Research Square

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Impacts of Heatwaves on Children and Policy Gaps in South India

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Abstract

Heatwaves are an escalating climate hazard in South Asia, disproportionately affecting children due to physiological immaturity, behavioral dependencies, and systemic vulnerabilities. This mixed-methods study examines the multidimensional impacts of heatwaves on children in South India through the Social-Ecological Model. Quantitative survey data (n = 1,500) and qualitative interviews reveal cascading effects across five domains: health, psychosocial functioning, education, nutrition, and institutional response. Findings indicate that 77% of children experienced heat-related illnesses, while behavioral disturbances and sleep disruption were prevalent, particularly in Andhra Pradesh and Odisha. Educational engagement declined markedly, with 34% reporting absenteeism and performance loss, and nutrition insecurity intensified during heatwaves, especially in Kerala and Andhra Pradesh. Policy review highlights limited child-specific integration in India's climate frameworks despite progress in surveillance and facility preparedness. Comparative analysis underscores regional disparities, reinforcing the need for decentralized, context-sensitive interventions. Drawing on global best practices such as France's Plan Canicule, Barcelona's school-based climate shelters, and Los Angeles' cool roof ordinances the study advocates embedding child-sensitive indicators into Heat Action Plans, strengthening school infrastructure, ensuring nutrition continuity, and integrating mental health supports. These findings position heatwaves as a child rights and social justice issue, demanding cross-sectoral adaptation strategies to safeguard health, education, and equity in a warming climate.

1. Introduction

Heatwaves have emerged as one of the most pressing climate-related threats to public health, particularly in tropical regions such as South India. Defined by the Indian Meteorological Department (IMD) as periods when temperatures exceed 40°C in plains, 37°C in coastal areas, and 30°C in hilly regions, these events are increasing in frequency, duration, and severity due to anthropogenic climate change (Goyal et al., 2023; IMD, n.d.-a). Globally, low- and middle-income countries bear the brunt of prolonged heat episodes, with South Asia among the most affected regions (Ebi et al., 2021).

Children aged 0–18 years are especially vulnerable to extreme heat due to physiological immaturity, limited thermoregulation, and higher metabolic rates. Their dependence on caregivers and exposure in poorly adapted environments compound these risks (Schapiro et al., 2024). UNICEF estimates that 76% of South Asian children approximately 460 million experience extreme heat for more than 83 days annually, far exceeding the global average of 32% (UNICEF, 2024a).

This study adopts the Social-Ecological Model to examine heatwave impacts across individual, interpersonal, community, and societal levels. In South India, high humidity, dense populations, and inadequate adaptive infrastructure exacerbate risks, leading to cascading effects on health, education, nutrition, and psychosocial well-being. Vulnerabilities are further amplified among marginalized communities lacking access to cooling, healthcare, and social protection. Despite emerging interventions, child-specific strategies remain limited in India's climate resilience frameworks (UNICEF, 2024b).

1.1 Research Questions

1. What are the physical, psychological, and behavioral health impacts of heatwaves on children at different developmental stages in South India?
2. How do heatwaves affect children's education and nutrition, and what coping strategies are used by families and institutions?
3. To what extent are children's vulnerabilities addressed in local and national climate resilience policies?

By addressing these questions, this study aims to inform child-sensitive adaptation strategies and strengthen inclusive disaster risk reduction frameworks.

1.2 Literature Review

1.2.1 Heatwaves and Paediatric Health

The frequency and intensity of heatwaves have risen significantly over the past five decades, driven largely by anthropogenic climate change (Schapiro et al., 2024). Children are particularly vulnerable to extreme heat due to physiological factors such as a higher surface area-to-body mass ratio, reduced sweating capacity, and slower acclimatization (Patel & McCarville, 2024). These vulnerabilities contribute to a range of adverse health outcomes, including dehydration, respiratory distress, heat-related illnesses, and complications during the perinatal period such as preterm birth and low birth weight (Xu et al., 2014; Schapiro et al., 2024). In India, Lala and Hagishima (2023) found that children frequently experience heat-related symptoms such as fatigue and absenteeism, particularly in poorly ventilated classrooms lacking cooling infrastructure. Principi et al. (2025) further emphasized the heightened risks faced by pregnant women and children, including gestational complications like pre-eclampsia and stillbirth.

Despite growing evidence, paediatric heat stress remains underrepresented in national health surveillance systems. Climate-sensitive protocols are rarely integrated into maternal and child health programs, leaving critical gaps in preparedness and response.

1.2.2 Educational Disruption and Family-Level Impacts

Heatwaves also disrupt children's daily routines, educational engagement, and family dynamics. High ambient temperatures compromise school attendance, concentration, and learning outcomes (UNICEF, 2025). In South Asia, many schools lack adequate infrastructure to cope with extreme heat, leading to closures, shortened school days, and reduced instructional time. Girls are disproportionately affected, often missing school to fetch water or care for siblings during heatwaves. Kagawa (2022), in a UNICEF-commissioned study, reported that heatwaves contribute to increased dropout rates and diminished academic performance, particularly in underserved regions. Bhandari et al. (2024) found that education systems are rarely considered in climate resilience frameworks, despite their central role in child development. The authors advocate for integrating climate education into curricula and developing school-based adaptation strategies.

At the household level, coping strategies are often informal and reactive such as encouraging children to stay indoors, increasing fluid intake, or adjusting daily schedules (Compas et al., 2019). However, these measures are frequently insufficient, especially in low-income households lacking access to cooling infrastructure or reliable water sources. Family stress levels tend to rise during heatwaves, affecting parenting practices and children's emotional well-being.

1.2.3 Mental Health and Psychosocial Effects

While physical health impacts of heatwaves are well-documented, their psychological and behavioural effects especially on children remain underexplored. Exposure to extreme heat has been linked to increased anxiety, irritability, sleep disturbances, and impaired cognitive functioning (Pappas, 2023; Clayton et al., 2023). Mechanisms include sleep disruption, HPA axis activation, and loss of coping routines (Baecker et al., 2025). Yet, mental health integration in climate policy remains minimal: only 22% of global Heat Health Action Plans include targeted interventions (Addison et al., 2025). These effects are particularly concerning for children with pre-existing mental health conditions or those living in high-risk environments.

1.2.4 Nutrition and Food Security

Climate change has profound implications for food systems and child nutrition. Extreme heat disrupts agricultural cycles, reducing access to fresh produce and nutritious food. UNICEF (2023) and Balel (2025) highlight that food insecurity during climate events disproportionately affects children, particularly in low-income households. Fanzo et al. (2018) emphasize the need for climate-resilient nutrition programs, especially in regions where children rely on school meals and community feeding schemes. However, most climate adaptation strategies in India do not include nutrition as a core component, leaving children vulnerable to malnutrition during heatwaves and other climate shocks. Patel and McCarville (2024) also note that heatwaves can disrupt infant feeding practices and exacerbate food and water insecurity.

1.2.5 Policy Gaps and Exposure Metrics

India's climate policies including the National Action Plan on Climate Change (NAPCC) and State Action Plans on Climate Change (SAPCCs) acknowledge vulnerable populations but rarely treat children as a distinct category. Balel (2025), in a review of seven state climate plans, found that early childhood development (ECD) is largely absent from adaptation strategies. The report calls for embedding child-sensitive indicators and integrating health, education, and social protection systems into climate planning. Bhandari et al. (2024) similarly found that maternal and child health concerns are inconsistently addressed across South Asian adaptation plans. The authors recommend stronger cross-sectoral coordination and the inclusion of child-specific metrics in climate resilience frameworks. Without targeted policy interventions, children remain at the margins of climate adaptation and disaster risk reduction efforts.

Evidence underscores multidimensional vulnerabilities such as health, education, nutrition, and psychosocial yet child-specific strategies remain marginal in climate resilience frameworks. Few studies integrate these domains within a single analytical model, particularly in South Indian contexts. This gap necessitates a comprehensive, child-centered approach to heatwave adaptation.

1.3 Conceptual Framework

Understanding the impacts of heatwaves on children requires a multidimensional lens that captures both biological vulnerability and the broader social, environmental, and policy contexts in which children live. This conceptual framework (Fig. 1) is grounded in the Social-Ecological Model (Table 1), which enables a layered analysis of how heatwaves affect children at the individual, interpersonal, community, and societal levels. By organizing the impacts into five key domains i.e. health outcomes, educational disruption, nutrition and food security, family and social dynamics, and policy and institutional gaps the framework highlights the complex interplay between personal susceptibility and systemic factors. It serves as a foundation for examining the lived experiences of children in South India and identifying leverage points for targeted interventions and policy reform.

Table 1
Linking Domains to Social-Ecological Layers

Domain of Impact	Individual	Interpersonal	Community	Societal
Health and Well-being	Age, physiology, pre-existing conditions	Caregiver support, family health practices	Access to paediatric care, mental health services	Inclusion in health policies, surveillance systems
Educational Outcomes	Cognitive development, learning capacity	Parental support for schooling	School infrastructure, teacher preparedness	Education policy, climate-resilient curricula
Nutrition and Food Security	Nutritional status, feeding needs	Infant feeding practices, household food habits	School meal programs, local food access	Agricultural policy, food security programs
Family and Social Environment	Emotional resilience, stress response	Parenting practices, family routines	Community support networks, water access	Social protection systems, housing regulations
Policy and Institutional Context	Awareness of rights and entitlements	Family engagement with institutions	NGO and school-based interventions	Climate adaptation plans, child-sensitive indicators

This framework helps guide your mixed-methods study by linking observed impacts to structural and systemic factors, and by identifying leverage points for policy and intervention.

2.Methodology

This study employed a mixed-methods design to assess the impacts of heatwaves on children in South India, integrating quantitative surveys with qualitative interviews and focus group discussions (FGDs). This approach enabled the capture of both statistical patterns and contextual insights into health, education, nutrition, and behavioural outcomes.

2.1 Study Design and Sampling

The primary data was collected by the across selected districts. Districts were selected based on heatwave-related mortality and morbidity data from 2023–2024, ensuring inclusion of both coastal and inland regions with varying climate profiles (see Supplementary).

Within each selected district, one block and one village panchayat were chosen through simple random sampling to ensure geographic and demographic diversity. The study population included children from the prenatal stage to 18 years, pregnant women, and families with children. Stratified random sampling was used to ensure representation across developmental stages and socio-economic strata. A total of 1,500 respondents were surveyed, with 300 individuals representing each stage: prenatal, infancy, early childhood, school-age, and adolescence (see Supplementary).

2.2 Data Collection

Quantitative data were collected using structured questionnaires designed to assess health status, educational engagement, nutrition, daily routines, and perceptions of heatwave impact. Qualitative data were gathered through semi-structured interviews and FGDs with a diverse group of stakeholders, including parents, children, educators,

health professionals, and disaster management officials. These discussions explored community-level experiences, institutional responses, and coping strategies employed during heatwave events.

Participation in this survey was entirely voluntary, and respondents were informed of the study's purpose prior to data collection. No personal identifiers or sensitive information were recorded. Informed consent was obtained from all participants, including consent for the use of anonymized data in academic publications. The study adhered to principles of confidentiality, transparency, and responsible data management.

2.3 Data Analysis

Quantitative data were analysed using descriptive statistics to identify patterns across age groups and regions. Qualitative data underwent inductive thematic analysis, to identify recurring themes and narratives. Coding was conducted iteratively, with peer debriefing sessions used to refine categories and ensure analytical rigor. To validate findings, stakeholder consultations were held with local authorities, subject-matter experts, and community leaders. These sessions helped triangulate data and contextualize results within local realities. The data collected through this mixed-methods approach directly inform the thematic structure of the findings (Section 4), which are organized to reflect the domains outlined in the conceptual framework (Section 2).

3. Result and Discussion

3.1 Heatwave Impact on Children

This section presents the results of the study, organized according to the five domains of impact identified in the conceptual framework (Section 3) and explored through the literature review (Section 2). Each theme integrates quantitative and qualitative data to provide a comprehensive understanding of how heatwaves affect children across different layers of the Social-Ecological Model.

3.2 Climate Perception and Awareness

A significant majority of respondents (73%) reported a noticeable increase in heatwave frequency, and 76% attributed this change to climate change. These perceptions suggest a growing public awareness of environmental shifts, even in rural and semi-urban communities. However, qualitative data revealed that while awareness is high, access to reliable information and adaptive resources remains limited, particularly among low-income families.

3.3 Physical and Maternal Health Impacts

Heatwaves have had widespread physical health effects on children. Approximately 77% experienced heat-related illnesses, with dehydration (16%) being the most common, followed by heat exhaustion and cramps (15%) followed by heat stroke (13%). Additional symptoms included rashes, sunburn, and other heat related illness. Maternal health outcomes, though less frequently reported, were serious. In Andhra Pradesh, complications such as preterm birth, placental abruption, and cardiovascular events were concentrated, highlighting the intersection of heat stress and maternal vulnerability. These findings underscore the need for targeted maternal-child health interventions during extreme heat events.

3.4 Psychological and Behavioural Effects

Mental health disturbances were reported in nearly a quarter of children, with poor sleep (23%) and anxiety (15%) being the most prevalent. Behavioural changes were observed in 42% of cases, including increased irritability, reduced patience, and emotional withdrawal. Regional disparities were notable in Andhra Pradesh (79%) and Odisha (52%) reported the highest rates of behavioural change, while Tamil Nadu (8%) reported the lowest. These patterns suggest

that heatwaves not only affect physical health but also disrupt emotional and cognitive development, particularly in regions with limited mental health infrastructure.

3.5 Educational Disruption

Heatwaves significantly interfered with children's educational engagement. Absenteeism was reported by 31% of respondents, while 22% noted academic decline. Combined attendance and performance issues affected 34% of children, and 59% reported reduced focus during school hours. Qualitative interviews with educators revealed that classroom environments often lack ventilation and cooling, contributing to fatigue and disengagement. These disruptions have long-term implications for learning outcomes and educational equity, especially in underserved areas.

3.6 Coping Strategies and Institutional Mitigation

Coping strategies varied across households and institutions. At the school level, 38% implemented cooling infrastructure, 36% adjusted school hours, and 23% improved hydration access. However, 4% of schools reported no mitigation measures at all. Household-level responses included reduced outdoor activities (41%), increased indoor time, and modified routines to avoid peak heat hours. Despite these efforts, only a minority adopted structured coping strategies. Indoor engagement was common, but passive entertainment (e.g., television) dominated over creative or physical outlets, raising concerns about sedentary behaviour and screen dependency.

3.7 Nutrition and Food Security

Dietary changes were reported by 64% of respondents, with 46% noting reduced access to fresh vegetables. A significant decrease in nutritious food availability was reported by 24%, while 31% experienced a slight decline. These findings point to broader issues of food insecurity exacerbated by climate stress, with direct implications for child growth, immunity, and development.

3.8 Support Systems and Policy Inclusion

Mental health support systems remain limited. Only 24% of respondents had access to community programs, and just 6% reported any form of policy-level inclusion. School-based support was available to 17%, while family and peer support accounted for only 3%. These gaps highlight the urgent need for integrated, child-sensitive climate resilience planning that includes mental health services, educational safeguards, and nutritional support.

The findings presented above reinforce the multidimensional vulnerabilities outlined in the conceptual framework and validate the evidence base reviewed in Table 2. They also provide empirical grounding for the development of child-sensitive climate resilience strategies discussed in the concluding sections.

Table 2
Summary of Heatwave Impact on Children in South India

Domain of Impact	Key Findings	Social-Ecological Layers
Health and Well-being	77% of children affected by heat-related illnesses; maternal complications in Andhra Pradesh	Individual, Interpersonal, Community, Societal
Educational Outcomes	34% affected by absenteeism/performance issues; poor classroom ventilation	Individual, Interpersonal, Community, Societal
Nutrition and Food Security	64% reported dietary changes; 24% reduced access to nutritious food	Individual, Interpersonal, Community, Societal
Family and Social Environment	Increased family stress; informal coping; screen dependency	Interpersonal, Community
Policy and Institutional Context	Only 6% reported policy-level support; limited school and community programs	Community, Societal

3.9 Regional Disparities in Heatwave Impacts on Children in South India

To understand the spatial variation in heatwave impacts, this section compares four South Indian states i.e. Andhra Pradesh, Odisha, Kerala, and Tamil Nadu across behavioural, health, educational, nutritional, and institutional dimensions. This comparative lens highlights how localized factors shape children's vulnerability and resilience, emphasizing the need for targeted climate-health interventions.

Andhra Pradesh

Andhra Pradesh emerged as the most severely affected state in terms of behavioural and psychological impacts. Nearly 79% of children exhibited behavioural changes such as irritability, emotional withdrawal, and reduced patience. The state also reported serious maternal health complications, including placental abruption, cardiovascular events, and preterm births. These findings suggest a high vulnerability due to both environmental severity and gaps in maternal-child health infrastructure. While some schools implemented mitigation measures, the overall institutional response remains fragmented.

Odisha

Odisha reported moderate levels of behavioural change (52%) and educational disruption. Children experienced significant heat-related illnesses, and 31% missed school or Anganwadi sessions due to heat stress. Although some schools adjusted hours and improved hydration access, qualitative data indicated limited awareness programs and insufficient mental health support. Odisha’s coastal exposure and socio-economic challenges contribute to its vulnerability, highlighting the need for integrated school and community-level interventions.

Kerala

Kerala showed intermediate levels of impact, with 42% of children exhibiting behavioural changes and 59% reporting reduced focus in school. Despite relatively better health infrastructure, the state’s increasing heatwave frequency has begun to strain its systems. Nutrition-related impacts were notable, with 54% reporting reduced access to fresh vegetables, pointing to emerging food security concerns. Kerala’s proactive disaster management framework offers a foundation for scaling child-sensitive climate adaptation.

Tamil Nadu

Tamil Nadu reported the lowest behavioural impact (8%), suggesting either better resilience or underreporting. The state showed relatively lower rates of heat-related illnesses and educational disruption. However, qualitative interviews revealed that many schools still lack adequate cooling infrastructure and ventilation. Tamil Nadu's relatively advanced public health system may buffer some impacts, but the absence of child-specific climate strategies remains a concern.

These regional disparities reflect the multi-layered nature of children's vulnerability to heatwaves, as conceptualized in the Social-Ecological Model (Table 3). From individual health symptoms to systemic policy gaps, the findings underscore the need for integrated, multi-level interventions tailored to local contexts.

Table 3
Social-Ecological Matrix Showing Regional Heatwave Impacts on Children in South India

Social-Ecological Layer	Andhra Pradesh	Odisha	Kerala	Tamil Nadu
Individual	High behavioural impact (79%), dehydration, emotional withdrawal	Moderate behavioural impact (52%), heat-related illnesses	Intermediate behavioural impact (42%), reduced focus (59%)	Low behavioural impact (8%), lower heat-related illness
Interpersonal	Maternal complications (preterm birth, cardiovascular events)	Caregiver stress, limited family coping strategies	Emerging family stress due to food insecurity	Relatively stable family environment
Community	Fragmented school response, limited local health services	School absenteeism (31%), limited awareness programs	Nutrition concerns (54% reduced access to vegetables), strained health systems	Inadequate school cooling infrastructure, ventilation gaps
Organizational	Partial school mitigation (cooling, hydration), inconsistent implementation	Some school adjustments (hours, hydration), weak mental health support	Proactive disaster management framework, school-level adaptations	Advanced public health system, but limited school-based mitigation
Societal	Gaps in maternal-child health infrastructure, limited policy integration	Socio-economic vulnerability, coastal exposure, limited integration in policy	Better infrastructure, but rising climate stress and limited child-specific strategies	Absence of child-specific climate strategies despite strong systems

3.10 Discussion and Policy Review

This study demonstrates that heatwaves impose cascading, multidimensional impacts on children in South India, spanning health, psychosocial well-being, education, nutrition, and institutional response. These findings reinforce global evidence that South Asia concentrates child heat exposure, with approximately 76% of children experiencing ≥ 83 days above 35°C annually (UNICEF, 2024a). The results underscore that heatwaves are not merely environmental hazards but developmental and social crises.

3.10.1 Health and Developmental Impacts

Children's physiological immaturity and exposure to poorly ventilated environments elevate risks for dehydration, heat exhaustion, and respiratory stress. Maternal complications observed in Andhra Pradesh align with emerging evidence

linking prenatal heat exposure to preterm birth and hypertensive disorders (The George Institute, n.d.; Climate Central, 2025). These findings highlight the need for integrating pediatric and maternal heat protocols into health systems.

3.10.2 Psychological and Behavioral Effects

Sleep disturbances, anxiety, and behavioral dysregulation were prevalent, particularly in Andhra Pradesh and Odisha. Global reviews link heat exposure to psychiatric symptoms, yet mental health integration in Heat Health Action Plans remains minimal only 22% include targeted interventions (Addison et al., 2025). School-based psychosocial supports and tele-mental health pathways offer practical entry points.

3.10.3 Educational Disruption and Equity

Absenteeism and reduced classroom focus mirror large-scale evidence that cumulative heat depresses learning outcomes and hot exam days harm performance (Park et al., 2020; Park, 2022). India's advisories for hydration breaks and ventilation improvements require codification into climate-smart school standards.

3.10.4 Nutrition and Food Security

We observe dietary downgrades and reduced access to fresh produce during heatwaves, especially in Kerala and Andhra Pradesh patterns consistent with disruptions to agricultural calendars, market chains, and school feeding continuity (ReliefWeb/UNICEF, 2024). Ensuring summer take-home rations, hydration, and fortified foods via POSHAN 2.0 can cushion heat-related nutritional gaps (CDPH, 2024).

3.10.5 Institutional Response and Policy Gaps

While some schools and households adopted mitigation measures such as cooling infrastructure and adjusted routines these responses were uneven and often informal. Tamil Nadu showed potential for scalable models, but gaps in infrastructure and policy inclusion persist across all states. The comparative analysis reveals stark regional disparities. Andhra Pradesh and Odisha face compounded risks due to high exposure, weak infrastructure, and limited institutional support. Kerala, despite better health systems, is beginning to show strain, particularly in nutrition. Tamil Nadu's relatively low impact may reflect stronger public health systems, but the absence of child-specific climate strategies remains a concern underscore the need for decentralized, context-specific interventions.

3.10.6 India's Policy Landscape and Global Best Practices

India's climate resilience architecture has evolved through NDMA heatwave guidelines, IMD advisories, and NPCCHH/NCDC protocols emphasizing surveillance, facility preparedness, and pediatric workflows (NDMA, n.d.; NCDC, 2024). The Ahmedabad Heat Action Plan (HAP) South Asia's first demonstrates municipal leadership with alerts, provider training, and cool roof initiatives, reducing summer mortality (NRDC, 2019; ClimaHealth, 2022). However, child-sensitive indicators remain absent from most Heat Action Plans and State Action Plans on Climate Change (SAPCCs).

Global Best Practices offer transferable models:

- **WHO/Europe Heat-Health Action Plans**: Core elements lead agency, HHWS/alerts, communications, indoor heat reduction, special care, health-system preparedness, surveillance, and evaluation have been institutionalized across many countries (WHO, 2008; WHO/Europe, 2025).
- **France's Plan Canicule**: Inter-ministerial governance, daily coordination (Météo-France, Santé publique France) and local ORSEC plans have improved outcomes and awareness since 2003 (UNDRR/WMO/GHHIN, 2025; Institut de Veille Sanitaire, 2005).

- **Barcelona Climate Shelters (schools-first)**: Blue–green–grey interventions in schoolyards, open to communities during heatwaves, provide an actionable child-centered urban cooling model (Barcelona City Council, 2021; Urban Innovative Actions [UIA], 2021).
- **Seville's Health-Based Naming**: proMETEO's naming and health-based categorization (e.g., heatwave "Zoe") improved risk communication and protective behaviors worth testing in Indian cities (Arsht-Rock, 2022; Metzger et al., 2024).
- **Los Angeles Cool Roof Ordinance**: City-wide requirements for aged SRI/reflectance/emittance illustrate how building codes can mainstream thermal comfort at scale (City of Los Angeles, 2014).

3.10.7 Policy Gaps and Opportunities

Current frameworks acknowledge vulnerable populations but rarely treat children as a distinct category. Mental health integration is minimal, and school infrastructure standards remain undefined. Nutrition continuity during heatwaves is not codified in climate adaptation plans (Table 4).

Table 4
Actionable Policy Matrix

Sector	What	How
Education	Climate-smart school standards (ventilation, shaded play, hydration stations); flexible exam calendars	Amend building codes; thermal audits; embed heat modules in teacher training
Health	Pediatric/perinatal heat protocols; Emergency Cooling SOPs; child-sensitive surveillance	Pre-season facility audits; cooling bays; ORS corners; real-time bulletins
Nutrition & Social Protection	Continuity of PM POSHAN/ICDS; fortified take-home rations	Heat-contingent triggers; cold chain support; joint monitoring
Urban Planning	Cool roof standards; schoolyard greening; climate shelters	Municipal bylaws; capital grants; open school grounds during alerts
Early Warning & Communication	Extended Heat Index; health-based naming	Integrate IMD bulletins with school and health actions; leverage school networks
Mental Health	Embed youth mental health supports in HAPs; school-based screening	Train counselors; tele-mental health; monitor uptake

3.10.8 Recommendations: Strengthening Child-Centered Climate Resilience

Based on the findings of this study and the policy review, it is evident that children in South India face multidimensional risks during heatwaves ranging from physical and mental health challenges to educational disruption and nutritional insecurity. Addressing these vulnerabilities requires coordinated action across sectors and levels of governance. The following recommendations are targeted at key stakeholders:

(i) For Policymakers

- **Integrate Child-Sensitive Indicators**: Include age-disaggregated data and child-specific vulnerability metrics in Heat Action Plans (HAPs) and State Action Plans on Climate Change (SAPCCs).
- **Mandate School-Based Preparedness Plans**: Require schools to implement heatwave mitigation strategies such as adjusted hours, cooling infrastructure, and hydration protocols.

- **Expand Nutrition Safety Nets**: Strengthen midday meal schemes and Anganwadi services during heatwaves to ensure continued access to nutritious food.
- **Include Mental Health in Climate Policy**: Develop guidelines for psychological first aid and mental health support for children during climate emergencies.

(ii) For Educators and School Administrators

- **Implement Climate Education Modules**: Introduce age-appropriate content on climate change, heatwave risks, and adaptive behaviours in school curricula.
- **Train Teachers in Psychosocial Support**: Equip educators to identify and respond to heat-induced stress, anxiety, and behavioural changes in students.
- **Improve Infrastructure**: Prioritize ventilation, shaded areas, and access to clean drinking water in school environments.

(iii) For Health Workers and Frontline Responders

- **Develop Paediatric Heat Illness Protocols**: Create clinical guidelines for diagnosing and treating heat-related conditions in children.
- **Strengthen Maternal-Child Surveillance**: Monitor heatwave-related complications during pregnancy and early childhood through community health workers.
- **Promote Preventive Care**: Conduct awareness campaigns on hydration, nutrition, and heat safety for families with children.

(iv) For Community Leaders and Local Institutions

- **Establish Cooling Canters**: Create safe, accessible spaces for children during peak heat hours, especially in low-income and rural areas.
- **Facilitate Community Engagement**: Use local media, storytelling, and participatory workshops to raise awareness and promote adaptive practices.
- **Support Peer Networks**: Encourage youth-led initiatives and peer support groups to foster resilience and agency among adolescents.

3.10.9 Future Research Directions: Advancing Child-Cantered Climate Resilience

The findings of this study underscore the urgent need for deeper, sustained inquiry into the impacts of heatwaves on children. While this research provides a foundational understanding, several areas remain underexplored and warrant further investigation. Future research should aim to capture the complexity of climate-health interactions across developmental stages, socio-economic contexts, and institutional settings.

(i) Longitudinal Studies on Developmental Impacts

- **Tracking Long-Term Outcomes**: Future studies should follow cohorts of children over time to assess the cumulative effects of repeated heatwave exposure on physical growth, cognitive development, and emotional well-being.
- **Maternal-Child Health Linkages**: Longitudinal research can illuminate how prenatal heat stress influences birth outcomes and early childhood health trajectories.

- **Educational and Behavioural Monitoring**: Regular assessments of academic performance, attendance, and behavioural patterns can help quantify the long-term educational consequences of climate stress.

(ii) Participatory and Child-Led Research

- **Children as Informants**: Engaging children directly in research through interviews, drawings, storytelling, or digital diaries can provide rich, context-sensitive insights into their lived experiences.
- **Youth-Led Climate Mapping**: Participatory mapping exercises can empower adolescents to identify local climate risks and propose community-based solutions.
- **Inclusive Methodologies**: Research should prioritize voices from marginalized groups, including children with disabilities, those from tribal communities, and those living in informal settlements.

(iii) Intersectional and Comparative Studies

- **Gender and Social Identity**: Investigate how gender, caste, and socio-economic status intersect with climate vulnerability and access to support systems.
- **Urban-Rural Comparisons**: Comparative studies can reveal differences in exposure, infrastructure, and institutional response between urban slums and rural villages.
- **Cross-Regional Analysis**: Expanding the geographic scope to include other climate zones (e.g., arid, mountainous) can help generalize findings and inform national policy.

(iv) Evaluation of Institutional Interventions

- **Impact Assessments of Heat Action Plans**: Rigorous evaluations of school-based and health-sector interventions can identify best practices and areas for improvement.
- **Policy Implementation Studies**: Research should examine how national and state-level climate policies are translated into action at the district and community levels.
- **Technology and Innovation**: Explore the role of digital tools, early warning systems, and mobile health platforms in enhancing child resilience.

4. Conclusion

This study reveals the urgent and multidimensional impacts of heatwaves on children in South India, spanning health, education, nutrition, and psychosocial domains. Through a mixed-methods approach, we document high prevalence of heat-related illnesses, behavioral disturbances, and educational disruptions, alongside emerging food insecurity and limited institutional support. Regional disparities such as severe behavioral impacts in Andhra Pradesh and nutrition concerns in Kerala underscore the need for localized interventions.

Heatwaves are not merely environmental phenomena; they represent a profound child rights and social justice challenge. Current policy frameworks, while advancing surveillance and facility preparedness, lack child-sensitive indicators and mental health integration. School infrastructure gaps and fragmented coping strategies further compound vulnerabilities.

To safeguard children's well-being in a warming climate, climate resilience planning must prioritize child-centered adaptation. This includes embedding pediatric protocols, codifying climate-smart school standards, ensuring nutrition continuity, and integrating psychosocial supports. By addressing these gaps, India can move toward inclusive, cross-sectoral strategies that protect health, education, and equity for its youngest citizens.

Declarations

Statement on the Use of Generative AI

Microsoft Copilot was utilized for language editing and phrasing during the preparation of this manuscript. After employing this application, the content was reviewed and revised where necessary. The use of generative AI has not affected the originality, reliability, or ethical integrity of this manuscript.

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Ethics approval and informed consent

This study was approved by the National Institute of Disaster Management, Government of India. All procedures involving human participants were performed in accordance with relevant institutional and national ethical guidelines and regulations and in accordance with the principles of the Declaration of Helsinki.

Informed consent was obtained from all adult participants prior to participation. For participants below 18 years of age, informed consent was obtained in advance from their parents or legally authorized guardians. Children below 14 years of age were not interviewed independently and were interviewed only in the presence of their parents or guardians.

Consent for publication

Not applicable. The manuscript does not contain any identifying personal information or images of participants.

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Authors' contributions

Conceptualization: Kumar Raka, Ranjan Kumar, and Balu I
Methodology: Kumar Raka, Ranjan Kumar, and Balu I
Formal Analysis: Kumar Raka, Ranjan Kumar, and Balu I
Investigation: Kumar Raka, Ranjan Kumar, and Balu I
Writing – Original Draft Preparation: Kumar Raka, Ranjan Kumar, and Balu I
Writing – Review & Editing: Kumar Raka, Ranjan Kumar, Balu I, Shailendra Rai, and Parveen Kumar, Somnath Bera
Supervision: Kumar Raka and Balu I

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Figures

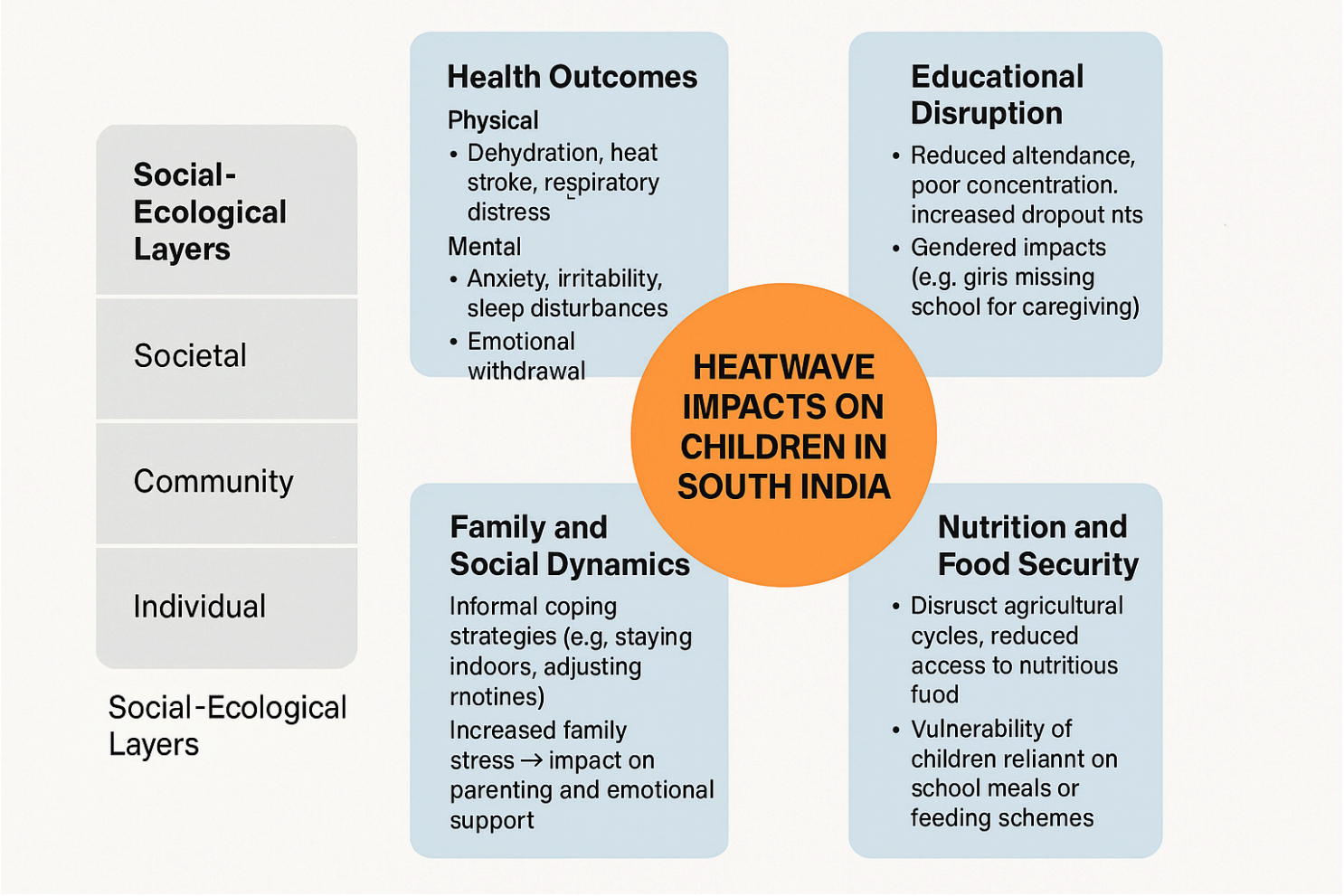


Figure 1

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