Urban Heat in South Asia

Integrating People and Place in Adapting to Rising Temperatures

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1 Introduction

Extreme heat is a hazard that is increasing in frequency, severity, and complexity due to climate change. In the last decade, heat waves caused more deaths globally than any other climate-related disaster (International Federation of Red Cross and Red Crescent Societies 2020). More importantly, while heat-related deaths are accounted for, the more chronic and subtly pervasive impacts of heat often go unreported and unmanaged. These impacts touch nearly every aspect of urban life, negatively impacting human, social, physical, financial, and natural capital. Together, these impacts can compromise human capital development, social mobility and welfare, and overall economic growth.

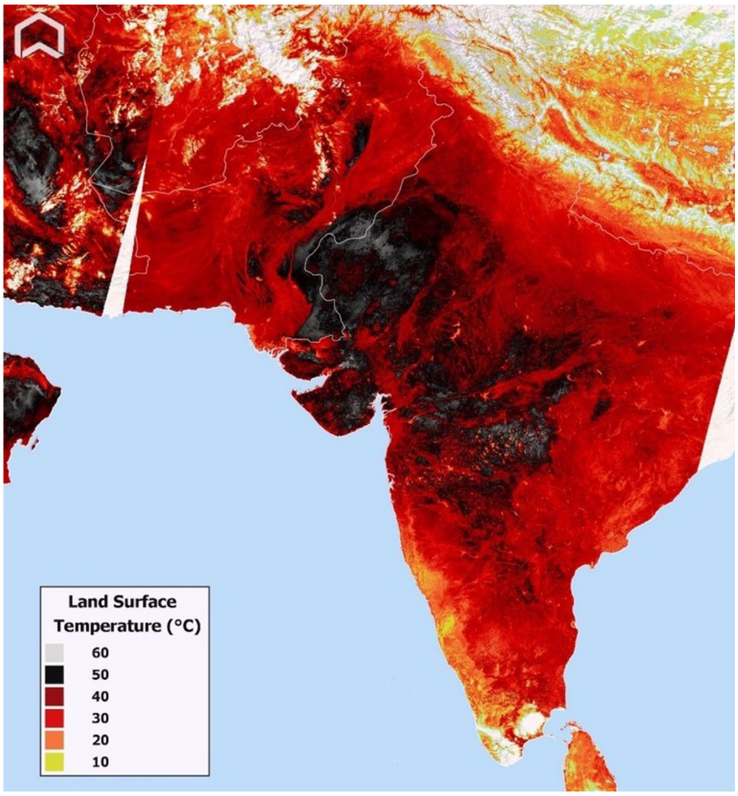
Heat has uneven spatial and social distributions, with wide variations in temperatures and adaptive capacities across buildings, communities, and cities around the world. Urban areas often experience higher temperatures by absorbing more solar radiation than surrounding rural areas, a phenomenon called the urban heat island (UHI) effect. Contributing factors may include reduced coverage of naturally cooling vegetation and water bodies, higher usage of heat-absorbing and heat-retaining building materials, reduced air circulation from densely built infrastructure, and higher output of anthropogenic heat sources, such as waste heat from vehicles and cooling devices (Stewart 2011; Mohajerani, Bakaric, and Jeffrey-Bailey 2017). These spatial vulnerabilities can overlap with socioeconomic vulnerabilities, often heightening heat risks beyond levels captured in average temperature data.

Existing heat risks in cities are amplified by warming temperatures from climate change. Global surface temperatures have risen 1.1°C above pre-industrial levels and are continuing to rise (Dodman et al. 2022). As global average temperatures rise, so do the frequency, severity, and intensity of heat waves (Dodman et al. 2022). These global effects of climate change are amplified at a local level through the UHI effect. Between 1950-2017, 60 percent of the world's urban population experienced warming twice as large as the global average, and by 2100, 25 percent of the world's largest cities could warm by 7°C (Estrada, Botzen, and Tol 2017). Critically, the number of people impacted by this warming is set to rise with two out of three people living in an urbanized area by 2050 (United Nations Department of Economic and Social Affairs 2019).

South Asia, home to a quarter of the world's population, is a region highly vulnerable to the impacts of urban heat. Although the region is accustomed to heat, rapid urbanization and climate change are pushing the region's limits of adaptation with lethal consequences. The impacts of heat in South Asia are already emerging with over 3,600 heat-related deaths in India and Pakistan during the 2015 heat waves (Wehner et al. 2016). More recently in 2022, at least 1 billion people in India and Pakistan experienced further record-breaking heat waves with temperatures reaching 51°C in some parts of Pakistan (see Figure 1). These impacts are set to worsen under a carbon-intensive scenario, with projections of more than 800 million South Asians living in locations that will become moderate to severe hotspots by 2050 (Mani et al. 2018). Between 2001 and 2011, South Asia's urban population grew by 130 million and is poised to rise by almost 250 million by 2030 (Ellis and Roberts 2016). More importantly, cities in South Asia are increasingly characterized by congestion, sprawl, and pollution from rapid and unplanned urbanization (Ellis and Roberts 2016), resulting in intense UHI effects (Coalitions for Urban Transitions 2021; Piracha and Chaudhary 2022) disproportionately impacting vulnerable communities with low adaptive capacities.

This policy brief probes urban heat vulnerabilities across both people and place in South Asia to underscore the importance of integrating population- and settings-based approaches in heat planning and policymaking processes at the municipal level. Section 2 probes heat in South Asian cities through the different layers of the urban environment: buildings, communities, and cities. Section 3 then adds the human element and explores different population groups that are vulnerable to urban heat in the region: children, informal workers, and residents of informal settlements. The relevance and reasonings for the groupings are discussed at the start of each section, noting where nuances and complexities lie. Finally, Section 4 provides three regionally specific recommendations for how urban heat management can be improved in South Asia.

Figure 1: Satellite-derived land surface temperatures in India and Pakistan; April 29, 2022



Source: Freedman 2022; Image: Antonio Vecoli via ADAM Platform

2 The Urban Environment

The built environment shapes spatial variability in urban heat. This section explores heat vulnerabilities and management strategies in the urban environment around three major clusters of increasing scale: buildings, communities, and cities[1]. The influence of the built environment on heat vulnerabilities and resilience in cities is highlighted in these three clusters, which is later linked to the differential social vulnerabilities to urban heat in the next section.

2.1. Buildings

Buildings play a central role in influencing overall heat exposure and thermal comfort. This arises from the large time spent indoors and the corresponding impacts indoor air temperatures have on heat risks. Indoor air temperatures can range widely, depending on the design and materials of a building. Key factors include roof and wall materials, window design and ventilation, aspect ratio, internal and external shading, and the availability of installed cooling devices. Depending on these factors, a building's design may act as a heat multiplier or heat diminisher, greatly influencing the heat exposure and adaptive capacities of its occupants.

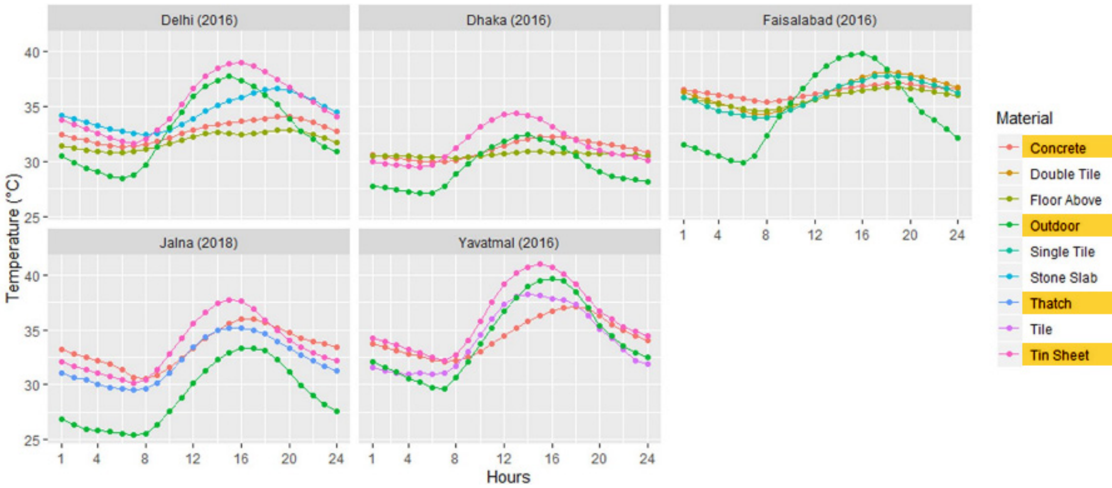
The use of heat-trapping materials is exacerbating urban heat risks in South Asia. Rapid urbanization and population growth have resulted in many buildings being non-engineered, temporary, or self-built. These buildings often do not meet building or planning standards and are made of heat-retaining materials such as tin, asbestos, or polyvinyl chloride (Asian Development Bank 2022). For instance, in Greater Mumbai, 46 percent of the population lives in houses with temporary roofing material (Brihanmumbai Municipal Corporation 2022). Figure 2 depicts the effects of different roofing material on indoor air temperatures in three South Asian cities (Delhi, Dhaka, and Faisalabad) and two villages (Jalna and Yavatmal) (Tasgaonkar et al. 2022). During the day, the indoor temperatures in tin-roofed houses were the highest, while roofs made from concrete and natural materials (such as thatch roofs) performed better. More importantly, at night, indoor air temperatures of buildings with tin roofs often exceeded outdoor air temperatures, with a difference of up to 4°C in many cases. This is alarming, given the limited heat adaptive behaviors that can be deployed overnight and the impact nighttime temperatures can have on sleep quality, cognitive function, and overall health (Tasgaonkar et al. 2022).

More studies are needed to understand the indoor heat profiles in South Asia. To date, most studies have occurred outside of South Asia or have relied on meteorological data from standardized outdoor weather stations that do not properly reflect the significant variations in indoor temperatures across buildings in the same area. Further studies are needed to assess the intra-urban variability across South Asia cities and identify how diel (24 hour) indoor air

1 These groupings were chosen based on the existing focus on the geographic scale of buildings and cities in urban heat management, while the addition of communities provides a bridge between these two groupings and an opportunity to highlight differential intra-urban vulnerabilities. Although analyzed in discrete clusters, it is acknowledged that these clusters do not function in isolation and have complex and interwoven interactions with each other.

temperatures are impacted by factors such as wall, roof, and floor materials; roof pitch and reflectance; window configuration and ventilation; site elevation and floor level; and proximity to anthropogenic heat sources, such as air conditioning vents and indoor cooking. Developing this understanding will help identify previously overlooked heat vulnerabilities, and moreover, design more effective urban heat management interventions at the building-level in the region.

Figure 2: Indoor-outdoor diurnal temperature variation for the summer months of May and June



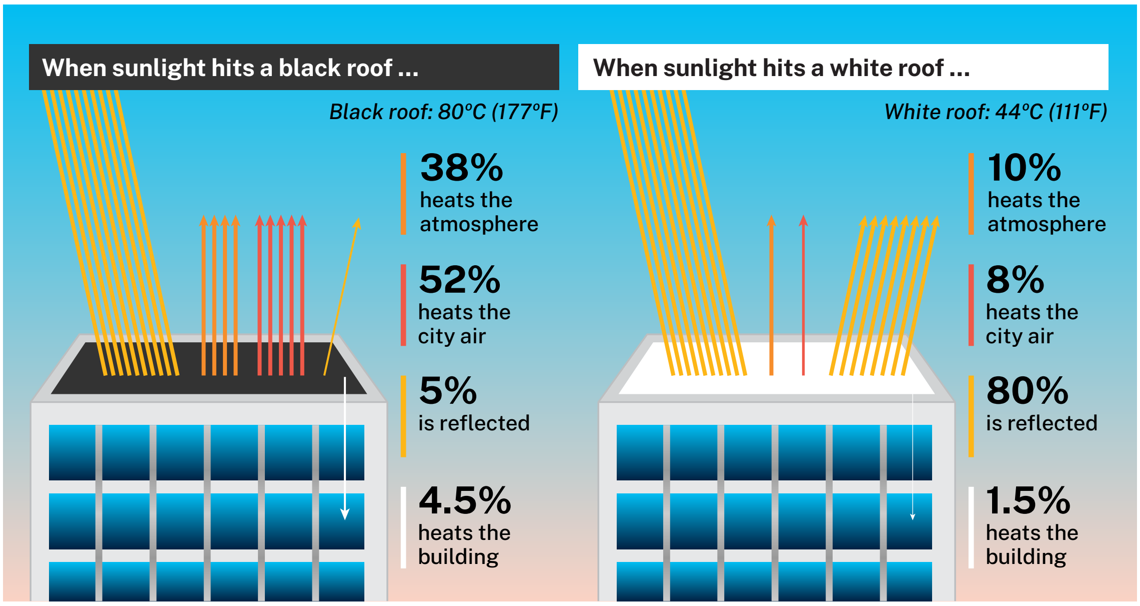
Source: Tasgaonkar et al. 2022. Creative Commons Attribution 4.0 International License.

Passive cooling offers a sustainable approach to managing building temperatures. Passive cooling refers to building designs and measures that aim to provide thermal comfort without mechanical cooling systems. Passive cooling measures may include a building's orientation, insulation, natural ventilation, reflective surfaces, and shading, while mechanical cooling systems involve appliances such as electric fans and air conditioning units. Buildings in South Asia have long deployed passive cooling techniques and vernacular climate-responsive architecture to manage local heat conditions. However, recent urbanization developments have seen traditional building materials (clay, mud, adobe, wood, and bamboo) be replaced with high heat-retaining materials (concrete, steel, glass) and traditional building designs be replaced by high-density settlements (Asian Development Bank 2022). This has increased the UHI effect, indoor air temperatures, and an increasingly unsustainable reliance on mechanical cooling systems to provide relief. Although mechanical cooling systems can improve thermal comfort, they require a stable and affordable energy source to operate and produce exhaust heat that elevates nearby temperatures. Hence, there are limitations and trade-offs to widely deploying mechanical cooling systems as the primary cooling medium across urban areas of South Asia.

Cool roof programs are gaining traction. Roofs cover approximately 20-25 percent of urban surfaces, and if darkly colored, can absorb more than 80 percent of contacted sunlight (Global Cool Cities Alliance 2012). This solar energy gets converted to heat, resulting in hotter indoor air temperatures and a heightened UHI effect. As shown in Figure 3, this can be greatly minimized by replacing or upgrading roofs with reflective coatings (Global Cool Cities Alliance

2012), a highly cost-effective measure to increase thermal comfort and decrease mechanical cooling requirements in buildings. Cool roofs can be applied to all building types, with larger efficiency gains possible in single-story structures with high roof-to-wall area ratios (Energy Sector Management Assistance Program 2020). This is particularly relevant for informal settlements in South Asia. Across India, several cool roof programs and pilots have been taking place, including initiatives in Ahmedabad, Hyderabad, and Delhi (Rallapalli and Gupta 2020). These initiatives have shown positive results with indoor air temperatures declining by 2-3°C in Ahmedabad and 2°C in Hyderabad, while Hyderabad roof surface temperatures dropped 15°C and 10°C lower than asbestos and cement roofs, respectively (Energy Sector Management Assistance Program 2020).

Figure 3: Comparison of a black and a white flat roof on a summer afternoon with an air temperature of 37°C (98°F)



Source: Global Cool Cities Alliance 2012

There are widespread opportunities to improve building designs and materials across South Asia, especially due to rapid urbanization. In India, 70 percent of buildings are yet to be constructed (International Finance Corporation 2017). Mandating cool roof requirements in building codes is a cost-effective policy intervention to both adapt buildings to future climates and reduce energy usage and operating costs. This is already somewhat occurring on new commercial buildings in India through the Energy Conservation Building Code (Bureau of Energy Efficiency 2017) which specifies a minimum solar reflectance for certain roof types (Rallapalli and Gupta 2020). The challenge is applying this more broadly to non-commercial buildings throughout South Asia, ensuring adequate compliance and enforcement, and upgrading existing buildings.

In the absence of targeted public policies and programs, non-governmental organizations are helping to improve the heat resilience of buildings. Across India, a not-for-profit organization, the Mahila Housing Trust, is working with women in the informal sector to improve household resilience to heat stress. To date, more than 27,000 households across 1,066 informal settlements have been supported in installing sustainable cooling technologies, including modular roofs with solar reflective white paint (Yeung 2022). Other initiatives include The One Million Cool Roofs Challenge, a philanthropic initiative designed to rapidly scale up solar-reflective roofs across developing countries suffering from heat stress. This initiative helped a Bangladesh team paint the roofs of two factories and 105 other buildings in Dhaka, resulting in average indoor air temperatures falling by more than 7°C (Sustainable Energy for All 2021).

2.2. Communities

Intra-urban temperature differences arise between communities. Urban landscapes in South Asia are highly complex and heterogeneous. As such, intra-urban temperature differences and microclimates exist. These can occur due to natural geographical differences between communities, such as the local elevation, relief, and proximity to a coastline or urban boundary. Intra-urban heat islands can also arise from manmade factors, including the local ratio of the built environment to vegetative surfaces and water bodies, the structure and density of the built environment, and the physical properties of the materials in the built environment. Finally, the extent of local anthropogenic heat sources from industrial sites, vehicle exhausts, and air conditioning outlets influences intra-urban temperature differences. Together, these factors can affect the way heat is absorbed, trapped, and released in a community, impacting local temperatures, thermal comfort levels, and community heat risks.

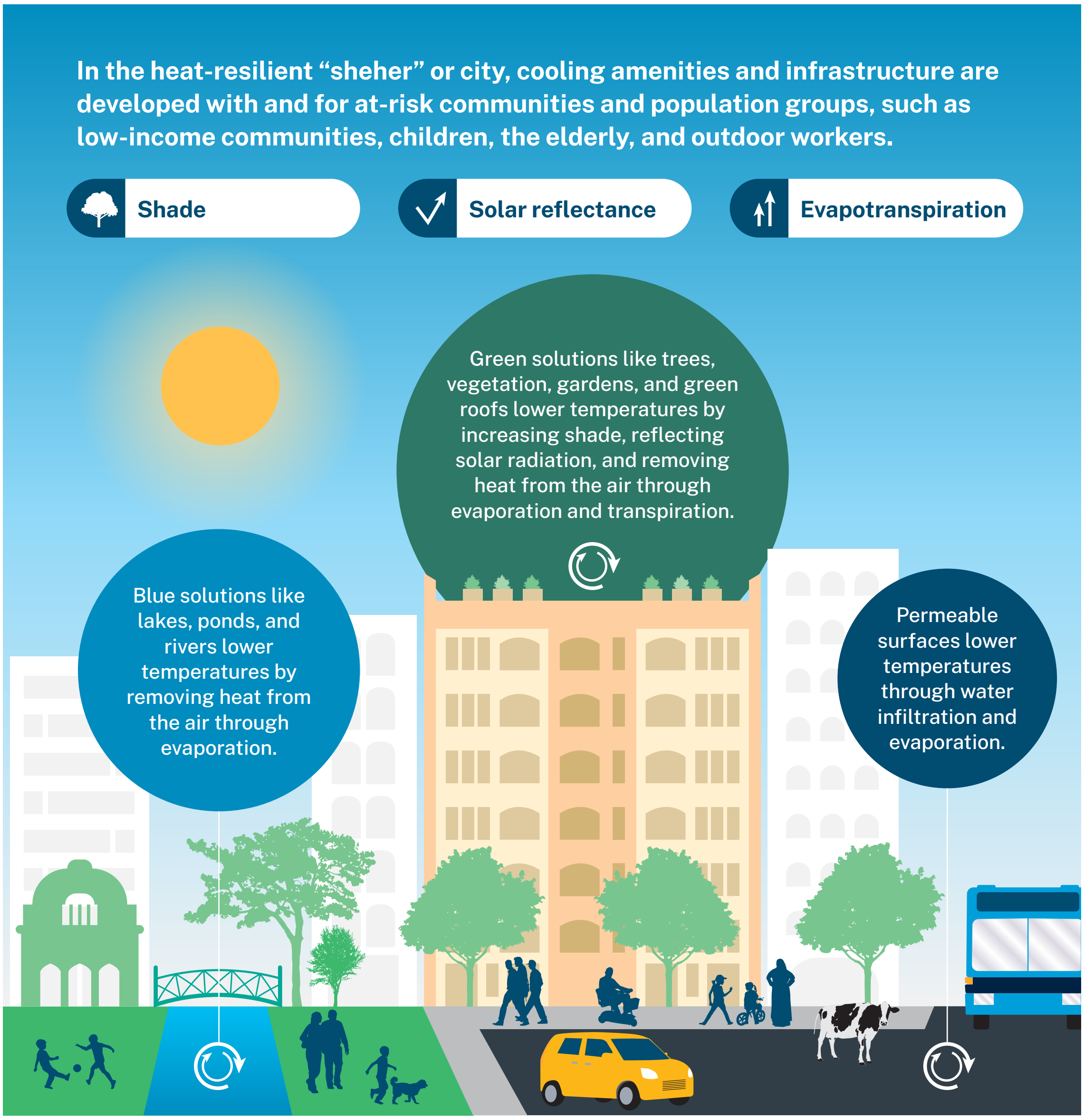
Seemingly small attributes of the built environment can result in significant intra-city temperature differences. Rajan and Amirtham 2021 assessed the outdoor temperatures and humidity levels in eight neighborhood locations in Chennai's Thyagaraya Nagar district, demonstrating the impacts of the built environment on intra-city temperature differences. Each location shown in Figure 4 varied in street orientation, aspect ratio, sky view factor, and proximity to green space. In the middle of the day, location 2 reached the highest temperature of 40°C, approximately 5.8°C above locations 3,4, and 5 at the same time of day. By 22:30, location 2 only cooled down by 5°C to 35°C, while all other locations had cooled down an additional 2-4°C below this. While location 2 does have higher density, attribution of the temperature differences found that streetscape design details, such as the narrow streets with a low height-to-width (H/W) ratio of 1.75, the east-west orientation of the street, and the low sky view factor contribute significantly to the temperature differentials in otherwise similar communities.

Figure 4: Eight location points within Thyagaraya Nagar where temperature and humidity levels were assessed across February 15–March 15 and April 30–May 30, 2018.

Source: Rajan and Amirtham 2021 © Springer Nature. Adapted with permission from Springer Nature; further permission required for reuse.

Green and blue spaces play a key role in managing community heat risks. Green spaces can help mitigate the UHI effect through shade cover and evapotranspiration. A study of 262 urban green spaces in Bengaluru found these areas to be on average 2.23°C cooler than nearby areas and provide cooling benefits for almost 350 meters beyond their boundaries (Shah, Garg, and Mishra 2021). Similarly, surface water bodies provide cooling through evaporation and the oasis effect. A three-year study of temperatures near the Sukhna Lake in Chandigarh city demonstrated an average summer temperature drop of 7.51°C and a cooling effect of up to 1,200 meters from each side of the lake's center (Gupta, Mathew, and Khandelwal 2019). Figure 5 below depicts a heat-resilient "sheher" or city in South Asia that strategically leverages green and blue spaces, along with permeable surfaces, to manage urban heat risks. These solutions allow policymakers to address multiple objectives, including not just urban heat reduction, but also flood protection; avoidance and/or removal of carbon emissions; habitat and biodiversity benefits; and air, soil, and water quality improvements.

Figure 5: Illustration of a heat-resilient "sheher" or city



Many South Asian urban communities are ill-equipped for managing current and future heat risks. High-density living, along with low permeation of green and blue spaces, creates heat management challenges for a large number of communities in South Asia. These built environment factors are especially important considering that heat adaptive measures, such as mechanical cooling through air conditioning, are rarely afforded in South Asia. In India, only 7 percent of households owned an air conditioner in 2018 (Sachar, Campbell, and Kalanki 2018), while other countries in the region are likely to have even lower rates. In addition, in many South Asian communities, air conditioning use is impractical due to shortages in electricity supply or electricity affordability. For instance, across Pakistan, electricity demand often exceeds supply resulting in blackouts lasting 3-4 hours per day (Tao et al. 2022). These factors are not limited to low-income communities and extend across many urban communities in South Asia, highlighting the magnitude of community vulnerabilities in the region.

Further studies on intra-urban temperature differences are needed in South Asia. Managing community heat risks first requires understanding local heat profiles. To date, knowledge of urban temperatures in South Asia has been largely limited to satellite data or studies that have not accounted for spatial variability (Shastri et al. 2017). This has limited the awareness and understanding of intra-urban heat differences in South Asian cities. Some exceptions include the study by Rajan and Amirtham 2021 and additional studies by Jacobs et al. 2019 and Yadav and Sharma 2018. Jacobs et al. 2019 characterized intra-urban differences in heat exposure in Delhi (India), Dhaka (Bangladesh), and Faisalabad (Pakistan) through traverse measurements of air temperature, humidity, solar radiation, wind speed, and derived heat indices. Yadav and Sharma 2018 used a mobile transverse technique to assess intra-city heat differences in Delhi and observed differences of up 6 °C across different regions of Delhi. These studies have shown the occurrence of intra-urban temperature differences and the myriad of factors that contribute to such differences, pointing to the need to better understand the differential intra-urban heat vulnerabilities to target policy interventions to the communities most in need across the region.

2.3. Cities

The impacts of extreme heat can be greatly minimized through city-level measures. The heat adaptive capacities of individuals and communities are shaped by factors beyond their immediate environment, such as weather forecasts, early warning systems, urban cooling operations, emergency response plans, and larger municipal planning and policymaking processes around land-use and urban development (Wu et al. 2022). These elements of heat management require dedicated resources, institutions, and governance to deliver. Cities therefore can and should play a vital role in developing and deploying plans and policies at the municipal level that protect their citizens and economies from the impacts of urban heat.

Urban heat is a rising risk across South Asian cities that is often underestimated and underreported. Unlike many other climate hazards, urban heat is a relatively predictable hazard that can be largely measured and protected against. However, its management is often overlooked due to the complex and chronic nature of impacts which are not always fully understood. Cities can increase local knowledge of risks through heat mapping processes which combine climate and socioeconomic data to identify local heat vulnerabilities (C40 Cities Climate Leadership Group 2021). Cities can enhance the accuracy of this mapping by increasing ground sensors for surface-level temperature collection to understand and monitor heat profiles. Combining these actions with heat forecasts and early warning systems can help improve overall risk perceptions and deploy preventative measures to prevent excess morbidity and mortality.

Ahmedabad's Heat Action Plan (HAP) has been a leading example of city-led action. Heat management plans can take many different forms but generally consist of a central framework for assessing, managing, coordinating, and responding to local heat risks. Following the 2010 heat wave in Ahmedabad which caused 1,344 deaths, the Ahmedabad Municipal Corporation and partners prepared South Asia's first heat management plan. Ahmedabad subsequently became the first South Asian city to have a comprehensive plan for managing heat-health threats (Knowlton et al. 2014), and a 2018 study found that nearly 2,380 deaths had been avoided in the post-HAP period (Hess et al. 2018). Ahmedabad's HAP aims to build public awareness of heat risks and implement practices that prevent heat-related deaths and illnesses; initiate early warning systems and facilitate inter-agency coordination during periods of predicted heat extremes; build capacity among healthcare professionals to recognize and respond to heat-related illnesses; and reduce heat exposure and promote adaptive measures by launching initiatives such as a draft city-wide Cool Roofs Program (Ahmedabad Municipal Corporation 2019).

The number of urban heat plans is growing across South Asia but with much room for improvement. Since the implementation of Ahmedabad's HAP, many other South Asian states and cities have implemented similar frameworks, including ones in Karachi, Surat, Andhra Pradesh, and Telangana. India's national government is furthering this progress, releasing the "National Guidelines for Preparation for Action Plan — Prevention and Management of Heat Wave" (National Disaster Management Authority 2019), and working with over 130 cities and districts to implement heat management plans across heat-prone areas of the country (Natural Resources Defense Council 2022). These plans are helping to raise awareness and preparation levels for addressing the health-related risks of extreme heat. Some South Asian cities, including Karachi and Ahmedabad, have developed their own heat wave early warning systems (HEWS) with notifications formulated and disseminated based on forecasts and monitoring of trigger indicators by relevant national meteorological agencies or departments. However, many of the region's plans lack local climate analyses and ground-level assessments of heat-prone areas, fail to incorporate longer-term strategies such as urban management and planning, and overlook periodic monitoring and evaluation to improve overall effectiveness (Pillai and Dalal 2023; Magotra et al. 2021; Kotharkar and Ghosh 2022). Without adequately addressing these limitations, heat management plans may remain static in function and fail to identify and protect vulnerable groups. Furthermore, the reviewed plans focus on addressing acute health impacts and neglect the long-term socioeconomic implications of sustained heat exposure in a changing climate, such as the impacts of heat on labor productivity or learning and human capital accumulation.

There are global examples of cities implementing advanced urban heat management plans. Cities in South Asia face unique challenges, competing demands, and resource constraints that cities in developed economies may not face. Nevertheless, lessons in city-level heat management can be drawn from outside of South Asia to understand best practices and potential heat management improvements. Examples include the City of New York's Cool Neighborhood NYC program which has seen over one million trees planted, over 6.7 million square feet of rooftop space coated, and initiatives launched that provide training on heat protective measures for vulnerable adults (New York City Mayor's Office of Recovery and Resiliency 2017). Another example is the Los Angeles Sustainable City pLAn 2019 which takes a holistic approach to heat management by focusing on urban ecosystems and resilience (Los Angeles Mayor's Office 2019). Measures include updating the cool roof ordinance to cover all roof types, progressing cool surface regulations to cover 50 percent of all non-roof surfaces, implementing a street furniture program to reduce heat exposure, and expanding spatial mapping to optimize cooling strategies.

Advanced heat management strategies can deliver more targeted interventions with greater co-benefits. A major difference between the US examples and the existing South Asian heat management plans is the dedication of specific resources and capacities to address urban heat, along with the careful targeting of interventions to the most vulnerable locations and groups. Greater data collection and mapping allow targeted heat management measures by identifying the most vulnerable areas, directing action toward these areas, and monitoring progress over time to understand the effectiveness of different interventions in the local context. These plans can in turn be highly cost-effective, delivering urban co-benefits, such as improved air quality, reduced energy consumption, enhanced living and recreational space, improved social mobility, improved stormwater management, and increased biodiversity. Together, these highlight the potential improvements heat management plans could deliver to South Asian cities with dedicated financial, technical, and human resources.

A core element of all effective heat management plans at the municipal level is clear responsibility and ownership. As outlined, heat management plans can take many different forms and vary significantly in scope and function. Regardless of their form, all heat management plans must have roles, responsibilities, and ownership clearly outlined for the many moving parts involved in city-level heat management. Unlike many other hazards, no single organization or department is often responsible for coordinating responses to extreme heat (Keith et al. 2021), often resulting in inefficient or ineffective heat management. Heat plans provide a forum for addressing this fragmentation through the formulation of a dedicated institutional structure that facilitates inter-agency coordination and designation of dedicated personnel and funds. As in the case of Nagpur, where the Nagpur Municipal Corporation's health department prepared the city's heat action plan and designated staff to implement and monitor the plan, a heat-centered team or organization can be placed within an existing municipal institution (ICLEI - Local Governments for Sustainability - South Asia Secretariat 2021). Alternatively, the city can start a new institution and/or appoint a dedicated nodal officer (or emergency response coordinator as in the case of Ahmedabad and Karachi) to provide leadership and coordinate with various relevant departments. Appointments of chief heat officers in cities across the globe, such as Freetown, Sierra Leone; Monterrey, Mexico; and Santiago, Chile, and the establishment of heat-centered institutions, such as the Office of Heat Response and Mitigation in Phoenix, Arizona are other examples of how heat governance can be improved through clear ownership (Keith et al. 2021).

In addition to establishing a dedicated institutional structure, cities in South Asia can address the structural drivers of urban heat vulnerabilities in their heat management plans (Figure 6). First, within heat management plans, cities should outline processes to better understand urban heat risks. They can do this by i) systematically measuring heat in both outdoor and indoor environments, ii) assessing current and future trends affecting urban heat, including climate change, land-use patterns, urban density, and use of surface materials, and iii) mapping the urban heat island effect, vegetation, and overall heat vulnerability by zone and/or ward. Second, cities need to identify and dedicate human, technical, and financial resources for urban heat management. In particular, innovative solutions like public-private partnerships, creation of a specific fund or a subnational pooled financing mechanism, or tax increment financing (TIF) can allow local governments to access loans, bonds, and other forms of finance (Abubakar et al. 2022). Lastly, South Asian cities should leverage the full suite of planning and policy tools available to enhance urban heat resilience. Given that the majority of the infrastructure in South Asian cities is yet to be built, cities can utilize heat management plan development and implementation processes to also formulate heat risk-informed building codes, zoning ordinances, and land-use plans. Greenfield development should be designed and built to minimize increases in the urban heat island effect and be adapted to rising temperatures, including cost-effective passive cooling strategies at the building-level, increasing green and blue spaces to alleviate intra-urban temperature differences, and the provision of heat-resilient public infrastructure and facilities.

3 Vulnerable Population Groups

Urban heat vulnerabilities extend beyond the built environment to include the people within it. This section explores the relationship between people and place in urban heat in three vulnerable population groups in South Asia that are particularly relevant for the region's economic development and poverty alleviation: children, informal workers, and residents of informal settlements[2].

3.1. Children

Children are naturally vulnerable to heat stress and these vulnerabilities are heightened in South Asia. In the latest IPCC Working Group II Report, young children in cities are noted as particularly sensitive to heat waves, and as potentially having little experience or capacity to cope with heat extremes (Dodman et al. 2022). The IPCC adds that these vulnerabilities are compounded by the impacts of rapid urbanization and infrastructure deficiencies, an issue prevalent across much of South Asia (Dodman et al. 2022). Children's heat sensitivities arise from their small surface-to-body ratios and higher proportions of body weight that is water, increasing susceptibilities to heat stress and dehydration (Stanberry, Thomson, and James 2018). Heat waves also exacerbate allergens and air pollution (Deng et al. 2020; Grigorieva and Lukyanets 2021) posing substantial risks to children's underdeveloped respiratory and immune systems in South Asia where urban pollution levels can be dangerously high. Finally, children from the poorest communities often lack access to coping mechanisms that offer protection, such as air conditioning, shelter, water for hydration, and healthcare for treatment (United Nations Children's Fund 2022). Therefore, children in the region face heightened heat risks.

Heat exposure can compromise children's quality of life and development trajectories. During heat waves, children are more likely to suffer from heat-related illnesses, including respiratory diseases, kidney disease, electrolyte imbalances, and fever (Stanberry, Thomson, and James 2018; Dodman et al. 2022). Children are also more likely to suffer from heat-related symptoms, which may not require urgent medical care but impact their ability to learn and play, including headaches, lethargy, cramps, and exhaustion (Dodman et al. 2022). A recent study in Nepal showed that higher temperatures are associated with a higher prevalence of diarrhea, particularly among young children (Bhandari et al. 2020). Further, higher air pollution exposure, which may occur during high-temperature periods, was associated with malnutrition in children. Other studies in South Asia have shown that higher temperatures are associated with food insecurity across the short- (Kroeger, Reeves, and Fledderjohann 2022) and long-term (Ali et al. 2017), amplifying malnutrition risks in children. Chronic malnutrition can lead to stunting, which can cause lifelong physical and cognitive deficits (The World Bank 2021).

2 These are not the only vulnerable population groups in South Asia, and there are many other groups such as the elderly and people with existing medical conditions and disabilities who are more vulnerable to extreme heat. Although analyzed in distinct groups, it is recognized that the lines between groups may be blurred and many individuals may have overlapping features with other vulnerable groups, highlighting the complexity of identifying and categorizing social and spatial vulnerabilities when developing heat management plans.

Protecting South Asia's youth population from heat stress is vital to unleashing the region's human capital potential. South Asia faces large and persistent human capital deficits limiting current and future economic development (The World Bank 2021). The region has the highest stunting levels in the world (33 percent), affecting 56 million children (The World Bank 2021). Children born in South Asia are currently expected to attain less than half of their full potential, the second-lowest level of human capital attainment in the world (The World Bank 2021). The health and education of children play a key role in determining their adulthood productivity levels. Both of these factors are negatively influenced by acute and chronic heat stress. Hence, unmanaged heat exposure among children can have long-term consequences on individual economic mobility and national economic growth. Despite such risks, studies on the relationship between heat and education in South Asia are lacking, limiting the overall awareness and understanding of the magnitude of this threat.

Studies outside of South Asia have shown negative correlations between heat and learning. Park, Behrer, and Goodman 2020 combined standardized test scores with detailed weather data across 58 countries and 12,000 US school districts, discovering an increase in the number of hot school days led to lower test scores. Further, the findings suggested a regressive relationship between heat and learning, with greater effects evident in school districts with lower socioeconomic status. Cho 2017 matched weather data to 14 million college entrance examination scores from Chinese students across 2,227 counties between 2005 and 2011, finding that high summer temperatures had both immediate and cumulative negative impacts on students' math and English test scores. Other studies on adults have shown high temperatures to negatively impact cognitive performance. Pilcher, Nadler, and Busch 2010; Merhej 2019 show through a meta-analysis that dehydration, even at mild levels, is associated with impaired cognitive function.

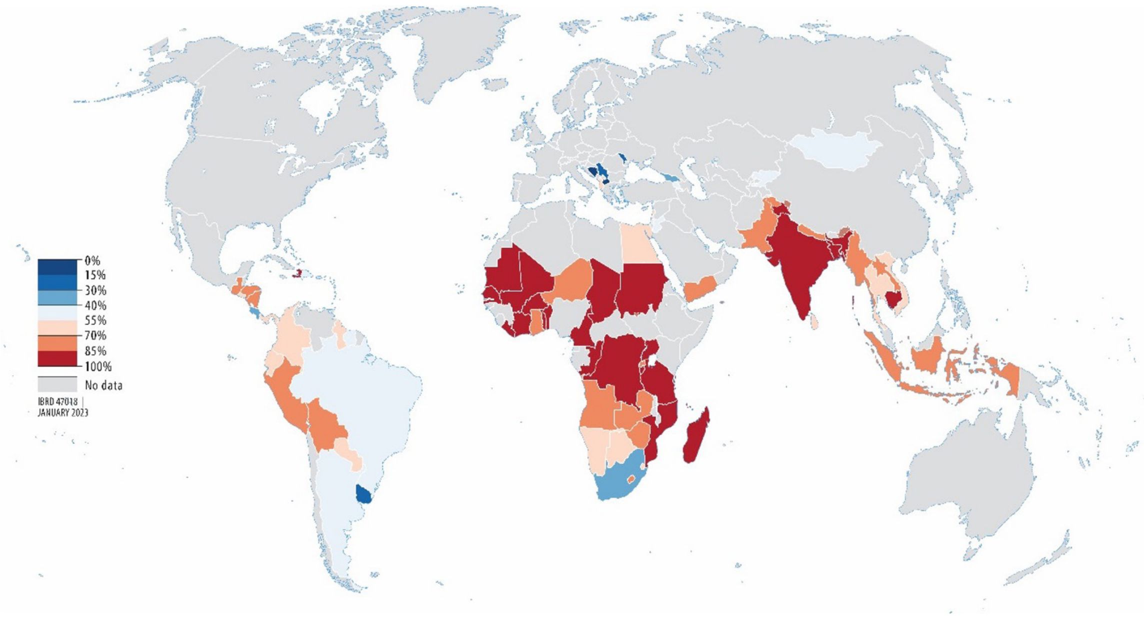
Learning impacts may extend beyond the classroom. Most studies to date have focused on the impact of heat on learning through student test scores. However, childhood learning and development extend beyond what can be evaluated in classroom tests. As a recent UNICEF report (Kagawa 2021) highlights, the ways students learn are being impacted by climate change. Increasing heat across South Asia is decreasing the viability and practicality of teachers taking students outdoors for experiential learning. This may extend to the home environment where students' unstructured learning may be disrupted by extreme heat through reduced mobility, increased domestic duties, or decreased capacity to engage in after-school activities.

Local studies are needed to understand how heat is impacting learning in South Asia. It is clear the impacts of heat on learning could have unforeseen economic implications if left unmanaged. To address these impacts, the region must first understand the magnitude and drivers of impacts occurring. This first requires local studies that evaluate the effects of classroom temperatures, sleeping temperatures, hydration status, missed school days, and changes to routine to understand the specific causal relationships between heat and learning in South Asia. This can help identify the sources of vulnerability and where the most effective intervention points can occur, and furthermore, enable urban heat management plans and policies to address these important, longer-term impacts of heat.

3.2. Informal Workers

Rising temperatures are a major occupational hazard for South Asia's informal workers. South Asia has some of the highest numbers of informal workers in the world (Figure 6). Between 2010-2017, nearly three-quarters of South Asia's nonagricultural workers were informal (Bussolo and Sharma 2022). This informality creates risks for workers who are often not covered by formal employment protection laws and social protection programs (Bussolo and Sharma 2022). During periods of heat, formal workplace measures, such as more frequent breaks, decreased working hours, or modified work activities, may not be available for informal workers, creating occupational hazards that can cause heat-related injury and illness.

Figure 6: Share of informal employment by country (in percent), latest year



Source: Copyright © International Labor Organization 2021.

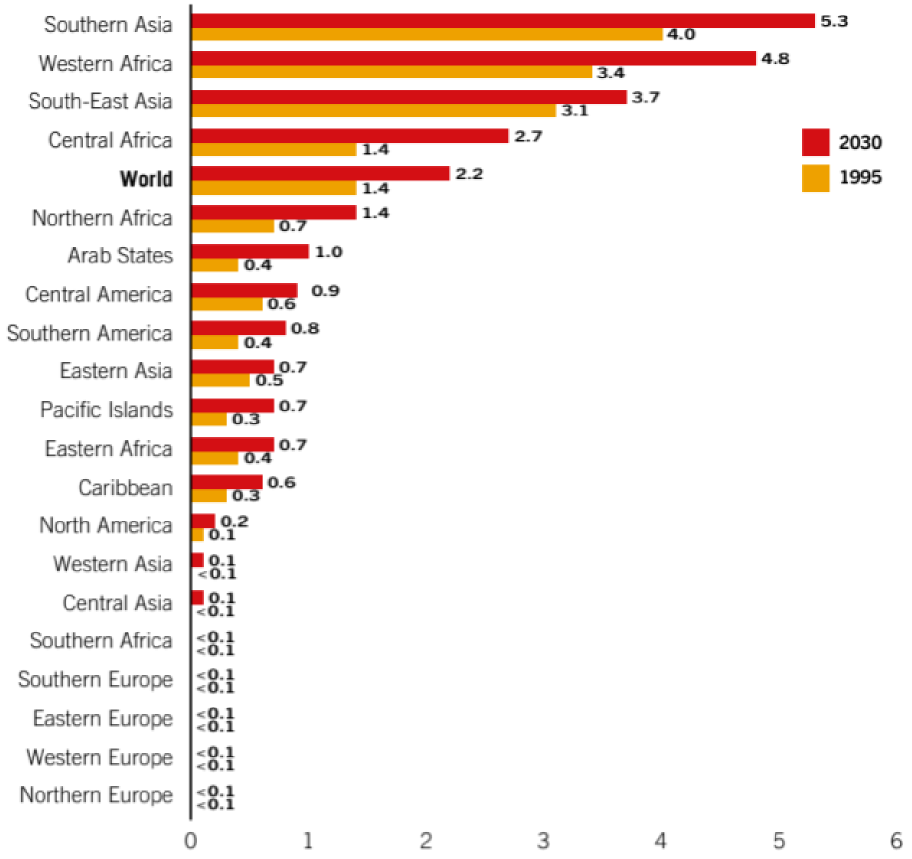
Informal workers are more likely to engage in manual or outdoor work which increases heat risks. Venugopal et al. 2015 evaluated workers' perceived health and productivity impacts from heat stress in the Indian cities of Chennai, Tiruchirapalli, Bengaluru, and Mumbai. The study found workers with heavy workloads reported more heat-related health issues and reduced productivity levels, especially among those engaged in outdoor work. The study had workers from the formal (22 percent) and informal (78 percent) sectors and found that heavy manual work was predominately performed in the informal sector (Venugopal et al. 2015). Hence, workers in the informal sector face increased vulnerabilities from the higher likelihood of engaging in heavy manual and/or outdoor work, along with the fewer protections and compensations they have in the workplace.

Many informal workers lack the capacity to absorb heat-related work disruptions. Venugopal et al. 2015 showed how the impacts of heat stress are already being felt across urban Indian workplaces, with 57 percent of respondents reporting they had experienced productivity losses due to heat stress, including 62 percent reporting missed targets, 30 percent reporting absenteeism, and 25 percent of workers' reporting lost wages due to workplace heat-induced fatigue or sickness. Workers also reported heat-related symptoms, such as excessive sweating, fatigue, headaches, cramps, nausea and vomiting, and heat-related health issues, including heat rashes, dehydration, heat-syncope, and urinogenital symptoms (Venugopal et al. 2015). The consequences of these impacts are likely to be greater among informal workers unlikely to have sick leave or income insurance and may also have lower levels of savings, poorer access to credit, and greater barriers to receiving medical care.

Decreased workplace productivity can have unforeseen implications for informal workers. As discussed, heat stress can have negative implications on workers and their families due to lost productivity and income. However, decreased productivity can also have direct implications on workers' wellbeing and safety. A paper by the International Labor Organization (ILO) spotlighted these risks through the garment sector in Bangladesh, where the perceived or actual decrease in productivity levels is a driver of gender-based violence and harassment (Anderson Hoffner et al. 2021), pointing to the potential for workplace violence from increasing heat-induced productivity losses. Further research is needed to better understand the exact impacts informal workers face with rising workplace temperatures in South Asia.

Lost labor due to rising heat and humidity levels is an economic risk to South Asia. Given the expanse of South Asia's workforce that is vulnerable to heat stress, the impacts of occupational heat exposure extend to the macroeconomic scale. The ILO projects that 5.3 percent of working hours could be lost to heat stress in South Asia by 2030. As seen in Figure 7, this is the highest percentage from any region in the world (International Labor Organization 2019). Sectors with greater manual labor and outdoor work will be disproportionately impacted, such as the construction sector which is set to lose over 8 percent of shaded working hours. Without action, these lost labor hours will have significant effects on South Asian economies. In India, an increase in lost labor hours due to rising heat and humidity levels is predicted to put 2.5-4.5 percent of India's GDP at risk by 2030, equivalent to $150-250 billion (Woetzel et al. 2020). In many cases, the most vulnerable regions and communities will be more severely affected, jeopardizing future growth and poverty alleviation prospects.

Figure 7: Working hours lost to heat stress by subregion, 1995 and projections for 2030 (percentages)



Source: Copyright © International Labor Organization 2019

3.3. Residents of Informal Settlements

Residents of informal settlements face heightened heat risks in South Asia. In South Asia, approximately 130 million people live in informal settlements characterized by poor construction, insecure tenure, and underserviced housing plots (Ellis and Roberts 2016). In the latest IPCC Working Group II report, occupants of informal settlements are noted as being *"particularly exposed to climate events, given the low-quality housing, limited capacity to adapt, and limited or no risk-reducing infrastructure* (Dodman et al. 2022)."

Spatial vulnerabilities intersect with socioeconomic vulnerabilities in informal settlements. Globally, and within South Asia, the poorest households tend to live and work in the hottest locations to begin with (Park et al. 2018). Both the location of housing and the quality of the shelters in informal settlements tend to be vastly inadequate in providing protection from current temperature variability and future climatic changes (Satterthwaite et al. 2018). Through a survey of over 800 households across different housing typologies in Ahmedabad, India, Mahadevia et al. 2020 showed that informal settlement residents experienced up to 7.6°C higher temperatures than people in formal housing. A study comparing adjacent formal and informal settlements in the metropolitan area of Lahore, Pakistan found that houses in the formal settlement were newer, had better insulation and ventilation, and had more open green spaces than the informal settlement, leading to lower indoor temperatures in the summer. While women in both settlements were mostly stay-at-home family caregivers and spent most of their days indoors, women in the informal settlement were much more likely to be hospitalized due to heat stress (Rana et al. 2022). Within informal settlements, the structural vulnerabilities of heat-trapping buildings may be heightened by socioeconomic elements such as overcrowding, the use of solid fuel burners indoors, and closed off ventilation due to neighborhood air pollution.

Residents of informal settlements are less likely to have access to the basic services or infrastructure necessary to adapt to rising temperatures. The 2022 Lahore study found that while residents of both the formal and informal settlement had access to water and electricity, none of the residents of the informal settlement had an air conditioner, in contrast to the 89 percent of the residents of the formal settlement that did. Instead, the residents of the informal settlement employed coping mechanisms such as hanging wet sheets from windows or wearing light-colored and loose-fitting clothing. In addition, the residents of the informal settlement had limited access to Internet and rarely used social media, implying unequal access to information regarding heat events and response measures (Rana et al. 2022). These barriers limit residents of informal settlements' ability to plan for and respond to urban heat, perpetuating existing thermal inequities in South Asia.

Urban heat management in South Asia needs to recognize and address the impacts of heat for the residents of informal settlements. To date, there is limited empirical literature on the differential heat vulnerabilities and adaptive capacities of formal and informal settlements in South Asia and across the world. In addition, most heat management plans and policies have focused on the micro-or macro-levels, with either building-level interventions or national adaptation planning processes, with little attention to informality (Kotharkar and Ghosh 2022; Adegun, Mbuya, and Njavike 2022). Future urban heat analysis and management efforts in the region need to account for the nuances and complexities of informality to better target resources towards the more vulnerable households in riskier areas of South Asian cities.

4 Recommendations

This policy brief reviews the current state of knowledge of urban heat in South Asia, outlining the gaps in theory and practice for urban heat management in the region. First, the brief examines heat in South Asian cities through the different layers of the urban environment: buildings, communities, and cities. Next, it adds the human element and explores different population groups that are vulnerable to urban heat in the region: children, informal workers, and residents of informal settlements. Together, this analysis forms the basis of three major recommendations and a conceptual framework to provide policymakers with direction on where greater attention and resources are required to improve urban heat management in South Asia.

Recommendation 1: Improve data collection and analysis.

Further data are required to adequately identify, manage, and monitor South Asia's urban heat risks. Satellite data are not sufficient in providing an accurate representation of the thermal conditions being experienced throughout urban areas of South Asia. Systematic data collection and analysis are required to understand urban microclimates and actual temperatures experienced, especially in different indoor environments and varying times across the day, and to identify heat-vulnerable environments and populations within each city. This information can help develop more effective and targeted heat management plans. Therefore, improving the understanding of urban heat profiles through high-resolution data collection and mapping should be a major priority for South Asia.

Section 2 highlighted the large temperature differences that occur within the urban environment and the impacts this can have on heat exposure.

Section 2.1: Buildings spotlighted the differences between average satellite temperatures and indoor building temperatures. Tasgaonkar et al. 2022 showed that the indoor temperatures in households with poor quality roofing materials can remain several degrees above outdoor temperatures during summer nights. Despite these differences having large impacts on health and cognitive function, they are often unquantified and understudied throughout many urban areas of South Asia.

Section 2.2: Communities highlighted the lack of local data available to identify intra-urban temperature differences in many areas of South Asia. Where data has been collected, such as the studies by Rajan and Amirtham 2021 and Yadav and Sharma 2018, intra-urban temperature differences of over 5°C have been recorded.

Section 2.3: Cities discussed global best practices of heat management plans through New York's Cool Neighborhood NYC program and the Los Angeles Sustainable City Plan. In both examples, data collection, mapping, and modeling are key measures in identifying heat-prone areas within the cities. Ongoing data collection also allows for the monitoring and evaluation of interventions to iterate and optimize heat management interventions.

Recommendation 2: Integrate people and place in urban heat management.

Improving South Asia's heat management requires a greater integration of people and place. This brief shows how urban heat risks and vulnerabilities have important spatial and social variations, and how these aspects intersect with and can compound each other. To date, most heat management plans and policies have taken either a settings-based or a population-based approach. Examples include programs that focus primarily on the built environment, such as cool roofs, green spaces, and shade facilities, and/or heat stress prevention programs that focus primarily on specific groups of people, such as occupational standards or regulations for elderly care and healthcare facilities.

Future heat management efforts should be designed to address both social and spatial vulnerabilities. Cities need to map out overall heat vulnerability, including both heat risk factors, such as building density, materials, and access to green/blue spaces, and demographic and socioeconomic determinants, such as income, age, education, gender, health, and social isolation. Cities also should ensure inclusive heat planning and policymaking processes to address thermal inequities, particularly in the most heat-vulnerable communities and population groups.

Section 3 showed that many vulnerable population groups also face vulnerabilities in the urban environment in which they live and work. This was particularly clear in Section 3.3 where it was shown that residents of informal settlements face social, spatial, and physical (built environment-based) vulnerabilities to urban heat. Together, these factors compound their heat risks through higher exposure levels and lower adaptive capacities. Current isolated approaches are unlikely to fully recognize and address the intersectionality in the vulnerabilities they face.

Recommendation 3: Manage slow-onset, longer-term impacts of urban heat.

Going beyond heat management plans that focus on preventing excess morbidity and mortality, cities in South Asia should develop planning and policymaking processes that aim to incorporate and address slow-onset, longer-term impacts of heat that threaten human capital accumulation, social welfare, and economic development. In making use of the full suite of planning and regulatory tools and strategies available to address urban heat resilience, South Asian cities should prioritize housing quality; indoor and outdoor cooling accessibility, especially in schools and workplaces; transit accessibility; and energy affordability. As much of urban Asia remains to be built, planners and policymakers should embed urban heat resilience in building codes, zoning, and land-use regulations to ensure new development does not contribute to heat and is also adapted to rising temperatures, with a focus on heat-resilient affordable housing, schools, public buildings, and transit infrastructure.

Section 2.3: Cities showed that most of South Asia's current heat management plans are focused primarily on acute health-related impacts and fail to address slow-onset, longer-term risks.

Section 3.1: Children highlighted some long-term consequences of poor heat management, particularly on children's learning and physical development. The detrimental impacts on individuals' social mobility and adulthood productivity were discussed, alongside the broader implications on the region's human capital and economic trajectories.

Section 3.2: Informal Workers emphasized the impacts of urban heat on South Asia's unprotected informal workers and the consequences this can have on workplace safety and productivity levels. The magnitude of these impacts on South Asia's economy were discussed, noting the high proportions of informal workers that make up the region's workforce.

Section 3.3: Residents of Informal Settlements discussed how residents of informal settlements are less likely to have the resources to access basic services and infrastructure necessary to adapt to rising temperatures, which in turn, also constrain longer-term development prospects.

Based on these recommendations, this policy brief outlines a framework for South Asian planners and policymakers to enhance urban heat resilience, with practical considerations to integrate people and place in addressing the longer-term impacts of urban heat on the region's economic development and prosperity (Figure 8).

Figure 8: Urban heat resilience planning framework

Understanding Urban Heat Risks

- Historical and projected climate data
- Indoor and outdoor heat measurements in different areas of the city, including not only remote sensing of land surface temperatures, but also ambient air temperatures
- Current and future trends of land-use patterns, urban density, and use of surface materials
- Heat vulnerability maps including heat risk factors, such as building density, materials, and access to green/blue spaces, and other socioeconomic determinants, such as income, age, education, gender, health, and social isolation
- Community needs assessments targeting the most heat-vulnerable communities and population groups

Resourcing for Urban Heat Resilience

Human and technical resources

- Institutional structure enabling multi-sector/agency coordination and collaboration
- Dedicated staffing and training
- Peer-to-peer knowledge exchange among cities
- Inclusive planning and policymaking processes to address thermal inequities

Financial resources

- Enabling environment for private sector investments in urban heat resilience (real estate, construction)
- Resource mobilization using PPPs, TIF, etc.

Embedding Urban Heat Resilience in Planning and Development

Building codes

- Thermal performance standards for building envelope components
- Efficiency criteria for building systems and equipment
- Cool roof requirements
- Cool surface requirements

Streetscape design guidelines

- Recommended species and locations for urban trees and vegetation
- Provisions for shade in seating areas and along walkways
- Seating materials and colors to reduce temperatures

Zoning and land-use regulations

- Building and street orientations to minimize solar exposure
- Incentives for green/blue spaces, such as density bonuses
- Cool/permeable road and surface requirements
- Mixed-use development to increase walkability and use of public transit

Heat poses a growing and inequitable threat to cities in South Asia. Planners and policymakers in the region need to ensure that urban planning and development does not contribute to and is adapted to higher temperatures in the face of climate change and the urban heat island effect. Cities in the region should integrate people and place in managing the acute and chronic impacts of urban heat by better understanding heat risks; garnering the necessary human, technical, and financial resources; and embedding urban heat resilience into planning and development processes.

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