SMART SURFACES COALITION

Healthcare Cost Burden of Heat Islands in Indian Cities

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The Smart Surfaces Coalition is made up of more than 40 leading national and international organizations with a shared commitment to creating cooler, healthier, and more resilient cities by cost-effectively reducing the impacts of extreme urban heat and flooding. Smart Surfaces — reflective, porous, and green urban surfaces along with trees and solar PV — can cut peak summer temperatures by 5°F or more, decrease flood risk, slow climate change, and improve public health, with the greatest improvements in low-income neighborhoods and communities of color.

{This is where we would add the logos and descriptions of organizations with whom we are co-publishing the report.)

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Abstract

This research paper investigates the Urban Heat Island (UHI) effect and its profound consequences on public health, specifically within the context of India. The UHI effect is characterized by significantly elevated temperatures in cities — averaging 1–7°F higher in the daytime and about 2–5°F higher in the nighttime — compared to their rural surroundings. Heat islands result from various factors such as increased building density, heat-absorbing building materials, human activities, and lack of natural landscapes. India, being one of the most climate-vulnerable countries globally, faces exacerbated UHI challenges due to its geographical location, population density, and widening socioeconomic disparity gaps (World Inequality Report, 2022).

The paper explores the multifaceted health impacts of the UHI effect, including heat-related illnesses, cardiovascular issues, respiratory problems, maternal and child health concerns, and mental health challenges. These health implications are further compounded by disparities in access to resources and healthcare services, making vulnerable populations more susceptible to the adverse effects of heat.

Moreover, the study underscores the economic repercussions of the UHI effect in India, estimating substantial healthcare costs and potential productivity losses. It highlights the urgent need for comprehensive policy measures to mitigate the UHI effect, emphasizing the incorporation of heat-related factors into the Climate Vulnerability Index (CVI), data collection on urban microclimates, and the promotion of district cooling systems (DCS) for energy-efficient cooling, among other suggestions.

The paper concludes by emphasizing the critical importance of addressing the UHI effect through evidence-based policies, including enhancing thermal comfort in affordable housing programs, improving appliance efficiency, and raising awareness about the health impacts of extreme heat. Such measures are crucial for creating sustainable, resilient, and healthier urban environments in India and beyond.

In light of the substantial benefits witnessed in American cities such as Baltimore (Baltimore Report, 2022), the adoption of Smart Surfaces in Indian cities emerges as a promising strategy to mitigate the UHI effect. Smart Surfaces not only reduced ambient air temperatures and flood risk, but also cost-effectively created jobs, reduced pollution, and increased city health, livability, and equity in the face of a changing climate fostering cooler, more sustainable urban environments.

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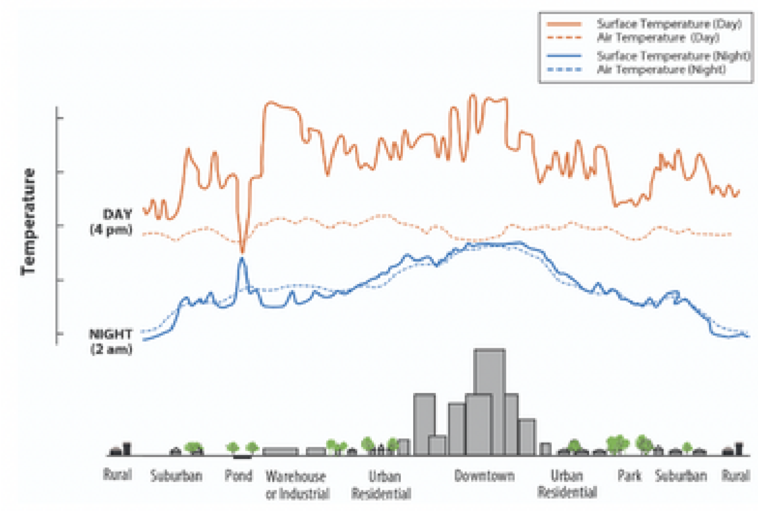
Introduction

Urban areas worldwide have specific physical characteristics compared to rural surroundings. Urban areas tend to have a higher density of buildings, concrete, asphalt, and other heat-absorbing materials. These materials have a low albedo, which means they absorb a large portion of the incoming solar radiation rather than reflecting it into space. As a result, urban surfaces become heat reservoirs, leading to elevated city temperatures both during the daytime as well as nighttime.



Heat Island Effect Diagram
Source: EPA

Additionally, urbanization replaces vegetation and green spaces with impervious surfaces, such as roads, parking lots, and buildings. These surfaces reduce the amount of vegetation available for natural cooling via shading and evapotranspiration (the combination of evaporation and plant transpiration). With fewer trees and plants, urban areas experience reduced evapotranspiration (Winbourne et al., 2020), leading to higher surface temperatures.

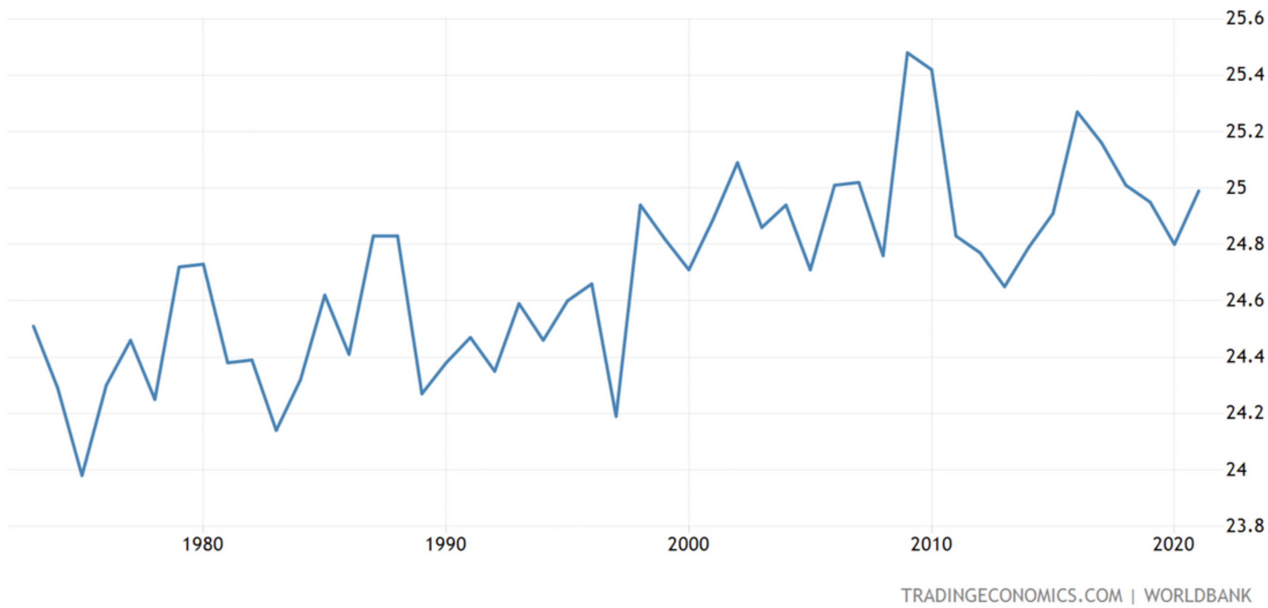
Moreover, human activities in urban areas contribute to heat generation. Industries, vehicles, air conditioning units, and other sources release excess thermal energy into their surroundings, adding to the already elevated temperatures in urban areas.

Collectively, these factors create the urban heat island (UHI) effect — a microclimate in urban environments where the temperature is higher than that of the surrounding rural areas. This temperature difference can vary but has been observed to be as much as 10°F (5.6°C) or more, according to UCAR.

The urban heat island effect has diverse consequences. According to the EPA, it increases energy consumption, worsens air quality, impairs water quality, and exacerbates many health conditions. Mitigating the urban heat island effect is crucial for creating healthier urban environments.

Implementing heat-limiting infrastructure such as Smart Surfaces — cool roofs and pavements, trees, solar PV, rain gardens, and more — offers significant and enduring advantages in terms of economic prosperity, public health, and social well-being. This research also aims to incorporate India-specific health-related benefits, supporting an enhanced understanding of the potential benefits of deploying Smart Surfaces in hot, humid climates undergoing rapid urban development with minimal access to air conditioning for city residents.

India's Unique Position



Average December temperatures in India over the last 50 years
Source: World Bank, 2021

According to the 15th edition of the Global Climate Risk Index 2020, India ranks as the fifth most susceptible nation to the adverse effects of climate change. In the summer of 2023, North India experienced a catastrophic heatwave that affected two of its most densely populated states, resulting in the loss of 96 lives over several days. But before loss of life, extreme heat bears significant ramifications for public health, agriculture, labor productivity, and energy infrastructure. These repercussions manifest as illnesses, power outages, resource shortages, loss of productivity, and substantial economic setbacks.

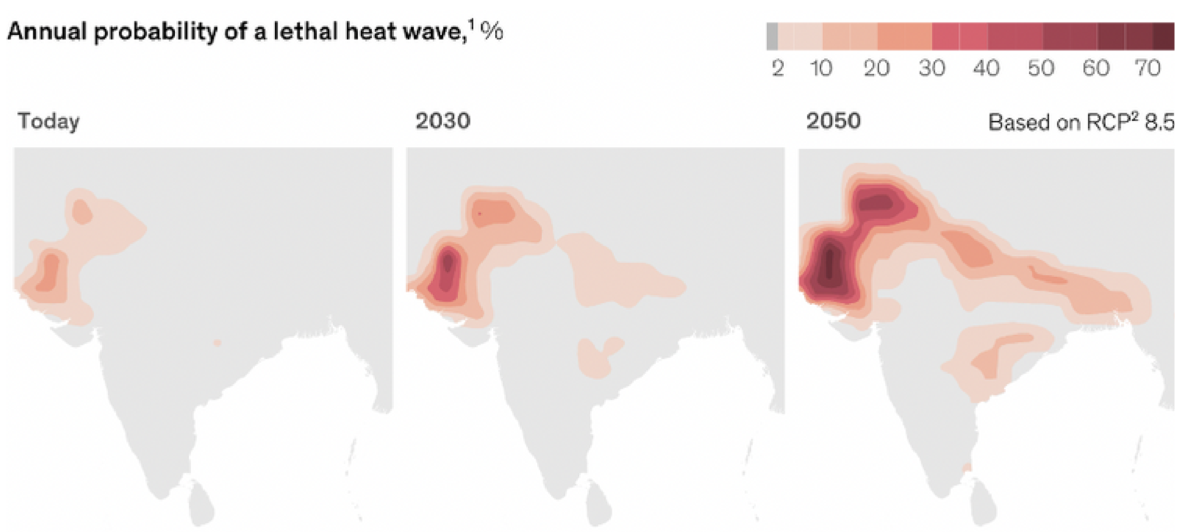
Furthermore, Indian urban centers face a heightened vulnerability to the UHI phenomenon. This susceptibility is rooted in India's unique geographical location, high population density, disparities in socioeconomic status, resource constraints, and heavy reliance on agriculture (Global Trends Report, 2009). While India has undertaken measures to combat climate change, the effective implementation of adaptation strategies and regional knowledge dissemination may be inadequate, leaving communities at risk and ill-equipped to confront the challenges posed by extreme heat events.

A study projecting future climatic conditions in India has discerned that temperature will increase steadily in the future during all the seasons, with maximum warming of ~4–5°C by the end of the current century (Salunke et al, 2023). Notably, the country's northwestern regions are anticipated to experience more pronounced warming trends, with the warming rate being higher in winter than in summer.

The implications of heat-induced health

health costs in India are mounting. Mortality attributable to hot and cold ambient temperatures in India accounts for 6.3% of all deaths or around 8 lakhs (800,000) per year (Hang Fu et al., 2018). A study analyzing the spatial variability of summer temperature and related mortality from 2006 to 2015 in Indian cities determined the per-day mean all-cause mortality increased to 39% and 11% for Jaipur and Hyderabad, respectively, at ≥45°C and 20% for the coastal city of Surat at ≥40°C as per IMD heatwave criteria (Rathi et al., 2023). India's position is particularly challenging because the Indian meteorological department also reported that during the above 2006-2015 period, there were 2,495 (69.3%) out of 3,602 summer days having feel temperatures/heat index (HI) of ≥41°C, which is above the heat adaptive limit of the human body. According to the Indian Meteorological Department (IMD) criteria for a heatwave, Surat has the maximum number of 75 days with a maximum temperature of ≥40°C, whereas Hyderabad has only 4 days and Jaipur faced 35 days with a maximum temperature of ≥45°C during the study period. Against the backdrop of a per capita healthcare expenditure of Rs. 4,742 (USD 57) in 2020, these health-related challenges loom large.

Unlike the commonly utilized dry-bulb temperature metric, which solely considers air temperature and omits moisture or radiation considerations, wet-bulb temperature integrates both air temperature and relative humidity, providing a more precise gauge of heat stress on human physiology. The theoretical human comfort threshold for wet-bulb temperatures stands at 35°C (95°F), akin to human skin temperature. Beyond this threshold, the human body faces the risk of overheating, even with access to ample water and shade (McKinsey, 2020). According to the McKinsey 2020 report, by 2050, portions of northern India could begin to experience heat waves that cross the 35-degree Celsius wet-bulb survivability threshold with a probability of occurrence at least once in the decade centered on 2050 approaching 80 percent (see image below).



The average probability of lethal heat waves in India is expected to increase between 2018 and 2020.
Source: McKinsey, 2020

Uttar Pradesh, Rajasthan, and Gujarat are likely to experience a few extremely hot days every year through 2100. In the worst-case scenario, if the world fails to cut greenhouse gas emissions, extremely hot days could persist for weeks or months on end in the three states, the report added.

A mere one-degree Celsius reduction in building temperatures could lead to a two to four percent reduction in peak electricity demand for cooling purposes.

The economic declines due to heat over the 30 years before 2021 may equate to roughly 1% of India's GDP, or about USD 32 billion, according to E. Somanathan, a professor of economics at ISI Delhi. The World Bank estimates that number will climb to 4.5% of India's GDP by 2030 — approximately USD 150-250 billion, solely from lost labor due to rising heat and humidity (World Bank, 2023). As a result of the exceptional pressures on healthcare and economic structures, heat waves triggered by climate change in India have the potential to undo the country's advancements in achieving sustainable development goals (SDGs). Recurring heat waves are likely to complicate India's ambitious emissions reduction goals, including pledges to reduce the emissions intensity of India's gross domestic product by 45% and generate half its power from non-fossil fuel sources by 2030 (Nikkei Asia, 2023).

The UHI effect disproportionately affects vulnerable populations with limited resource access, exacerbating existing inequalities. The state of urban planning for the poor has resulted in higher indoor than outdoor temperatures for the poor in India (Tasgaonkar et al., 2022). Residents of such densely populated low-income neighborhoods, lacking cooling amenities, access to clean water, or green spaces, remain exposed to heat stress even during nocturnal hours. The human body typically cools off at night, and with rising nocturnal temperatures when a human body does not get the chance to recover, heat stress can progress to heat stroke, which is associated with confusion, dizziness, and loss of consciousness. Without prompt treatment, heat stroke can be fatal.

Debnath's 2023 report details an analysis of the heat index (HI) or 'feels like' temperature in India, revealing that over 90% of the country registers at either an extremely cautious or dangerous level in terms of adversely affecting adaptive livelihood capacity, promoting the spread of vector-borne diseases, and maintaining urban sustainability.

India's primary objective in its India Cooling Action Plan (ICAP) is to curtail nationwide cooling demand by 25% by the year 2037-2038. Passive cooling strategies for urban buildings have the potential to reduce energy consumption by 20-30% by the same target year (World Bank, 2022).

In a study of thousands of Indian factories with varying cooling arrangements, researchers found that productivity dwindles by approximately 2% for every one-degree Celsius temperature increase (Somanathan et al., 2021). The Somanathan paper also links high temperatures with reduced crop yields as well as lower output in nonagricultural sectors.

Health Effects of Heat

To calculate health costs, this paper assumes the Value of a Statistical Life (VSL) in India to be estimated at INR 44.69 million (USD 0.64 million) and the estimated Value of Statistical Injury (VSI) is INR 1.67 million (USD 0.02 million) (Majumder & Madheswaran, 2018), calculated using the hedonic wage approach.

Temperatures in India are expected to rise by approximately 0.5°C by 2030, a magnitude akin to the total increase observed throughout the entire 20th century (National Intelligence Council, 2009). Looking further ahead, projections suggest that temperatures could surge by 4 - 5°C by the close of this century, with the most pronounced increase anticipated over northern India (Salunke et al., 2023). Notably, the urban heat island effect tends to elevate daytime city temperatures even more. A picture by NASA's ECOSTRESS tool revealed that during the 2022 summer heat wave, nighttime temperatures on May 5 in Delhi and several smaller villages were above 95 degrees Fahrenheit (35 degrees Celsius), peaking at about 102 degrees F (39 degrees C), while the rural fields nearby had cooled to around 60 degrees F (15 degrees C).

Direct Heat-Related Illnesses

The human body functions at a narrow temperature range, usually between 97 F (36.1 C) and 99 F (37.2 C), which it maintains by a neurological process called thermoregulation. The heat receptors start perceiving high temperatures when the skin surface rises above 86°F (30°C) and are most stimulated at 113°F (45°C). Beyond this temperature, pain receptors take control, to avoid damage to the skin and underlying tissues (ScienceDirect, 2023) Urban heat islands contribute to elevated urban temperatures, leading to increased heat-related illnesses such as heat exhaustion, dehydration, heatstroke, and, in severe cases, organ failure or even death.

In May 2010, the city of Ahmedabad in India faced a deadly heat wave with 40 days of 40°C and higher, reaching a high of 46.8°C (116.24 F). Research analyzing all-cause mortality recorded a significant excess of 1,344 all-cause deaths, an estimated 43.1% increase (Azhar et al., 2014). Furthermore, in monthly pair-wise comparisons for 2010, the research found high correlations between mortality and daily maximum temperature during the locally hottest months of April, May, and June where temperatures regularly go above 40°C (104°F).

More than 11,000 people have died due to heat stroke in India in the last decade (India Today, 2023). A 4°C rise in average annual temperature in India by 2100 (Global Trends Report, 2009), with the average number of extremely hot days over 35°C around the country increasing eightfold per year from 5.1 (in 2010) to 42.8, is projected to result in an excess of more than 1.5 million deaths each year by 2100 (Climate Impact Lab, 2019). Given the lifetime cost of USD $0.64 million per person succumbing to heat, and assuming most deaths are of people in the productive or pre-productive age group, this results in an annual USD 13.71 billion healthcare cost of heat to India by the end of the century.

This doesn't include lost productivity and the estimated loss due to injury (USD 0.02 million) (Majumder and Madheswaran, 2018). Additionally, an American study estimated that electrical grid failures — a widespread problem in India — during heat waves could double heat-related mortality in some cities (Stone et al, 2023).

Cardiovascular

India has the second highest country-specific incidence of cardiovascular disease (CVD) worldwide, which is the leading cause of death and disability in the country (Kalra et al, 2023). A higher relative risk burden, an earlier age of onset, and higher case fatality characterize the CVD epidemic in Indians.

When heat gain exceeds the capacity of the body to lose heat, a series of pathological events can eventually result in cardiovascular impairment. Heat can increase heart, blood, and respiratory rates, placing additional stress on the cardiovascular system. This can lead to complications for individuals with pre-existing heart and lung conditions, and increase rates of hospitalization and mortality in the population.

A meta-analysis of 266 studies showed that in tropical countries, for every 1°C increase in temperature above reference temperatures there is an associated 2.1% increase in cardiovascular disease-related mortality and a 0.5% increase in cardiovascular disease-related morbidity (Liu et al, 2022). Additionally, Liu et al. found that during heatwaves the risk of cardiovascular disease-related mortality significantly increased by 11·7%, with the risk increasing as heatwave intensity increased.

Current CVD mortality is 4.77 million annually in India, with the per-patient cost of treating cardiovascular disease computed to be INR 2,47,822 (US $3842) (Kumar et al., 2022).

Calculating thus, the current cost of CVD mortality, assuming every mortality case is treated for CVD, could be USD 17,173,740,000 for India.

If mortality is to rise 2.1% for every degree, with a 4°C rise in cities this number will jump north of USD 20 billion.

This number only considers those treated in hospitals and assumes a uniform 4°C warming across India, not taking into account the extra warming experienced in cities due to the heat island effect. It also doesn't take into account morbidity losses due to CVD. Another paper establishes that CVD incidence is currently at 10% of the urban population of 508,368,361 and it has been estimated that the cost of CVD could be 200 billion rupees ($4.5 billion) to the nation (CADI Research).

Respiratory Issues

Urban heat islands can worsen air quality by promoting the formation and concentration of air pollutants. Higher temperatures enhance the chemical reactions that produce ground-level ozone, a harmful pollutant associated with respiratory problems, asthma attacks, and lung inflammation (Zhang et al., 2019). Heat islands can also trap pollutants, such as vehicle emissions and industrial pollutants, in stagnant air masses, further compromising air quality.

The contribution of chronic respiratory diseases to the total disability-adjusted life years (DALYs) in India increased from 4.5% in 1990 to 6.4% in 2016 (Paulson et al., 2016). Of the total global DALYs due to chronic respiratory diseases in 2016, 32% occurred in India, with COPD and asthma being the leading causes of chronic respiratory disease DALYs in the country. It is also important to note that of the DALYs due to COPD in India in 2016, 53.7% (43.1–65.0) were attributable to air pollution, both indoor and ambient, with the incidence being higher in the northern regions of Rajasthan and Uttar Pradesh.

A study conducted across 213 American counties found a clear and consistent increase in respiratory hospitalizations with increasing outdoor temperatures across the United States. Respiratory hospitalizations increased by 4.3% for each 10°F increase in daily mean summer temperature and results were similar for COPD and respiratory tract infections (Anderson et al, 2013).

However, data on the economic burden of respiratory disease in India is scant. A 2016 study determined the mean annual cost per respiratory disease patient in India to be USD 637. While the Ghoshal study was conducted only on adults over 18 years of age, it is important to note that the biggest cost component was productivity loss (Ghoshal et al, 2016). Another study reported the total direct cost of an acute respiratory infection (ARI) episode in India requiring outpatient care to be USD 4-6 for public and $3-10 for private institutions based on age groups. The direct out-of-pocket cost of hospitalized ARI was 34% of the annual per capita income (Peasah et al, 2015) for each patient.

With a pooled prevalence of COPD of 7.4% among adults in India, and assuming that every diagnosed patient is treated, the healthcare cost of respiratory illness is $104,192,000 among adults alone in India. However, the true numbers would far exceed this and it would help to have a national-level prevalence estimate for COPD, currently lacking in India.

Women, Maternal, and Child Health

Extreme heat is a global public health risk and women are particularly vulnerable, especially during pregnancy, greater exposure to indoor pollution, with lower access to healthcare services, and greater vulnerability to gender-based violence which is linked to increased heat (van Daalen et al, 2022).

Maternal exposure to heat was associated with an increased risk of preterm and early-term birth, low and decreased birth weight, stillbirth, and harmful newborn stress.

It is estimated that 27,000 women die each year in India on average due to heat-related excess mortality. Even by conservative estimates, in India, this is projected to multiple by more than 2.5 times to 73,500 by 2050. Furthermore, in an extremely hot year, it could rise even further to 131,000 deaths. This will account for approximately 1.1% of total female deaths, surpassing deaths caused by cervical cancer (1.03% of female deaths) (Scroll.in, 2023).

There is little data to calculate the Value of a Statistical Life (VSL) of women in vulnerable communities in India. Various studies suggest that the cross-country multiplier on GDP-per-capita to estimate a range on the VSL would be about 100-200. For instance, the $9.6 million VSL estimate of the US, with a GDP per head of about $52,500, yields a multiplier of about 183.

Using the same multiplier range for India, we can estimate the VSL for India with a per capita income of $2,500 (International Monetary Fund estimate, March 2021) is a central estimate of about ₹3 crore ($361,413.30) (Mint, 2020).

Calculating thus, the burden of heat illness faced by women is $26,383,170,900. However, this number overlaps with the cost burden of other diseases.

Mental Health

The heat and discomfort caused by urban heat islands can have mental health consequences. Prolonged exposure to high temperatures, especially during heat waves, can contribute to increased stress, irritability, sleep disturbances, and reduced overall well-being. Vulnerable populations, such as the elderly, children, and individuals with pre-existing mental health conditions, may be particularly susceptible to these effects.

High temperatures are also strongly associated with an increase in suicides, researchers have found. Heat has been linked to a rise in violent crime and aggression, emergency room visits and hospitalizations for mental disorders, and deaths — especially among people with schizophrenia, dementia, psychosis, and substance use (The New York Times, 2023).

Researchers from British Columbia (Lee et al, 2023) found that people with schizophrenia had 3 times higher odds of dying during a heat event. Additionally, depression was associated with nearly 2 times higher odds of death from heat.

Lithium is a commonly prescribed mood-stabilising agent, largely administered in bipolar patients. It increases sweating and the body demands a higher intake of water. Heat waves increase dehydration and electrolyte imbalances in such patients, or make them stop taking the medication — triggering a relapse. Studies have found that per one standard deviation change toward warmer temperatures, the frequency of interpersonal violence rises by 4% and the frequency of intergroup conflict rises by 14% (Hsiang et al., 2013).

India's high dependence on the agricultural sector has a strong influence on heat-related suicide rates. The research found that for temperatures above 20°C, a 1°C increase in a single day's temperature causes 70 suicides, on average (Tamma A. Carleton, 2017). This effect reportedly occurs only during India's agricultural growing season when heat also lowers crop yields. The season starts in June and ends in October, overlapping with the tail end of summer temperatures.

A study (Yadav et al, 2023) analyzing data from Indians who reported mental illness found that in lower income households, Rs. 2,115 ($25.45) was spent out of pocket towards treatment, comprising 18% of household income every month. The study also brought to light that about 20.7% of the households were forced to become poor from non-poor due to treatment care expenditure on mental illness.

While it is difficult to report the drivers of mental health costs since the National Survey data is aggregated, the World Health Organization estimated the economic loss due to mental health conditions in India, between 2012-2030, to be USD 1.03 trillion.

Disparities and Social Inequity

Urban heat islands exacerbate existing social inequalities in health. Vulnerable populations, including low-income communities, the elderly, and individuals with limited access to air conditioning or green spaces, may face more significant health risks due to the lack of resources to cope with high temperatures. These disparities can lead to unequal health outcomes and increased vulnerability during heat waves.

Current Policy Gaps

This segment explores key policy gaps and recommendations aimed at addressing heat-related challenges in India. From incorporating advanced heat discomfort criteria to promoting sustainable cooling technologies and bolstering data collection efforts, these proposed measures seek to enhance resilience, safeguard public health, and strengthen India's position as a leader in combating the adverse effects of climate change.

Incorporate Humidex as a Heat Discomfort Criterion

Consider adopting the Humidex index as a measure of heat discomfort in India. The Humidex, utilized by countries like Canada, provides a more comprehensive assessment of heat by factoring in both temperature and humidity, offering a more accurate representation of heat-related health risks.

Incorporate Heat in the Climate Vulnerability Index (CVI)

Integrate heat-related variables into the existing Climate Vulnerability Index (CVI) to enhance its effectiveness in assessing and addressing the impact of rising temperatures and extreme heat events on vulnerable populations and regions.

Enhance Data Collection and Research on Urban Microclimates

Gathering more data and research on urban microclimates and heat-vulnerable populations. These initiatives should incorporate social and spatial factors into urban planning processes and embed urban heat resilience considerations into building codes, zoning regulations, and land-use policies.

Include Thermal Comfort in Pradhan Mantri Awas Yojana (PMAY)

Revise the Pradhan Mantri Awas Yojana PMAY), the Government of India's affordable housing program for the underprivileged, to encompass thermal comfort as a vital aspect of housing design and construction standards.

Implement a National Policy on District Cooling Systems (DCS)

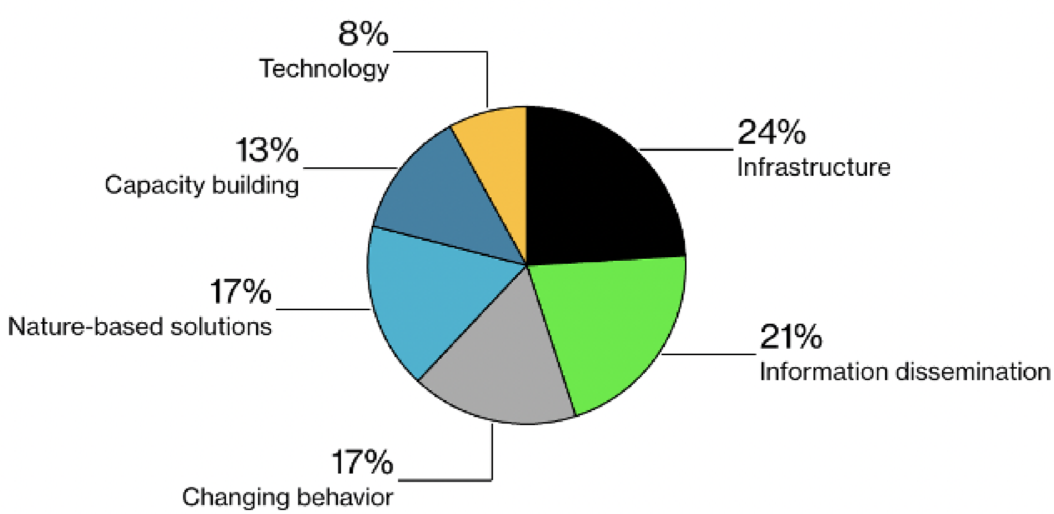
Develop and implement a national policy promoting the adoption of District Cooling Systems (DCS) in urban areas. DCS represents a highly efficient, centralized cooling approach for clusters of buildings, significantly reducing energy consumption when compared to individual building cooling solutions. In India's context, DCS has the potential to reduce power consumption by 20-30%, which can increase to 60-80% compared to average three-star air conditioning systems (Down To Earth, 2022).

Enhance Efficiency of Cooling Appliances

Prioritize efforts to enhance the efficiency of air conditioning systems, refrigerators, and related appliances. Address refrigerant leakage issues, which currently contribute to 35% of carbon emissions from these appliances48. Implementing measures to reduce leakage can not only mitigate environmental impact but also generate employment opportunities, with the potential to create 2 million jobs for technicians over the next two decades48. Additionally, this approach can reduce the demand for refrigerants by 31% within the same timeframe.

Interventions on India's Heat Action Plans

Main areas of focus for cities fighting high temperatures



Note: Data drawn from the analysis of 37 heat action plans across 18 Indian states.

Source: Centre for Policy Research, March 2023

Position India as a Global Leader in Green Cooling Technologies

Recognize the opportunity for India to emerge as a global hub for green cooling technologies. Formulate pragmatic policies and strategies in alignment with this objective, as outlined in the current report. Such measures can propel India to the forefront of sustainable cooling solutions and contribute significantly to global efforts in combating climate change (Kouame report).

Improve Recording and Attribution of Heat-Related Admissions and Deaths

Establish a systematic approach to record and attribute hospital admissions and fatalities directly resulting from heat-related illnesses. Address the challenges highlighted in the report (The Third Pole, 2023) to ensure accurate and transparent reporting of heat-related health impacts, enabling more effective policy responses and resource allocation.

Conclusion

The urban heat island effect is a pressing issue with far-reaching consequences for India's environment, public health, and economy. As this paper has detailed, rising temperatures, exacerbated by urbanization and climate change, pose a significant threat to the well-being of Indian communities, particularly vulnerable populations. The ramifications span from direct health effects such as heat-related illnesses to indirect impacts like reduced labor productivity and increased healthcare costs.

India's unique vulnerabilities, including its geographical location, high population density, and socioeconomic disparities, make it imperative to address the urban heat island effect comprehensively and urgently. The projected increase in temperatures, especially in northern regions, along with the potential for more frequent and severe heatwaves, underscores the urgency of this issue.

Research shows that on a high carbon emissions pathway, temperatures in India could increase by as much as 1.8°C by 2050. On a low carbon emissions pathway, this drops to 1.2°C (G20 Climate Risk Atlas). India presently employs a national Climate Vulnerability Indicator (CVI) to assess climate vulnerability and devise adaptation strategies. While the CVI incorporates numerous socioeconomic, biophysical, institutional, and infrastructural factors, it notably lacks a specific physical risk indicator for heat waves (Debnath et al, 2023). This deficiency limits the ability of policymakers to comprehensively assess the impact of extreme heat on the Indian populace. By 2030, the situation may worsen to the point where poor communities may need public assistance to endure along with facilities like air conditioning or cooling centers. The initial expenses associated with supplying these essential resources could amount to as much as $110 billion, as outlined in McKinsey's 2020 report.

Furthermore, the economic costs associated with heat-related health issues and productivity losses are substantial and could hinder India's progress in achieving its sustainable development goals. Mitigating the urban heat island effect is not only a matter of public health but also a crucial step toward environmental sustainability and economic resilience.

This paper has outlined several policy recommendations aimed at addressing the challenges posed by rising temperatures and the urban heat island effect in India. From incorporating advanced heat discomfort criteria and enhancing data collection efforts to promoting sustainable cooling technologies and improving housing standards, these recommendations provide a roadmap for policymakers to navigate the complex landscape of urban heat resilience.

However, amid these challenges, there exists a powerful solution: the integration of Smart Surfaces into urban planning and development. Smart Surfaces, characterized by their ability to reflect heat and reduce surface temperatures, can play a pivotal role in mitigating the urban heat island effect. They offer a tangible and sustainable solution to combat rising temperatures, reduce energy consumption, and enhance the overall quality of life for urban dwellers. In the face of India's rapid urbanization, Smart Surfaces are crucial cost-effective citywide cooling solutions, integrating the implementation of reflective, porous, and green surfaces, trees, and solar PV. Adopting of Smart Surfaces citywide would allow Indian cities to cool by at least 3˚C cost-effectively and improve air quality (Kats et al., 2023). These surfaces can be a vital component of resilient urban infrastructure, contributing to the reduction of energy demand, improvement of air quality, and enhancement of public health.

Tackling the urban heat island effect requires a coordinated effort from government, academia, industry, and civil society. By adopting the proposed policy measures and prioritizing heat resilience in urban planning and development, India can take significant strides toward creating healthier, more sustainable, and more equitable urban environments for its citizens. The time to act is now, as the consequences of inaction could be severe and far-reaching.

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References

Anderson, G. B., Dominici, F., Wang, Y., McCormack, M. C., Bell, M. L., & Peng, R. D. (2013). Heat-related Emergency Hospitalizations for Respiratory Diseases in the Medicare Population. *American Journal of Respiratory and Critical Care Medicine*, 187(10), 1098–1103. https://doi.org/10.1164/rccm.201211-1969OC

Azhar, G. S., Mavalankar, D., Nori-Sarma, A., Rajiva, A., Dutta, P., Jaiswal, A., Sheffield, P., Knowlton, K., & Hess, J. J. (2014). Heat-Related Mortality in India: Excess All-Cause Mortality Associated with the 2010 Ahmedabad Heat Wave. *PLoS ONE*, 9(3), e91831. https://doi.org/10.1371/journal.pone.0091831

Cadi Research. (n.d.). *Economic Burden | Cadi.* https://cadiresearch.org/topic/asian-indian-heart-disease/cadi-india/economic-burden

Carleton, T. A. (2017). Crop-damaging temperatures increase suicide rates in India. *Proceedings of the National Academy of Sciences,* 114(33), 8746–8751. https://doi.org/10.1073/pnas.1701354114

Debnath, R., Bardhan, R., & Bell, M. L. (2023). Lethal heatwaves are challenging India's sustainable development. *PLOS Climate*, 2(4), e0000156. https://doi.org/10.1371/journal.pclm.0000156

Down to Earth. (n.d.). *Whopping $1.6 tn investment can be created for green cooling solutions in India by 2040: World Bank.* (n.d.). Retrieved December 11, 2023, from https://www.downtoearth.org.in/news/climate-change/whopping-1-6-tn-investment-can-be-created-for-green-cooling-solutions-in-india-by-2040-world-bank-86295

Eckstein, D., Künzel, V., Schäfer, L., & Winges, M. (2018). *GLOBAL CLIMATE RISK INDEX 2020.* https://germanwatch.org/sites/germanwatch.org/files/20-2-01e%20Global%20Climate%20Risk%20Index%202020_10.pdf

EPIC. (n.d). *Climate Change and Heat-Induced Mortality in India.* Retrieved December 7, 2023, from https://epic.uchicago.edu/research/climate-change-and-heat-induced-mortality-in-india

Fu, S. H., Gasparrini, A., Rodriguez, P. S., & Jha, P. (2018). Mortality attributable to hot and cold ambient temperatures in India: a nationally representative case-crossover study. *PLOS Medicine*, 15(7), e1002619. https://doi.org/10.1371/journal.pmed.1002619

G20 Climate Risk Atlas. (2021, October 19). *India.* https://www.g20climaterisks.org/india/#:~:text=The%20research%20shows%20that%20on

Ghoshal, A., Ravindran, G., Gangwal, P., Rajadhyaksha, G., Cho, S.-H., Muttalif, A. B. A., Lin, H.-C., Thanaviratananich, S., Bagga, S., Faruqi, R., Sajjan, S., Shetty, P., Syed, R., Hamrosi, K., & Wang, D. (2016). The burden of segregated respiratory diseases in India and the quality of care in these patients: Results from the Asia-Pacific Burden of Respiratory Diseases study. *Lung India*, 33(6), 611. https://doi.org/10.4103/0970-2113.192878

Government of Canada, C. C. for O. H. and S. (2023, April 5). *CCOHS: Humidex Rating and Work.* https://www.ccohs.ca/oshanswers/phys_agents/humidex.html#:~:text=Humidex%20is%20a%20measure%20of

Hsiang, S. M., Burke, M., & Miguel, E. (2013). Quantifying the Influence of Climate on Human Conflict. *Science,* 341(6151), 1235367–1235367. https://doi.org/10.1126/science.1235367

IEA. (n.d.). *India Cooling Action Plan (ICAP) – Policies.* Retrieved December 7, 2023, from https://www.iea.org/policies/7455-india-cooling-action-plan-icap

India Today (n.d.). I*n numbers: Heat strokes killed more than 2,500 people in UP, Bihar in 10 years.* Retrieved December 7, 2023, from https://www.indiatoday.in/diu/story/heat-strokes-killed-more-than-2500-people-in-up-bihar-ten-years-2396923-2023-06-23

Joint Global Change Research Institute and Battelle Memorial Institute, Pacific Northwest Division. (2009). India: The Impact of Climate Change to 2030

Kalra, A., Jose, A. P., Prabhakaran, P., Kumar, A., Agrawal, A., Roy, A., Bhargava, B., Tandon, N., & Prabhakaran, D. (2023). The burgeoning cardiovascular disease epidemic in Indians – perspectives on contextual factors and potential solutions. *The Lancet Regional Health - Southeast Asia*, 100156. https://doi.org/10.1016/j.lansea.2023.100156

Kats, G., Behal, M., & Kaldany, R. (n.d.). *Solving the Heat Threat to Urban India*. Retrieved December 7, 2023, https://static1.squarespace.com/static/5b104d0b365f02ddb7b29576/t/627db5f611c97d6b48be8e03/1652405752917/Solving+the+Heat+Threat+to+Urban+India.pdf

Kumar, A., Siddharth, V., Singh, S. I., & Narang, R. (2022). Cost analysis of treating cardiovascular diseases in a super-specialty hospital. *PLOS ONE*, 17(1), e0262190. https://doi.org/10.1371/journal.pone.0262190

Lee, M. J., McLean, K. E., Kuo, M., Richardson, G. R. A., & Henderson, S. B. (2023). Chronic Diseases Associated With Mortality in British Columbia, Canada During the 2021 Western North America Extreme Heat Event. *GeoHealth*, 7(3). https://doi.org/10.1029/2022gh000729

Liu, J., Varghese, B. M., Hansen, A., Zhang, Y., Driscoll, T., Morgan, G., Dear, K., Gourley, M., Capon, A., & Bi, P. (2022). Heat exposure and cardiovascular health outcomes: a systematic review and meta-analysis. *The Lancet Planetary Health,* 6(6), e484–e495. https://doi.org/10.1016/S2542-5196(22)00117-6

Macrotrends. (n.d.) *India Healthcare Spending 2000-2020.* https://www.macrotrends.net/countries/IND/india/healthcare-spending

Majumder, Agamoni & Madheswaran, S. (2018). VALUE OF STATISTICAL LIFE IN INDIA: A HEDONIC WAGE APPROACH.

Mandavilli, A. (2023, August 10). Heat Singes the Mind, Not Just the Body. *The New York Times.* https://www.nytimes.com/2023/08/10/health/heat-mental-health.html

McKinsey. (n.d.). *Will climate change mean India will get too hot to work?* https://www.mckinsey.com/capabilities/sustainability/our-insights/will-india-get-too-hot-to-work

NASA Jet Propulsion Laboratory (JPL). (n.d.). *NASA's ECOSTRESS Detects "Heat Islands" in Extreme Indian Heat Wave*. Retrieved December 7, 2023, from https://www.jpl.nasa.gov/news/nasas-ecostress-detects-heat-islands-in-extreme-indian-heat-wave

Nikkei Asia. (n.d.). I*ndia's deadly heat waves preview disruptions of a hotter future*. Retrieved December 11, 2023, from https://asia.nikkei.com/Spotlight/Environment/Climate-Change/India-s-deadly-heat-waves-preview-disruptions-of-a-hotter-future

Paulson, K., Smith, M., & Dandona, L. India State-Level Disease Burden Initiative CRD Collaborators. (2018). The burden of chronic respiratory diseases and their heterogeneity across the states of India: the Global Burden of Disease Study 1990–2016. *The Lancet Global Health*. 12 September 2018. doi:10.1016/S2214-109X(18)30409-1

Peasah, S. K., Purakayastha, D. R., Koul, P. A., Dawood, F. S., Saha, S., Amarchand, R., Broor, S., Rastogi, V., Assad, R., Kaul, K. A., Widdowson, M.-A., Lal, R. B., & Krishnan, A. (2015). The cost of acute respiratory infections in Northern India: a multi-site study. *BMC Public Health,* 15(1). https://doi.org/10.1186/s12889-015-1685-6

Piketty, T., Saez, E., Zucman, G., Duflo, E., & Banerjee, A. (2022). *INEQUALITY REPORT 2022.* https://wir2022.wid.world/www-site/uploads/2021/12/WorldInequalityReport2022_Full_Report.pdf

Popat Salunke, Narayan Prasad Keshri, Mishra, S. K., & Dash, S. K. (2023). Future projections of seasonal temperature and precipitation for India. *Frontiers in Climate*, 5. https://doi.org/10.3389/fclim.2023.1069994

Premsagar Tasgaonkar, Zade, D., Ehsan, S., Ganesh Gorti, Nabir Mamnun, Siderius, C., & Singh, T. (2022). Indoor heat measurement data from low-income households in rural and urban South Asia. *Scientific Data,* 9(1). https://doi.org/10.1038/s41597-022-01314-5

Ramachandran, N. (2020, April 27). Opinion | The statistical value of a citizen's life isn't incalculable. *Mint.* https://www.livemint.com/opinion/columns/the-statistical-value-of-a-citizen-s-life-isn-t-incalculable-11588006980642.html

ScienceDirect. (n.d.). *Thermoreceptor - an overview | ScienceDirect Topics.* Retrieved December 11, 2023, from https://www.sciencedirect.com/topics/neuroscience/thermoreceptor#:~:text=The%20heat%20receptors%20start%20perceiving

Smart Surfaces Coalition. (n.d.). *Smart Surfaces.* https://smartsurfacescoalition.org/smart-surfaces

Somanathan, E., Somanathan, R., Sudarshan, A., & Tewari, M. (2021). The Impact of Temperature on Productivity and Labor Supply: Evidence from Indian Manufacturing. *Journal of Political Economy*, 129(6). https://doi.org/10.1086/713733

Stone, B., Gronlund, C. J., Mallen, E., Hondula, D., O'Neill, M. S., Rajput, M., Grijalva, S., Lanza, K., Harlan, S., Larsen, L., Godfried Augenbroe, E Scott Krayenhoff, Broadbent, A., & Georgescu, M. (2023). How Blackouts during Heat Waves Amplify Mortality and Morbidity Risk. https://doi.org/10.1021/acs.est.2c09588

Suresh Kumar Rathi, Sodani, P. R., & Sharma, P. (2023). Spatial Variability of Summer Temperature and Related All-cause Mortality from 2006 to 2015 for Indian Cities: A Time Series Analysis. *Journal of Health Management*, 25(2), 179–190. https://doi.org/10.1177/09720634231175957

Tanvi Deshpande. (2023, September 9). Extreme heat mortality among Indian women could double by 2050, says study. *Scroll.in.* https://scroll.in/article/1055600/extreme-heat-mortality-among-indian-women-could-double-by-2050-says-study#:~:text=Extreme%20heat%20could%20claim%20the

The Dialogue. (n.d.). *India: The Impact of Climate Change to 2030 | Inter-American Dialogue.* https://globaltrends.thedialogue.org/publication/india-the- -of-climate-change-to-2030/

The Third Pole. (2023, July 6). *India heatwave: medical processes hide the true number of deaths.* https://www.thethirdpole.net/en/climate/medical-processes-hide-true-number-of-deaths-from-india-heatwave/

Trading Economics (n.d.). *India Average Temperature | 1796-2015 Data | 2020-2021 Forecast | Historical | Chart.* https://tradingeconomics.com/india/temperature

UCAR Center for Science Education. (n.d.). *Urban Heat Islands.* Retrieved December 1, 2023, from https://scied.ucar.edu/learning-zone/climate-change-impacts/urban-heat-islands#:~:text=An%20urban%20heat%20island%20

United States Environmental Protection Agency. (2014, June 17). *Heat Island Impacts.* US EPA. https://www.epa.gov/heatislands/heat-island-impacts

van Daalen, K. R., Kallesøe, S. S., Davey, F., Dada, S., Jung, L., Singh, L., Issa, R., Emilian, C. A., Kuhn, I., Keygnaert, I., & Nilsson, M. (2022). Extreme events and gender-based violence: a mixed-methods systematic review. *The Lancet Planetary Health*, 6(6), e504–e523. https://doi.org/10.1016/s2542-5196(22)00088-2

Wager, A., Becce, J., Clayton, Z., Panitz, G., Panner, S., Liu, P., Davison, K., Kats, G., & Jarrell, R. (2021). *Cooling Cities, Slowing Climate Change and Enhancing Equity: Costs and Benefits of Smart Surfaces Adoption for Baltimore.* Retrieved December 1, 2023, from https://static1.squarespace.com/static/5b104d0b365f02ddb7b29576/t/6329dcea7ec0c202e8255ebc/1663687919882/Baltimore+Draft+Document9.20.22_Reduced.pdf

World Bank. (n.d.). *A Greener Cooling Pathway Can Create a $1.6 Trillion Investment Opportunity in India, says World Bank Report.* Retrieved December 7, 2023, from https://www.worldbank.org/en/news/press-release/2022/11/30/a-greener-cooling-pathway-can-create-a-1-6-trillion-investment-opportunity-in-india-says-world-bank-report#:~:text=A%20new%20World%20Bank%20report

World Bank. *Climate Investment Opportunities in India's Cooling Sector (English).* Washington, D.C.: World Bank Group. http://documents.worldbank.org/curated/en/099920011222212474/P15743300f4cc10380b9f6051f8e7ed1147

World Bank. (n.d.). *Cooling the Heat: Can India Lead the World in Green Cooling Innovation.* Retrieved December 7, 2023, from https://www.worldbank.org/en/news/opinion/2023/07/11/cooling-the-heat-can-india-lead-the-world-in-green-cooling-innovation#:~:text=By%202030%2C%20lost%20labor%20due

World Health Organization (n.d.). *Mental health.* Retrieved April 29, 2021, from https://www.who.int/india/health-topics/mental-health#:~:text=WHO%20estimates%20that%20the%20burden

Yadav J, Allarakha S, John D, Menon GR, Venkateswaran C, Singh R. Catastrophic Health Expenditure and Poverty Impact Due to Mental Illness in India. *Journal of Health Management*. 2023;25(1):8-21. doi:10.1177/09720634231153210

Zhang, J., Wei, Y., & Fang, Z. (2019). Ozone Pollution: A Major Health Hazard Worldwide. *Frontiers in Immunology*, 10. https://doi.org/10.3389/fimmu.2019.02518