-monsoon heat stress in the Indo-Gangetic Plain, the season when dangerous heat events occur and when applied water volumes are in fact minimal. This is consistent with Kuemmerle and Huybers (in review), whose irrigation cooling signal is concentrated in mid-winter months when rabi crops are actively irrigated, and is weak or absent at the seasonal margins.

Why the suppression may not persist

Both aerosol loading and irrigation—the two most quantified contributors—are themselves subject to change in ways that could accelerate warming over northern India.

Aerosol loading may decline under a clean-air policy. India's National Clean Air Programme and related state-level initiatives are designed to reduce ambient particulate matter. Aerosol reductions would improve public health even while removing a partial radiative mask on greenhouse warming, leading to moderate increases in winter daytime temperatures over northern India (Nair et al., 2023). The nighttime effect runs in the opposite direction: Because aerosols currently warm nights through longwave trapping, cleaner air is expected to lead to cooler nights, widening the diurnal temperature range.

Irrigation intensity is constrained by groundwater availability. The Indo-Gangetic Plain sits above one of the most rapidly depleting aquifer systems on Earth (Rodell et al., 2009; Tiwari et al., 2009). Districts where Kuemmerle and Huybers (in review) find the strongest January irrigation increases coincide with GRACE-detected groundwater losses in Punjab-Haryana and the western Ganges basin. If irrigation intensity falls or is redistributed—whether due to groundwater depletion, efficiency improvements, or crop diversification—the associated evapotranspirative cooling will diminish with it. The rate at which irrigation expands or contracts is likewise important: Evidence from California and other irrigated regions suggests that as irrigation growth stabilizes or reverses, the cooling trend it once sustained slows or stops (Bonfils and Lobell, 2007).

In both cases, the recent historical temperature record in northern India understates the warming that the coming decades will bring. The combination of continued greenhouse gas accumulation and weakening of transient suppression from aerosols and irrigation creates conditions in which warming over the Indo-Gangetic Plain could accelerate relative to the rates observed since 1980—even before accounting for changes in land use or circulation.

Implications for the chapters that follow

This matters for the rest of this paper in one concrete way: The historical temperature record cannot be taken at face value as a planning baseline for Northern India. Observed trends over recent decades combine a greenhouse-driven signal with regional aerosol, irrigation, and land-use effects whose future trajectories differ from their recent past. Heat action plans, agricultural forecasts, labor protections, and financial instruments calibrated to historical averages risk systematic underestimation of the exposures populations will face within those instruments' own planning horizons. A warming trend that has appeared modest over recent decades may not remain so.

2. FORECASTS FOR FARMERS

Lucas Vargas Zeppetello

Source: Unsplash

Approximately 56 percent of India's cultivated farmland is rainfed; farmers across India depend on monsoon rainfall each year for reliable harvests. Specific decisions like what crops to grow, when to sow, when to apply pesticides and fertilizers are all time-bound, and farmers require timely and effectively communicated information on the length of potential dry spells, the probability of a false start to the monsoon, and the degree of temperature stress during crop maturity. This chapter discusses (i) the current state of how these projections are made, (ii) the potential for improvements, and (iii) the impact of climate change on long-term agricultural forecasting in India.

The current state of agricultural forecasts

Currently, the Indian Meteorological Department (IMD) uses a numerical model that couples the dynamics of the atmosphere, ocean, and land surface to predict Indian summer rainfall and temperatures at three characteristic timescales (Madolli et al., 2022). The first are short-range forecasts, which provide information at 8-day lead times and correspond to a standard weather forecast. The second are "extended-range" forecasts that give information no more than three weeks in advance. The final forecasts are "long-range" and attempt to give accurate information in April for the summertime (June-September) monsoon rainfall over India. As short-range forecasts are not issued with enough lead time to provide relevant information for farmers, we focus on the "extended-range" and "long-range" forecasts in this chapter. Both longer-timescale forecasts exhibit substantial limitations (Pattanaik et al., 2019; Madolli et al., 2022) that make them difficult to apply to the kinds of decisions that farmers need to make at relevant timescales. In particular, both kinds of forecasts are based on numerical weather predictions and have not shown substantial improvement over the past few decades. Large-scale oceanic variations like the El

Niño Southern Oscillation (ENSO) and the Indian Ocean Dipole (IOD) continue to cause problems for extended and seasonal forecasts because of predictability gaps around these modes of variability in ocean temperatures.

For extremely high temperatures, the IMD provides a short-range forecast (a two-week outlook) with probabilistic guidance for the entire country on likelihood of extreme temperatures. Extended-range forecasts are experimental and are not typically made available to the public in the same way that the IMD rainfall and temperature data are (Mandal et al., 2019). While seasonal indicators of extremely high temperatures exist (Mandal et al., 2025), long-range forecasts of individual heat waves over India are unlikely to be reliable due to the fundamental mismatch in timescales between the synoptic atmospheric conditions that generate extremely high temperatures and the seasonal indicators that evolve on monthly timescales.

Potential for improvements

Two main avenues for improving Indian rainfall forecasts have been proposed. The first is increasing the spatial resolution of numerical weather prediction systems. While increasing spatial resolution has been shown to improve representation of extreme precipitation (Mishra et al., 2023), the computational cost of higher-resolution simulations makes their potential for operational forecasting limited. So far, the evolution of coupled climate models (including their increasing spatial resolution) has not improved simulations of Indian summer monsoon rainfall (Choudhury et al., 2021).

The second is deployment of machine-learning models to generate large ensembles of forecasts and build communications infrastructure to more efficiently disseminate the resultant forecasts to farmers. A recent effort centered at the Development Innovation Lab at the University of Chicago does precisely this. Efforts to disseminate information involved on-the-ground discussions with farmers and aimed to understand the kinds of information required and the best practices around communication. Through partnership with the Indian government, SMS texts containing probabilistic predictions of monsoon onset were sent to 38 million farmers roughly every two weeks in 2025. The forecasts successfully predicted a late onset across most of the monsoon, despite an atypical pattern of rainfall that featured a 10-day dry spell in the center of India after an initial wet period in mid-May. The advantage of this approach is that the forecasts are cheap and quick to generate once the underlying machine-learning model has been trained.

While the results from this combination of cost-effective machine-learning forecasting and evidence-based communication to farmers shows potential, there are still avenues for improvement that should be emphasized moving forward with respect to farmer-relevant forecasts of rainfall. These include extending the machine-learning forecasting techniques to include seasonal “long-range” forecasting and evaluating whether they have more skill than traditional numerical weather prediction, making usable predictions of total precipitation and dry spell length (rather than just monsoon onset date), and improving the system for disseminating the forecasts to farmers.

With respect to forecasting extremely high temperatures, considerable research into the meteorological drivers behind these events is required before operational extended or long-range predictions of heat waves are ready to be disseminated to farmers. An in-depth analysis of historical combinations of extremely high temperature and humidity events, the large-scale environmental conditions associated with those events, and their predictability at timescales longer than a few weeks would be an essential first step in understanding whether extended or long-range forecasts of extreme heat waves are possible. Another important area of research is ensemble-boosting experiments with climate models, where conditions amenable to the generation of extreme heat waves are preferentially selected for model simulations. Such simulations are important to understand the likelihood of extreme heat waves, the large-scale atmospheric conditions that give rise to these events, and whether numerical weather prediction systems or machine-learning models agree with the historical record in terms of these extended and long-range predictors.

Climate change and the future of forecasts for farmers

The Indian summer monsoon exhibits considerable variability, on timescales ranging from individual years to entire decades (Sahastrabuddhe et al., 2023), making predictions of the influence of climate change on this extremely consequential rainfall pattern extremely difficult (Wang et al., 2023). While the latest generation of global climate models on average predict more rainfall in response to increasing atmospheric carbon dioxide concentrations, there is considerable model spread. Some models predict that annual precipitation over India will increase by more than 20 percent by the end of the century in a worst-case climate change scenario; others predict increases of more than 60 percent. Both scenarios would require tremendous amounts of adaptation by farmers, and efforts to better constrain this model uncertainty are an urgent research priority. Furthermore, climate models predict increases in interannual variations as the climate warms (Wang et al., 2023), highlighting the need for accurate long-range predictions for farmers.

Extremely high temperatures are predicted to worsen under all climate change scenarios, and the historical trends in relative humidity across India are cause for concern if they are found to be forced by anthropogenic carbon emissions. More frequent exceedances of historical temperature thresholds are a near certainty, but the consequences of this for agricultural productivity are likely dependent on water availability. However, outdoor workers like farmers are projected to face losses in labor time given the increasing frequency of dangerous environmental conditions (Masuda et al., 2024). Given this trend, developing an infrastructure for making and disseminating extended and long-range heat wave forecasts are critical, particularly in the pre-monsoon season when heat waves are most dangerous.

There is a need to reframe forecasting as a public service infrastructure rather than a scientific product. This would entail not only improving predictive skill but also building institutional capacity to define relevant metrics, disseminate forecasts through accessible channels, and support responsive action at the village and block levels. In the absence of such integration, the availability of increasingly sophisticated climate forecasts will remain tangential to the everyday decisions that shape agricultural risk and resilience. New methods of prediction show promise of improving skill, but increased collaboration between farmers, scientists (local and international), and the Indian government is required if action around farmer-relevant forecasts is to be effective. Even the most advanced machine-learning techniques for farmer-relevant forecasting are limited to predicting the onset of the monsoon at spatial scales equivalent to a climate model grid cell (roughly 100-by-100 kilometers). Future efforts may be able to downscale these projections, but the state-of-the-art has considerable opportunities for improvement, particularly when combined with evidence-based dissemination techniques for getting information to farmers.

3. HOW HOT IS TOO HOT?

Robert Douglas Meade, Aditya Valiathan Pillai, Satchit Balsari

Source: David Trilling

Extreme heat is an increasingly regular feature of India's climate, catalyzing governments, public health agencies, and civil society to develop heat action plans (HAPs), policies, and emergency response measures to safeguard the public (Pillai and Dalal, 2023; Singh et al., 2024). Yet key questions remain unanswered about the thresholds that define dangerous heat and the evidence supporting interventions to mitigate its health impacts.

Identifying thresholds for triggering action: How hot is too hot?

A central challenge in crafting any action plan or emergency response is deciding on its trigger point—the conditions above which exposure becomes hazardous and protective measures must be enacted. Perhaps the most intuitive answer to the question "how hot is too hot?" is when conditions exceed the capabilities of human physiology. The goal of the body's thermoregulatory mechanism is to ensure a balance between the heat gain and loss to maintain its temperature within narrow limits for normal function (Meade et al., 2024). Beyond a certain point, heat gain from the environment outstrips the body's ability to cool itself through sweating, especially when high humidity prevents sweat from evaporating. A wet bulb temperature (Twb) of 35°C (95°F) is frequently cited as the physically bound survivability threshold. Above this limit, even a young, healthy person resting in the shade with access to ample drinking water and skin fully coated in sweat would experience a continual rise in core temperature, leading to death from heatstroke within hours (Sherwood and Huber, 2010; Meade et al., 2025).

Such notion of a hard physiological limit has become a popular anchor in discussions among scientists and policymakers of the current and future dangers of extreme heat. However, this framing overlooks several important complexities. For one, recent laboratory studies and physiological models suggest that the true physiological limit for human thermoregulation is lower than 35°C Twb and that how much lower depends on the prevailing air temperature (Wolf et al., 2022; Vanos et al., 2023). For example, Wolf et al. observed minimally active young adults can withstand up to 31°C Twb (88°F) without thermoregulatory failure in hot humid environments but only 26°C Twb (79°F) when conditions were very hot and dry1. Updated empirical limits from these studies have been used to argue that exposures to non-survivable heat in already hot countries like India will expand dramatically with further global warming (Vecellio et al., 2023; Powis et al., 2023). However, it has not been considered that this research was conducted on participants in temperate, continental climates of the Global North and is therefore unlikely to be generalizable to India, where inhabitants are both physiologically and socially acclimatized to heat (Taylor, 2014).

While defining India-specific thermoregulatory limits is not itself an intractable problem, heat stroke is not the only—and is not even the predominant—cause of death during heat waves. Most heat-related fatalities result from major adverse cardiovascular events likely due to the elevated strain thermoregulation places on the heart (Meade et al., 2025). Heat exposure is also known to precipitate kidney injury, reduce sleep quality, and exacerbate numerous chronic conditions including diabetes, respiratory illnesses, and mental health conditions (Minor et al., 2022; Vaidyanathan et al., 2019). Epidemiological data clearly show that mortality due to these "indirect" causes begins to occur in temperatures well below physiological limits for thermoregulation (Vaidyanathan et al., 2019; Gasparrini et al., 2015; Tobias et al., 2021). Accordingly, HAPs and emergency responses are often triggered at the point where epidemiological data show a rise in all-cause mortality. While this approach is intuitive and allows for more organic incorporation of local adaptation (e.g., by using country-, region-, or city-level data), it overlooks the myriad ways in which heat undermines health and well-being without necessarily killing.

For example, fieldwork suggests that work productivity begins to decline at much lower air temperatures (Ioannou et al., 2025), which can have cascading consequences for individuals paid at piece- or day-rates, reducing the ability to afford foods or medications (Meade et al., 2025). There is also considerable heterogeneity in how individuals experience heat and in their capacity to cope with it. People living in poorly insulated and ill-ventilated housing are exposed to higher heat stress than those in well-constructed homes with adequate cooling (García et al., 2024; Reckford and Aki-Sawyerr, 2023). Many of the same individuals in overheated homes, whether in low-income housing projects or informal settlements, must also perform heavy physical labor outdoors or in hot factories to earn a living wage (Meade et al., 2025). Their risk of heat-related health impacts is heightened because they cannot limit their exposure.

Heat-health risks are also elevated in groups less able to tolerate heat physiologically, such as those with reduced sweat rates or other vulnerabilities (Meade et al., 2024). These include very young children, older adults, and individuals with certain pre-existing health conditions or taking medications interfering with physiological responses to heat stress. The impact of high heat and humidity is further amplified when sustained for days, weeks and even months. When heat persists for weeks or months, its compounding effects on health, livelihoods, energy, and infrastructure can drive morbidity and mortality that extend well beyond the heat season: these delayed impacts remain difficult to attribute.

Thus, the seemingly straightforward question of "how hot is too hot?" cannot be answered without first

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1 High humidity impairs thermoregulation at any given air temperature by preventing sweat from evaporating, which is precisely why wet bulb temperature (Twb) is used as a more comprehensive metric. However, at a given Twb, thermoregulatory failure occurs more rapidly in hot, dry conditions than in humid ones—a counterintuitive finding that reflects the limitations of Twb as an indicator of heat stress across different climate types.

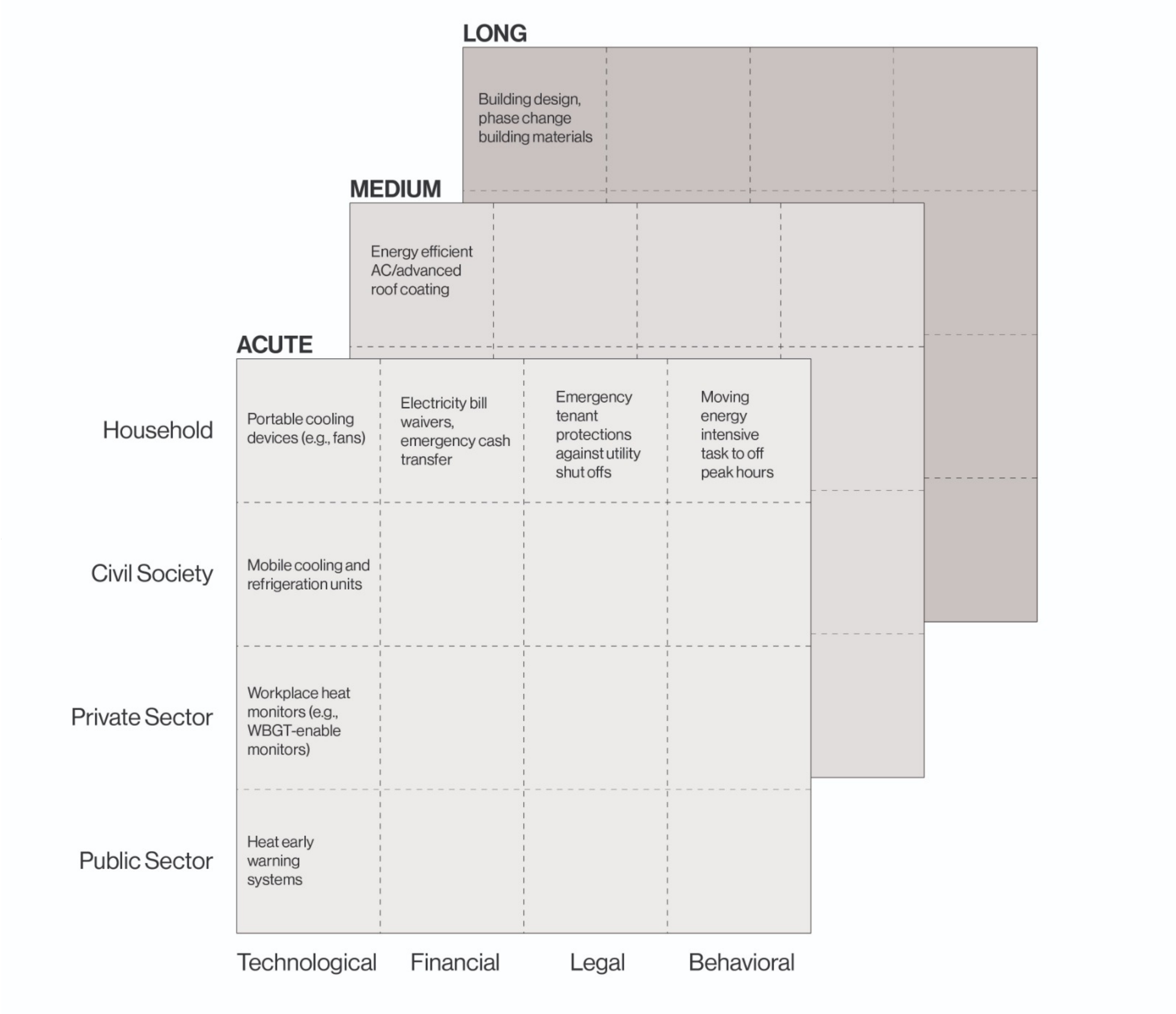

Fig. 2: Conceptual framework mapping emerging heat adaptations. Graphic by: Karthik Girish

A key barrier to deciding which interventions should be prioritized is a lack of data on their effectiveness, particularly in the Indian context. For example, it is well established that air conditioning is highly effective in preventing heat-related morbidity and mortality (Bouchama et al., 2007). However, this strategy is energy intensive and expensive, and therefore remains inaccessible to many of the most vulnerable. At least 80 million working poor in India can't afford even the most basic necessities; additional hundreds of millions more live just above the poverty line, all of whom have limited access to adequate protections from heat (e.g., cooling, shelter, healthcare) (ILO, 2024). Regularly promoted alternatives such as cool roofs typically deliver only a fraction of the cooling power (Das et al., 2025), and it remains unclear whether the provided reduction in indoor temperature, which can amount to only a few °C, is truly sufficient to protect health (Meade et al., 2025). Similarly, although emerging evidence from India suggests that HAPs may reduce heat-related mortality (Hess et al., 2018), it remains unclear whether they effectively reach—and protect—the most vulnerable members of society (Pillai and Dalal, 2023).

Even the establishment of robust evidence supporting the efficacy of an intervention does not guarantee that lives will be saved in the real world, as effectiveness can be compromised if the intervention comes with large economic costs. For instance, oft-discussed strategies like mandatory work breaks, occupational safety equipment and cooling centers, changes to school timings and transport schedules all affect the revenues of businesses and the wages of the vulnerable. There are incentives for employers and employees to circumvent heat-specific costs and effectively sacrifice health to protect business and livelihoods. Despite health risks, low-wage earners around the world advocated for work restoration during the COVID-19 pandemic.

Identification and evaluation of solutions must therefore be heavily grounded in local context, to ensure feasibility and scalability in the long term.

Answering tough questions

The considerable hurdles in identifying physiological upper limits and developing effective, scalable solutions for limiting heat's growing burden do not mean these efforts should be abandoned altogether. Rather, the opposite is true—the challenges underscore that much work is needed to build evidence-based and contextually grounded protections for India and the rest of the world. Doing so will require expanding our understanding beyond laboratory studies and models to include community-informed research linking physiological and epidemiological data with the lived realities of those at greatest risk. Such an approach is the surest way toward the creation of thresholds and interventions that are not only scientifically robust but also socially legitimate and responsive to the diverse ways heat affects health, work, and daily life.

4. HEAT SOLUTIONS AREN'T JUST ON THE ROOF

Rajan Rawal, Radhika Khosla

Source: Dhruval Gadhvi

Heat is often associated with the daytime sun. This has shaped much of the visual imagery of heat to focus on the relationship between building rooftops, external window shading, and solar radiation. This narrow imagery fosters the belief that shielding from solar radiation alone can help achieve thermally comfortable conditions inside buildings. Consequently, the range of solutions preached and practiced for achieving thermal comfort in the built environment are often constrained and focus mostly on cool roofs. This is often seen in geographies dominated by high cooling needs, where the advisory frameworks and supporting narratives can be shaped by, and constrained within, this narrow conceptualization of heat—limiting consideration of the much larger scope of passive design strategies and technological adoption options. While cool roofs are important, focusing on them alone can foster a false sense of achievement in the assumption that their application will single-handedly resolve the overheating problem within buildings and reduce the urban heat island effect (UHIE).

Cool roofs do lower roof surface temperatures during both the day and night. The contribution of cool roofs to mitigating the UHIE is also well recognized, particularly when implemented at a sufficient scale within concentrated urban areas. However, their effectiveness diminishes when deployment is sporadic, in which case their fractional coverage within a defined urban land area is a more reliable indicator of their potential benefits for lessening the overall UHIE.

Cool roofs reduce ceiling temperatures, decrease cooling loads in air-conditioned buildings, and lower mean radiant temperatures (the average temperature of surrounding surfaces that exchange heat with a body via thermal radiation) in naturally ventilated spaces. Variations in mean radiant temperature impact on occupant thermal comfort to a greater extent than the natural convective heat transfer experienced as air moves over the skin. However, it is important to note that the roof and ceiling constitute only a small portion of a building's envelope. Additional surfaces, such as walls, floors, and windows, exert a far greater influence on both cooling demand and occupant thermal comfort.

Limits of surface-temperature heat mapping

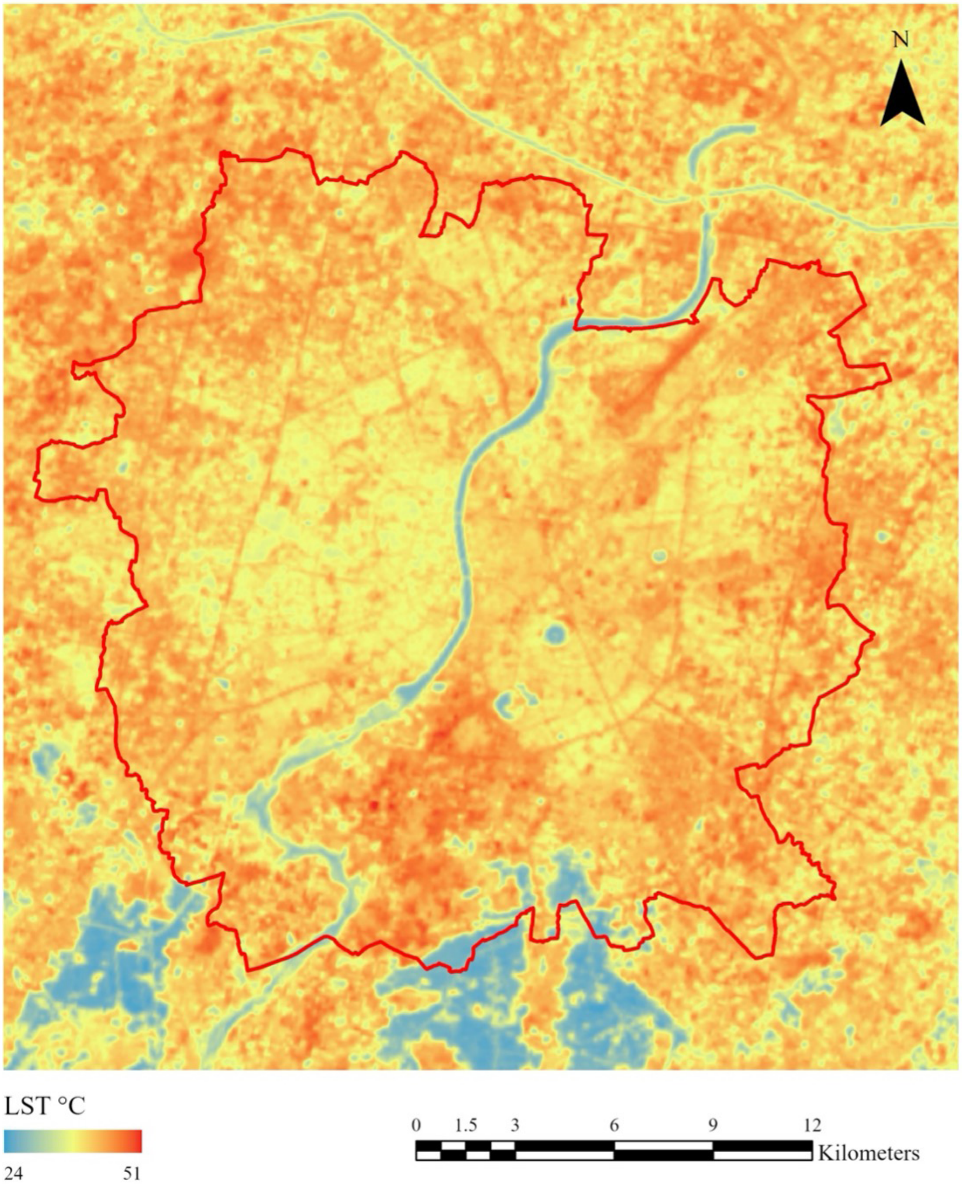

Fig. 3: Land Temperature (LST) across Ahmedabad, India. Source: Satellite imagery (public domain)

When considering the impact of cool roofs, and cool surfaces more broadly, it is important to consider two scientific concepts. First, roof surface temperatures are determined using remote sensing–based urban surface temperature heat maps (Figure 3). These frequently reveal elevated thermal conditions in and around urban areas; however, this is just one side of the story. These visualizations predominantly depict daytime land surface temperatures (LST); their emphasis often overlooks, and in many cases fails to examine, nighttime UHIE, along with air temperature and relative humidity (Sun et al., 2020; Shi et al., 2021; Naserikia et al., 2023; Briegel et al., 2025; Zhan et al., 2025). Each of these parameters, along with wind speed and solar radiation exposure, is critical to determining occupant thermal comfort, and have substantial implications for energy demand, and public health. This warrants greater attention from both researchers and urban planners, as the prevalent method of over-reliance on LST leads to interventions that deal with surfaces only, often leading interventions that focus alone on changing surface temperature.

Humid heat and the physiology of thermal comfort

Variables in addition to surface temperature are also key to thermal comfort. Humans possess an advanced thermoregulatory system in which body heat dissipation through perspiration plays a critical role. This mechanism provides exceptional resilience to heat stress; however, its effectiveness declines in elevated ambient humidity conditions (Bright et al., 2025). This focus on heat stress—which refers to the combined influence of environmental conditions, metabolic activity, and worn clothing causing an increase in bodily heat storage—is a precursor to achieving thermal comfort, which is a combined psychological and physiological state in which an individual perceives and experiences satisfaction with the surrounding thermal environment. In cooling-dominated climates, the increasing frequency, duration, and spatial extent of high-humidity conditions pose additional challenges to finding solutions that can effectively address both temperature and humidity. Focusing on roofs alone can deflect efforts to address the potentially dangerous impacts of humid heat.

Passive design as an integrated strategy for heat resilience

What is of note here is that cool surfaces and cool pavements do contribute to desired thermal performance at both building and urban scales, but they are not silver bullets. It is therefore imperative to prioritize other passive design strategies (often incorrectly termed “passive cooling strategies,” despite operating primarily to prevent heat incursion) that address building materials, construction techniques, and spatial configuration. A holistic integration of passive measures targeting all three modes of heat transfer—conduction, convection, and radiation—can substantially reduce dependence on active cooling systems. Passive design strategies for comfort apply these principles and comprise a range of heat protection, heat modulation and heat dissipation techniques.

The benefits of integrated passive design strategies are widely documented historically and around the world. These are based on empirical evidence, underscoring the effectiveness of features like courtyards, trellises, oriel windows, and wind catchers across diverse climates. For example, local material—specifically stone and lime—have been used to ensure thermally comfortable interiors (Ghosh et al., 2021). Passive design strategies, despite their historical and global roots, are limited in their adoption at scale. This is often a function of the availability and affordability of appropriate materials and construction technologies, and in local sociocultural norms around heat adaptation. While often perceived as a technology-driven solution, passive design fundamentally depends on the capacity of architects, urban designers, and urban planners to deliver spatial solutions tailored to local climate and culture, best conceptualized and put into effect at the design and construction stage itself. Their effectiveness is subsequently assessed through performance-based evaluation.

Promoting passive design through targeted policy instruments and market incentives can advance the goal of a thermally comfortable built environment while safeguarding environmental resources. At the same time, prescriptive implementation, relying solely on codes or regulations, can constrain both adaptability and the impact of such strategies. To achieve the overarching goal of thermal comfort in buildings and cities, the immediate priority should be the reduction or elimination of heat stress to adapt to increasing temperatures and extreme heat.

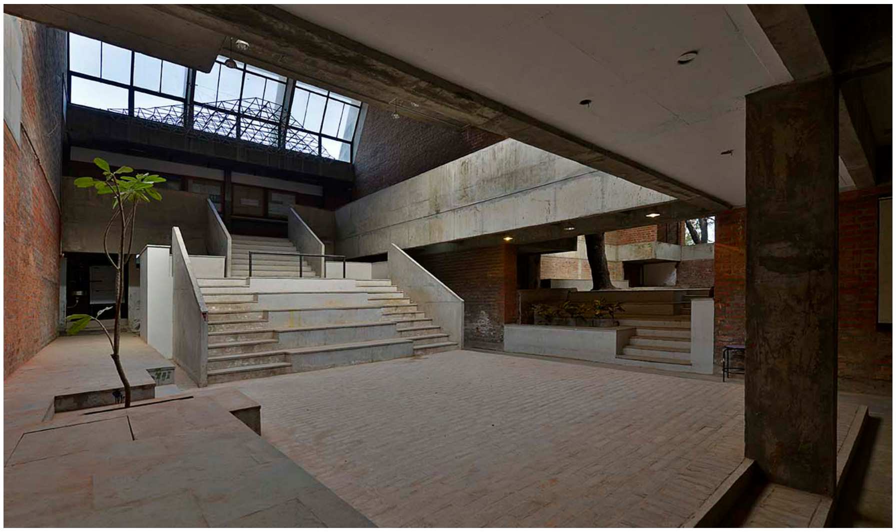

Image: Shading, ventilation, and material choices at CEPT University in Ahmedabad, India. Source: Dinesh Mehta

In an increasingly warming climate, passive design strategies can reduce or eliminate heat stress; however, their impact on thermal comfort depends on the severity of the climatic conditions being addressed. Well-optimized building and city designs can cut cooling loads substantially, reducing the need for active or mechanical cooling and providing a range of benefits including for the electricity grid and energy security. While such passive design strategies may slightly increase capital costs, they lower operational expenses and energy use over the life of the buildings, leading to significant long-term gains. Spatial configurations often achieve these benefits without added cost or embodied energy. By reducing active cooling demand and operating hours of active cooling, passive strategies also limit waste heat rejection from buildings, helping mitigate the UHIE. Successful implementation of passive design strategies relies on integrating spatial design and building construction technologies. Contemporary buildings often combine several key approaches, such as site planning, building orientation and form, fenestration design, and the selection of building materials (Manu et al., 2019; Doctor-Pingle et al., 2019). As countries around the world grapple with escalating heat, looking to and beyond cool roofs to the wide range of passive design strategies will deliver significant energy savings and additional benefits for the vulnerable and others across urban communities.

5. HEAT ACTION PLANS: A CAUTIONARY NOTE AND A WAY FORWARD

Aditya Valiathan Pillai

Source: David Trilling

Over the past three decades, heat extremes have given rise to a new tool in public policy: the heat action plan. These plans have a broadly similar flavor across the world; they define when and how the state should react to extreme heat and feature a script of actions that stretch across the breadth of government machinery. They are ambitious in scope, linking science, early warning systems, emergency aid, infrastructure change and coordinating institutions together.

Yet the very ambition of their scope creates a weakness: Without careful integration into existing workflows of government, they risk being overwhelmed by the conflicting priorities of daily administration and, eventually, ignored. Reviews of heat plans in democracies across the world, from India to the U.S. and Europe, suggest that they generally lack legislative or financial backing which makes them less likely to be implemented. This is perhaps unsurprising given that extreme heat is an emergent public health problem in a crowded field of policy priorities.

Unlike many other policy challenges, however, the nature of the problem is going to change in fundamental ways in the coming years. Several assessments, including the IPCC, point to more frequent, intense and longer heatwaves because of continued carbon emissions (IPCC, 2022). In governance terms, this means longer periods of low productivity and incomes for heat-exposed workers, an additional source of concentrated pressure on the health system (alongside a range of other hazards) and, almost inevitably, more suffering and deaths as adaptability limits are crossed.

Across much of the world, heat plans are aiming at a moving goalpost while struggling to adequately address current challenges. A recent analysis of the implementation of heat plans in India, a country recognized as an early mover in heat planning, showed that the plans focus on important short-term emergency responses to heat (such as on water stations or on the designation of public cooling), while falling short in the implementation of long-term structural changes such as increasing shade coverage, changing building codes, or preparing the grid for future cooling demand.

An important area of future research is to find how common this focus on the short-term is across developing countries, where larger shares of the population are heat-exposed and state capacity is low. While the contents of heat action plans have been reviewed across regions, far fewer studies examine their implementation. Water provision, heat alerts and, in some places, drives to ensure workers have mandatory rest breaks, all pre-date the ascent of heat action plans. Social scientists and policy researchers must offer closer inspections of their actual effects on historical rhythms of summertime governance.

At this point, the reader might legitimately ask whether heat plans are even the right instrument for the structural changes needed to deal with 2 or 2.5°C of warming (or higher). The answer depends on: (a) whether they can find a reasonable way of incentivizing politicians and implementers to act and (b) whether they can do that in sector after sector, across the many areas they must intervene in.

To alter the incentives of local stakeholders, plans will have to acknowledge what they want and start working with the grain of local politics. They might have to offer up a set of visible actions that offer rewards to politicians and implementing bureaucrats; financial incentives that allow local governments to supplement politically attractive developmental expenditure in heat-related areas (such as for water supply infrastructure in a city approaching 'day-zero') and strong, inclusive monitoring frameworks that publicly repudiate or sanction ineffective implementation. A combination of all three might yield a consistently implemented plan.

At present, however, heat plans are written to be comprehensive rather than implementable. A focus on incentives and implementation—while remaining uncompromising on the determination of thresholds, vulnerability assessments and the specificity of solutions—suggests a productive way forward. We are yet to see plans that manage this balancing act. An example of how to solve this dilemma could help speed the rollout of heat protections as the climate warms. To be truly multi-sectoral, the second crucial element of efficacy, heat plans must be able to shift the priorities and routines of a range of departments. Most already attempt to do this. They establish coordinating institutions that can call meetings before, during and after heatwaves. They also designate responsibility for action to a team or individual, and thus serve the crucial function of establishing accountability within the state.

But the structure of these institutions is an important determinant of whether these plans will succeed. Since coordination is a function of power, what authority is the coordinating institution vested with? Does it have the imprimatur of the head of government, the head of the home department or some other powerful node of decision-making? Or is its remit limited to technical coordination, led by sectoral bureaucrats? Each of these options has its advantages and disadvantages; the former is more likely to sacrifice science to political imperatives, while the latter may not be able to shift the functioning of large, entrenched departments. The emerging trend of local governments appointing chief heat officers acknowledges the importance of allocating responsibility, but more research is needed to understand how to structure institutions to allocate power correctly in the case of heat policy.

This appraisal of the idea of heat planning cautions against triumphalism around the commissioning of heat plans, which in most jurisdictions are signals of intent. Heat plans could lead to maladaptive outcomes if officials lose focus after earning plaudits for merely putting a plan in place. Heat proofing the future will require ensuring they can align science with political realities and outcomes by changing incentive structures.

6. SHOULD PARAMETRIC INSURANCE BE SCALED?

Caroline Buckee, Owen Gow

Source: David Trilling

Recent efforts to establish protections against extreme heat for informal sector workers have led to the creation of parametric heat insurance schemes by several of the largest insurance and reinsurance firms (Nanavaty and Saxena, 2025). Like insurance against floods or cyclones, these schemes are designed to pay out during short heat waves when it is too hot to work, not only as a mechanism to protect wages but also to protect the health of workers who may otherwise be exposed to dangerously high temperatures.

The promise and appeal of parametric heat insurance

Parametric heat insurance policies pay policyholders when a predefined set of parameters are met. These parameters can include proxy measures for thermal stress such as air temperature, as well as time durations that a threshold must be exceeded. Compared to traditional (indemnity) insurance policies, parametric insurance has been utilized for its comparative transparency, speed of payout, and reduced administrative burden.

What then is the broader promise of parametric heat insurance? By collecting premium payments from participants in the scheme, an insurance model with a sufficiently diversified risk pool could be substantially more financially sustainable than a cash transfer model, easing the pressure on national and state governments and philanthropies. An instructive example applied to other hazards is African Risk Capacity, which offers drought, flood and cyclone insurance across a risk pool that includes multiple countries across the African continent (Ndlovu, 2025).

Such insurance is however not suitable for mitigating all health and financial effects of recurring disasters. Particularly as a complex financial instrument being newly applied to heat, parametric heat insurance runs the risk of being portrayed as a standalone fix. Expectations that the insurance should pay out each year if premiums are paid run contrary to the very qualities that make insurance more financially viable for workers, businesses or governments than alternatives such as cash transfers. These insurance products are therefore to be best deployed in conjunction with heat-risk mitigation programs that kick in far below dangerous heat conditions, with rapid-to-long-term infrastructure investments that safeguard health, and with other financial schemes that activate when worker health and livelihoods are at risk.

Practical and technical challenges in trigger design

While it sounds like a reasonable idea, parametric heat insurance faces logistical hurdles and gaps in data availability. Designing payout triggers for extreme heat is more difficult than it might appear. The obvious candidates—meteorological thresholds or physiological markers of danger—are either poorly standardized, weakly linked to actual health or economic outcomes, or likely to shift upward as climate change progresses (Nairn and Mason, 2025). In practice, insurers' models instead trigger around expected income losses in the summer, taking into account the interaction between temperature, duration, and persistence. But calibrating these models requires granular local data that often does not exist.

Risk modeling ideally incorporates local productivity data to calibrate payouts more closely to actual livelihood loss rather than arbitrary heatwave criteria. Agriculture and construction workers laboring outdoors in the sun will clearly experience far greater heat stress than home-based weavers or shopkeepers. Yet, there remains limited physiological and epidemiological data to guide such distinctions. Most research on heat exposure and human performance has focused on young men, often in military or athletic settings, and few studies have examined women, older adults, or workers in informal, low-income environments where heat exposure is most severe. Without such data, it is difficult to design triggers that meaningfully align with either health or productivity losses across diverse occupations.

The Self-Employed Women's Association (SEWA) and the Atlantic Council's Extreme Heat Income Micro-Insurance scheme initially covered 21,000 women across seven trades in Gujarat (Ro 2023), yet even with a pool deliberately composed of informal women workers, calibrating triggers across occupations as varied as street vending, salt-pan harvesting, and home-based garment work remains an open problem.

SEWA is now leading the world's largest study of occupational heat exposure across eight occupations in several regions of India, measuring the impact of heat and humidity in the microenvironments of the working poor.

Large variations in local exposure also complicate these efforts. While the closest weather station may record 45°C, actual temperatures within particular neighborhoods, factories, or homes may be substantially higher, and its impact across occupations significantly different. If the goal then is to protect workers' health and income, developing payout criteria that reflect such heterogeneity remains a major challenge. This difficulty is inherent in all population-level financial instruments for extreme heat, including insurance and cash transfers. Later chapters in this paper provide alternative mechanisms like anticipatory financing that address these implementation challenges.

Fundamental limits of insurance for a chronic climate hazard

If parametric heat insurance is intended to protect health, another structural problem emerges: Daily wage workers must decide whether to stop working on a given day before knowing whether the payout conditions will be met. Forecasting uncertainties—since heat waves are typically defined as a set of consecutive days above a temperature threshold—mean that workers are unlikely to forgo wages based on a forecast that might not trigger a payout. They may eventually benefit retrospectively from compensation, but few can afford to risk daily income in anticipation. Unlike other natural hazards such as floods or cyclones, work can continue under dangerously hot conditions, even when it is physiologically unsafe. While improvements in sub-seasonal heat forecasting may help, the fundamental economic reality remains: For households living in or near poverty, the immediate necessity of income often outweighs the uncertain protection of future insurance payouts. As currently designed, the insurance payouts are more likely to function as hazard pay—compensating for heat stress, but not always accompanied by work cessation and protecting health.

As extreme heat becomes more frequent and prolonged, large sections of the labor force may experience sustained exposure for weeks or even months at a time. When the hazard becomes chronic, the underlying logic of insurance—protecting against rare, unpredictable losses—will no longer hold. Alternatively, in order to avoid skyrocketing premium costs, the conditions required for the policy to trigger may be made progressively more severe, increasing the gap between levels of heat stress that harm human health and those that trigger the product. As this gap widens, insurance will be decreasingly viable as a solution for a widespread, recurring climate stressor like heat.

Parametric heat insurance is thus a promising innovation, but it likely remains a transitional and complementary mechanism, not a durable or stand-alone solution. Its success depends on how effectively it is embedded within a broader system of protection: one that includes improved occupational safety standards, adaptive social protection, and investments in urban design and infrastructure that reduce exposure altogether. Deployed strategically, it can provide temporary financial relief and incentivize adaptation investments, but it cannot substitute for the structural changes required to make work safe in an increasingly hot world.

7. CONTEXTUALIZING WORKFORCE PROTECTIONS IN THE MODERN ECONOMY

Rajesh Nayak, Sharon Block

Source: David Trilling

In India, as around the world, many workers are affected by rising temperatures while at work, whether that work takes place outdoors or indoors. Most workers have little control over their workplace conditions, and this is especially true for informal workers, who constitute as much as 90 percent of India's workforce (ILO, 2024). From agricultural laborers and street vendors to gig workers and warehouse staff, millions are forced to choose income over health as they endure long hours in extreme heat. All workers need access to basic protections such as water, rest breaks, and shade, yet too few have enforceable rights to these measures.

For workers in the formal sector, the most effective approach to ensuring safety and health in extreme heat involves establishing a nationwide framework of clear, enforceable protections tied to climate realities. This approach has proven effective in countries with predominantly formal labor markets, such as the United States, which proposed such a regime in a 2024 Department of Labor rulemaking (OSHA, 2024).

But designing worker protections is more challenging for the informal sector, where fewer workers have an employer or even a workplace setting. This chapter discusses the challenges and opportunities of protecting workers in the informal sector; we then articulate a path forward for additional research and social dialogue to advance protections for workers in the formal and informal sectors alike.

Protecting workers in informal settings

Most workers in the informal sector do not have access to enforceable workplace protection. Absent policy interventions, workers bear the greatest physical risk of working in extreme heat and, too often, a disproportionate share of the cost. For example, if a self-employed outdoor construction worker decides not to work due to the physical effects of heat—or if they fall ill due to the short- or long-term effects of exposure to heat—they lose income during that time, and also bear additional medical costs.

Extreme heat also imposes financial risks on employers, businesses, and consumers, given the productivity losses that accompany unsafe conditions. One recent study of the manufacturing industry in India showed that the output of both individual workers and teams declined on hot days absent climate-control efforts, and absenteeism increased regardless of such efforts. (Somanathan, 2021). In other words, failing to take actions to protect workers from heat will have spillover effects on industry and on consumers alike as productivity dips and the increased cost of production results in lost profits and higher prices. Where economic impact is demonstrable, some employers may act in the absence of regulation. While there are robust studies of the impacts of workplace exposure to extreme heat, many involve data that fail to account for the unique nature of the informal workforce. We need additional study on the impact of sustained extreme heat on informal workers, given that the relevant literature relies on lab-based or short-term workplace observations, precluding a robust evidence-based case to make to policymakers.

Whether protections are mandatory or voluntary, key questions remain about how best to protect informal workers: What level and duration of heat should trigger protections in various informal workplaces; how should costs be allocated across employers, suppliers, governments, and the workers themselves; and how may workers themselves shape efforts to adapt these measures to all workplaces? The answers to these questions can only arise from an interdisciplinary exploration of evidence drawing broadly from economics, climate science, occupational physiology, and labor regulation, not to mention input from stakeholders who are impacted, especially workers.

Informal workers must be directly involved in developing the policies, plans, and programs designed to protect them. Because informal work often blurs the boundaries between home and workplace, effective solutions must account for both. Social dialogue that brings together workers, civic authorities, and the private sector is essential to designing practical and trusted protections.

Worker participation ensures that policies reflect lived conditions and real constraints. One example is the Dindigul Agreement in Tamil Nadu (Jerrentrup and Kuruvilla, 2024) a legally binding accord between a women-led union, a local supplier, and an international brand in the leather sector. It establishes enforceable commitments on labor rights, workplace conditions, and grievance procedures, monitored by the workers themselves rather than external auditors. Crucially, the agreement extends beyond voluntary codes of conduct, holding all parties contractually accountable, including the buyer. While it was originally created in response to gender-based violence, its architecture offers a powerful model for embedding enforceable protections—including heat-related standards—within fragmented (loosely organized) supply chains.

A comparable model can be found in the Coalition of Immokalee Workers' Fair Food Program (FFP) in the United States (Rivero, 2024) a worker- and consumer-driven initiative operating in Florida's agricultural sector. The program is anchored in two innovations: a price premium paid by corporate buyers (supermarkets and fast-food chains) that supports wage increases, and a legally binding code of conduct co-developed by farmworkers, growers, and buyers. The code enforces labor-rights protections across participating farms and empowers workers to directly monitor implementation on the ground. The FFP model especially demonstrates how binding agreements and worker-led monitoring can produce enforceable safeguards in decentralized, subcontracted, and seasonal industries, conditions that mirror much of India's informal economy.

Governments should not use informality as an excuse to avoid imposing enforceable protections. There are multiple pathways to protect workers in the informal sector:

1. Workplace protections can be written to ensure coverage for informal workers in small-scale manufacturing and even for street vendors dependent on a single supplier (who functions essentially as an employer). For example, in Nova Scotia, Canada, worker protection statutes, including safety and health protections, are written to hold both employers and companies that engage "dependent contractors" liable for providing safe working conditions.
2. In the absence of political or legal will to implement such a regime, state and local governments can encourage voluntary adoption of protective measures that help all workers. For example, state and local governments can adopt heat action plans that encourage employers, contractors and businesses to institute cessations of commerce for rest breaks and to facilitate shifting of work hours away from the hottest parts of the day. While heat action plans do not establish mandatory standards, they can promote measures that benefit workers in both the formal and informal economies. For example, encouraging access to cool water informs employers of their responsibilities toward workers, but it also suggests greater public responsibility for the city, and for entities like business improvement districts, and even for local businesses to provide water-cooling stations accessible to street vendors. Municipal regulations, at the very least, also can be amended to eliminate obstacles to street vendors adopting protective measures. For example, the Comptroller of the City of New York recommended that the City's Street Vending Code be amended to drop the restriction on food vendors using awnings for shade (Office of the New York City Comptroller, 2024).
3. Labor unions and worker associations have already demonstrated that workers are investing in their own adaptations and organizing around changing workplace conditions. These organizations are indispensable partners in developing effective protections against heat exposure.
4. The most effective funding mechanisms for informal-sector protections remain uncertain. Because workers in the informal sector are self-employed, laws and rules cannot simply require an employer to offset the cost of protections for example, through a combination of diverted profits, higher prices, increased productivity or public subsidies to those employers. Other mechanisms must be developed to both fund and deliver protections. Various approaches have been piloted, including cash transfers that allow workers to purchase protective equipment, offset lost income during heat waves, or maintain cooling devices in home-based workplaces; parametric heat insurance schemes (as discussed in Chapter 6); investments in public cooling stations; and grants to worker organizations and nonprofits to implement protection programs. However, rigorous evaluation of these mechanisms, and of which combinations yield the best outcomes, remains limited.

Protecting informal workers from extreme heat requires coordination among many stakeholders, including employers, business owners, workers, consumers, insurance companies and civil society institutions. Until comprehensive regulatory protections are in place, each has an important role in designing and implementing measures that balance competing interests. Each stakeholder holds critical data—both aggregated and grounded in lived experience—that can inform the development of practical, evidence-based solutions.

Perhaps the central question to resolve across formal and informal sectors alike concerns who bears responsibility for increased risk during periods of extreme heat—workers, employers, suppliers, consumers, or the state. Allocating the costs of adaptation across these groups will require sustained negotiation, experimentation, and policy innovation. Governments will play a central role in designing and administering these systems, whether through broad-based taxation or targeted levies and fees.

Paths forward for worker protections

Critical data gaps continue to constrain effective policy design. More evidence is needed on the impact of extreme heat across both formal and informal sectors, particularly on productivity and non-fatal health outcomes. Closing these gaps requires collaboration among public agencies, private employers, and community and worker organizations. Employers already collect important data on productivity and absenteeism, while community-based groups can partner with workers to apply innovative research tools such as time–motion studies that capture the real effects of heat exposure. Collaboration among medical researchers, climate scientists, and experts in occupational health and the built environment can further strengthen understanding of how climate change affects work and how infrastructure and technology can mitigate its effects.

A practical starting point is to build on existing social protection infrastructure to encompass protections from extreme heat. Lessons from COVID-19 relief programs, broader poverty alleviation initiatives, and India's Construction Workers' Welfare Boards—statutory bodies that collect industry levies to fund benefits for registered workers—offer valuable models for integrating climate-related protections into established systems.

Policymakers should consider large-scale interventions that incentivize markets to embrace seasonal variation in productivity across sectors. Construction work just may not be tenable in the hot summer months in many parts of the world, requiring workers to be reskilled or diverted to other seasonal work. Some industries may need significant restructuring of their supply chains; for example, manufacturing demand for back-to-school products including uniforms peaks in the summers when working conditions are the worst for the majority of the home-based and small-scale workshop-based workers in the Global South.

Finally, policy dialogues at both national and international levels must recognize the connection between environmental impacts and worker well-being. Global forums such as the United Nations Framework Convention on Climate Change Conference of the Parties (COP) and the G20 should address labor and climate issues together. Worker organizing is a critical component of environmental resilience, and any agenda on climate science must include the implications for working people. Protecting workers from extreme heat is fundamental to safeguarding health, productivity, and economic stability in a warming world.

8. WHAT IS THE HEALTH AGENDA FOR CLIMATE ADAPTATION?

Nitya Mohan Khemka, Bhargav Krishna

Source: David Trilling

Climate change is already reshaping health outcomes across India through more frequent and intense heat waves, erratic rainfall, wildfires, and coastal degradation. Among these, extreme heat poses the most direct and immediate threat to human health and well-being. Rising temperatures exacerbate infectious disease patterns, reduce agricultural productivity, and strain India's already burdened health system. Without urgent investments in adaptation, escalating heat and climate impacts will outpace the capacity of India's health infrastructure and workforce, deepening inequities across regions and populations.

To frame a credible health agenda for climate adaptation, we first need to understand the limits of what we know, and why our data systems fail to capture the true scale of climate-related health impacts.

Ascertainment challenges

Accurately measuring the health impacts of heat remains one of the central challenges in developing a credible climate-health agenda. Many heat-related illnesses and deaths go unrecorded or are misclassified under other causes, making the true burden of heat exposure difficult to ascertain. Attribution is further complicated by India's climatic and social diversity: Human adaptability to heat varies across regions, occupations, and housing conditions, while underlying health, gender, and socioeconomic inequalities shape vulnerability.

While global studies illuminate broad climate-health trends, India's highly heterogeneous environments demand fine-grained analyses of vulnerability and exposure. Yet, much of India's current evidence base relies on coarse environmental thresholds or extrapolations from temperate regions (Mazdiyasni et al., 2017). Heat-health research must evolve to capture the synergistic effects of temperature, humidity, and radiation—metrics such as wet-bulb temperature or heat indices are better aligned with physiological stress than simple ambient temperature measures.

Building an evidence base will require local, contextually grounded research and improved epidemiological data. Current thresholds for declaring heat waves in India are environmental, not epidemiological. As a result, they fail to reflect the actual temperature-mortality relationships that should guide preparedness and response. Finer-grained epidemiological data would enable threshold-setting that reflects real health impacts rather than arbitrary meteorological categories. Similarly, vector-borne disease models must be recalibrated to account for local environmental and behavioral realities rather than relying on generalized temperature-transmission correlations.

Finally, timely and transparent communication of uncertainty must become a central norm in climate-health modeling. All models carry uncertainty; formal mechanisms to communicate confidence ranges would strengthen public trust and enable policymakers to make risk-informed decisions. Long-term, large-scale cohort studies that track heat exposure and outcomes will be critical to understanding chronic climate-health interactions, but interim progress can and should be driven by locally owned, shorter-term surveillance systems and sentinel sites.

Data challenges

Beyond scientific uncertainty, India's ability to measure and respond to heat-health impacts is further constrained by fragmented data systems. India has begun enhancing surveillance and digitizing data on climate-sensitive health outcomes, including heat-related illness and vector-borne diseases. However, significant gaps persist. Data from the private sector, which delivers nearly two-thirds of all inpatient care, remain largely absent from national registries (National Sample Survey Office, 2019; La Forgia and Nagpal, 2012). Where records exist, inconsistent coding and limited digitization impede their integration into usable datasets. The absence of updated demographic baselines (India's last census was conducted in 2010) further undermines accurate disease burden estimation. Civil registration systems still fail to fully capture mortality, and morbidity data remain fragmented across institutions with limited interoperability. The monetization of meteorological data by national agencies adds a further barrier, constraining access to information that should be treated as a public good.

Bridging these gaps requires both regulatory reform and a shift in mindset. Mandating aggregated and anonymized health reporting from the private sector, treating publicly funded meteorologic and public health data as open-access infrastructure as clearly articulated by the government's Digital Public Infrastructure goals (Chawla and Iyer, 2025), and improving data interoperability, would transform the ability to link local environmental exposures with health outcomes. Investments in minimum viable datasets that integrate meteorological and health data—even if imperfect—would deliver far more value than delayed, high-precision systems. Integrating insurance claims and electronic health records could further accelerate the creation of a robust indigenous evidence base on climate-health linkages.

Possible intervention pathways

To be meaningful, the health agenda for climate adaptation must first center heat, the most pervasive and measurable stressor linking climate change and health. Heat offers a diagnostic lens for systemic weaknesses across surveillance, infrastructure, and governance. A credible adaptation agenda must therefore transform how India anticipates and manages both acute and chronic exposures, strengthening prevention, workforce readiness, data integrity, and institutional coordination, all while embedding equity as its guiding principle. Adaptation is not only about protecting lives during extreme events; it is also about rebuilding health systems for resilience under sustained climatic stress.

The three approaches we propose below (of several other possible approaches) acknowledge that Alma-Ata goals from the late 20th century remain unattained for the vast majority of the world's population, and these interventions must be seen not as a panacea but as complementary efforts to strengthen primary care, and to invest in improving social determinants of disease.

Human capacity

Across South Asia, frontline clinicians frequently misdiagnose heat-related illness, mistaking it for other conditions (Chakraborty, 2024). Updating medical, nursing, and allied health curricula to include climate-health competencies is essential. In-service training modules must enable providers to recognize, treat, and prevent heat stress, while managing its interactions with chronic diseases, maternal health, and mental health. Task-sharing models—empowering community health workers to monitor vulnerable populations and deliver early interventions—can extend the reach of care in resource-constrained settings.

Programmatic pathways

Heat resilience must also be embedded within existing health programs. Maternal and child health, noncommunicable disease management, and WASH programs should integrate heatwave-specific protocols. Nutrition schemes, including school meals and the public distribution system, must adapt to heat- and drought-induced food insecurity. The National Programme on Climate Change and Human Health provides a national scaffolding for such integration, but sustained progress will depend on state-level innovation, financing, and accountability

Infrastructure

A credible adaptation agenda also must confront the challenge of building climate-resilient health systems—particularly those capable of responding to extreme heat. Heat waves and floods routinely strain India's health facilities, disrupt power and water supply, and overwhelm staff. Strengthening resilience, however, requires both structural and functional reforms, including in facility design and siting, updated building codes for public and private providers, and national standards for climate-resilient infrastructure. Existing frameworks such as the Indian Green Building Council's rating system and the Ministry of Health and Family Welfare's guidelines for green and climate-resilient health facilities (NCDC, 2023) provide useful starting points. Mandating their application to future building codes and standard procurement processes for health facilities would be a practical first step.

In conclusion

India's health system stands at a crossroads. The country has made commendable progress in data digitization, surveillance, and programmatic innovation. Yet, the accelerating pace of climate change—and the centrality of heat as its most visible manifestation—demands an urgent shift from incremental adaptation to systemic reform. Strengthening data systems, building locally relevant evidence, and investing in resilient infrastructure and workforce capacity will be essential to safeguard health in a warming world. Centering heat adaptation within this agenda can provide the practical and conceptual foundation for a broader transformation toward climate-resilient health systems.

9. FINANCE FOR HEAT ADAPTATION

Kartikeya Bhatotia, Mihir Bhatt, Jorge Gastelumendi

Source: David Trilling

The escalating impacts of climate change demand timely and adequate financial resources for adaptation. Yet finance for adaptation continues to lag dangerously behind projected needs. Global flows of adaptation finance reached $65 billion in 2023-24 (Climate Policy Initiative, 2025), but developing countries alone require more than $310 billion annually (UNEP, 2025). This gap is especially stark in the context of extreme heat, where costs are dispersed across sectors and often excluded from national and subnational budgets. Unlike cyclones or floods, extreme heat does not typically leave visible scars of damage, even as its human and economic toll is immense in the form of ill health, reduced productivity, higher energy demand and accelerated damage to infrastructure. Policymakers and financiers alike have long underestimated heat's macroeconomic effects, and an apathy toward cooling finance persists even though demand for air-conditioning, thermal retrofits and shaded infrastructure expands across India's cities.

Adaptation finance has gained prominence across recent international climate negotiations, evolving from a marginal issue to a core pillar of the Paris Agreement and subsequent COPs as countries pressed for stronger support for resilience. At COP30 in Belém, this trajectory sharpened significantly. Countries signaled intent to triple adaptation finance by 2035, philanthropic funders expanded climate and health commitments, and India began developing a unified climate finance platform with support from the Green Climate Fund to operationalize its first National Adaptation Plan (Mishra, 2025). These developments create a timely opening to integrate heat resilience into national planning and fiscal systems.

Integrating heat into India's fiscal frameworks

Financing heat resilience faces multiple challenges. The near invisibility of heat impacts within fiscal, financial, and planning systems undergirds the persistent underfunding of adaptation projects. Consequently, informal workers, small businesses, and families shoulder significant heat-related costs—spending on cooling devices, lost income on dangerously hot days, and higher health expenses—with little support from public financing.

India's federal architecture shapes how heat resilience is financed. Municipalities rely on limited own-source revenues, Centrally Sponsored Schemes, state-sponsored programs, and statutory grants from the Finance Commission (Finance Commission of India, 2020). These fragmented financial channels complicate coherent investment in heat resilience. Tracking these flows is increasingly necessary as India develops a climate finance taxonomy that may eventually include adaptation categories (Gupta and Bhatotia, 2025). Disaster financing structures also hold potential. The National Disaster Management Authority and state disaster management authorities (SDMAs) administer funds divided into the State Disaster Response Fund and the State Disaster Mitigation Fund. The mitigation window remains underused and can support resilience investments, including heat-mitigation programs, more systematically.

Ultimately, making heat visible means reframing it not just as a public health issue, but as a macroeconomic and fiscal risk. Extreme heat affects labor productivity, energy stability, and agricultural output, which are core pillars of economic performance. Emerging research in India, for example, has pointed to the effect of heatwaves on food inflation (Bhandari, 2024), and our own field work demonstrates crippling economic effects of hot days on daily wage earners. Recognizing these linkages would justify integrating heat metrics into macroeconomic forecasting and public expenditure reviews.

Path ahead

At the national level, where fiscal and disaster management powers are distributed across governments, there is scope to clarify how the financial instruments of the Finance Commission, the National Disaster Management Authority, and the Ministry of Finance align with one another. Performance-based grants could encourage states to integrate heat resilience into local planning. Urban local bodies, including municipal corporations, municipalities and nagar panchayats (city councils), can further support visibility by creating budget lines for heat resilience under health and environment.

Budget tagging, a system that assigns identifiable codes to expenditures linked to specific policy priorities (World Bank, 2021), helps governments track how much is being spent across ministries and programs. India applies this approach for gender-responsive budgeting and sustainable development goals spending (NITI Aayog, 2024), providing a framework that could extend to heat resilience. Tagging could track heat-related expenditures across departments such as health, labor, housing, and urban development (PIB, 2023). States such as Gujarat, Odisha, and Telangana—with active heat action plans and established disaster management systems—are positioned to pilot heat tagging within the State Disaster Response Fund and climate budget statements.

Other fiscal tools could complement these approaches. Instruments like taxation have been proposed, including levies on products and processes that contribute to urban heat—such as asphalt, glass façades, and energy-intensive construction materials. These revenues could be earmarked for local cooling initiatives or energy-efficiency measures. While no Indian municipality has yet implemented heat-specific levies, analogous environmental tax mechanisms are already in use (e.g., the construction levy under the Building and Other Construction Workers Act). Additional options include redirecting a share of building-permit fees or environmental-compensation funds toward cooling projects, offering rebates for reflective materials and using congestion or parking charges to finance shaded public spaces.

Household financial resilience

Disaster-risk finance provides liquidity during climate shocks and supports rapid public response. In the case of extreme heat, where losses relate largely to income rather than assets, traditional indemnity insurance has limited relevance. Parametric, community-based, and publicly reinsured models offer more practical alternatives. Parametric insurance triggers automatic payouts when predefined thresholds such as temperature, humidity or heat index are breached. The Extreme Heat Income Micro-Insurance pilot by the Self-Employed Women's Association (SEWA and the Atlantic Council's Climate Resilience Center illustrates one such model (Ro, 2023)). Covering 21,000 women workers across seven sectors, the scheme compensates participants when heat makes it unsafe to work. Public reinsurance pools through Insurance Regulatory and Development Authority or National Bank for Agriculture and Rural Development (NABARD) can help stabilize premiums and support scale. The limitations of parametric triggers, and the structural hurdles to expanding these schemes, are discussed in Chapter 6 of this paper.

The All India Disaster Mitigation Institute's experience across 11 cities shows willingness among heat-exposed households to pay modest premiums when coverage is reliable (AIDMI, 2025). Linking insurance to social protection systems such as health or education subsidies can reduce costs and deepen resilience. Insurance works best when paired with public investment that reduces exposure, including cooling infrastructure, climate information services and anticipatory finance.

Anticipatory finance, or forecast-based financing, is emerging as an effective way to act before disasters occur. For heat, this approach can be transformative. By linking India Meteorological Department early warnings to pre-authorized disbursements from the State Disaster Response Fund or urban climate budgets, governments can release funds for water distribution, health outreach, and cooling-center activation before temperatures reach dangerous levels. Evidence from forecast-based financing pilots (IFRC 2021) in other disaster contexts suggests that early action can also be significantly cheaper than post-event relief, reducing overall response costs by acting before conditions deteriorate and needs compound.

Global pilots offer models for such localization. The National Disaster Management Authority and state authorities can formalize trigger-based funding protocols in heat-prone states and create a predictable regime that reduces delays between forecast and response. These releases may include direct cash transfers to vulnerable households and informal workers who face income loss during extreme heat. As noted in Chapter 6, however, recurring cash transfers require careful consideration of fiscal sustainability. At the community level, no-regret micro-grants to self-help groups and small businesses can prevent income loss and reduce post-event relief needs. Contingent credit lines through NABARD or state treasuries can provide liquidity to municipalities during prolonged heat periods. These mechanisms rely on existing fiscal infrastructure and remain scalable at low cost. They avoid the daunting task of having to distinguish between different forms of extreme precarity, as other instruments may require.

Toward a unified investment strategy for heat resilience

The potential funding sources for heat resilience are diverse but remain fragmented. At the domestic level, governments can mobilize intergovernmental transfers, tax revenues, user fees, and land-value capture. International sources include official development assistance, concessional loans and dedicated climate funds such as the Green Climate Fund and Global Environment Facility. India must, however, remain pragmatic about climate finance during a period of donor fatigue and high global debt (Tandon, 2025). States and municipalities can expand fiscal space by experimenting with climate-linked bonds or resilience funds, which pool resources across adaptation priorities and attract private capital through partial guarantees or blended finance. Over time, a unified cooling finance facility could coordinate public, philanthropic and private flows into a coherent pipeline of investable projects.

Private-sector investment in heat resilience requires realistic expectations. Many heat-related costs are easily externalized, weakening the commercial case for large businesses to invest directly in adaptation. Regulatory standards, risk-sharing arrangements and targeted incentives are therefore more likely to mobilize private participation than market forces alone. Fiscal and credit incentives can support firms in investing in worker cooling, retrofitting and supply-chain resilience when these investments serve clear operational needs. Micro-enterprises, which dominate India's informal economy, can access support through municipal and cooperative credit programs that finance cooling and hydration infrastructure (AIDMI, 2023; 2025).

Recognizing cooling as a productive asset class would direct capital toward households and firms most exposed to rising temperatures. Over the longer term, India will require a financing architecture that brings together the diverse sources of finance. A blended architecture could support resilient cooling, climate-smart urban development, social protection and infrastructure suited to higher temperatures, shifting heat adaptation from isolated projects to a coherent national strategy that strengthens health, productivity, and economic stability. The following strategies are likely to be complementary:

1. India's immediate task is to establish the fiscal and institutional foundations for heat resilience. This includes defining budget lines, strengthening early-warning systems and anticipatory financing, and improving coordination between states and cities. Sectoral budgets in health, labor, housing, disaster management, and transport will need to converge to provide enforceable expenditure pathways for heat action plans, as colleagues have argued elsewhere in this paper. Pooling small interventions like sectoral schemes and programs into larger facilities like pooled financing mechanisms and climate bonds can lower transaction costs and attract institutional investors.

2. Demand-driven financing: Insurance and forecast-based financing provide short-term support, but lasting resilience depends on reforming how adaptation investments are valued and financed. Heat resilience generates benefits that include higher productivity, lower healthcare burdens, and reduced energy demand, yet these gains are rarely captured in current appraisal frameworks. Who captures these gains depends on who bears the underlying costs. Where governments fund healthcare, reduced heat-related illness translates directly into fiscal savings, strengthening the case for public investment in adaptation. Where businesses absorb health and productivity costs, the incentive to invest shifts to employers. In India, however, most informal workers bear health expenses out-of-pocket, meaning the economic benefits of adaptation accrue to those least able to finance it. This mismatch reinforces the need for public and blended financing mechanisms that internalize benefits currently dispersed across the system. Developing valuation methods for heat adaptation, supported by improved data systems, can enable new instruments such as impact bonds and resilience credit lines. Community-defined metrics, such as caregiving burdens, wage losses and local exposure patterns, should inform project design so that financing aligns with lived experience.

Without deliberate financial architecture that matches the scale and urgency of rising heat exposure, India risks a future where adaptation remains perpetually reactive, inequitably distributed, and insufficient to protect the health, livelihoods, and economic stability upon which hundreds of millions depend. Advancing this agenda will require cross-sectoral working groups drawing on government finance and disaster management officials, public health agencies, private insurers, and worker organizations to develop a shared framework for heat adaptation financing. India's forthcoming National Adaptation Plan and recent developments toward unified national platforms (Mishra, 2025; Bhatotia, 2025) offer immediate institutional entry points for this effort. The choices made now—in budget allocations, institutional design, and financing mechanisms—will determine whether India builds resilience alongside growth, or whether heat becomes an escalating constraint on both.

REFLECTION: CONVERSATIONS ACROSS THE CLIMATE DIVIDE

Tarun Khanna

Conflicting emotions consumed me during the India 2047: Building a Climate-Resilient Future Symposium in Delhi: trepidation at the enormity of the adaptation task; dismay at the insouciance and resigned indifference of some of the authorities. At the same time, I was energized by the possibility that even simple actions could have dramatic effects; and bemused by how hard it was for different communities to communicate across divides, even on what is an existential challenge for the world, especially for 'hot' countries like India. It appears that a lot gets 'lost in translation' between well-meaning entities, to borrow from Bill Murray and Scarlett Johansson's celebrated film.

Two vignettes anchor my memory of the symposium. In the first, a young woman, a SEWA sister from the fabled Indian union of informal women workers, raised her hand during the question-and-answer part of a rather humdrum panel of experts and in confident Gujarati bluntly asked the equivalent of 'What does all this have to do with me?"

She could not fathom her connection to the jargon-filled discussions on El Niño, erratic rainfall patterns, genetically modified crops, and other esoterica. Her lived experience suddenly made the hour preceding it worthwhile, and watching the panelists—genuine experts as they were—struggle to respond brought home to me the importance of engaging with the young lady's perspective, as much as experts wrestle intellectually with each other.

The second was a panel on informal work, the part of the symposium in which I was most engaged. A prominent food-delivery company, valued in the billions of dollars, was represented by the executive handling relations with the thousands of gig workers who brave the roads and weather hazards in executing their timely deliveries. His representation of what the company did to take care of the gig workers was met with a frank accusation of falsehoods from an attendee who seemed to represent the company's union.

I recalled that there is evidence, albeit from the U.S. public markets, of large companies investing—in their own self-interest—in so-called climate adaptation and resilience, increasingly at scale, often to protect workers who are more exposed (Wong & Kim, 2025). So, I prefer not to think of the manager's representations as intentionally disingenuous. Rather it just seemed like different worlds colliding—the elite manager unable to grasp what the gig workers endure in the heat, unaware of the existence of a universe of experiments unfolding in different parts of the world. In both vignettes, just lost in translation.

So what is one to do? I learned, also from the conference, how some existing efforts at bridging the informational and cognitive divides had proved futile. One young Cambridge academic told me of his lab's work showing the dismal failure of a litany of behavioral interventions that were believed—by expert opinion—to induce greater awareness of climate change and trigger concrete actions in response (Vlasceanu et al., 2024). These did not, in a statistical sense, seem to meaningfully move the needle on awareness, however, except for those who were already predisposed to believe in the importance of climate change adaptation; it did nothing for the skeptics. Further, the one intervention where the respondents had to exert some effort to demonstrate intent, rather than purely evince cheap talk, showed no result whatsoever. Dismal!

Later, when I reconnected with this colleague, almost begging to see if any later results were less dispiriting, he offered a study that seems to show that appeals to moral values such as purity and sanctity can trigger public support for climate action at scale (Goldwert et al., 2026). Meanwhile, I became aware of my neurosurgeon colleague reporting insights for how to promote climate-adaptation-supportive behavior by understanding the wiring of the brain (Duhaime 2022). I'll take solace in these advances for now, but clearly we're very far from where we collectively need to be!

For the social scientists among us, we need to experiment with greater abandon—our existing repertoire isn't quite yielding results. My hunch is that tapping into forms of expertise from outside our somewhat parochial and elite circles is long overdue. It is important to examine how and where we seek solutions. As I think of the gleaming glass and steel structures—willfully oblivious to the local climate—that have now redefined Delhi's aspirational skyline, my mind is drifting to the floating structures in Bangladesh's riverine deltas as water levels rise, and to my childhood home in exceedingly hot old Delhi where deep underground structures offered deliciously cool subterranean air with no fossil fuels burned, or the beautiful stepwells of Gujarat simultaneously addressing heat and water supplies and providing a social milieu to boot. In stark contrast, current modes of experimentation seem so limited, so unimaginative—where, to date, even the wealthiest nation in the world struggles to guarantee access to water, sanitation, and rest breaks to workers toiling in heat.

How do we tamp our hubris and expand our horizons of inquiry as we desperately try to forge a way out? Relying on us so-called 'experts' isn't cutting it, at least not yet. The SEWA sister who, in the New Delhi panel, dismissed the findings we were regaling ourselves with as irrelevant to her day-to-day life, was clearly on to something. But those most affected by climate change are not yet at any negotiating table. They are excluded from academic deliberations, geopolitical discourse, as well as financial arrangements. The conference was an attempt to change this phenomenon, ensuring that the people we are planning for are front-and-center in these conversations. Routinely engaging with the exposed farm worker in the Central Valley in California, or the fisherwomen in coastal Bangladesh, or the ship breakers in Gujarat, or the two-wheeled gig workers delivering meals and bobbles ever faster to consumers around the planet already being forced to adapt—this can't but move us forward.

Embracing Mother Nature is hardly a new idea. But for the 'experts' among us to implement this at scale in any real sense would be refreshingly novel. It's hard to break free of existing informational, social and cognitive shackles, fossilized as they are in our university and policy silos. But this difficulty does not excuse us from finding a way to replace today's cacophonous discussions across the climate divide with more constructive dialogue. Questions from the marginalized may stump us. Isn't that the point? It forces reckoning. In whose service do we seek to deploy our scientific advances?

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