PLOS CLIMATE

RESEARCH ARTICLE

How are Indian cities adapting to extreme heat? Insights on heat risk governance and incremental adaptation from ten urban Heat Action Plans

Chandni Singh*, Divyanshi Vyas, Sheetal Patil, Nihal Ranjit, Prathijna Poonacha, Swati Surampally

School of Environment and Sustainability, Indian Institute for Human Settlements, Bangalore, India

* chandni.singh@iihs.ac.in

Citation: Singh C, Vyas D, Patil S, Ranjit N, Poonacha P, Surampally S (2024) How are Indian cities adapting to extreme heat? Insights on heat risk governance and incremental adaptation from ten urban Heat Action Plans. PLOS Clim 3(11): e0000484. https://doi.org/10.1371/journal.pclm.0000484

Editor: Jamie Males, PLOS Climate, UNITED KINGDOM OF GREAT BRITAIN AND NORTHERN IRELAND

Received: April 7, 2024

Accepted: August 13, 2024

Published: November 15, 2024

Peer Review History: PLOS recognizes the benefits of transparency in the peer review process; therefore, we enable the publication of all of the content of peer review and author responses alongside final, published articles. The editorial history of this article is available here: https://doi.org/10.1371/journal.pclm.0000484

Data Availability Statement: Data is available in the supplementary material.

Abstract

Cities are exposed to and concentrate heat. Indian cities are particularly at risk with terrifying projections of extreme heat, especially for vulnerable populations. Recognising this growing heat risk, Indian cities have been frontrunners in heat action planning, experimenting with a range of actions, typically through city-level 'Heat Action Plans' (HAPs). These plans articulate a range of imaginations about which sectors or population groups are considered vulnerable, what actions are deemed effective and feasible, and what capacities cities are investing in. Reports of the efficacy of these HAPs from recent heatwaves in 2022 and 2023 demonstrate the uneven and inadequate nature of these plans. This study begins with the hypothesis that urban heat action planning in India has made significant strides but remains incremental in nature. This hypothesis is explored through a review of ten HAPs and 25 in-depth interviews with HAP designers, funders, and implementers. We find that current heat management governance structures, institutional capacities, and financial mechanisms, carry with them the 'institutional thinness' of Indian climate governance and a hangover of relief-oriented approaches in disaster management. This overlooks lessons from adaptive governance, which highlights the importance of flexible, forward-looking decision-making. Further, incremental actions such as water kiosks in public spaces and public awareness campaigns on heat impacts, while essential, often preserve the status quo, and need to be complemented with transformational, system-wide agendas such as targeted implementation of heat-resilient building codes or a better articulation of how cities can balance grey-green-blue infrastructure solutions. Currently, the highly evolving HAP governance arena is infused with new actors, technologies, and metrics of defining effective urban heat management and this dynamism is promising. However, not tasked with or equipped with a transformational agenda, heat risk governance is missing an opportunity to institutionalise proactive, decisive, and effective heat action planning in the country.

Funding: This work was funded under the Climate Change Local Adaptation Pathways (CLAPs) project (Project number 300126) by UK aid from the UK government; however, the views expressed do not necessarily reflect the UK government's official policies.

Competing interests: On behalf of all authors, I confirm there are no competing interests that could be perceived to bias this work.

1. Introduction: Rising heat in India and the imperative to adapt

All climate change projections point to one undeniable fact: extremely hot days are going to increase in intensity and frequency in the near future, and South Asia is going to be at the forefront of this rising heat hazard [1, 2]. India in particular, is in the unenviable position of being highly exposed to this increasing heat while being home to a large and deeply vulnerable population [1, 3, 4]. In this narrative of rising heat, cities are particularly exposed and concentrate highly vulnerable populations and livelihoods. In cities, urban geometry and heat-generating activities heighten temperatures, all of which contribute to the urban heat island effect [5]. When overlaid with poor abilities to invest in cooling infrastructures, and existing matrices of poverty and livelihoods vulnerability, heat in Indian cities exacerbates socio-economic marginalisation and inequality [6].

What will this changing nature of heat look like? Currently, wet-bulb temperatures (a measure of temperature and humidity) in India rarely exceed 31˚C, with most of the country experiencing maximum wet-bulb temperatures of 25 to 30˚C. Under high greenhouse gas emissions scenarios, cities like Lucknow and Patna in north India are expected to reach wet-bulb temperatures of 35˚C by 2100, while Bhubaneswar, Chennai, Mumbai, Indore, and Ahmedabad are at risk of reaching wet-bulb temperatures of 32 to 34˚C. While this appears far into the future, we are already seeing signals of changing heat today. Heatwaves are coming earlier in the year [7] (spring in 2022 was notably hotter and this trend continued into 2023); night-time temperatures, crucial for the body to regulate and recover from daytime heat, are going up [8]; and humid heat is already testing coastal areas. A quantitative decline in work performance of up to 40% under high-emissions and 35% under lower emissions scenarios is projected [9]. Even at current warming levels, it is estimated that annually, 1116 deaths were attributable to heatwaves in India [4] with substantial regional variations [10].

This heightening and changing nature of extreme heat is expected to have direct, tangible impacts on human health, livelihoods, water availability; and cascading impacts on incomes, energy demand, infrastructure functioning, and food security. For example, at current warming, 2 out of 1000 children die as infants in India from heat during pregnancy [11]; it is estimated that current humid heat may have led to labour losses up to 7% of India's GDP (at 2017 levels) [12]; and increasing frequency of concurrent droughts and heatwaves [13] are already impacting agricultural yields [14].

Promisingly, over the past decade (especially since Ahmedabad's foundational Heat Action Plan (HAP) in 2013), India has been experimenting with a range of solutions to prepare for, manage, and ameliorate heat risk [15].

It is estimated that the country has more than 100 Heat Action Plans at state, district, and municipal scales, with cities at the frontline of heat action planning [16]. An assessment of 37 of these Heat Action Plans finds an impressive array of infrastructural, nature-based, informational, technological, and behavioural solutions being implemented, piloted and proposed [17]. This begs the question, in this moment of increasing heat risk and active urban heat management action, are the lacunae in India's 'thinly institutionalized' climate governance [18] and 'fast-acting (disaster) state' [19], also replicated in heat governance in the country? Or, despite being sites of deep and unequal heat risk, are cities and their Heat Action Plans undertaking transformational adaptation? Finally, what lessons does this first decade of heat action planning and management hold for disaster governance in India and similarly heating geographies?

In this paper, we begin examining these questions, recognising the changing role of climate governance in cities as well as the expanding solution space for urban heat management in India. Indian cities have been repeatedly applauded for being at the forefront of heat action

regionally and globally. A decade into their experiences of heat management and planning, it is an opportune moment to examine what is emerging.

2. Adapting to heat: Insights from the literature

2.1 Insights from adaptation theory and governance

The climate change adaptation literature on reducing risk to extreme events has coalesced to argue for three ideas that are relevant to understanding heat management and adaptation. First, there is a deep acknowledgement that *structural drivers of vulnerability determine overall risk* [20–23]. Second, the literature calls for moving away from discrete adaptation interventions to more strategic, sequences of actions or *adaptation pathways* [24–27] that have a transformational agenda [28, 29]. Finally, one of the ways to deliver this transformational agenda is the vehicle of *adaptive governance*, i.e. flexible decision-making processes with adequate human and institutional capacities to manage and prepare for increasing risk despite large and often incompletely knowable uncertainty. Let us now examine these three aspects in detail.

Acknowledging underlying vulnerability mediates risk. Planning for extreme heat has typically tended to use an emergency framing [30], emphasising the need to prevent heat-related deaths and minimise heat stress without an accompanying focus on addressing the root causes of unequal exposure and vulnerability to heat. This focus is in sharp contrast to the climate change adaptation and vulnerability literature, which has demonstrated that hazard intensity and frequency is one part of a more complex story—exposure to the hazard and underlying societal vulnerabilities mediate overall risk deeply [22]. For example, heat is underestimated in informal settlements even though they tend to face higher chronic heat stress because of negligible weather stations in them [31, 32]. Intra-city segregation based on caste or livelihood also shapes exposure to heat [33] and those engaged in outdoor work or precarious livelihoods are most vulnerable. Thus, heat adaptation efforts must acknowledge how vulnerability mediates heat risk—how histories of underinvestment in poor settlements, continued socio-economic marginalisation of certain castes and genders, and power imbalances—shape vulnerability to heat.

From discrete reactive interventions to planned adaptation pathways. The adaptation pathways literature [25, 34] calls for suites of solutions that sequentially build upon each other as heat risk increases, and can help avoid hitting limits of human survivability, especially for the most exposed and most vulnerable. Central to this approach is the need to move away from short-term, discrete, techno-infrastructural solutions to suites of strategies that complement each other and build adaptive capacities for multiple risks. How solutions are sequenced is key—from work on flooding and sea level rise, researchers demonstrate that investing in infrastructural solutions that need high investments reduce risk in the short-term but have negative impacts on coastal livelihoods and ecosystems in the long-term. On the other hand, planning measures such as building codes to protect coasts have long lead times but can be more effective in the long run. Most crucially, 'hybrid solutions' where suites of infrastructural, nature-based, social, and behavioural interventions are used, risk to flooding is reduced the most [35]. Applied to heat management [24, 26], the adaptation pathways literature pushes us to ask questions of what solutions should be prioritised and how they should be sequenced: for example, should amendments in built infrastructure be prioritised over large-scale greening or does flipping this sequence change the outcomes in terms of avoided heat mortality and morbidity?

The imperative of adaptive governance. An adaptive approach to climate governance argues that for complex wicked problems such as climate change, that are dynamic, multi-scalar, and deeply cross-sectoral, institutional structures and processes need to be flexible and

enable forward-looking decision-making, with mechanisms that allow iterative learning. Also needed are targeted investments in individual and institutional capacities to allow for making decisions under deep uncertainty [36]. However, in practice, adaptive governance remains constrained by (1) inadequate capacities among adaptation practitioners and policy makers (including sectoral line departments) to define and operationalise flexible decision-making under uncertainty; (2) low availability of flexible financing; and (3) lack of appetite for experimentation in typical disaster management governance structures [37–39].

Overall, the climate change adaptation literature has been emphasising that for adaptation to be inclusive, engaging with a transformational agenda is necessary. Adaptation research has examined various ways to categorise climate change adaptation actions. Typically, typologies disaggregate adaptation by timing (anticipatory, concurrent or reactive), degree of spontaneity (autonomous or planned) and by scale (adaptation by individuals, households, communities or institutions) [40]. More recently, adaptation actions tend to be characterised as encompassing incremental changes (adjustments) and transformational actions, which signify more radical change that shifts the values and rules underpinning a system [41, 42] (The distinction between incremental and transformational change is blurrier in practice: at times, incremental adaptation when repeated over time can get embedded in systems; sometimes transformative change may be rapid and top-down (Newell, 2021).

Taking these typologies further, work on urban adaptation has argued that in practice, adaptation is more of a continuum, along a scale of incremental-reformist-transformative approaches to managing risk [43]. Here, incremental change denotes making adjustments to maintain business as usual, reformistic change encompasses changing features that cause the problems without fundamentally changing the systemic structures, and transformative change denotes a fundamental change to the system which goes beyond techno-infrastructural interventions to deeper changes in "sense-making, world views, political and power relations, social networks and ecosystems, physical infrastructure and technology" [44]. Ideally, a transformational change agenda entails explicitly engaging with justice and equity considerations by carefully assessing who is exposed, who is vulnerable, and who has the capacities to prepare for/adequately respond to a risk *a priori* [42, 45–48].

Termeer et al. (2017) [47] characterise transformational change as a function of depth, speed, and scale. Depth or level of change "aims to radically change these practices by altering values, frames, and logics underlying the system", moving away from superficial improvements in current practices without altering underlying assumptions. Scope or scale of what is to be changed captures whether the change is large-scale and system-wide versus narrow, i.e., where only specific elements or subsystems are changed. And finally, speed of change refers to the timeframe of change. Berrang-Ford et al. (2021) [49] add a fourth component that examines the extent adaptation actions approach or overcome the limits known to constrain adaptation. Transformational change is thus understood as radical, deep change; that inherently multi-dimensional, multi-component, multi-aspectual, and multi-level; and can either be sudden, a 'revolutionary jump', or change over a long period of time.

The above synthesis of literature is summarised in Fig 1, which demonstrates incremental-reformist-transformational approaches to adaptation as a function of how they approach differential vulnerability; how they prioritise adaptation strategies; and how they govern and implement adaptation. In reality, the continuum caricatures actual adaptation by pressing for incremental and transformational action as two ends of a spectrum. In reality, adaptation is fuzzier (with combinations of incremental, reformist and transformational visible) [50] but the categorisation and push towards these ends forces decisionmakers to examine the nature of different adaptation solutions.

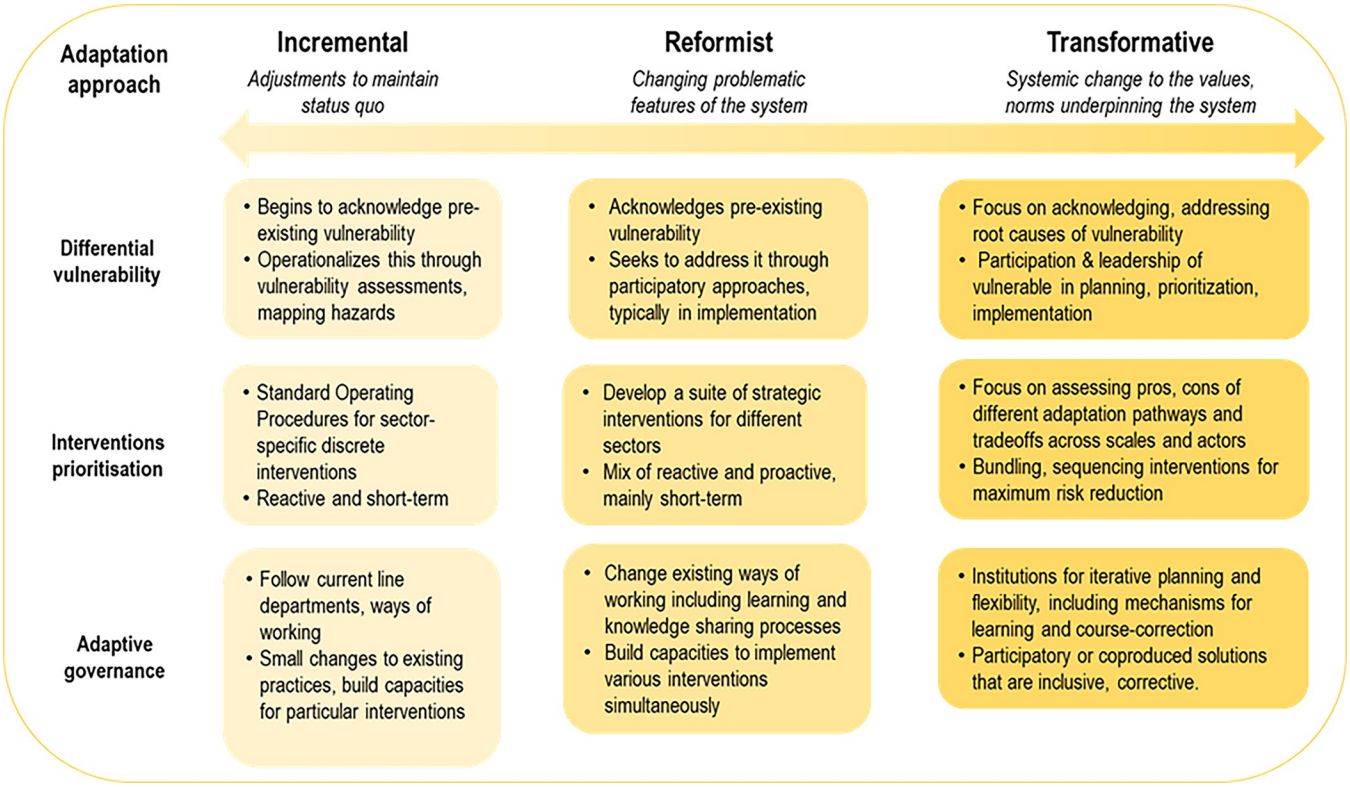

Fig 1. Conceptual framework to examine adaptation approach by how it operationalises differential vulnerability, prioritises adaptation interventions, and governs adaptation action. Source: Authors.

https://doi.org/10.1371/journal.pclm.0000484.g001

2.2 Adaptation and disaster risk management approaches in India

In the Indian context, various approaches to governance of climate change in development planning have been suggested, from mainstreaming approaches that call for articulating climate change goals within development planning (Sharma & Tomar, 2010) to co-benefits approaches that highlight how climate actions can have synergies for development goals and vice versa [51].

Urban climate plans and actions in India have been critiqued for lack of definitional clarity [52], absence of a nation-wide urbanization policy [37] and incomplete implementation of national and state climate policy at city scales. Newer work from urban climate action discusses 'strategic urbanism' where climate adaptation is realised by engaging in discrete, intentional, sectoral interventions (e.g., Chu et al., 2016 [53] in Surat) to the reality of 'superimposition' of climate change *over* present urban planning and development (e.g., Bhardwaj & Khosla, 2021 in Rajkot and Coimbatore [54]).

In parallel, the larger literature on and longer experience from disaster governance offers lessons for climate governance in India. First, disaster management in India is deeply rooted in the colonial legacy of the Indian relief state [55] where "narratives of improvement pursued both by colonial rulers and postcolonial development regimes" (p. 2) render certain communities, livelihoods, and places as valuable or discardable, revealing underlying narratives of what is valued. These narratives of 'improvement' rather than radical disruption of the root causes of socially constructed disasters mirror ideas of incremental adaptation—they offer the solace of visible action while allowing historical vulnerabilities to sediment, thereby reproducing and intensifying socially constructed disasters. This literature also cautions that disasters are socio-

environmental ruptures where capitalist agendas are "harnessed for radical social and economic re-engineering" [56, p. 49] and this is incipiently visible in pushes towards rolling out short-term, often expensive, infrastructural solutions such as cool roofs in India, at the cost of deeper changes in how cities are built and planned.

Given these insights on planning for and managing extreme events, including heat, how are heat action plans (HAPs) in Indian cities taking these calls for adaptive governance and adaptation pathways into consideration? What solutions are they proposing and implementing against this context of the changing nature of heat? And most critically, given that Indian cities are the loci for accruing (unequal) heat risk, are urban governance structures fit for purpose? This paper explores these questions by examining ten city-level HAPs across the country starting from Ahmedabad, South Asia's first HAP, published in 2013.

3. Methodological approach

Assessing heat governance is particularly challenging because of the lack of any centralised repository of HAPs in the country. Over the decades, heatwaves have been coming more frequently and following the 2015 National Disaster Management Authority (NDMA) guidelines on prevention and management of heatwaves, several states and cities have developed HAPs (Fig 2).

In this paper, we draw on ten city-level HAPs (Fig 3), which was sourced through municipal websites and by contacting specific State Disaster Management Authorities. For cities with multiple iterations of HAPs, the latest version was examined (e.g., for Ahmedabad, the 2019 HAP document was used, for Nagpur, the 2022 updated HAP was used).

Each HAP was assessed for the actors involved in developing and implementing the plan, and the heat preparedness and management actions they list in pre-season, heat season, and post-season periods. This desk-based review of the plans (conducted over 01/02/2023 to 25/01/2024) was supplemented with interviews at the national level (two government officials engaged in disaster management including heat management, two climate scientists, and two non-governmental organisation staff working on implementing heat solutions in informal settlements) and 25 key informant interviews (KII) across the ten Indian cities with HAPs. The KIIs were done from 15/07/2023 to 23/12/2023, with at least one government official and additionally, civil society actors and those involved in designing, implementing, and/or revising the HAPs (Table A in S1 Text).

Each KII lasted 45–60 minutes and captured the types of adaptation actions being implemented, how vulnerability was operationalised, how actions were prioritised, and governance arrangements to implement and monitor progress. Each interview was audio recorded and at the start of each interview, verbal consent was sought and recorded. Ethics clearance for this study was received from The Indian Institute for Human Settlements (IIHS)–Research Ethics Committee on 11/07/2023. We acknowledge that this dataset does not capture 'views from the vulnerable' [57], i.e. those experiencing extreme heat and the intended 'beneficiaries' of HAPs. Subsequent work aims to complement these narratives of adaptation from 'the above' [58] with voices from 'the frontline' [19].

Each HAP was coded by at least two people to ensure intercoder reliability, re-code any unreliable codes, and address conflicting codes. The codebook is given in Table C in S1 Text. The HAPs were analysed using the analytical frame in Fig 1 that categorises urban adaptation approaches along a continuum of incremental-reformist-transformative approaches [43]. The interview data were transcribed and coded according to three aspects of risk [22]: i.e., (1) how is the *hazard* of extreme heat understood and assessed and are projections into the future considered? (2) who is identified as *vulnerable* and what processes are in place to identify vulnerable groups or places?, and (3) in what terms is heat *exposure* assessed? To examine the

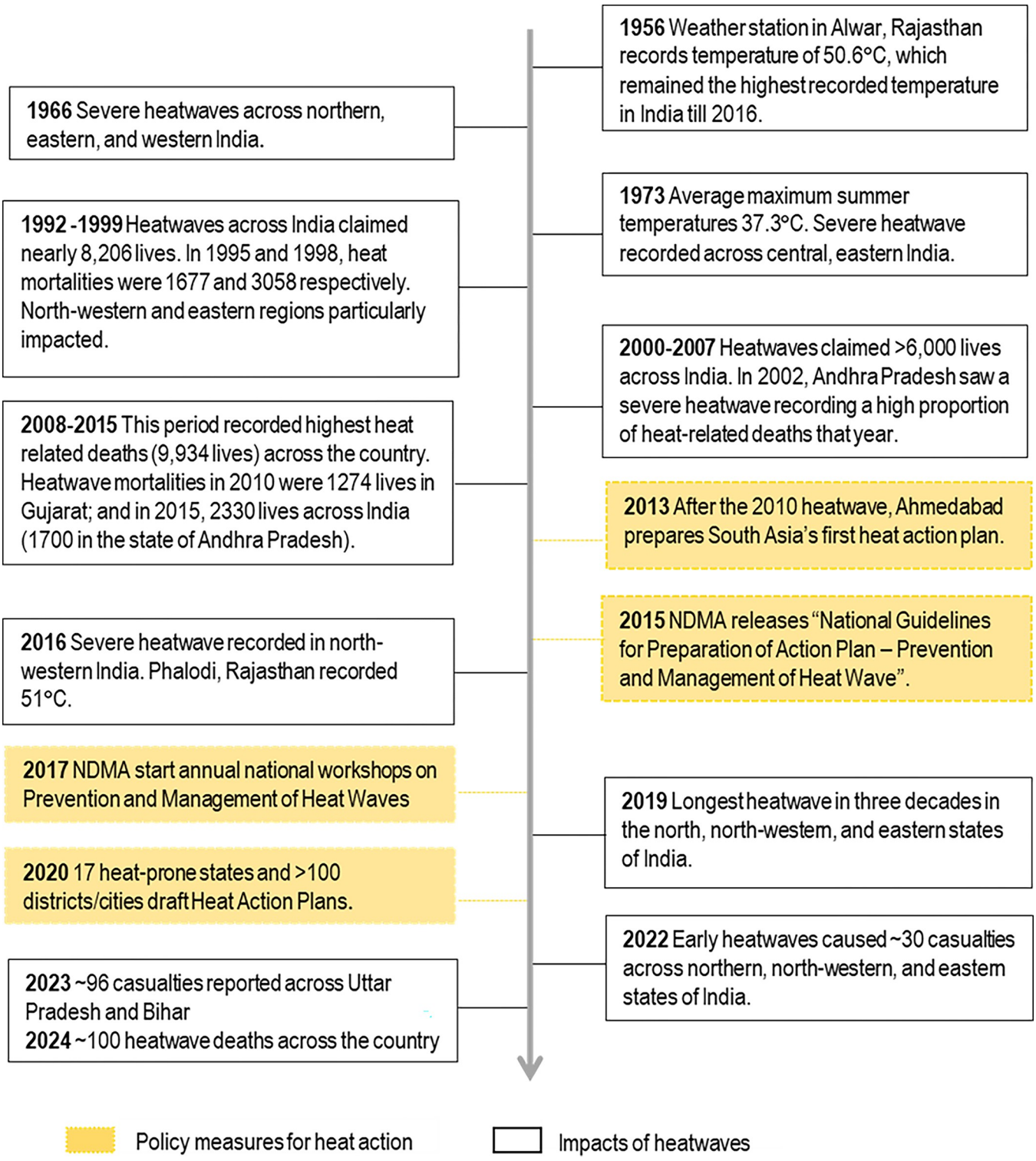

Fig 2. Timeline of major heatwaves in India and the emergence of Heat Action Plans. Source: Authors, based on literature and policy review.

https://doi.org/10.1371/journal.pclm.0000484.g002

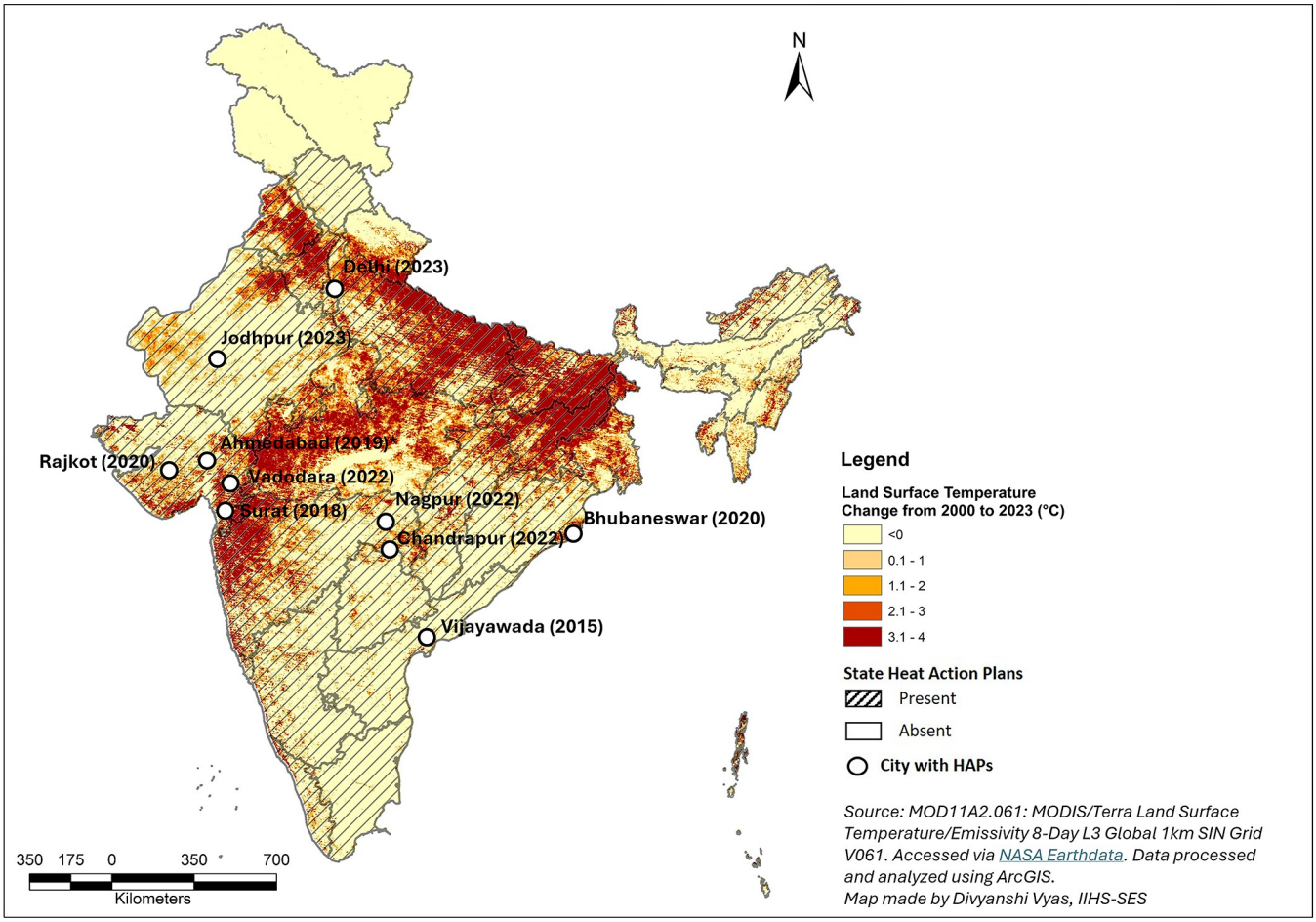

Fig 3. Map of urban Heat Action Plans (HAPs) assessed. [* Year of HAP assessed]. For details on each HAP, see Table B in S1 Text. Base layer for map from: MOD11A2.061: MODIS/Terra Land Surface Temperature/Emissivity 8-Day L3 Global 1km SIN Grid V061. NASA LP DAAC. Accessed via NASA Earthdata. Data processed and analysed using ArcGIS.; Survey of India (2019) from https://onlinemaps.surveyofindia.gov.in/Digital_Product_Show.aspx.

https://doi.org/10.1371/journal.pclm.0000484.g003

evidence on whether an intervention within a HAP is incremental or transformational adaptation, we examine specific proposed interventions (Table B in S1 Text) for their potential for transformation. For example, setting up cooling shelters during heatwaves are coded as incremental because they are reported as one-time, potentially recurring activities in the HAPs, whereas a city-wide cool roofs plan is coded as transformational because it is systemic and denotes a wider intention at a cross-city scale.

Thematic analysis also focussed on heat governance to examine who are the actors in this space, what types of solutions are being piloted or implemented, and the institutional processes and capacities around heat risk management (from preparedness to risk mitigation). Evidence to support the analysis is given in the form of codes (e.g., STATE_TYPE OF ACTOR_KII No. leading to codes for Maharashtrian cities as MH_GOV_1) which denote a specific interview.

4. Findings

We report the findings on how heat risk management is governed (Section 4.1) followed by insights on implementation of HAPs in various cities (Section 4.2), and the outcomes of HAPs as visible currently (Section 4.3).

4.1 Heat risk management in Indian cities: Governance architecture

The institutional architecture of disaster management in the country (a nested system of national, state and district disaster management authorities) elevates the District Commissioner as responsible for disaster preparedness and response. This was a 'colonial innovation' [59] and does not explicitly map onto current urban governance structures that have devolved incompletely under the 74th Constitutional Amendment (The 74th Constitutional Amendment Act (1992) provided constitutional status to *Nagar Palikas* or Urban Local Bodies (ULBs), aiming to decentralise power, finances, and decision-making from central and state governments to ULBs. However, this has been incomplete and ineffective: as Debolina Kundu (2020:65) notes, "The empowerment of urban local bodies (ULBs)—i.e. local government units—through funds, functions and functionaries, as envisaged in the 74th CAA still remains a distant dream." Also see Idiculla, 2020).

The Disaster Management Act passed in 2005, on the heels of three major disasters that struck India—1999 Super Cyclone, 2001 Bhuj Earthquake, and 2004 Indian Ocean Tsunami—is the guiding framework for disaster risk governance nationally. The Act marked a shift from relief- and response-centric disaster governance to one that includes preparedness, risk reduction, and capacity building and mandated establishing national, state and district disaster management authorities. It concentrated significant authority with the central government by tasking the NDMA with planning and executing disaster management plans and policies, and providing guidance for state-level planning [59, 60]. This meant that successive authorities have less leverage, with local bodies having a relatively miniscule role [60]. The Act states that local authorities can take measures necessary for disaster management but does not provide any guidance on what these could be nor on how these activities integrate with those of the district and state authorities. While specific HAPs articulate the Municipal Commissioner as the apex officer of the HAP, Standard Operating Procedures and funding flow through state and/or district disaster management and/or health departments (Fig 4).

In several cities the Municipal Commissioner or municipal nodal officer plays a central role in the heat alert dissemination, alerting state authorities, communicating with the media, and disseminating information to various vulnerable groups. Most HAPs demonstrate how the flow of information from the Indian Meteorological Department (IMD) triggers action and message through line departments and suggests centrality of certain departments such as health, water and women and child welfare.

From the interviews, a range of challenges related to heat management governance architecture emerged. First is the aforementioned issue of mismatches in administrative boundaries between a district where the District Disaster Management Authority (DDMA), chaired by District Collector, is the nodal agency for preparing the District Disaster Management Plan and HAP. The city may or may not overlap with district boundaries and has the Municipal Corporation as the nodal office. The DDMA (with members from different departments) coordinates with government line departments and civic bodies at the district level but NGO participation is restricted to relief and implementation stages for specific vulnerable groups (e.g., street vendors, informal settlements), not HAP preparation (MH_C_02, IN_05).

Second, while anchored and 'implemented' by the state and its various departments, the HAPs uniformly invoke non-state actors and the public at large in managing heat. This occurs in various ways and we illustrate two examples. In Odisha, each district has a HAP (not assessed in this paper) and the capital city of Bhubaneswar also has a HAP. Heat governance is centrally anchored at the state level (the Odisha State Disaster Management Authority or OSDMA), with districts reporting actions to the state. In this model, apart from Bhubaneswar, urban governance actors and structures are somewhat invisibilised. OSDMA organises inter-

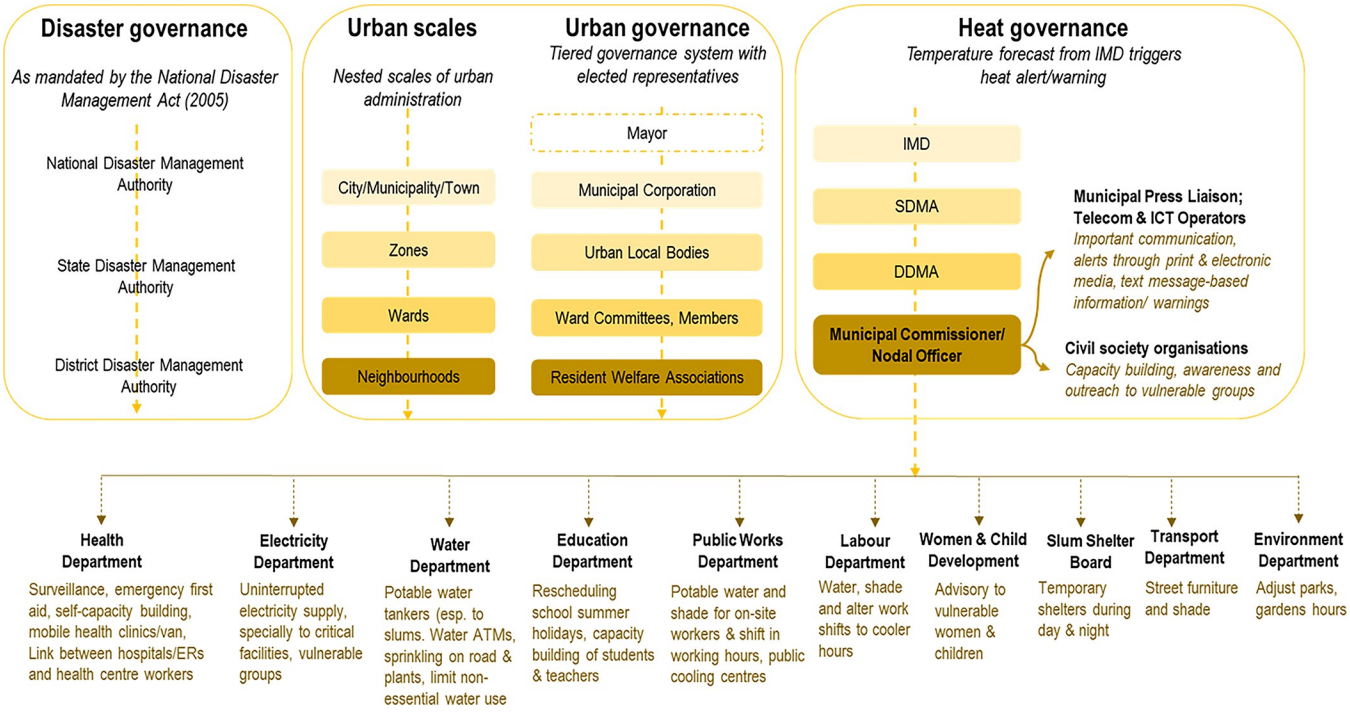

Fig 4. Heat governance architecture in the context of urban governance structures in India. The HAPs identify the municipal commissioner as key in initiating heat preparedness and relief actions. Source: developed by authors based on NDMA (2019) [61] and author analysis of 10 city HAPs.

https://doi.org/10.1371/journal.pclm.0000484.g004

departmental meetings with the state government line departments, knowledge partners to train emergency and health personnel and NGOs to spread public awareness about heat waves. To enable preparation and capacity building, a state-level inter-agency group partners with OSDMA and annual state-level workshops occur where line departments share preparatory measures and actions. A State Executive Committee serves as an apex body for approvals of any activity (OD_B_03, OD_B_04, OD_B_05). In Chandrapur (Maharashtra), the DDMA, chaired by the District Collector is the nodal agency, and the HAP is prepared as part of the District Disaster Management Plan. The DDMA, functioning at the district level, coordinates with various line departments and civic bodies on heat risk management strategies. Further, the DDMA involves NGOs but not at planning stages; ten NGOs working with street vendors are leveraged for awareness campaigns just before or during heat alerts, demonstrating a smaller role of non-state actors (MH_C_02).

The HAP documents list religious organisations and NGOs to support public awareness campaigns, and sites of worship as cooling centres. This is a useful procedural innovation which corrects the oversights that heat governance makes globally, e.g., in European cities, where "an extensive public responsibility borne by local authorities is regarded as pivotal to safeguarding the protection of vulnerable citizens" . . .(but) "where the contribution of private actors, such as health practitioners, community volunteers, families and friends is not viewed as necessary" [62, p. 1075].

Replicating a common trope in disaster governance—that of the paternalistic state (e.g., Chhotray 2022 in the case of cyclones in Odisha [55]), the NDMA guidelines and HAPs articulate the state's role as central to avoiding heat-related deaths. This zero-causality approach is laudable in intent but can divert attention from other preparedness and risk management priorities such as reducing exposure to heat stress or minimising heat impacts of the most

vulnerable (RJ_J_01, IN_04, IN_05). However, there is less decisive guidance or clarity on the state's responsibility to minimise heat stress and cascading heat impacts. In this way, avoiding heat deaths, an undeniably critical and pressing goal on its own, is not matched by a similar focus on avoiding and managing heat impacts on livelihoods, critical infrastructure, and system functioning (e.g., energy, water or health systems).

Most pressingly, at present, India lacks a concrete financial architecture to combat extreme heat. The National Disaster Response Fund and the State Disaster Response Fund constituted under Section 46 and 48(1) of the National Disaster Management Act, 2005, currently does not include heatwaves in the list of disasters that are eligible for assistance (gratuitous relief, relief measures, emergency supply of drinking water, and immediate restoration and repair of infrastructure) from these funds [63]. While, funding up to 10 percent of the State Disaster Response Funds is available for disasters that are notified as 'state-specific disasters' by respective state governments, only a few states—Chhattisgarh, Odisha, Kerala, Andhra Pradesh, Maharashtra, Karnataka, Uttar Pradesh, and more recently Tripura—have included heatwaves in their list of 'state-specific disasters'.

4.2 Heat risk management in practice: A focus on hazard estimation

The IMD issues heatwave forecasts and warnings at seasonal, monthly and daily scales, with an aim to inform and initiate disaster mitigation measures. It differentiates between "hot day," "heat wave," and "severe heat wave" categories and in February/March, the IMD issues a 'Seasonal Outlook' for the summer months (April-June), to inform planning and preparedness [64]. It also provides an 'Extended Range Outlook' during the heat season, every Thursday. Colour-coded warnings for severe weather including heat wave warnings are issued daily for five days (ten days from July 2023) with an outlook for another two days.

In state and district Disaster Management Plans and HAPs, heat, like other extreme events, tends to be viewed as a discrete, singular, hydrometeorological or 'climatic' event. This is visible in the articulation of extreme heat as 'knowable' by assessing past trends of temperature anomalies above a mean (used in all HAPs assessed) and 'measurable' in the form of anomalous extreme temperatures from an average (using the traffic light heat warning system of the IMD). This conceptualisation of heat hazard comes at the cost of other facets such as duration of extreme heat conditions; night-time temperatures, which are critical for the body to recuperate; and interactions of extreme temperatures with humidity.

Defining heat as a singular, knowable event can lend itself to solutions to tackle the hazard rather than holistically examine its interactions with built form, green cover, wind speed etc. Kotharkar et al. (2021) show for Nagpur city that when all these factors are taken into consideration, the city transforms into several islands of differential exposure—a patchwork of uneven heat that mirrors uneven green cover and ventilation, is overlaid on the density of informal settlements, and demonstrates the differential nature of hazard exposure [65].

Currently, departments implementing HAPs do not (and are not expected to) invest in developing localised temperature thresholds because the skills and responsibility of ascertaining and declaring a heatwave sits with the IMD. However, this is changing, as one respondent noted, *"Since 2022–23, different cities are trying to experiment with localised heat thresholds. . .the methodologies are a challenge since each place will have to localise global metrics. . .but there is innovation. . .there is some progress."* (RJ_J_01). Outside the formal HAP process, several researchers too are pushing methodological boundaries of localised heat threshold estimation (e.g., Golechha et al., 2018 for Rajkot and Nagpur [66]).

Given limited two-way communication channels between those who declare heatwaves and those with intimate knowledge of these cities, heatwave declaration becomes a top-down

proclamation of temperature without the scaffolding of understanding how this imprints onto urban social systems. For instance, the IMD declares a heatwave after the criterion for heatwave (i.e. based on the departure from normal temperature and on the maximum temperature) is met for two consecutive days. After this heatwave declaration, the protocol for response set in, implying a reactive approach. Populations that are already vulnerable to heat risk due to higher exposure and/or sensitivity and lower adaptive capacities may be severely impacted even before the formal response mechanism kicks in. "*Kerala has experienced above normal temperatures in the past. For instance, in 2016 and 2019, warnings for intense heat were issued, but heatwaves have been rare*" (IN_01).

Since 2017, the NDMA has conducted multi-stakeholder national workshops on heat preparedness at the start of the year. Through conversations at these annual events, feedback from various state, district and city government officials, as well as inputs from academia and civil society, recent years have seen a nuancing of how the hazard of heat is understood. First, the IMD is now (since 2022–2023) giving advisories that cover hot days and hot nights, duration and intensity of heat, short and medium-term heat forecasts along with advisories on possible actions (e.g. change labour timings etc.). Second, since July 2023, the IMD has been developing a heat index and 'heat hazard score' from 1–10 on an experimental basis, which is expected to be launched in the 2024 heat season [67]. These are promising advances in heat hazard estimation.

4.3 Vulnerability to heat: Who is counted as vulnerable?

4.3.1 Who is vulnerable to heat?. In the ten urban HAPs, vulnerable population groups tend to encompass outdoor workers, elderly individuals, children, pregnant women, and those from economically disadvantaged backgrounds (equated with informal settlements in most HAPs). Further, specific occupations, such as vegetable vendors, auto repair mechanics, cab drivers, and construction workers, are consistently acknowledged as vulnerable livelihoods requiring targeted attention.

Despite the commendable efforts in acknowledging the vulnerability of specific groups, the HAPs treatment of gender and intersectionality is underwhelming and insufficiently transformative in intent. All HAPs identify women as vulnerable, which at first glance, is promising, and in line with India's National Action Plan on Climate Change, which calls for a focus on acknowledging, assessing, and planning for gender-mediated vulnerability [68, 69]. A closer analysis highlights three key points. First, while all HAPs acknowledge gendered vulnerabilities by identifying specific groups like pregnant and lactating mothers, old people, and young children as most vulnerable, they tend to categorise all women as homogeneously vulnerable. Chandrapur, Nagpur, and Vijayawada mention pregnant women and lactating mothers cursorily. These plans overlook how gender intersects with economic status, livelihoods, access to resources, and demographic characteristics such as age, caste, literacy. Bhubaneshwar's HAP demonstrates an intersectional understanding of risk, where the interplay of gender and income are acknowledged in several places. The HAP discusses gender-specific impacts, wage loss by gender, and vulnerability of working women, particularly those in poor households but this does not translate into gender-specific interventions. HAPs like Surat, Delhi, and Jodhpur take a gender-targeting approach (e.g. outreach to women's groups for targeted heat risk awareness in Surat; attempts to create gender-based heat health guidelines on the diagnosis and treatment of heat wave, heat exhaustion, and heat stroke in Delhi) but do not overcome the homogenising logic of categorising women as equally vulnerable.

This lopsided and broad-brush characterisation of all women as vulnerable tends to lead to similarly vague solutions that do focus on specific groups, such as women and the elderly, but

fall short in addressing underlying unequal structures that generate differential and gendered vulnerability.

4.3.2 How is vulnerability to heat measured?. There is a commonsensical understanding of vulnerable groups across HAPs. However, these perceptions of who is identified as vulnerable are based on large, often homogenous groupings of people based on age, gender, livelihood, or income levels. For example, in Gujarat, SEWA Trust has built metrics for threshold-based health insurance, which accounts for economic vulnerability based on occupation. In Vijayawada and Nagpur, researchers are experimenting with methodologies to assess vulnerability based on Local Climate Zones [65] to inform inter-city risk mapping. However, overall, vulnerability assessments focus on one to several indicators but do not necessarily draw from comprehensive, place-based vulnerability assessments. As one district collector articulated, *"We concentrate on educating the people especially old people and pregnant ladies so that they would not get adversely affected during heat waves and accordingly we coordinate. . .We have no access to any scientific study about heat vulnerability. . ."* (MH_C_02).

Some experts also question the focus on vulnerability and advocate for a greater understanding around sensitivity (The IPCC defines vulnerability as the propensity or predisposition to be adversely affected, while sensitivity is the degree to which a system or species is affected, either adversely or beneficially, by climate variability or change (see https://apps.ipcc.ch/glossary/). For example, all pregnant and lactating women are sensitive to heat but those belonging to households without access to clean drinking water (due to underlying factors such as income, social standing etc.) are more vulnerable than others). A public health expert and HAP designer noted, *"Vulnerability is not the right indicator, sensitivity is the one we should look for. People who are exposed and maybe otherwise vulnerable (living in slums, construction workers etc) but if they are acclimated to the hazard should not be considered vulnerable* (GJ_A_01)." Further, vulnerability assessments and resulting heat management actions tend to focus on health (GJ_A_01, MH_N_03, IN_02) without similar attention to spatio-economic vulnerabilities and occupational exposure.

Different HAPs use different approaches and metrics to assess vulnerability. Chandrapur, Nagpur, Surat and Vijayawada HAPs do not have any visible vulnerability assessment in the HAP, pointing to a gap in heat risk planning and targeting. Other cities are leading the way—Ahmedabad's HAP assessed vulnerability among informal settlement dwellers and highly exposed occupational workers focussing on multiple indicators (e.g., preexisting health conditions, heat-related illnesses and symptoms, indoor/outdoor heat exposure, occupational settings, behavioural adaptations to heat, sources of weather and health information, and social connectedness [70].

Bhubaneswar's ward-level vulnerability assessment uses remote sensing (Landsat 8) and data on ambient air temperature to map thermal hotspots across the city. Approximately 100 individuals were interviewed from 10 hotspot clusters to understand occupational risk to heat (The Bhubaneshwar HAP (2020) identifies casual workers as highly vulnerable and impacted by heat stress, with average losses of ₹1–999 (but it is unclear if these are daily or monthly losses). Productivity losses of up to 40% over 1–15 days are also reported but the HAP does not detail). Jodhpur's HAP characterises ward-level vulnerability through socio-economic, physiological, climatological, and behavioural variables, assigning risk scores to decide where interventions are targeted. The assessment identifies vulnerable groups spatially, based on heat-sensitive populations and community assets.

Most respondents mentioned that heat action is targeted towards vulnerable groups but typically had not conducted vulnerability assessments at city or sub-city scales. The targeting of vulnerable groups is often inconsistent and opportunistic. As one civil society respondent said, *"Labourers and people with weaker immunity living in specific locations suffer severe*

impacts. Women and senior citizens are more vulnerable. Observation-based selection of vulnerable areas to distribute these medicines, specifically the market place, high-density areas, where schools and colleges are located." (MH_N_01). However, some innovations around institutionalising vulnerability assessments are underway. For example, *"SOP has been created for gram panchayats to assess sector-wise vulnerability and for each sector there are indicators and thresholds" (GJ_A_03)*. It remains unclear to what extent cities in Gujarat also have SOPs around vulnerability assessments.

4.4 Heat preparedness and management actions in Indian HAPs: Incremental, reformist, or transformative?

Overall, city HAPs exhibit a wide range of heat preparedness actions (e.g., seasonal heat advisories, public awareness campaigns about dos and don'ts, stocking Oral Rehydration Salts (ORS) supplies) and heat management actions (e.g., reducing exposure by providing cooling shelters in public spaces, altering school and outdoor work timings). Table 1 summarises the range of actions listed in the ten city HAPs, categorising them as incremental, reformist, or transformative. A full list of actions in each city HAP are presented in Table B in S1 Text.

The list is impressive in its breadth and scope, covering multiple departments (typically, a HAP details actions for anywhere between 8–15 government line departments) and various types of solutions (from informational and technological interventions, to nature-based and infrastructural solutions). However, a close reading of the solutions demonstrates that most fall towards the incremental end of the spectrum and can be categorised as relief measures once a heatwave has been declared by the IMD. Fewer actions are reformist and focus on particular barriers to an effective heat management approach (e.g., enabling an agile health system by developing specific checklists and protocols for medical emergency workers in Ahmedabad or intentions to build 'cool pavements' to avoid heat reflection from cemented surfaces as in Vijayawada). An important caveat to the categorisation of heat risk management solutions is, as several KIIs noted, the HAPs have transformational aspirations (e.g., focus on green cover in cities) but end up being incremental or reformist when implemented (e.g., one-off planting exercise).

The categorisation of heat management options as incremental, reformist, or transformative has overlaps but is put forth to emphasise that there are many more incremental than transformative solutions for heat currently implemented or planned. There is negligible evidence that HAP actions are transformative (in intent or action) and the few examples that fall in this category focus on built infrastructure (e.g., changing building codes) and nature-based solutions (allotting green spaces within cities) without clear mechanisms of how this will be done, where funding will come from, and which agencies have the mandate and capacity to execute these more systemic shifts. Other analyses of heat-health actions plans have also reported this short-termism [71, 72] where an assessment of 45 plans showed that most plans implement alert systems but implement longer-term urban management and planning strategies most infrequently.

Almost all key informant interviews confirmed that, in their current form, HAPs are incremental and status-quoist. Let us examine the following quotes from different actors:

> *(A) more dedicated team and approach for heat preparedness is required. Dealing with heat should not be treated as formality for just a month or two, it should run over the entire year. We need to look at heatwave impacts from lenses other than medical aspects alone. Currently, we are not thinking creatively. . .no one is thinking about these long-term things.* MH_N_01 —domestic civil society actor

Table 1. Illustrative list of heat preparedness and management actions detailed in ten city-level HAPs in India. The actions are categorised as incremental, reformist or transformational but may span these categories depending on depth and scope of implementation. For a detailed list of all solutions mentioned in the urban HAPs, see Table B in S1 Text.

City (State)	Year	Nodal agency technical partners	Incremental solutions	Reformist solutions	Transformative solutions
Ahmedabad (Gujarat)	2019	**Ahmedabad Municipal Corporation (AMC)** IIPH, Gandhinagar, PHFI, NRDC, Icahn School of Medicine at Mount Sinai, University of Washington, and CDKN	• Activate "cooling centres," such as temples, public buildings, malls, during a heat alert	• Heat checklists for Labour, Health and other relevant departments • Tree-plantation campaign in hotspot areas	• City-wide Cool Roofs programme
Surat (Gujarat)	2018	**Health and Hospital Department of the Surat Municipal Corporation** Resilience Strata Research and Action Forum, GSDMA	• Activate cooling shelters • Public awareness campaigns and information dissemination during a heat wave (e.g., public temperature displays using electronic boards) • Health department-led training and outreach for health workers, link workers, school children, self-help groups, local community • Suspension of non-essential water uses • Tree-plantation campaign along roads, plantation festival in June	• Expand access to shaded areas for outdoor workers, informal settlements, vulnerable groups (e.g., night shelters remain open all day for migrants during heat alert).	
Vadodara (Gujarat)	2020	**Vadodara Municipal Corporation** Fire and Emergency Services, Gujarat State Disaster Management Authority	• Limiting heavy work during extreme heat • Drinking water, staying out of the sun, wearing light clothing	• Collaboration with NGOs/CSOs to improve bus stands, building temporary shelters	
Rajkot (Gujarat)	2020	**Rajkot Municipal Corporation** IRADE supported by IDRC Canada; IIPH Gandhinagar and IMD (specific role unclear)	• Painting roofs white, distributing gunny bags for covering tin roofs/asbestos in slums • Building temporary shelters, provided water in public spaces	• Encourage investing in water bodies, fountains and greeneries in urban areas • Improvising urban landscapes through vertical greenery, roof gardens	
Chandrapur (Maharashtra)	2022	**Chandrapur City Municipal Corporation**	• 'Cold wards' in hospitals, free 'Heat-line' • Daily tap water supply to all households • Covered boxes for traffic police, shaded bus stops, install traffic cameras	• Develop all open spaces in residential lay-outs into parks/ gardens	
Nagpur (Maharashtra)	2022	**Nagpur Municipal Corporation** Public Health Department and Health Division of City Municipal Corporation;	• Drinking water kiosks, shelters in public places • Altered school and work hours • Keep gardens open for the entire day • Awareness programs in vulnerable places		
Vijayawada (Andhra Pradesh)	2015	**Disaster Management Unit, Municipal Corporation of Vijayawada** UNDP, USAID (roles unclear)	• Temporary sheds/shelters for public, orphans, beggars • Potable drinking water at public places (bus and railway stations, prominent junctions) • White wash on houses for reflection	• Investing in cool pavements, promote green building technology and rooftop gardening • Enforce rainwater harvesting in each house	

(*Continued*)

Table 1. (Continued)

City (State)	Year	Nodal agency technical partners	Incremental solutions	Reformist solutions	Transformative solutions
Bhubaneshwar (Odisha)	2020	**Bhubaneswar Municipal Corporation** OSDMA, IRADe (supported by IRDC, Government of Canada), BMC, OSDMA, IIPH-Gandhinagar (role unclear).	• Cool wards in hospitals, medical vans in high heat risk wards, ice pack dispensaries for easy access by vulnerable communities • SMS and WhatsApp early warnings to citizens, NGOs, citizen welfare groups, construction contractors	• SATARK app ('Alert'!) by IMD and OSDMA	• Increasing insulation and building standards, improved building bye-laws and increasing heat tolerance for new infrastructure
Jodhpur (Rajasthan)	2023	**Jodhpur Municipal Corporation—North** NRDC, Mahila Housing Sewa Trust	• Distribute reusable soft plastic ice packs, fresh drinking water • Cooling centres and temporary shelters for affected populations • Sensitization programs, outreach activities, SMS heat alerts	• Household rainwater harvesting • Upkeep of traditional water resources • Communication on water utilisation and local utility protocols to prioritise electricity maintenance for critical facilities. • Tree planting campaigns especially in high-risk zones	• Cool Roof deployment in households in high-risk wards • Modifying urban development plans
Delhi	2023	**Delhi Disaster Management Authority**	• Public awareness campaign during heatwave • Training, outreach for health workers, school children, self-help groups, local community • Altered school and work hours, bus timings • Bus shelters with drinking facilities and cool roofs	• Collaboration with NGOs/CSOs to improve bus stands, build temporary shelters • Expand access to shaded areas for outdoor workers, vulnerable groups (e.g., night shelters remain open all day for migrants during heat alert).	

https://doi.org/10.1371/journal.pclm.0000484.t001

WhatsApp groups (to coordinate heat planning and action) are active throughout the summer months. After the summer months, there is no coordination. There is one-sided conversation, as the work gets assigned but getting an update on implementation is difficult, as heat is not prioritised over other work that the departments already have. Departments involved need awareness and capacity building, and coordination needs to happen throughout the year. MH_N_03—international donor agency working on climate resilience and heat adaptation in India

Awareness campaigns are carried out by the Corporation. WhatsApp groups become very active during the heat periods and messages are circulated in different languages. Awareness is restricted to privileged classes and it is difficult for these messages to reach the most vulnerable. GJ_S_02—city government officer

In most Indian cities, heat action is reactive and more inclined towards corrective action. There is some focus on early warning and reducing health impacts, but there is little to no action aimed towards minimising future risk. These are particularly crucial for small and medium cities that are rapidly urbanising and have scope to incorporate these measures. AP_V_01—researcher working on urban heat mitigation

The quotes above cover multiple aspects of the issues around the practice of urban heat management. First, the sectoral focus on reducing health impacts, while necessary, is not sufficient, given the range of people and sectors exposed to extreme heat. Since solutions tend to be framed as Standard Operating Procedures (SOPs) to specific line departments, which work well for incremental and relief or preparedness actions but are not necessarily well-suited to

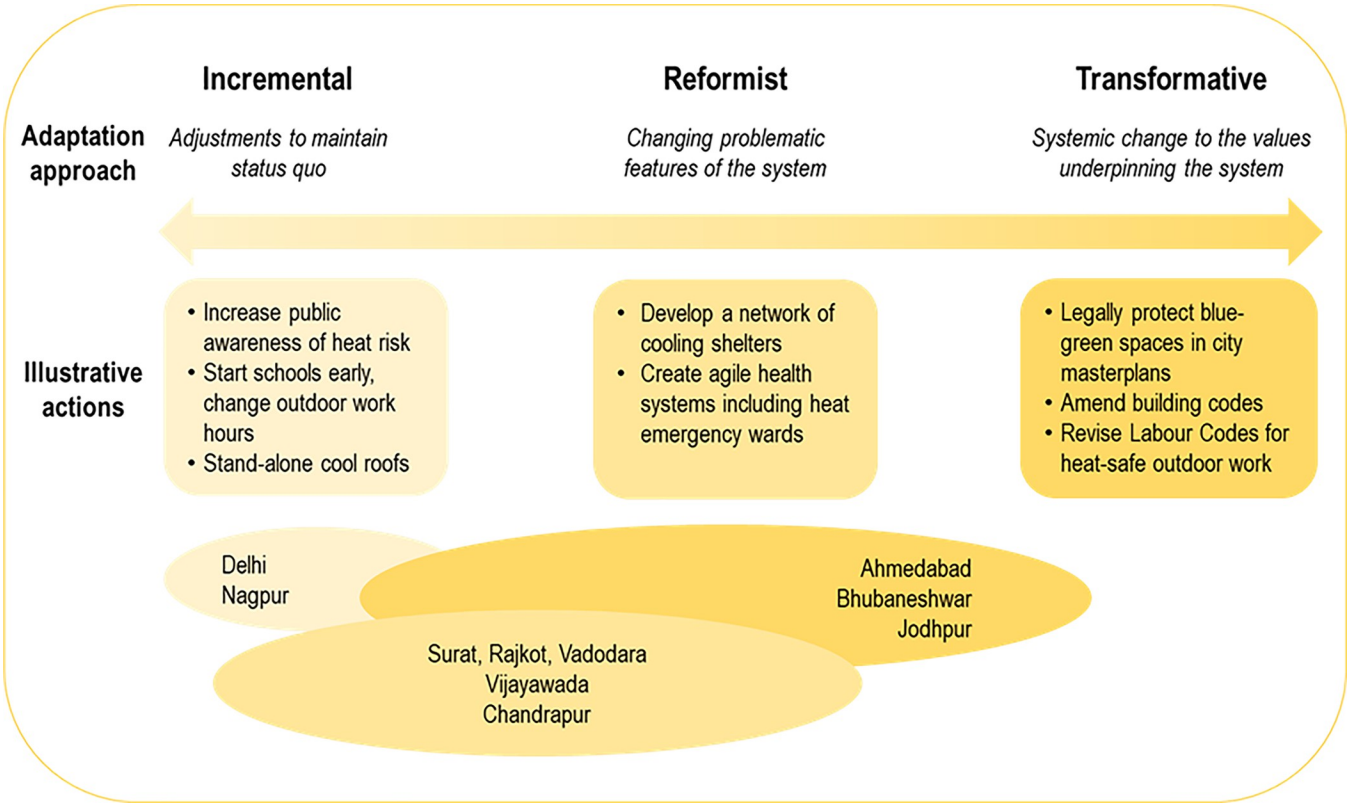

Fig 5. Mapping city HAPs as incremental, reformist, or transformative. HAPs are living documents and as such, may shift as they get revised.

https://doi.org/10.1371/journal.pclm.0000484.g005

reforming systems or leading to systemic change (Fig 5). Such sectoral actions and procedures tend to also avoid acknowledging the compounding of heat with other hazards (e.g., heatwaves coupled with droughts as Sharma & Mujumdar, 2017 show [13]) and cascading nature of heat impacts leading to cross-sectoral negative spillover effects [73]. Second, long-term all-year-round planning is essential and while it is done in an ad-hoc manner, currently, heat preparedness kicks in in February/March (IN_03, RJ_J_01) and relief works take place in May-June. Inadequate long-term planning over 5–10 years means that urbanisation is locking in urban heat through ill-planned built infrastructure. Multiple interviewees echoed that myopic urbanisation is as much a risk multiplier as climate change is. Third, while 'inter-agency coordination' is explicitly mentioned in most HAPs, mechanisms to enable this are sparse. Coupled with the sectoral SOPs approach, it predisposes HAPs to implement a series of disconnected, discrete actions. Finally, a point mentioned by six of the 25 interviewees was that beyond-government collaborations hold potential to invigorate heat management: current partnerships are not institutionalised and the ad hoc nature of engagement with NGOs, donor, and think tanks providing support and expertise intermittently leads to duplication, unnecessary competition, and unclear arenas of engagement (IN_03, IN_04, IN_05).

Some cities like Jodhpur have a nodal officer but heat-related tasks are an additional burden and institutional capacities specific to heat risk management remain low. Some cities are able to leverage lessons and capacities from other hazard management experiences—for example from cyclone preparedness in Odisha. Speaking to the pros and cons of a zero-casualty approach to hazard management, a civil society actor noted, *"(The) intent (towards zero casualties) is there. Odisha was one of the first states to take this approach during cyclone Phailin. It is*

very difficult to gaze at the tipping point when the disasters like droughts and heatwaves, but Odisha has an advantage because of its experience" (OD_B_01).

Since inter-agency coordination is repeatedly invoked as a vehicle for effective heat risk management, we discuss this in some detail. Overall, respondents noted all urban HAPs explicitly mention interagency coordination as a vehicle of coordinated heat risk management, but operationalising this is difficult and ad hoc. Typically, interagency coordination is done through in-person meetings (e.g. all districts meeting in Odisha, anchored by OSDMA) as well as regular online interactions through dedicated WhatsApp groups (mentioned by interviewees in all cities). The flow of information on heat solutions and preparedness measures is typically top to bottom (from state, district to city) (OD_B_05, MH_N_03, IN_02) and heat impacts (mainly on mortality) is from bottom to top. Interagency coordination is also not universal and certain directly impacted sectors such as health are more prominent. For example, a respondent highlighted: '*Inter-departmental coordination is not much, it is there just between the weather department and health. (Departments anchoring) building codes and water supply need to be part of the longer-term strategy*' (GJ_A_01). Further, key departments such as the labour department are involved in a limited manner, mainly as recipients of heat preparedness information rather than active shapers of HAPs and long-term risk planning (MH_C_02). This restricted imagination of interagency coordination as focussed on preparedness and relief without adequate attention to longer-term heat resilience building through, for example, changes to urban planning or revisions to building bye-laws, is a crucial reason why most interventions remain incremental.

Finally, across all the cities, respondents discussed state-non-state cooperation as crucial enablers for state-citizen interactions (OD_B_04, MH_C_02, GJ_S_02). Typically restricted to preparedness and relief approaches, enlisting NGOs and CSOs for heat risk management throughout the year, would be a necessary institutional innovation, with established precedence [74].

5. Discussion and conclusion

This study began with the premise that despite significant progress, planning and implementation around urban heat risk management in India remains reactive and incremental in nature, thereby leading to a potential heat 'adaptation gap'. We reviewed ten city heat action plans (HAPs) and interviewed HAP designers and implementers to understand how HAPs are being formulated and implemented.

Against the backdrop of the growing scale and dynamic nature of current and projected heat risk in Indian cities, we find that current heat management governance structures, institutional capacities, and funding, are somewhat stuck in relief-oriented and incremental preparedness measures, thereby missing an opportunity for transformational adaptation. Certain cities like Bhubaneswar, Ahmedabad, and Jodhpur are demonstrating HAPs that hold transformative potential, with dedicated ward-level vulnerability assessments being used to design and target heat solutions. To what extent these are effective is somewhat established (e.g., in the case of Ahmedabad where HAP performance has been assessed [75]) but for most of the city HAPs, effectiveness for heat risk reduction remains unknown. This needs further research. What has worked in the case of these cities is strong intent and leadership from the city government, robust engagement and expertise from technical partners, and deliberate partnerships with civil society actors across the HAP process. Other research in Indian cities confirms these findings, arguing that urban adaptation governance works when government intent, 'policy entrepreneurs' [76] and community collectives [77] come together.

Across the ten HAPs, we find that current urban heat risk management tends to focus on informational and infrastructural solutions that are not always based on heat projections or

detailed heat vulnerability assessments. Nature-based solutions remain restricted to tree planting without adequate reimagination of integrating blue-green infrastructure in urban planning. Heat management interventions are operationalised as Standard Operating Procedures (SOPs) for specific line departments and during specific time periods, and thus become short-term, producing incremental change, and overlooking the social construction of heat risk. Given the lack of strong climate governance leadership at the city level in India, heat governance remains 'thinly institutionalised' [18], replicating the concerns others have raised on inadequate and fragmented climate governance in India and in cities in particular [54, 78].

Heat risk in Indian cities coagulates in places, people, and livelihoods that are exposed to heat, least equipped to cool their surroundings, and vulnerable due to structural conditions that drive marginalisation. Currently, the Indian state is caught between the expectation and need for urgent action on managing heat, and the long shadow of colonial and postcolonial disaster management institutions and processes. This has led to a disbalanced focus on reducing heat-related deaths through a 'zero deaths approach' (the importance of which cannot be refuted) at the cost of longer-term actions that build capacities for averting heat stress and related cascading impacts on health and wellbeing.

In conclusion, we reiterate three takeaways, with implications for urban heat risk governance in India and how we conceptualise incremental and transformational adaptation. First, there is a reductionist framing of the hazard of heat as contained to certain months and in certain cities, which does not reflect latest science on humid heat, hot nights, summers starting earlier, and the interactions between built form and temperature (Section 2). While this is changing every year, more is possible. Developing localised temperature thresholds for different Indian cities [66] is key and requires dedicated research and funding. Second, while straddling a range of heat preparedness and management actions, HAPs tend to focus on short-term, status quoist, incremental solutions rather than longer-term reformist or transformative solutions. Relief measures such as providing water, shade, and shelter are necessary but without accompanying systemic change in how cities are planned and built; how blue and green infrastructure in our cities are conserved and restored; and how underlying vulnerabilities are ameliorated; these measures remain piecemeal and reactive. While some measures have transformative potential (e.g., increasing green cover; shifting outdoor work timings), they must be done repeatedly and align with other system-wide changes (e.g., amending building codes, changing labour laws) to realise this transformation potential. Third, HAPs are guided by SOPs before, during, and after a narrowly defined heat season, and when this is superimposed on an already weak urban governance system, heat management remains inadequate and fragmented, leading to an 'adaptation gap' between planned and required adaptation.

Cities are innovating by state-non-state institutional arrangements and running large, multi-media public awareness campaigns that also involve religious and civil society actors. These steps are promising and can be strengthened by expanding non-state involvement beyond relief and short-term preparedness measures to engagement in longer-term resilience building. Overall, heat risk governance requires transdisciplinary capacity building at state and city scales along with dedicated finances for preparedness and relief, as seen in cyclone preparedness along the east coast [79]. In cities especially, the implementation of the 74th constitutional amendment to strengthen multiscalar planning at city and ward levels is a possible route to better local decision-making, similar to financial devolution in rural areas, where panchayat development plans are increasingly becoming sites of adaptation governance [80].

Taken together, urban heat risk management in Indian cities paint a picture of an increasing and uneven 'adaptation gap' where those most exposed and vulnerable to heat continue to fall through the cracks of inadequate and incremental action. This is especially pressing when seen in relation to the changing and growing nature of heat risk (Section 1). Thus, our HAPs

are at best, coping with and responding to current and past heat; they are not preparing for future heat.

The wider literature and experiments in cities across the world and in India offer glimpses of what could work. We know that emergent, unfamiliar risk regimes require fit-for-purpose/updated governance that can undertake flexible decision-making for longer-term planning through the development of heat adaptation pathways [81]. This will require multi-scalar and transdisciplinary capacity building (e.g., in government; of architects and urban planners, medical staff, and ecologists and climate change specialists; and in implementing organisations such as NGOs). It will also need better articulation and processes for inter-agency coordination, expanded involvement of civil society actors beyond relief provision, building human and institutional capacities that are flexible and forward-looking, and a reorientation of actors and institutions tasked with disaster management institutions to avoid seeing hazards in siloes.

Supporting information

S1 Text. Table A List of interviews done per city and at national level. Table B Details of who is vulnerable and what solutions are proposed in 10 urban HAPs. Source: Author compilation. Table C Code book used to assess HAPs.
(DOCX)

Acknowledgments

C.S., S.P., and P.P. are grateful for funding by the British Academy project Urban and Peri-urban Agriculture as Green Infrastructure (UPAGrI) (2019–2021, Project No. I207993) that initiated the idea to assess Heat Action Plans in Indian cities. Thank you to Amruth Kiran from the IIHS Geospatial Lab for making the map, Amir Bazaz and Kamal Kishore for comments on an earlier draft, and to all the respondents for their time. An earlier draft of this paper was presented in the 'Cities and Climate Change Workshop' by Centre for the Advanced Study of India (CASI), University of Pennsylvania, and the Oxford India Centre for Sustainable Development (OICSD), University of Oxford, and we gratefully acknowledge feedback from Tariq Thachil, Nikhil Anand, Lalitha Kamath, Deepak Malghan, and Vinita Govindarajan.

Author Contributions

Conceptualization: Chandni Singh.

Data curation: Chandni Singh, Divyanshi Vyas, Sheetal Patil, Nihal Ranjit.

Formal analysis: Chandni Singh, Divyanshi Vyas, Sheetal Patil, Nihal Ranjit, Prathijna Poonacha, Swati Surampally.

Methodology: Chandni Singh.

Project administration: Chandni Singh.

Visualization: Chandni Singh, Divyanshi Vyas, Nihal Ranjit.

Writing – original draft: Chandni Singh, Divyanshi Vyas, Sheetal Patil, Nihal Ranjit.

Writing – review & editing: Chandni Singh, Sheetal Patil, Nihal Ranjit, Prathijna Poonacha, Swati Surampally.

References

1. Arulalan T, AchutaRao K, Sagar AD. Climate science to inform adaptation policy: Heat waves over India in the 1.5˚C and 2˚C warmer worlds. Clim Change [Internet]. 2023; 176(5):1–19. Available from: https://doi.org/10.1007/s10584-023-03527-y
2. Im ES, Pal JS, Eltahir EAB. Deadly heat waves projected in the densely populated agricultural regions of South Asia. Sci Adv [Internet]. 2017; 3(8):1–8. Available from: https://doi.org/10.1126/sciadv.1603322 PMID: 28782036
3. Parsons LA, Shindell D, Tigchelaar M, Zhang Y, Spector JT. Increased labor losses and decreased adaptation potential in a warmer world. Nat Commun. 2021; 12(1):1–11.
4. Bont J De, Nori-sarma A, Stafoggia M, Banerjee T, Ingole V, Jaganathan S, et al. Impact of heatwaves on all-cause mortality in India: A comprehensive multi-city study. Environ Int [Internet]. 2024; 184(October 2023):108461. Available from: https://doi.org/10.1016/j.envint.2024.108461 PMID: 38340402
5. Rao KK, Jyoteeshkumar Reddy P, Chowdary JS. Indian heatwaves in a future climate with varying hazard thresholds. Environ Res Clim. 2023; 2(1):015002.
6. Singh C, Nirwan N. Effective heat adaptation must engage with unequal heat risk. One Earth. 2024;
7. Murari KK, Ghosh S, Patwardhan A, Daly E, Salvi K. Intensification of future severe heat waves in India and their effect on heat stress and mortality. Reg Environ Chang. 2015; 15(4):569–79.
8. Mukherjee S, Mishra V. A sixfold rise in concurrent day and night-time heatwaves in India under 2˚C warming. Sci Rep [Internet]. 2018; 8(1):1–9. Available from: http://dx.doi.org/10.1038/s41598-018-35348-w
9. Koteswara Rao K, Lakshmi Kumar T V., Kulkarni A, Ho CH, Mahendranath B, Desamsetti S, et al. Projections of heat stress and associated work performance over India in response to global warming. Sci Rep [Internet]. 2020; 10(1):1–14. Available from: https://doi.org/10.1038/s41598-020-73245-3
10. Choudhary RK, Joshi P, Ghosh S, Ganguly D, Balakrishnan K, Singh N, et al. Excess Mortality Risk Due to Heat Stress in Different Climatic Zones of India. Environ Sci Technol [Internet]. 2024 Jan 9; 58(1):342–51. Available from: https://pubs.acs.org/doi/10.1021/acs.est.3c05218 PMID: 38151765
11. Banerjee R, Maharaj R. Heat, infant mortality, and adaptation: Evidence from India. J Dev Econ [Internet]. 2020; 143(January 2018):102378. Available from: https://doi.org/10.1016/j.jdeveco.2019.102378
12. Parsons LA, Masuda YJ, Kroeger T, Shindell D, Wolff NH, Spector JT. Global labor loss due to humid heat exposure underestimated for outdoor workers. Environ Res Lett. 2021 Nov 26;(Ii):https://doi.org/10.1088/1361-6463/aad7de.
13. Sharma S, Mujumdar P. Increasing frequency and spatial extent of concurrent meteorological droughts and heatwaves in India. Sci Rep [Internet]. 2017; 7(1):1–9. Available from: http://dx.doi.org/10.1038/s41598-017-15896-3
14. Sidhu BS. Likely impacts of the 2022 heatwave on India's wheat production. Environ Res Lett. 2023; 18(10).
15. Kotharkar R, Ghosh A. Review of heat wave studies and related urban policies in South Asia. Urban Clim [Internet]. 2021; 36(January):100777. Available from: https://doi.org/10.1016/j.uclim.2021.100777
16. Natural Resources Defense Council. Expanding heat resilience across India: Heat Action Plan Highlights [Internet]. 2022. Available from: https://www.nrdc.org/sites/default/files/india-heatresilience-20220406.pdf
17. Pillai A, Dalal T. How Is India Adapting to Heatwaves?: An Assessment of Heat Action Plans With Insights for Transformative Climate Action. New Delhi, India; 2023.
18. Dubash NK. Varieties of climate governance: the emergence and functioning of climate institutions. Env Polit [Internet]. 2021; 30(1):1–25. Available from: https://doi.org/10.1080/09644016.2021.1979775
19. Singh C, Tebboth M, Arvind J, Udupa Y. Representing Disasters and Long-term Recovery–Insights from Tamil Nadu [Internet]. Bangalore; 2021. Available from: https://iihs.co.in/knowledge-gateway/representing-disasters-and-long-term-recovery-insights-from-tamil-nadu/
20. Birkmann J, Liwenga E, Pandey R. Poverty, Livelihoods and Sustainable Development. In: Climate Change 2022: Impacts, Adaptation and Vulnerability Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. 2022. p. 1171–274.
21. Kuhlicke C, Madruga de Brito M, Bartkowski B, Botzen W, Doğulu C, Han S, et al. Spinning in circles? A systematic review on the role of theory in social vulnerability, resilience and adaptation research. Glob Environ Chang. 2023; 80(March).
22. IPCC. Summary for Policymakers. In: Pörtner HO, Roberts DC, Poloczanska ES, Mintenbeck K, Tignor M, Alegr\'\ia A, et al., editors. Climate Change 2022 –Impacts, Adaptation and Vulnerability [Internet]. Cambridge University Press; 2022. p. 3–34. Available from: https://www.cambridge.org/core/product/identifier/9781009325844%23pre2/type/book_part

23. Ford JD, Pearce T, McDowell G, Berrang-Ford L, Sayles JS, Belfer E. Vulnerability and its discontents: the past, present, and future of climate change vulnerability research. Clim Change. 2018 Nov 25; 151 (2):189–203.

24. Singh C, Ramesh A, Hagenlocher M, Shekhar H, Siemons ASS, Okunola OH, et al. Applying recent advances in climate adaptation research to urban heat risk management. Wiley Interdiscip Rev Clim Chang. 2024;(December 2023):1–16.

25. Werners SE, Wise RM, Butler JRA, Totin E, Vincent K. Adaptation pathways: A review of approaches and a learning framework. Environ Sci Policy. 2021 Feb; 116(November 2020):266–75.

26. Muccione V, Biesbroek R, Harper S, Haasnoot M. Towards a more integrated research framework for heat-related health risks and adaptation. Lancet Planet Heal [Internet]. 2024; 8(1):e61–7. Available from: https://doi.org/10.1016/S2542-5196(23)00254-1 PMID: 38199725

27. Haasnoot M, Kwakkel JH, Walker WE, ter Maat J. Dynamic adaptive policy pathways: A method for crafting robust decisions for a deeply uncertain world. Glob Environ Chang. 2013 Apr; 23(2):485–98.

28. Deubelli TM, Mechler R. Perspectives on transformational change in climate risk management and adaptation. Environ Res Lett. 2021; 16(5).

29. Nightingale AJ, Gonda N, Eriksen SH. Affective adaptation = effective transformation? Shifting the politics of climate change adaptation and transformation from the status quo. Wiley Interdiscip Rev Clim Chang. 2021;(December 2020):1–16.

30. Bolitho A, Miller F. Heat as emergency, heat as chronic stress: policy and institutional responses to vulnerability to extreme heat. Local Environ [Internet]. 2017; 22(6):682–98. Available from: http://dx.doi.org/10.1080/13549839.2016.1254169

31. Mahadevia D, Pathak M. Climate Change, Heat Waves and Thermal Comfort—Reflections on Housing Policy in India. 2020;

32. Ramsay EE, Fleming GM, Faber PA, Barker SF, Sweeney R, Taruc RR, et al. Chronic heat stress in tropical urban informal settlements. iScience [Internet]. 2021 Nov; 24(11):103248. Available from: https://linkinghub.elsevier.com/retrieve/pii/S2589004221012177 https://doi.org/10.1016/j.isci.2021.103248 PMID: 34849460

33. Shah A, Thapliyal S, Sugathan A, Mishra V, Malghan D. Caste inequality in occupational exposure to heat waves in India. Demography. 2024;

34. Kingsborough A, Jenkins K, Hall JW. Development and appraisal of long-term adaptation pathways for managing heat-risk in London. Clim Risk Manag [Internet]. 2017; 16:73–92. Available from: http://dx.doi.org/10.1016/j.crm.2017.01.001

35. Haasnoot M, Brown S, Scussolini P, Jimenez JA, Vafeidis AT, Nicholls RJ. Generic adaptation pathways for coastal archetypes under uncertain sea-level rise. Environ Res Commun [Internet]. 2019 Aug 1; 1(7):071006. Available from: https://iopscience.iop.org/article/10.1088/2515-7620/ab1871

36. Kwakkel JH, Walker WE, Haasnoot M. Coping with the Wickedness of Public Policy Problems: Approaches for Decision Making under Deep Uncertainty. J Water Resour Plan Manag. 2016; 142 (3):1–5.

37. Sethi M, Sharma R, Mohapatra S, Mittal S. How to tackle complexity in urban climate resilience? Negotiating climate science, adaptation and multi-level governance in India. Ali G, editor. PLoS One. 2021 Jul 1; 16(7):e0253904. https://doi.org/10.1371/journal.pone.0253904 PMID: 34197514

38. Varma N, Kelkar U, Bhardwaj S, Singh P, Mishra A. Climate Change, Disasters and Development: Testing the Waters for Adaptive Governance in India. Vis J Bus Perspect. 2014 Dec 8; 18(4):327–38.

39. Zaidi RZ, Pelling M. Institutionally configured risk: Assessing urban resilience and disaster risk reduction to heat wave risk in London. Urban Stud [Internet]. 2015 May 15; 52(7):1218–33. Available from: http://journals.sagepub.com/doi/10.1177/0042098013510957

40. Smit B, Burton I, Klein RJT, Wandel J. An anatomy of adaptation to climate change and variability. Vol. 45, Climatic Change. 2000. p. 223–51.

41. Rickards L, Howden SM. Transformational adaptation: Agriculture and climate change. Crop Pasture Sci. 2012; 63(3):240–50.

42. Pelling M, O'Brien K, Matyas D. Adaptation and transformation. Clim Change. 2015 Nov 18; 133 (1):113–27.

43. Heikkinen M, Ylä-Anttila T, Juhola S. Incremental, reformistic or transformational: what kind of change do C40 cities advocate to deal with climate change? J Environ Policy Plan [Internet]. 2019; 21(1):90–103. Available from: https://doi.org/10.1080/1523908X.2018.1473151

44. Feola G. Societal transformation in response to global environmental change: A review of emerging concepts. Ambio [Internet]. 2015 Sep 28 [cited 2017 Dec 9]; 44(5):376–90. Available from: http://link.springer.com/10.1007/s13280-014-0582-zs PMID: 25431335

45. Tschakert P, van Oort B, St. Clair AL, LaMadrid A. Inequality and transformation analyses: a complementary lens for addressing vulnerability to climate change. Clim Dev. 2013; 5(4):340–50.

46. Few R, Morchain D, Spear D, Mensah A, Bendapudi R. Transformation, adaptation and development: relating concepts to practice. Palgrave Commun. 2017 Oct 1; 3(1):17092.

47. Termeer CJAM, Dewulf A, Biesbroek GR. Transformational change: governance interventions for climate change adaptation from a continuous change perspective. J Environ Plan Manag. 2017 Apr 3; 60 (4):558–76.

48. Reckien D, Magnan AK, Singh C, Lukas-Sithole M, Orlove B, Schipper ELF, et al. Navigating the continuum between adaptation and maladaptation. Nat Clim Chang. 2023; 13(9):907–18.

49. Berrang-Ford L, Siders AR, Lesnikowski A, Fischer AP, Callaghan MW, Haddaway NR, et al. A systematic global stocktake of evidence on human adaptation to climate change. Nat Clim Chang. 2021; 11 (11):989–1000.

50. Shukla R, Maskell G, Jagannathan K, Browne KE, Ulibarri N, Campbell D, et al. Dichotomy or Continuum? A global review of the interaction between autonomous and planned adaptations (in press). Ecol Soc. 2024;

51. Khosla R, Bhardwaj A. Urbanization in the time of climate change: Examining the response of Indian cities. Wiley Interdiscip Rev Clim Chang. 2019 Jan 26; 10(1):e560.

52. Unnikrishnan H, Nagendra H. Building climate resilient cities in the global South: assessing city adaptation plans in India. Round Table [Internet]. 2021; 110(5):575–86. Available from: https://doi.org/10.1080/00358533.2021.1985268

53. Chu E. The political economy of urban climate adaptation and development planning in Surat, India. Environ Plan C Gov Policy. 2016; 34(2):281–98.

54. Bhardwaj A, Khosla R. Superimposition: How Indian city bureaucracies are responding to climate change. Environ Plan E Nat Sp [Internet]. 2021 Sep 25; 4(3):1139–70. Available from: http://journals.sagepub.com/doi/10.1177/2514848620949096

55. Chhotray V. A supercyclone, landscapes of 'emptiness' and shrimp aquaculture: The lesser-known trajectories of disaster recovery in coastal Odisha, India. World Dev [Internet]. 2022; 153:105823. Available from: https://doi.org/10.1016/j.worlddev.2022.105823

56. Klein N. The shock doctrine: The rise of disaster capitalism. Macmillan; 2007.

57. Tschakert P. Views from the vulnerable: Understanding climatic and other stressors in the Sahel. Glob Environ Chang. 2007; 17(3–4):381–96.

58. Srivastava S, Mehta L, Adam HN. Climate change and uncertainty. Polit Clim Chang Uncertain India. 2021;1–26.

59. Ogra A, Donovan A, Adamson G, Viswanathan KR, Budimir M. Exploring the gap between policy and action in Disaster Risk Reduction: A case study from India. Int J Disaster Risk Reduct [Internet]. 2021; 63(November 2020):102428. Available from: https://doi.org/10.1016/j.ijdrr.2021.102428

60. Rumbach A. Disaster Governance in Small Urban Places: Issues, Trends, and Concerns. In: Disaster Governance in Urbanising Asia. Singapore: Springer Singapore; 2016. p. 109–25.

61. National Disaster Management Authority. Beating the Heat: How India successfully reduced mortality due to heat waves [Internet]. 2019. Available from: https://ndma.gov.in/sites/default/files/IEC/Booklets/HeatWave A5 BOOK Final.pdf

62. Mees HLP, Driessen PPJ, Runhaar HAC. "Cool" governance of a "hot" climate issue: public and private responsibilities for the protection of vulnerable citizens against extreme heat. Reg Environ Chang [Internet]. 2015; 15(6):1065–79. Available from: http://dx.doi.org/10.1007/s10113-014-0681-1

63. Disaster Management Division. Ministry of Home Affairs, Government of India. 2024 [cited 2024 Jul 11]. National Disaster Risk Management Fund (NDRMF) and State Disaster Risk Management Fund (SDRMF). Available from: https://ndmindia.mha.gov.in/ndmi/responsefund

64. India Meteorological Department. Ministry of Earth Sciences, Government of India. 2023 [cited 2024 Jan 10]. Standard operation procedure—weather forecasting and warning services. Available from: https://mausam.imd.gov.in/imd_latest/contents/pdf/forecasting_sop.pdf

65. Kotharkar R, Bagade A. Local Climate Zone classification for Indian cities: A case study of Nagpur. Urban Clim [Internet]. 2018 Jun; 24:369–92. Available from: https://linkinghub.elsevier.com/retrieve/pii/S2212095517300226

66. Golechha M, Shah P, Mavalankar D. Threshold determination and temperature trends analysis of Indian cities for effective implementation of an early warning system. Urban Clim [Internet]. 2021 Sep; 39:100934. Available from: https://linkinghub.elsevier.com/retrieve/pii/S2212095521001644

67. PTI (Press Trust of India). India will get its own index to quantify heat impact next year: IMD chief. The Hindu [Internet]. 2023 May 20; Available from: https://www.thehindu.com/news/national/india-will-get-its-own-index-to-quantify-heat-impact-next-year-imd-chief/article66807483.ece

68. NAPCC. National Action Plan on Climate Change. 2008.

69. Singh C, Solomon D, Rao N. How does climate change adaptation policy in India consider gender? An analysis of 28 state action plans. Clim Policy. 2021 Aug 9; 21(7):958–75.

70. Tran K, Azhar G, Nair R, Knowlton K, Jaiswal A, Sheffield P, et al. A Cross-Sectional, Randomized Cluster Sample Survey of Household Vulnerability to Extreme Heat among Slum Dwellers in Ahmedabad, India. Int J Environ Res Public Health [Internet]. 2013 Jun 18; 10(6):2515–43. Available from: https://www.mdpi.com/1660-4601/10/6/2515 https://doi.org/10.3390/ijerph10062515 PMID: 23778061

71. Kotharkar R, Ghosh A. Progress in extreme heat management and warning systems: A systematic review of heat-health action plans (1995–2020). Sustain Cities Soc [Internet]. 2022; 76(October 2021):103487. Available from: https://doi.org/10.1016/j.scs.2021.103487

72. Turek-Hankins LL, de Perez EC, Scarpa G, Ruiz-Diaz R, Shwerdtle PN, Joe ET, et al. Climate change adaptation to extreme heat: A global systematic review of implemented action. Oxford Open Clim Chang. 2021; 1(April):1–13.

73. Simpson NP, Mach KJ, Constable A, Hess J, Hogarth R, Howden M, et al. A framework for complex climate change risk assessment. One Earth. 2021 Apr; 4(4):489–501.

74. Izumi T, Shaw R. Role of NGOs in Community-Based Disaster Risk Reduction. In: Shaw R, editor. Community-Based Disaster Risk Reduction (Community, Environment and Disaster Risk Management) [Internet]. Leeds: Emerald Group Publishing Limited; 2012. p. 35–54. Available from: https://www.emerald.com/insight/content/doi/10.1108/S2040-7262(2012)0000010009/full/html

75. Hess JJ, Sathish LM, Knowlton K, Saha S, Dutta P, Ganguly P, et al. Building resilience to climate change: Pilot evaluation of the impact of India's first heat action plan on all-cause mortality. J Environ Public Health. 2018; 2018. https://doi.org/10.1155/2018/7973519 PMID: 30515228

76. Tanner T, Zaman RU, Acharya S, Gogoi E, Bahadur A. Influencing resilience: the role of policy entrepreneurs in mainstreaming climate adaptation. Disasters. 2019; 43:388–411. https://doi.org/10.1111/disa.12338 PMID: 30945768

77. Chu EK. Urban climate adaptation and the reshaping of state–society relations: The politics of community knowledge and mobilisation in Indore, India. Urban Stud. 2018; 55(8):1766–82.

78. Sami N. Local Action on Climate Change. Moloney S, Fünfgeld H, Granberg M, editors. Local Action on Climate Change: Opportunities and Constraints. Routledge; 2017. 92–110 p.

79. Pal I, Ghosh T, Ghosh C. Institutional framework and administrative systems for effective disaster risk governance–Perspectives of 2013 Cyclone Phailin in India. Int J Disaster Risk Reduct [Internet]. 2017; 21(January):350–9. Available from: http://dx.doi.org/10.1016/j.ijdrr.2017.01.002

80. Fischer HW. Decentralization and the governance of climate adaptation: Situating community-based planning within broader trajectories of political transformation. World Dev [Internet]. 2021 Apr; 140:105335. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0305750X20304629

81. Bednar-Friedl B, Biesbroek R, Schmidt D. Europe. In: Climate Change 2022: Impacts, Adaptation and Vulnerability Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. 2022. p. 1817–927.