Appendices

These are appendices of the report 'A review of Heat and Health research in India: Knowledge gaps in building climate change adaptation responses' by Prayas, available at Prayas website

आरोग्य, ऊर्जा, शिक्षण आणि पालकत्व
या विषयांतील विशेष प्रयत्न

Contents

Appendix: A-1:

Historical trends in heat stroke deaths in India

Name of author, Publication year, Study location	Study description	Findings
Malik, P. et al, 2021 India Mallik, Bhardwaj, and Singh, "Heat Wave Fatalities over India: 1978–2014."	*Study design* Trend analysis *Study timeline* 1978-2014 *Primary outcome* Direct deaths due to exposure to extreme heat, Heat wave events *Source of outcome data* Indian Meteorology Department *Disaggregated analysis by* Gender	The analysis has shown that a total of 660 heat wave events have caused 12,273 fatalities (about 332 fatalities every year). Only five states namely, Andhra Pradesh (42%), Rajasthan (17%), Odisha (10%), Uttar Pradesh (7%) and Bihar (7%) have accounted more than 80% of the heat wave fatalities, although nine states namely, Arunachal Pradesh, Nagaland, Manipur, Meghalaya, Tripura, Sikkim, Mizoram, Uttarakhand and Goa have never reported heat wave events and fatalities during 1978–2014. Interestingly, each event has resulted about 104 fatalities in Andhra Pradesh state. Further, fatality and density rates have been witnessed to the tune of 0.35 and 3.81 respectively. Temporally, heat wave events have displayed large differences with a significant increasing trend ($P < 0.01$), whereas no trend could be noticed in fatalities. Majority of events have been witnessed in May and June months. It has been observed that men have been more harshly affected compared to women and children.
Ray, K., et al, 2021 India Ray et al., "An Assessment of Long-Term Changes in Mortalities Due to Extreme Weather Events in India."	*Study design* Trend analysis *Study timeline* 1970-2019 *Primary outcome* Direct deaths due to exposure to extreme heat, heat wave events Source of outcome data Indian meteorological department Disaggregated analysis by – States	The contribution of heat waves to total mortality caused by extreme weather events was 12.3%. The trend analysis of last 50 years shows a significant decreased mortality per event and a positive trend in mortality per year per million population (r2=0.026). The rates have increased by almost 27% in 2010–2019 as compared to 2000–2009 with a corresponding increase (24%) in the number of heatwave events. Mortality due to heatwaves was very high in Andhra Pradesh, Uttar Pradesh, Odisha, Bihar, and Rajasthan

Kumar, A. et al, et al, 2021 India Kumar and Singh, "Heat Stroke-Related Deaths in India."	*Study design* Trend analysis *Study timeline* 2001-2015 *Primary outcome* Direct deaths due to exposure to extreme heat *Source of outcome data* NA Disaggregated analysis by Age, gender	It was found that there 3014 men died from heat-related causes in 2001–05, which increased to 5157 in the period 2011–15. For women the number of deaths in the corresponding periods were 849 and 1254 respectively. Deaths caused by heatwaves were found to be higher than those resulting from avalanches, exposure to cold, cyclone, tornado, starvation due to natural calamity, earthquake, epidemic, flood, landslide, torrential rain and forest fire. The study revealed that there are regional variations in the number deaths due to heatstroke. From the perspective of disaster preparedness, it is important to note that deaths from heat strokes occur every year. With rising temperatures, the numbers are likely to increase. The findings of the study highlight this concern.
Mahapatra, B. et al, 2018 India Mahapatra, Walia, and Saggurti, "Extreme Weather Events Induced Deaths in India 2001–2014."	*Study design* Trend analysis) *Study timeline* 2001-2014 *Primary outcome* Direct deaths due to exposure to extreme heat *Source of outcome data* Government of India through its National Data Sharing and Accessibility Policy (NDSAP) *Disaggregated analysis by* Age, gender	During 2001–14, 25% of all accidental deaths due to natural causes happened as a result of extreme weather events. Deaths due to extreme precipitation and tropical cyclones declined over time, whereas increasing trend was observed for lightning, and extreme temperature conditions. Most of the extreme weather event induced deaths were due to lightning, followed by extreme precipitation and temperature extremes. The burden of death was highest in the central part of India. States of Andhra Pradesh, Bihar, Uttar Pradesh, Maharashtra and West Bengal were affected the most by extreme weather events. More males and older population died than their counterparts. Findings suggest that people are adaptive to some extreme weather events such as cold wave and cyclones; whereas adaptation and coping with the heat wave and extreme precipitation seems to be less

Appendix A-2:

Risk of heat induced mortality and vulnerable populations – ecological analyses

<table>
<tr><th>Author, year, Study location</th><th>Study details</th><th>Findings</th></tr>
<tr><td rowspan="6">Dutta, P. et al,

2020

Nagpur, Maharashtra

Dutta et al., "Extreme Heat Kills Even in Very Hot Cities."</td><td>Study design
Ecological analysis, Time series analysis</td><td rowspan="6">From the ecological analysis, 580 and 306 additional deaths were observed in 2010 and 2014, respectively. Moving average results also gave similar findings. DLNM results showed that the relative risk was 1.5 for the temperature above 45 °C; forward perspective analysis revealed that the attributable deaths during 2010 and 2014 were 505 and 376, respectively. Results from different methods showed that heat waves in different years had variable impacts for various reasons. However, all the results were consistent during 2010 and 2014; there were 30% and 14% extra-mortalities due to heat comparing to non-heat wave years.</td></tr>
<tr><td>Study timeline:
2009-2015</td></tr>
<tr><td>Primary outcome
All-cause mortality</td></tr>
<tr><td>Exposure variable
Daily temperature (maximum, minimum), Relative humidity</td></tr>
<tr><td>Source of outcome data
Birth and Death Registration Department of municipal corporation</td></tr>
<tr><td>Disaggregated analysis by – none</td></tr>
<tr><td rowspan="6">Azhar, GS, et al,

2014

Ahemedabad, Gujarat

Azhar et al., "Heat-Related Mortality in India."</td><td>Study design
Ecological analysis</td><td rowspan="6">The May 2010 heat wave was associated with significant excess all-cause mortality. 4,462 all-cause deaths occurred, comprising an excess of 1,344 all-cause deaths, an estimated 43.1% increase when compared to the reference period (3,118 deaths). In monthly pair-wise comparisons for 2010, we found high correlations between mortality and daily maximum temperature during the locally hottest "summer" months of April (r = 0.69, p,0.001), May (r = 0.77, p,0.001), and June (r = 0.39, p,0.05). During a period of more intense heat (May 19–25, 2010), mortality rate ratios were 1.76 [95% CI 1.67–1.83, p,0.001] and 2.12 [95% CI 2.03–2.21] applying reference periods (May 12–18, 2010) from various years.</td></tr>
<tr><td>Timeline
2009-2011</td></tr>
<tr><td>Primary outcome
All-cause mortality</td></tr>
<tr><td>Exposure variable
Daily temperature (max, min, mean)</td></tr>
<tr><td>Source of outcome data
Birth and Death Registration Department of municipal corporation</td></tr>
<tr><td>Disaggregated analysis by – Gender</td></tr>
</table>

Appendix A-3:

Risk of heat induced mortality and vulnerable populations – time series analysis

Author, year, Study location	Study details	Findings
Wei,Y. et al, 2021 Ahmedabad, Gujarat Wei et al., "Assessing Mortality Risk Attributable to High Ambient Temperatures in Ahmedabad, 1987 to 2017."	*Study timeline* 1987-2017 *Study design* Time series analysis *Primary outcome* All-cause mortality *Source of outcome data* Birth and Death Registration Department of municipal corporation *Climate variable* Daily maximum, minimum, mean temperature. Heat wave defined by relative threshold percentile and duration *Source of climate data* Indian Meteorology Department *Disaggregated analysis by* Age, sex, residential zone	The model with maximum and minimum temperatures and without heat wave indicator gave the best performance. With this model, we found a substantial and significant increase in mortality rate starting from maximum temperature at 42 °C and from minimum temperature at 28 °C: 1 °C increase in maximum and minimum temperatures at lag 0 were associated with 9.56% (95% confidence interval [CI]: 6.64%, 12.56%) and 9.82% (95% CI: 6.33%, 13.42%) increase in mortality risk, respectively. People aged ≥ 65 years and lived in South residential zone where most slums were located, were more vulnerable. The study observed flatter increases in mortality risk associated with high temperatures comparing the period of 2003-2017 to 1987-2002.
Rathi. S et al, 2021 Jaipur, Rajasthan Rathi, Sodani, and Joshi, "Summer Temperature and All-Cause Mortality from 2006 to 2015 for Smart City Jaipur, India."	*Study timeline* 2006-2015	A total of 75,571 deaths (all-cause mortality) for 1,203 summer days (2006–2015) were analyzed in relation to temperature and relative humidity. The mean daily all-cause mortality has been estimated at 62.8 ± 15.2 for the study period. There is a significant increase of 39% per day all-cause mortality at the maximum temperature of 45 °C and above. However only 10% rise per day all-cause mortality for extreme danger days (HI > 54 °C). The mean daily all-cause mortality shows a significant association with daily maximum temperature ($F = 34.6$, $P < .0001$) and HI (discomfort index) from caution to extreme danger risk days ($F = 5.0$, $P < .0019$).

	Study design Time series analysis *Primary outcome* All cause mortality *Source of outcome data* Birth and Death Registration Department of municipal corporation *Climate variable* Daily average temperature, daily maximum temperature, daily minimum temperature and daily average relative humidity *Source of climate data* Tutiempo Network *Disaggregated analysis by* Year-wise	The lag effect of extreme heat on all-cause mortality for the study period (2006 to 2015) was at a peak period on the same day of the maximum temperature (r = 0.245 at P < .01) but continues up to four days. The study concludes that the effect of ambient heat on all-cause mortality increase is clearly evident (rise of 39% deaths/day).
Nori-Sarma, A. et al, 2019 Mumbai, Maharashtra Jaipur and Churu, Rajasthan Idar/ Himmatnagar, Gujarat Nori-Sarma et al., "The Impact of Heat Waves on Mortality in Northwest India."	*Study timeline* 2000–2012 *Study design* Time series analysis *Primary outcome* All-cause mortality *Source of outcome data* Birth and Death Registration Department of municipal corporation *Climate variable* Daily maximum temperature *Source of climate data* Indian Meteorology Department *Disaggregated analysis by* City-wise	Community-specific average daily maximum temperature over the entire record ranged from 32.5 to 34.2 °C (90.5–93.6 °F). Across communities, total mortality increased 18.1% during heat wave days compared with non-heat-wave days [95% confidence interval (CI): −5.3%, 47.3%], with the highest risk in Jaipur (29.9% [95% CI: 24.6%, 34.9%]). Evidence of effect modification by heat wave characteristics (intensity, duration, and timing in season) was limited. Findings indicate health risks associated with heat waves in communities with high baseline temperatures

Nori-Sarma, A. et al, 2019 Mumbai, Maharashtra Jaipur and Churu, Rajasthan Idar/ Himmatnagar, Gujarat Nori-Sarma et al., "Advancing Our Understanding of Heat Wave Criteria and Associated Health Impacts to Improve Heat Wave Alerts in Developing Country Settings."	*Study timeline* 2000–2012 *Study design* Time series analysis *Primary outcome* All-cause mortality *Source of outcome data* Birth and Death Registration Department of municipal corporation *Climate variable* Heat waved defined by different temperature thresholds and duration *Source of climate data* Indian Meteorology Department *Disaggregated analysis by* City-wise	Propensity Score Matching (PSM) was used to obtain the relative risk of mortality and number of attributable deaths (i.e., absolute risk which incorporates the number of heat wave days) under a variety of heat wave definitions (n = 13) incorporating duration and intensity. Heat waves' timing in season was also assessed for potential effect modification. Relative risk of heat waves (risk of mortality comparing heat wave days to matched non-heat wave days) varied by heat wave definition and ranged from 1.28 [95% Confidence Interval: 1.11–1.46] in Churu (utilizing the 95th percentile of temperature for at least two consecutive days) to 1.03 [95% CI: 0.87–1.23] in Idar and Himmatnagar (utilizing the 95th percentile of temperature for at least four consecutive days). The data trended towards a higher risk for heat waves later in the season. Some heat wave definitions displayed similar attributable mortalities despite differences in the number of identified heat wave days
Singh, N. et al, 2019 Varanasi, Uttar Pradesh Singh et al., "Attributing Mortality from Temperature Extremes."	*Study timeline* 2009-2016 *Study design* Time series analysis *Primary outcome* All-cause mortality *Source of outcome data* Municipal Corporation of Varanasi *Climate variable* Daily minimum, maximum and mean temperature; relative humidity; Ambient air quality in terms of PM10, SO2, NO2 and ground-level O3 concentration *Source of climate data* Indian Meteorology Department *Disaggregated analysis by* age, gender, place of death, air pollution parameters (PM, SO2, NO2, O2)	A semiparametric quasi-Poisson regression model estimated the effects of temperature extremes on daily all-cause mortality adjusting nonlinear confounding effects of time trend, relative humidity and air pollution; stratified by seasons. An effect modification by age, gender and place of death as semi-economic indicator were also explored. Daily mean temperature was strongly associated with excess mortality, both during summer (5.61% with 95% CI: 4.69–6.53% per unit increase in mean temperature) and winter (1.53% with 95% CI: 0.88–2.18% per unit decrease in mean temperature). Daily mortality was found to be increased by 12.02% (with 95% CI: 4.21–19.84%) due to heat wave. The DTV has exhibited downward trend over the years and showed a negative association with all-cause mortality. Significant association of mortality and different metric of temperature extreme along with decreasing trend in DTV clearly indicate the potential impact of climate change on human health in the city of Varanasi.

Dutta, A. et al, 2020 Bhubaneswar, Odisha Dutta et al., "At Which Temperature Do the Deleterious Effects of Ambient Heat 'Kick-in' to Affect All-Cause Mortality?"	*Study timeline* 2007-2014 *Study design* Time series analysis *Primary outcome* All-cause mortality *Source of outcome data* Birth and Death Registration Department of municipal corporation *Climate variable* Daily temperature (maximum, minimum) and relative humidity *Source of climate data* Indian Meteorology Department *Disaggregated analysis by* None	Mortality risks rose when daily maximum temperatures were >36.2°C (lower threshold), and even more when >40.5°C (upper threshold). Every degree above36.2°C increased the mortality risk by 2% (mortality rate ratio: 1.02; 95% CI 1.01, 1.03). The effects of maximum temperature increased on days when minimum temperatures were >25.6°C (median). The effect of heat was immediate and lasted for 0–1 day with no lagged effect. Two temperature thresholds with varying mortality risks provided an opportunity for a graded heat warning system.
Hang Fu, et al, 2018 India Fu et al., "Mortality Attributable to Hot and Cold Ambient Temperatures in India."	*Study timeline* 2001-2013 *Study design* Time series analysis *Primary outcome* cause specific mortality (stroke, IHD, respiratory diseases; malaria, and cancers were taken as reference) *Source of outcome data* mortality data from India's Million Death Study (MDS) *Climate variable* Daily mean temperature *Source of climate data* Indian Meteorology Department *Disaggregated analysis by* age	Mortality from all medical causes, stroke, and respiratory diseases showed excess risks at moderately cold temperature and hot temperature. For all examined causes, moderately cold temperature was estimated to have higher attributable risks (6.3% [95% empirical confidence interval (eCI) 1.1 to 11.1] for all medical deaths, 27.2% [11.4 to 40.2] for stroke, 9.7% [3.7 to 15.3] for IHD, and 6.5% [3.5 to 9.2] for respiratory diseases) than extremely cold, moderately hot, and extremely hot temperatures. In 2015, 197,000 (121,000 to 259,000) deaths from stroke, IHD, and respiratory diseases at ages 30–69 years were attributable to moderately cold temperature, which was 12- and 42-fold higher than totals from extremely cold and extremely hot temperature, respectively. The main limitation of this study was the coarse spatial resolution of the temperature data, which may mask microclimate effects

Ingole, V. et al, 2017 Vadu, Maharashtra Ingole et al., "Socioenvironmental Factors Associated with Heat and Cold-Related Mortality in Vadu HDSS, Western India."	*Study timeline* 2004-2013 *Study design* Time series analysis *Primary outcome* All-cause mortality *Source of outcome data* Health and Demographic Surveillance System (HDSS) *Climate variable* Daily mean temperature, heat and cold season based on summer months and winter months *Source of climate data* National Oceanic and Atmospheric Administration (NOAA), Indian Meteorological Department *Disaggregated analysis by* sex, age, ownership of agricultural land, house type, education and occupation	Temperature above a threshold of 31 °C was associated with total mortality (OR 1.48, CI = 1.05–2.09) per 1 °C increase in daily mean temperature. Odds ratios were higher among females (OR 1.93; CI = 1.07–3.47), those with low education (OR 1.65; CI = 1.00–2.75), those owing larger agricultural land (OR 2.18; CI = 0.99–4.79), and farmers (OR 1.70; CI = 1.02– 2.81). In winter, per 1 °C decrease in mean temperature, OR for total mortality was 1.06 (CI = 1.00–1.12) in lag 0–13 days. High risk of cold-related mortality was observed among people occupied in housework (OR = 1.09; CI = 1.00–1.19). The study suggests that both heat and cold have an impact on mortality particularly heat, but also, to a smaller degree, cold have an impact
Mazdiyasni, O. et al 2017 Mazdiyasni et al., "Increasing Probability of Mortality during Indian Heat Waves."	*Study timeline* 1960-2009 *Study design* Probabilistic modelling *Primary outcome* heat-related mortality *Source of outcome data* Indian meteorological department *Climate variable* Summer mean temperature and heat wave days *Source of climate data* Indian meteorological department *Disaggregated analysis by* residential zones NA	Analysis of changes in summer temperatures, the frequency, severity, and duration of heat waves, and heat-related mortality in India between 1960 and 2009 using data from the India Meteorological Department was performed. Mean temperatures across India have risen by more than 0.5°C over this period, with statistically significant increases in heat waves. Using a novel probabilistic model, we further show that the increase in summer mean temperatures in India over this period corresponds to a 146% increase in the probability of heat-related mortality events of more than 100 people.

Rathi.S et al, 2017 Surat, Gujarat Rathi et al., "Summer Temperature and Spatial Variability of All-Cause Mortality in Surat City, India."	*Study timeline* 2014-2015 *Study design* Time series analysis *Primary outcome* All-cause mortality *Source of outcome data* Birth and Death Registration Department of municipal corporation *Climate variable* Daily average temperature, daily maximum temperature, daily minimum temperature and daily average relative humidity *Source of climate data* Tutiempo Network *Disaggregated analysis by* residential zones	Mean daily mortality was estimated at 50.2 ± 8.5 for the study period with a rise of 20% all-cause mortality at temperature ≥ 40°C and rise of 10% deaths per day during extreme danger level (HI: > 54°C) days. Spatial (Zone wise) analysis revealed rise of 61% all-cause mortality for Southeast and 30% for East zones at temperature ≥ 40°C
Desai, V. et al, 2015 Surat, Gujarat Desai et al., "Effect of Ambient Heat on All-Cause Mortality in the Coastal City of Surat, India."	*Study timeline* 2001-2012 *Study design* Time series analysis *Primary outcome* All-cause mortality *Source of outcome data* Birth and Death Registration Department of municipal corporation *Climate variable* Daily mean, maximum and minimum temperature and daily mean humidity *Source of climate data* Tutiempo Network *Disaggregated analysis by* Year-wise	A total of 36,167 deaths for 961 summer days (2001–12) were analyzed. Mean daily mortality was estimated at 37.6 ± 9.4 for the study period. There is an increase of 11% mortality when the temperature crosses 40°C. However, there is an increase of 3 (9%) deaths per day during danger-level heat-risk days and 6 (18%) deaths per day during high-risk heat days (extreme danger) respectively. Mortality seems to be well correlated with the high temperature (P < 0.001) and high heat index (HI) values (P < 0.001). The effect of extreme heat on mortality is at a peak on day-2 of the maximum temperature.

Ingole, V. et al, 2015 Vadu, Pune Ingole et al., "Impact of Heat and Cold on Total and Cause-Specific Mortality in Vadu HDSS—A Rural Setting in Western India."	*Study timeline* 2003-2012 *Study design* Time series analysis *Primary outcome* cause specific mortality (non-infectious, infectious, external causes) *Source of outcome data* Health and Demographic Surveillance System (HDSS) *Climate variable* Daily minimum and maximum temperature *Source of climate data* Indian Meteorology Department *Disaggregated analysis by* age, sex	Delays of 0 and 0–4 days were considered and relative risks (RR) with 95% confidence intervals (CI) were calculated. Heat was significantly associated with daily deaths by non-infectious diseases (RR = 1.57; CI: 1.18–2.10). There was an increase in the risk of total mortality in the age group 12–59 years on lag 0 day (RR = 1.43; CI: 1.02–1.99). A high increase in total mortality was observed among men at lag 0 day (RR = 1.38; CI: 1.05–1.83). The study did not find any short-term association between total and cause-specific mortality and cold days. Deaths from neither infectious nor external causes were associated with heat or cold.
Ingole, V. et al, 2012 Vadu, Pune Ingole et al., "The Short-Term Association of Temperature and Rainfall with Mortality in Vadu Health and Demographic Surveillance System."	*Study timeline* 2003-2010 *Study design* Time series analysis *Primary outcome* All-cause mortality *Source of outcome data* Health and Demographic Surveillance System (HDSS) *Climate variable* Daily mean temperature and rainfall *Source of climate data* Indian Meteorology Department *Disaggregated analysis by* age, sex	Mortality was found to be significantly associated with daily ambient temperatures and rainfall, after controlling for seasonality and long-term time trends. Children aged 5 years or below appear particularly susceptible to the effects of warm and cold temperatures and heavy rainfall. The population aged 20-59 years appeared to face increased mortality on hot days. Most age groups were found to have increased mortality rates 7-13 days after rainfall events. This association was particularly evident in women.

Appendix A-4:

Future projections of heat mortality

Author, year, Study location	Study details	Findings
Murari, KK. et al 2015 Murari et al., "Intensification of Future Severe Heat Waves in India and Their Effect on Heat Stress and Mortality."	*Source of heat data:* Indian Meteorology Department Source of mortality data: historical data of heat wave-induced mortality rates obtained from the Ministry of Home Affairs (Government of India)* *Forecasting methodology:* linear regression analysis to relate the number of heat wave days per year to the mortality per unit of population *Level of analysis:* Four states (Delhi, Maharashtra, Orissa, Rajasthan) *Assumption:* (1) the regression coefficients remain constant, (2) business-as-usual practice toward heat wave preparedness prevails, and (3) the adaptation capacity of communities does not change over time (4) population fixed as 2001 census	The paper projects future heat waves in India based on multiple climate models and scenarios for CMIP5 data. Projections indicate that a sizable part of India will experience heat stress conditions in the future. In northern India, the average number of days with extreme heat stress condition during pre-monsoon hot season will reach 30. The intensification of heat waves might lead to severe heat stress and increased mortality
Dholakia, H. et al 2015^ Dholakia, Mishra, and Garg, "Predicted Increases in Heat Related Mortality under Climate Change in Urban India."	*Source of heat data:* Coupled Model Inter-comparison Project Phase 5 (CMIP5) models *Source of mortality data:* Observed data on mortality from Sample Registration System (SRS) for the period of 2005-2012 *Forecasting methodology:* temperature-mortality relationships using Poisson regression models *Level of analysis:* 52 urban areas (population >1 million) that are located in diverse climactic regimes in India *Assumption:* Not specified	Mortality is projected to increase 71 and 140% in the late 21st century under the RCP 4.5 and 8.5 scenarios, respectively. Urban areas of Delhi, Ahmedabad, Bangalore, Mumbai and Kolkata are projected to experience the highest absolute increases in the heat related mortality in 2080s under the RCP 8.5 scenario

Climate impact lab, 2020** Climate Impact Lab, "Climate Change and Heat-Induced Mortality in India."	*Source of heat data:* Global climate models *Source of mortality data:* India specific mortality data was not used for defining mortality temperature relationship *Forecasting methodology:* Mortality-temperature relationship estimates *Level of analysis:* City level *Assumptions:* Not specified	India is projected to see around an increase of death rates due to climate change equal to about 10% of the current death rate. That is, 60 deaths per 100,000 population by the end of the century under a scenario of continued emissions (RCP 8.5). By 2100, around 1.5 million more people are projected to die each year as a result of climate change—at a rate as high as the death rate from all infectious diseases in India today

* no reference for the mortality data was provided and in our further search we could determine specific source of mortality data maintained by ministry of home affairs

** Report

^ Working paper

Appendix A-5:

Heat morbidity studies among working population

Author, year, Study location	Study details	Findings
Venugopal, V. et al 2021 Chennai, TamilNadu Agriculture, construction, salt, bricks, auto parts, foundry, garments, and steel industry workers Venugopal et al., "Epidemiological Evidence from South Indian Working Population—the Heat Exposures and Health Linkage."	*Study timeline* 2015-2019 *Study design* Cross sectional (n=1480) *Health outcome* Self-reported signs and symptoms, Core Body Temperature (CBT), Sweat Rate (SwR), and Urine Specific Gravity (USG *Disaggregated analysis by* Age, gender, education, smoking-alcohol, workload, sectors	Heat exposures (Avg.WBGT: 28.4 ± 2.6 °C) exceeded the Threshold Limit Value (TLV) for 70% of workers and was significantly associated with the rise in CBT >1 °C in 11.3% and elevated USG >1.020 in 10.5% of the workers. The heat-exposed workers had 2.3 times higher odds of reporting adverse health outcomes (84%) compared to the unexposed workers (95% CI: 1.74-3.19; p value ≤ 0.0001). Mild reduction in kidney function observed in 49% of salt - pan workers, and a high prevalence of kidney stones (33%) among the 91 steelworkers subjected to kidney ultrasound had a significant association with chronic high WBGT exposure above the TLV (p value < 0.034).
Venugopal. V et al 2020 Chennai, Tamil Nadu Steel Industry Worker Venugopal et al., "Risk of Kidney Stone among Workers Exposed to High Occupational Heat Stress - A Case Study from Southern Indian Steel Industry."	*Study timeline* 2019 *Study design* Cross sectional (n=340) *Health outcome* Core Body Temperature (CBT), Urine Specific Gravity (USG) and Sweat Rate (SwR) *Disaggregated analysis* age, sex, education, alcohol, smoking, work intensity	The results show that heat exposures (Avg. WBGT = 33.2 °C ± 3.8 °C) exceeded the Threshold Limit Value (TLV) for 220 workers. 95% of the workers reported symptoms of heat strain and dehydration and significant associations between heat exposures, rise in Core Body Temperature (CBT) (p = 0.0001) and Urine Specific Gravity (USG) (p = 0.018) were observed. Of the 91 workers subjected to renal ultrasound, 33% were positive for kidney/ureteral stones (n = 25) & other structural renal anomalies (n = 5). Renal/urologic anomalies were higher in the heat-exposed workers (AOR = 2.374; 95% C.I = 0.927 to 6.077; p = 0.072) 29% of workers were from exposed group and 4% were from unexposed group. Years of exposure to heat (≥5 vs b5) were significantly associated with the risk of renal anomalies/calculi.

Sen J, et al. 2019 Burdwan and Hooghly, West Bengal Paddy and potato farmers Sen and Nag, "Human Susceptibility to Outdoor Hot Environment."	*Study timeline* 2015-2017 *Study design* Cross sectional (n=1114) *Health outcome* Core Body Temperature (CBT), Heart rate, body weight loss due to sweating, Self-reported signs and symptoms *Heat Exposure* Ambient temperature (indices) at workplace and individual level *Disaggregated analysis by* Gender,	The study explored the thermal stress level identified by different indices. December and January were recognized the comfortable months by most of the thermal indices. March and April were strong to very strong heat stress, with exception noted for SET*. In comparison to rational indices, the Esk, a thermoregulatory parameter, signified the relative change in the evaporative exchange with the increasing environmental warmth. The defined level of Esk at ~200 W/sq·m corresponded to the comfortable temperature range within 19.5 to 22.5 °C for WBGT, PET, and Ta. Beyond this specific range of warmth, a proportionate increase in Esk would result in cumulative heat-related symptoms of stress and strain. The study noted a sizeable number of farmworkers manifested moderate to high intensity of heat-related symptoms, with a relatively higher percentage in case of females. The principal component analysis yielded three principal components of heat-related responses, labeled as (a) physical fatigue and responses, (b) neural stressors, and (c) behavioural effects.
Venugopal. V et al 2019 Chennai, Tamil Nadu Steel Industry Workers Venugopal et al., "Association between Occupational Heat Stress and DNA Damage in Lymphocytes of Workers Exposed to Hot Working Environments in a Steel Industry in Southern India."	*Study timeline* *Study design* Cross sectional (n=120) *Health outcome* Core body temperature, sweating rate, urine specific gravity Disaggregated analysis age, education, alcohol, smoking, years of work	There was a significant increase in the MN-frequency in exposed workers compared to the unexposed workers (X2 = 47.1; $p < 0.0001$). While exposed workers had higher risk of DNA damage (Adj. OR = 23.3, 95% CI 8.0–70.8) compared to the unexposed workers, among the exposed workers, the odds of DNA damage was much higher for the workers exposed to high-heat levels (Adj. OR = 81.4; 95% CI 21.3–310.1) even after adjusting for confounders. For exposed workers, years of exposure to heat also had a significant association with higher induction of MN (Adj. OR = 29.7; 95% CI 2.8–315.5). Exposures to chronic heat stress is a significant occupational health risk including damages in sub-cellular level, for workers

Raval. A et al 2018 Ahmedabad, Gujarat Police officers Raval et al., "Effects of Occupational Heat Exposure on Traffic Police Workers in Ahmedabad, Gujarat."	*Study timeline* 2015 Study design Cross sectional (n=16) *Health outcome* Internal temperature *Disaggregated analysis* age, sex, height, weight, as well as work structure, heat impacts on productivity, clothing, heat	Wet bulb globe temperature (WBGT) levels ranged from 28.2°C to 36.1°C during the study period. Traffic police workers who participated in this study were exposed to WBGT levels higher than the recommended threshold limit value as per American Conference of Governmental Industrial Hygienists guidelines even beyond the hottest months of the season. Our findings suggest that airport measurements by the Indian Meteorological Department may not accurately capture heat exposures among individuals who work in and alongside highdensity traffic junctions. Based on our temperature estimates, traffic police are at risk for heat stress
Das B et al 2018 Hoogly, West Bengal Brick workers Das, B. et al., "Thermal stress, cardiovascular stress and work productivity among the female brick field workers of West Bengal, India"	*Study timeline* 2012-2013 *Study design* Cross sectional (n=112) *Health outcome* cardiovascular stress index Disaggregated analysis age, education, BMI, type of workers, group of workers, shift duration	Cardiac strain in different seasons were measured in terms of work heart rate (WHR), relative cardiac cost (RCC), net cardiac cost (NCC), cardiovascular stress index (CSI) and other recovery indices among the female brick field workers. The net cardiac costs of the brick stackers were higher in comparison to brick moulders and carriers. NCC and the RCC levels were higher among the brick stackers than in other groups of brick field workers. The CSI levels were the maximum in the case of carrying raw mud activities. In these activities, the brick field workers changed their posture frequently during loading and unloading and walking with mud. The frequent change of postures imposed extra load on the cardiovascular system.
Lundgren-Kownacki. K et al 2018 Chennai, Tamil Nadu Migrant Brick Kiln Workers Lundgren-Kownacki et al., "Climate Change-Induced Heat Risks for Migrant Populations Working at Brick Kilns in India."	*Study timeline* 2013-2015 *Study design* Case study analysis (Summer n=87 and winter n=61) *Health outcome* Heat stress Disaggregated analysis Season and work location	Around Chennai, the situation is alarming since occupational heat exposure in the hot season from March to July is already at the upper limits of what humans can tolerate before risking serious impairment. The aim of the study was to identify new pathways for change and soft solutions by both reframing the problem and expanding the solution space being considered in order to improve the quality of life for the migrant populations at the brick kilns. Technical solutions evaluated include the use of sun-dried mud bricks and other locally appropriate technologies that could mitigate the worsening of climate change-induced heat.

Krishnamurthy. M et al 2017 Steel City, South India Steel Industry Workers Krishnamurthy et al., "Occupational Heat Stress Impacts on Health and Productivity in a Steel Industry in Southern India."	*Study timeline* 2014 *Study design* Cross sectional (n=84) *Health outcome* Heat stress Disaggregated analysis plant location, symptoms	Some 90% WBGT measurements were higher than recommended threshold limit values (27.2 - 41.7°C) for heavy and moderate workloads and radiational heat from processes were very high in blooming-mill/coke-oven (67.6°C globe temperature). Widespread heat-related health concerns were prevalent among workers, including excessive sweating, fatigue, and tiredness reported by 50% workers. Productivity loss was significantly reported high in workers with direct heat exposures compared to those with indirect heat exposures (c2 ¼ 26.1258, degrees of freedom ¼ 1, p < 0.001). Change in urine color was 7.4 times higher among workers exposed to WBGTs above threshold limit values (TLVs).
Dutta.P et al 2015 Gandhinagar, Gujarat Construction workers Dutta et al., "Perceived Heat Stress and Health Effects on Construction Workers."	*Study timeline* 2013-2014 *Study design* Mixed methods (cross sectional n = 219 and Focused group discussions) *Health outcome* occupational heat stress Disaggregated analysis age, sex, education, occupational experience, anthropometry, lifestyle	The survey findings suggest that heatrelated symptoms increased in summer; 59% of all reports in summer were positive for symptoms (from Mild to Severe) as compared to 41% in winter. Focus groups revealed four dominant themes: (1) Nonoccupational stressors compound work stressors; (2) workers were particularly attuned to the impact of heat on their health; (3) workers were aware of heatrelated preventive measures; and (4) few resources were currently available to protect workers from heat stress. Working conditions often exceed international heat stress safety thresholds. Female workers and new employees might be at increased risk of illness or injury.
Sett.M et al 2014 West Bengal Brick Workers Sett and Sahu, "Effects of Occupational Heat Exposure on Female Brick Workers in West Bengal, India."	*Study timeline* 2008-2010 *Study design* Cross sectional (n=120) *Health outcome* cardiac problems due to heat Disaggregated analysis age, height, weight, experience, nature of brick worker (brick carriers or brick moulders)	The subjects experience summer for about 5 months with additional heat stress radiating from the brick kiln. The weekly productivity data show a linear decline in productivity with increased maximum air temperature above 34.98C. The cardiac parameters (peak heart rate (HRp), net cardiac cost (NCC), relative cardiac cost (RCC), and recovery heart rates) were significantly higher on hotter days (Wet Bulb Globe Temperature (WBGTout) index: 26.98C to 30.748C) than on cooler days (WBGTout index: 16.128C to 19.378C) for the brick molders; however, this is not the case for the brick carriers. As the brick carriers adapt to hotter days by decreasing their walking speed, their productivity decreases

Sahu. S et al 2013 West Bengal Rice Harvesters Sahu, Sett, and Kjellstrom, "Heat Exposure, Cardiovascular Stress and Work Productivity in Rice Harvesters in India."	*Study timeline* 2011 *Study design* Cross sectional (n=124) *Health outcome* Cardiac stress Perceived health problems Disaggregated analysis age, height, weight	Hourly heat exposure in rice fields in West Bengal were measured and perceived health problems were recorded via interviews of 124 rice harvesters. In a sub-group (n = 48) heart rate was recorded every minute in a standard work situation. Work productivity was recorded as hourly rice bundle collection output. The hourly heat levels (WBGT = Wet Bulb Globe Temperature) were 26-32°C (at air temperatures of 30-38°C), exceeding international standards. Most workers reported exhaustion and pain during work on hot days. Heart rate recovered quickly at low heat, but more slowly at high heat, indicating cardiovascular strain. The hourly number of rice bundles collected was significantly reduced at WBGT>26°C (approximately 5% per°C of increased WBGT).

Appendix A-6:

Heat morbidity studies among urban and rural households

Author, year, Study location	Study details	Findings
Swain. S et al 2019 Bubhaneshwar and Cuttack, Odisha Urban households- slum and non-slum general population Swain et al., "Vulnerability and Adaptation to Extreme Heat in Odisha, India."India during the summer. Methods: A cross-sectional study included 766 households (HHs	*Study timeline* 2017 *Study design* Cross sectional (n=1099) (Stratified cluster random sampling) *Health outcome* Self-reported signs and symptoms, Disaggregated analysis by age, sex, caste, religion, housing characteristics (roofs, electricity, power cut, water supply)	Nearly, 49% of the study participants were female and the mean age was 38.36 years (95% confidence interval (CI): 37.33–39.39 years). A significant difference of living environment was seen across the groups. More than two-thirds of the study participants at least once had heat illness. In the non-slum population, males (adjusted odds ratio (aOR): 3.56; 95% CI: 2.39–5.29), persons under medication (aOR: 3.09; 95% CI: 1.15–8.29), and chronic conditions had higher association with heat illness. Whereas, in the slum population, having a kitchen outside the home (aOR: 1.63; 95% CI: 1.02–3.96) and persons with chronic conditions were positively associated with heat illness. Use of cooling practices in slum areas reduced the risk of heat illness by 60%.
Pradyumna. A et al^ 2018 Jalna, Maharashtra Rural households- general population Pradyumna et al., "Heat Stress – Vulnerability, Health Impacts, and Coping Strategies in Rural Communities in the Semi-Arid Region of Maharashtra, India."	*Study timeline* 2016 *Study design* Cross sectional (n=1224) *Health outcome* Heat stress *Disaggregated analysis* age, sex, wealth ranking, caste, education, occupation	Exposure to heat in various circumstances, both outdoors and indoors were reported. The major HRS were found to be headache, heavy sweating and fatigue, which were mild or moderate in nature. Age, gender, wealth and pre-existing health conditions were significantly associated with occurrence of HRS. Regarding exposure, working outdoors during mid-day, roofing material and indoor ventilation were significantly associated with occurrence of HRS.
Tasgaonkar. P et al^ 2018 Yavatmal, Maharashtra Rural households- general population Tasgaonkar et al., "Vulnerability to Heat Stress: A Case Study of Yavatmal, Maharashtra, India."	*Study timeline* 2016 *Study design* Cross sectional (n=326) *Health outcome* Heat stress *Disaggregated analysis* age, sex, education, type of roof	

Tran. K et al 2013 Ahmedabad, Gujarat Slum dwellers Tran et al., "A Cross-Sectional, Randomized Cluster Sample Survey of Household Vulnerability to Extreme Heat among Slum Dwellers in Ahmedabad, India."	*Study timeline* 2011 *Study design* Cross sectional (n=1650) (randomized, cluster-sampled survey) *Health outcome* Heat stress *Disaggregated analysis* age, sex, education, occupation, work location	Associations between heat-related morbidity and vulnerability factors were identified using multivariate logistic regression with generalized estimating equations to account for clustering effects. Age, preexisting medical conditions, work location, and access to health information and resources were associated with self-reported heat illness.

^ Report

Appendix A-7:

Heat morbidity studies among hospitalized patients

Author, year, Study location	Study details	Findings
Kalaiselvan et al 2015 Chennai, Tamil Nadu Kalaiselvan, Renuka, and Arunkumar, "A Retrospective Study of Clinical Profile and Outcomes of Critically Ill Patients with Heat-Related Illness."	*Study timeline* 2012 *Study design* retrospective case series *Health outcome* Heat illness *Disaggregated* analysis age, sex, comorbidity, medications	The common presenting symptoms (to Intensive Care Unit) were fever with neurological impairment (100%) and gastrointestinal symptoms (30%). Major organ systems involvement include neurological (100%), renal (57%), hepatic (34%) and coagulation abnormalities (26%). Most common metabolic abnormality noted was hyponatraemia (73%). Magnetic resonance imaging findings suggestive of heat stroke were seen in 5 of 26 patients. Mortality rate was 34%. 8 of 17 survivors had residual neurological impairment. imaging findings suggestive of heat stroke were seen in 5 of 26 patients. Mortality rate was 34%. 8 of 17 survivors had residual neurological impairment.
Kiranmayi, Patnala. 2014 Nellimarla, Andhra Pradesh Kiranmayi, "Climate Change and Chronic Kidney Disease."	*Study timeline* 2011-2012 *Study design* Case control study (n)= 198 *Health outcome* chronic kidney disease *Disaggregated analysis* age, sex, occupation, months, height, weight	Most of the CKD (48.4%) cases are registered relatively high between the months of March and May. In the present study, creatinine clearance values using CG, MDRD and MCQE in CKD patients are significantly lowered when compared with control ($p < 0.001$). Most of the people registered are agricultural workers (24%), construction workers or laborers (23%) and industrial labor workers (18%) who belong to low income group. In the present investigation, it was observed that there was a progressive decline in GFR as the age advanced, these are more at risk of developing renal disease when exposed to heat stress.

Appendix B-1:

Population based vulnerability and adaptation assessments

Author, year, Study location	Study details	Findings
Gulrez Azhar et al, 2017 India Azhar et al., "Heat Wave Vulnerability Mapping for India."	*Study design* Developing district level composite Heat Vulnerability Index (HVI) for India. *Data Sources* Demographic, socioeconomic, and environmental vulnerability factors and combined district level data from several sources including the most recent census, health reports, and satellite remote sensing data	Of the total 640 districts, 10 and 97 districts were in the very high and high risk categories (> 2SD and 2-1SD HVI) respectively. Mapping showed that the districts with higher heat vulnerability are located in the central parts of the country. On examination, these are less urbanized and have low rates of literacy, access to water and sanitation, and presence of household amenities.

Appendix B-2:

Early warning systems

Author, year, Study location	Study details	Findings
Golechha, M., et al, 2021 City of Rajkot and Nagpur Golechha, Shah, and Mavalankar, "Threshold Determination and Temperature Trends Analysis of Indian Cities for Effective Implementation of an Early Warning System."	*Study design* Trend analysis, percentile-based method was used to determine maximum temperature thresholds *Study timeline* 2003-17 *Primary outcome* All-cause mortality *Source of outcome data* Birth and Death Registration Department of municipal corporation *Climate variable* Daily maximum temperature *Source of climate data* Indian Metrological Department (IMD)	There was a significant association between all-cause mortality and extreme heat events and it was more profound when temperatures were above 40.1 ◦C, but V-shaped relationship of mortality-temperature was noted only for Nagpur city. The dose-response relationship between maximum temperatures and deaths alert thresholds to activate heat health response for red alert set at 46 ◦C and 44 ◦C for Nagpur and Rajkot city respectively. This study suggests that determining local thresholds is important for developing and implementing scientific early warning systems to prevent heat-related illnesses.

Appendix B-3:

Studies on effectiveness of heat action plans or their components

Author, year, Study location	Study details	Findings
Hess, J. et al, 2018 Ahmedabad, Gujarat Hess et al., "Building Resilience to Climate Change."	*Study design* Evaluation (pre-post design) *Study timeline* 2007-10, 2014-15 Primary outcome All-cause mortality *Source of outcome data* Birth and Death Registration Department of municipal corporation *Climate variable* Daily maximum temperature *Source of climate data* Meteorological Aviation Report (METAR) system *Intervention* Heat action plan implemented in the city of Ahmedabad during 2014-15 *Disaggregated analysis* None	The maximum pre-HAP RR was 2.34 (95%CI 1.98–2.76) at 47°C (lag 0), and the maximum postHAP RR was 1.25 (1.02–1.53) estimated at 47°C (lag 0). Post-to-pre-HAP nonlagged mortality IRR for Tmax over 40°C was 0.95 (0.73–1.22) and 0.73 (0.29–1.81) for Tmax over 45°C. An estimated 1,190 (95%CI 162–2,218) average annualized deaths were avoided in the post-HAP period
Das S. et al, 2012 Odisha Das and Smith, "Awareness as an adaptation strategy for reducing mortality from heat waves. "	*Study design* Evaluation (quasi-experimental, difference in difference regression analysis) *Study timeline* 1998 to 2010 *Source of outcome data* Odisha State Disaster Mitigation Authority and Senior Relief Commissioner's office. *Climate variable* None *Intervention* Grassroots awareness campaign on "dos and don'ts during heat wave conditions through the Disaster Risk Management program	The results suggest that heat wave awareness campaigns can significantly reduce heat stroke deaths during heat waves in a developing country context. The study also looked at interaction of the grassroots program impact with the concurrent media program impact. Information may first be received via the newspaper (conveyed verbally in the case when household members are illiterate), or seen on television at a village center, and then may be reinforced by visits of grassroots program officers. Similarly, people may be reminded of the in-depth information they received from the village visits when hearing a brief message on the radio. Thus, the two programs may be mutually reinforcing. For some individuals or communities, mass media may carry more credibility and the grassroots campaign serves as a reminder; in other communities the reverse may be true. We find a significant negative coefficient, indicating that the two approaches may be complementary as awareness strategies in helping to avert mortality.

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