SWELTERING NIGHTS

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Introduction

The Government of National Capital Territory of Delhi (NCT, Delhi) has announced its Heat Wave Action Plan 2023, to build heat resilience during summer. The implementation of this plan is expected to begin after it has been cleared by the National Disaster Management Authority where it is currently pending for consideration.

This plan, while outlining the measures for emergency response and preparedness, also defines the responsibilities of stakeholder departments in the event of a heatwave. This policy intervention assumes significance at a time when heat and temperature trends are expected to worsen due to climate change and growing urbanization.

The relevance of this policy action needs to be understood against the rapidly changing global climate. The technical summary of the Intergovernmental Panel on Climate Change (IPCC), Working Group-I, Sixth Assessment Report (AR6 WG-I), notes that it is almost certain that the frequency and intensity of heat extremes and duration of heat waves have increased since 1950 and this will keep increasing even if global warming is stabilized at 1.5°C.[1] Combining climate change projections with urban growth scenarios, it can be said with very high confidence that future urbanization will amplify the projected increase in local air temperature.

With reference to urban centres, the IPCC Working Group-II, in its assessment (AR6 WG-II), also notes with confidence that hot extremes, including heat waves, have intensified in cities. It further notes that urban areas experience air temperatures that are several degrees warmer than surrounding areas, especially during the night. The urban heat island effect can add 2°C to local warming, reducing the adaptive capacity of cities and increasing the aforementioned risks.[2] This is due to reduced ventilation, heat trapping by closely-spaced tall buildings, heat generated directly from human activities, heat-absorbing properties of concrete and urban building materials, and limited vegetation. Infrastructure related to transportation, water, sanitation, energy and others has been compromised by extreme and slow-onset events, resulting in economic losses and disruption of services, impacting the well-being of people.

This emerging scientific evidence of the adverse impact of rising heat on urban populations builds the case for a city-specific heat management regime and the urgent implementation of heat action plans in cities. Such planning approaches also need to go much deeper than the immediate emergency response to help cope with specific heat events during summer and prevent heat lock-in. This is not only about summer action for public health protection but more sustained action throughout the year to heat proof the city and undertake heat mitigation, along with monitoring, to improve the overall adaptive thermal comfort of built structures and reduce energy and carbon intensity of the built environment.

Such planning and intervention are possible if cities develop a tracking mechanism for annual and diurnal trends in temperature, humidity and the overall heat index to inform planning and implementation. Understanding the trend in heat and humidity patterns over time as well as during the day and night is necessary.

It is often noted that health emergency action considers the high day time temperatures and not the nighttime temperatures and relative humidity. This overall trend poses risks to both public health and the energy security of the city, underlying the need to integrate this consideration into informing the heat action plan. The heat problem is not just about focusing on daily maximum temperatures crossing the 45°C benchmark—the standard focus during summer—but involves a much more complex set of indices.

Urban heat mitigation also requires more robust scientific tracking of key indicators—not just ambient heat and temperature, but also surface heat absorption and land surface temperatures, changing land-use, including vegetative cover and water bodies that are determinants of the heat island effect. This requires effective leveraging of the available satellite technology. Given advancements in technology, such data is available but needs policy integration.

It is equally important to track the various impacts of rising heat in cities. The increasing heat is known to compromise the adaptive thermal comfort of people in cities, raise the demand for active cooling and increase the use of mechanical cooling systems, including air conditioning which is an energy guzzler. This impacts the overall energy demand and energy security of the city and the region. Yet, this dilapidating aspect of heat on the city's natural cooling abilities, including the rising trend in electricity demand to keep cool, is never tracked and considered for the active thermal management of cities.

This deeper conversation has to begin now because Delhi and several other states and cities have started developing their respective heat action plans.

In view of this, the Centre for Science and Environment has carried out this case study of Delhi to analyze the trends in heat, humidity, land surface temperature, as well as electricity demand, to bring out the complex nature of heat management in cities. This detailed analysis of the heat scape of Delhi considers the time frame from the summer of 2001 till today.

This analysis has focused on trends in day and nighttime temperatures, humidity levels, seasonal variations, impact of climatic trends on electricity consumption in the city, heat trends during day and night, trend in land surface temperature and trend in green cover in Delhi. Analyzing these trends have provided deep insight into what is needed to inform the heat management practice in the city.

Methodology and data

The study is based on comparative statistical analysis of temperature and the humidity condition observed in Delhi since 2001. The study's definition of summer is the period from March to August. It is furthered divided into pre-monsoon (March-May) and monsoon (June-August) as per IMD classification. This is based on publicly available datasets from various national and global agencies. Ambient temperature and humidity data have been sourced from Indian Meteorological Department (IMD) weather stations at Palam and Safdarjung. An average of the findings from these two weather stations is used to represent Delhi in this study. Heat Index computation has been done using the U.S. National Oceanic and Atmospheric Administration's (NOAA) formula. Complex geospatial calculations have been done in python and ArcGIS.

Moreover, freely accessible MODIS Land Science data from NASA Earth Observations has been used for seasonal and long-term analysis of land surface temperature. For more granular analysis of heat and land use conditions on extremely hot days, satellite imagery data from the United States Geological Survey (USGS) Earth Explorer website has been used. Landsat 7 Enhanced Thematic Mapper Plus (ETM+) and Landsat 8 operational land imager/thermal infrared sensor (OLI/TIRS) satellite imagery were downloaded and used to analyze the land surface temperature, land use, land cover and Normalized Difference Vegetation Index (Green cover).

This city-level assessment focuses on changes in heat patterns over the years for the summer season, urban expansion over the years, and land surface temperature variation during the summer of 2003, 2013, and 2022. For Delhi, the later analysis is based on 10 May, 2003, 29 May, 2013, 14 May, 2022, and 9 May, 2023.

Likewise, power demand data has been sourced from the real-time data portal of the State Load Dispatch Centre, Delhi.

Key findings

The pattern of heat trend in Delhi is changing, seasonal ambient temperature is stable but the city is getting more humid: Summertime seasonal daily mean ambient temperature has been quite stable since 2011. The 2022 summer was the hottest, with a seasonal average of 31.2°C, while the summer of 2023 has been the least hot with a seasonal average of 28.9°C *(see Graph 1: Trend in summertime seasonal average ambient temperature 2011-2023)*. This was largely influenced by the unseasonal rains during this summer.

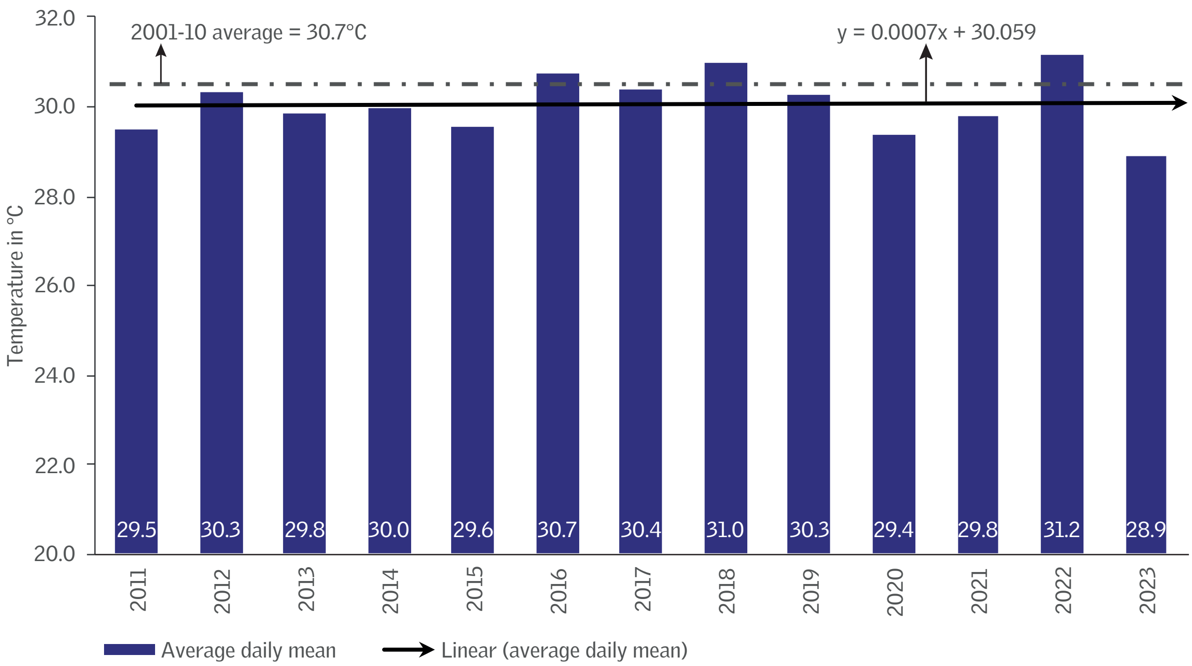
In fact, the decadal average of the last 10 summers is marginally lower than the decadal average for 2001–10. But this doesn't mean Delhi is getting cooler. A change in the pattern of rain, especially unseasonal rains in the pre-monsoon period, has led to an increase in relative humidity which is making the city weather muggier and more uncomfortable despite there being no significant change in ambient temperatures.

Average Relative Humidity (RH) has significantly increased in the last 10 summers compared to the average of 2001–10. This pre-monsoon season the average RH stood at 49.1 per cent which was about 21 per cent more humid than the 2001–10 average. This monsoon season, the average RH stood at 73.2 per cent and it was 14 per cent higher than the 2001–10 average *(see Graph 2: Trend in summertime seasonal relative humidity 2011–2023)*. This rise in the city's humidity compared to its 2001–10 capacity has been observed throughout the study period of this analysis, starting from 2018.

The impact of this increasing humidity on human thermal comfort can be measured via means of Heat Index (HI). According to the U.S. National Weather Service, the heat index is a measure of how hot it really feels when humidity is factored in with the actual temperature. Just like RH, seasonal HI has been a rising trend since 2011 *(see Graph 3: Trend in summertime seasonal average Heat Index 2011–2023)*.

This combination of high heat and humidity can compromise the human body's main cooling mechanism—sweating. The evaporation of sweat from skin cools our bodies. However, higher humidity levels limit this natural cooling mechanism. As a result, people can suffer heat stress and illness, and the consequences can even be fatal even at much lower ambient temperatures. It is considered that a heat index of 41°C is dangerous to human health.

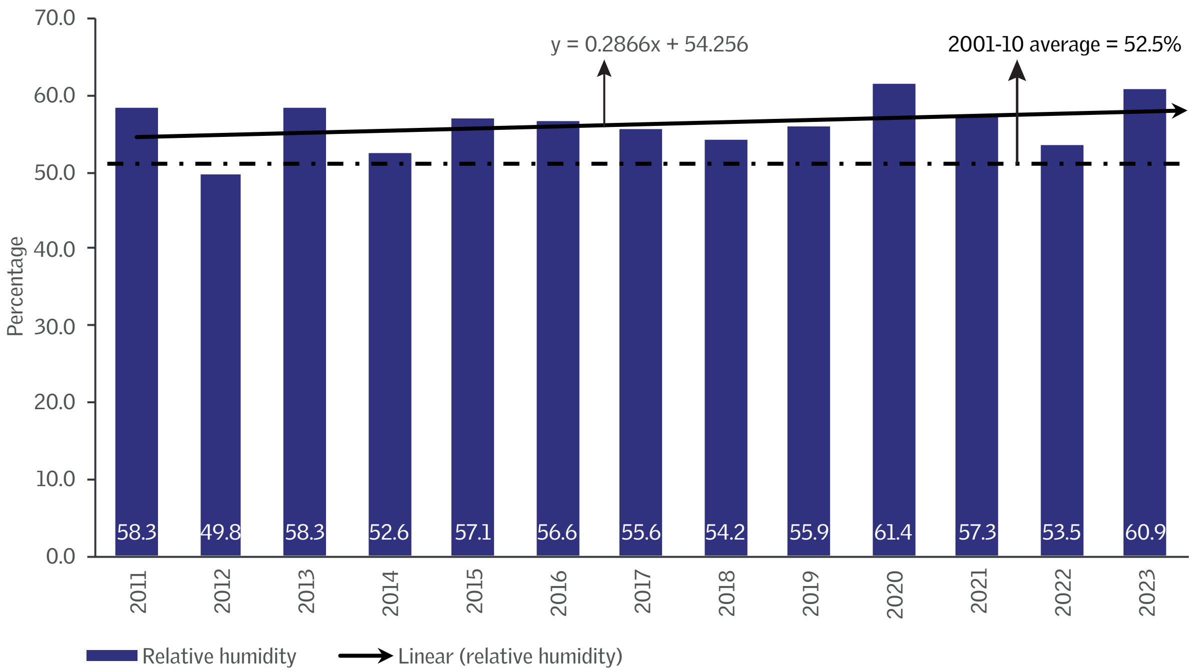
Graph 1: Trend in summertime seasonal average ambient temperature 2011–2023



Note: Summer is defined as the period from March to August. Delhi's weather data is based on the average of the data from two IMD weather stations at Palam and Safdarjung. * Data uptill 30 August, 2023.

Source: CSE analysis of climatological data from IMD

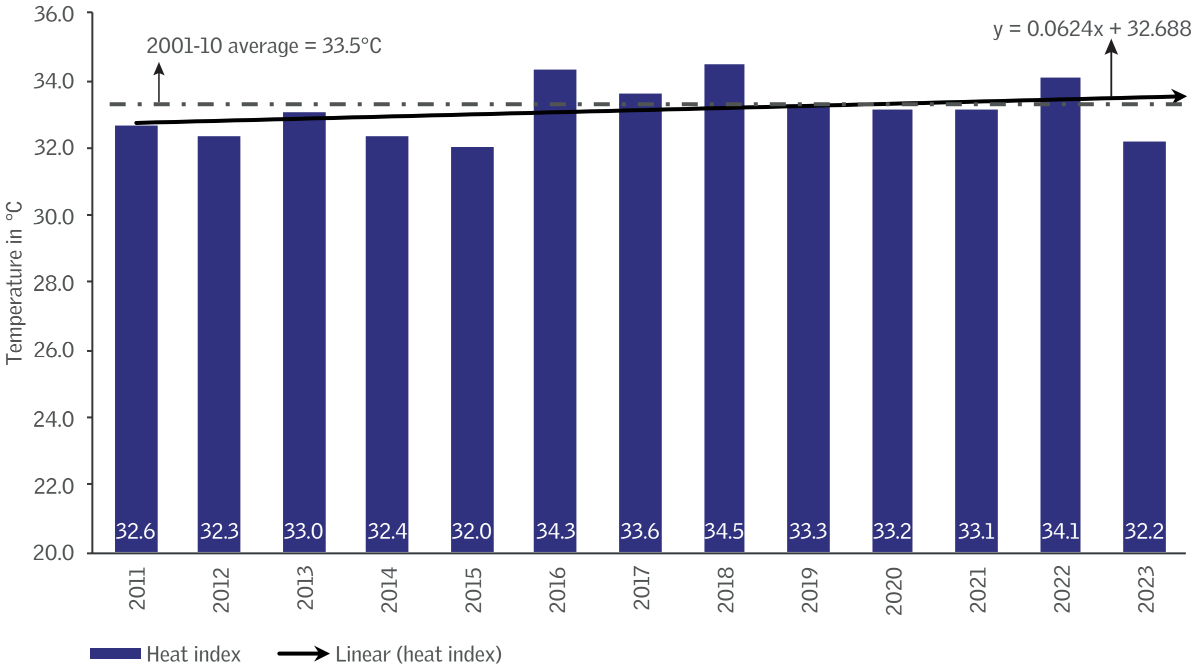
Graph 2: Trend in summertime seasonal relative humidity 2011–2023



Note: Summer is defined as the period from March to August . Delhi's weather data is based on average of the data from two IMD weather stations at Palam and Safdarjung. * Data uptill 30 August, 2023.

Source: CSE analysis of climatological data from IMD

Graph 3: Trend in summertime seasonal average heat index 2011–2023



Note: Summer is defined as the period from March to August. Delhi´s weather data is based on average of the data from two IMD weather stations at Palam and Safdarjung. Heat index has been calculated using th U.S. National Oceanic and Atmospheric Administration formula. * Data uptill 30 August, 2023.

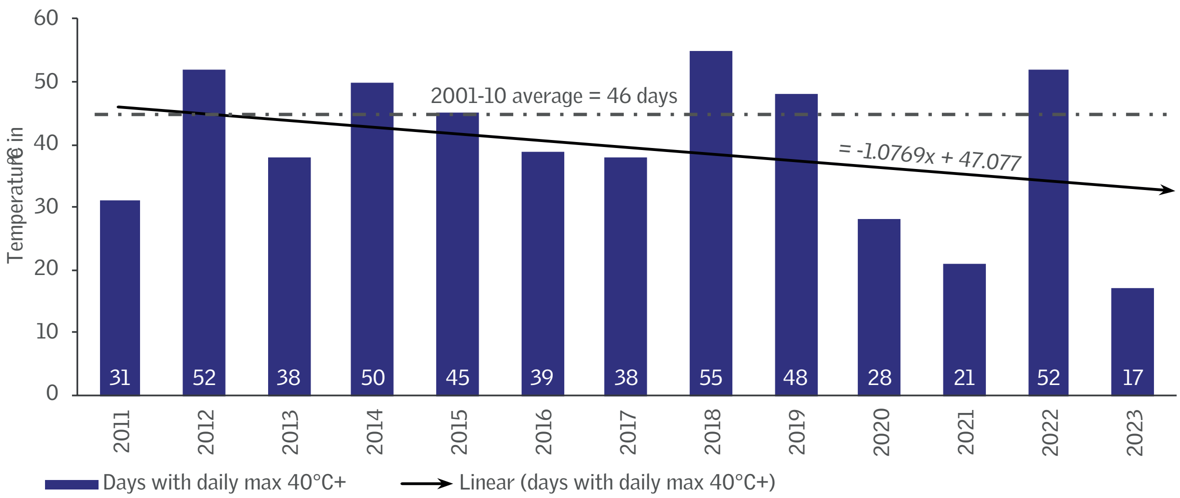
Source: CSE analysis of climatological data from IMD

Number of days with high ambient temperatures are declining but days with dangerously high heat index are on the rise: This year, the daily maximum ambient temperature of Delhi (based on the average of Palam and Safdarjung IMD stations) crossed 40°C threshold for only 17 days. This is less than half of the average of 2001–10 which stands at 46 days (see *Graph 4: Trend in days with 40°C+ daily maximum temperature 2011–2023*). The summers of 2020 and 2021 also registered significantly less days with 40°C+ days compared to the 2001–10 average. The highest number of days with 40°C+ ambient temperature was recorded in 2018 summer (55 days), followed by the summer of 2012 and 2022 (52 days each). Overall, there is a declining trend in the number of days with very high ambient temperatures.

However, only looking at daily maximum temperature figures is not a good measure as the daily average temperature and humidity are critical parameters as well. The human body is worse at handling humid heat than dry heat. If the heat index crosses the 41°C mark it is considered dangerous to human beings. The trend in days with dangerously high heat index is on the rise. This summer there have been

14 days when the daily average heat index crossed the danger threshold of 41°C *(see Graph 5: Trend in days with 41°C+ daily heat index 2011–2023)*. The summer of 2020 had 32 days with HI exceeding 41°C and that has been the maximum in any year for the study period.

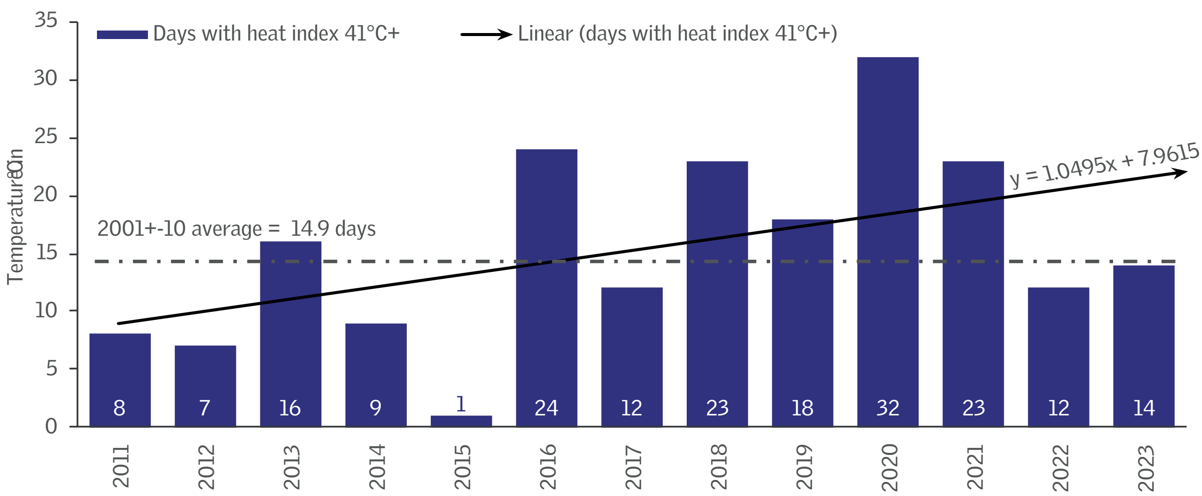
Graph 4: Trend in days with 40°C+ daily maximum temperature 2011–2023



Note: Summer is defined as the period from March to August . Delhi´s weather data is based on average of the data from two IMD weather stations at Palam and Safdarjung. * Data uptill 30 August, 2023.

Source: CSE analysis of climatological data from IMD

Graph 5: Trend in days with 41°C+ daily heat index 2011–2023



Note: Summer is defined as the period from March to August . Delhi´s weather data is based on average of the data from two IMD weather stations at Palam and Safdarjung. Heat index has been calculated using th U.S. National Oceanic and Atmospheric Administration formula. * Data uptill 30 August 2023.

Source: CSE analysis of climatological data from IMD

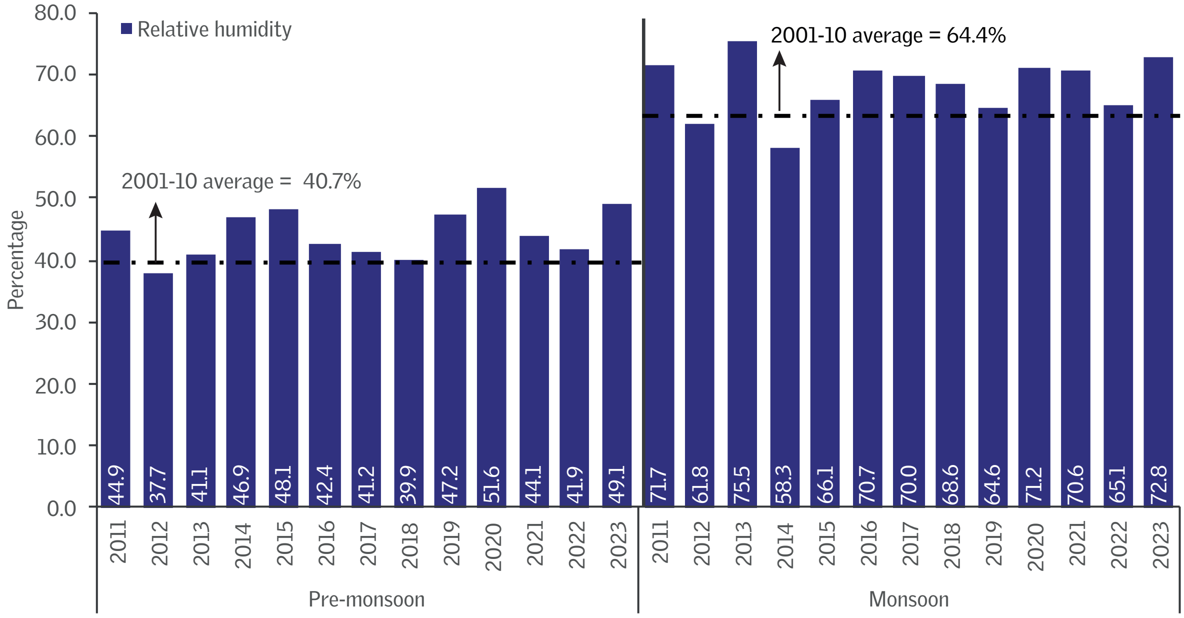
Monsoon is more thermally uncomfortable than the drier pre-monsoon season: Delhi summer can be divided into two distinct periods—pre-monsoon or dry heat period and monsoon or humid heat period. IMD defines the pre-monsoon period as March to May, while the period from June to August is considered as monsoon. Naturally, relative humidity is much lower during pre-monsoon compared to the monsoon period. The study has found that average Relative Humidity (RH) has significantly increased for both pre-monsoon and monsoon periods compared to the 2001–10 average. This pre-monsoon season the average RH stood at 49.1 per cent, which was about 21 per cent more humid than 2001–10 average. This monsoon season the average RH stood at 72.8 per cent and it was 14 per cent higher than the 2001–10 average (see *Graph 6: Trend in pre-monsoon and monsoon relative humidity 2011–2023*).

Increasing humidity has little impact on pre-monsoon heat conditions but it significantly alters the heat index (feels like temperature) during the monsoon period. It adds an additional 5–8°C heat to the ambient temperature. This monsoon it added 6.7°C on average to ambient temperature, which is much higher than the average of 2001–10 monsoons of 5.6°C (see *Graph 7: Trend in impact of relative humidity on the daily ambient air temperature per-monsoon vs monsoon 2011-2023*). This increase in the humidity fundamentally alters the nature of thermal discomfort the people in the city experience and challenges the efficacy of traditional means to keep cool during the season.

The number of days when the daily maximum temperature crossed 40°C mark in the last 10 pre-monsoon periods is down by 26 per cent compared to the 2001–10 average. But during the monsoon it is up by 10 per cent (see *Graph 8: Trend in number dangerously hot days pre-monsoon vs monsoon 2011-2023*). Similarly, the number of days when HI crossed the danger threshold of 41°C in Delhi during monsoon has increased by 19 per cent. There are generally no days during pre-monsoon when the HI crosses the 41°C threshold.

Delhi is not cooling down at night: Hot nights are as dangerous as midday peak temperatures. People get little chance to recover from daytime heat slaughter if temperatures remain high overnight, exerting prolonged stress on the body. A study published in the Lancet Planetary Health by a group of scientists from China, South Korea, Japan, Germany and the U.S., noted that the risk of death from excessively hot nights would increase nearly six-fold.[3] This prediction is much higher than the mortality risk from daily average warming suggested by climate change models.

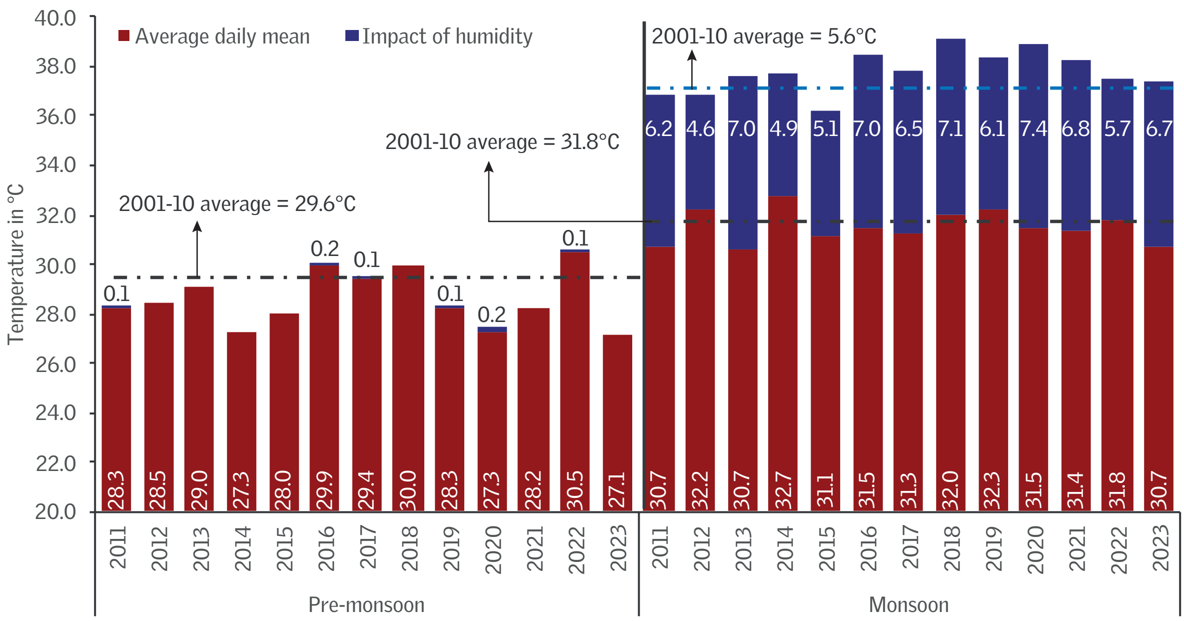
Graph 6: Trend in pre-monsoon and monsoon relative humidity 2011–2023



Note: Pre-monsoon refers to the months of March, April and June. Monsoon falls within June, July and August. Heat index has been calculated using th U.S. National Oceanic and Atmospheric Administration formula. Delhi´s weather data is based on average of the two IMD weather stations at Palam and Safdarjung. * Data uptill 30 August, 2023.

Source: CSE analysis of climatological data from IMD

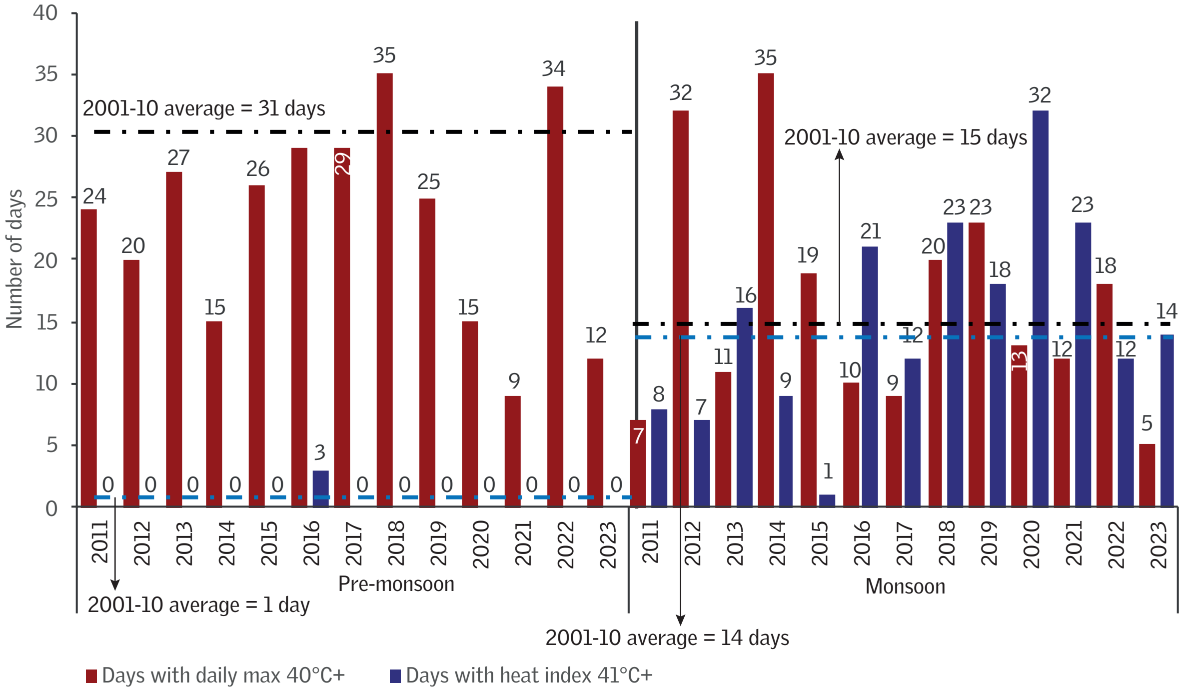
Graph 7: Trend in impact of relative humidity on the daily ambient air temperature; per-monsoon vs monsoon 2011–2023



Note: Pre-monsoon refers to the months of March, April and June. Monsoon falls within June, July and August. Heat index has been calculated using th U.S. National Oceanic and Atmospheric Administration formula. Delhi´s weather data is based on average of the two IMD weather stations at Palam and Safdarjung. * Data uptill 30 August, 2023.

Source: CSE analysis of climatological data from IMD

Graph 8: Trend in the number of dangerously hot days; pre-monsoon vs monsoon 2011–2023



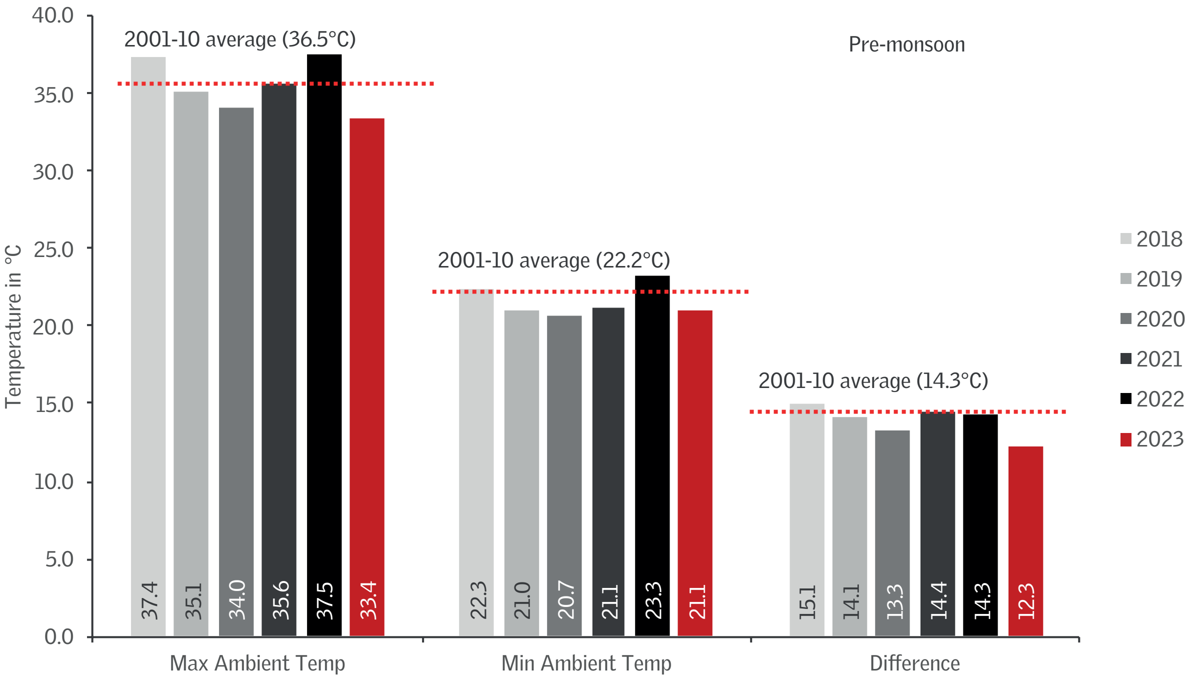
Note: Pre-monsoon refers to the months of March, April and June. Monsoon falls within June, July and August. Heat index has been calculated using th U.S. National Oceanic and Atmospheric Administration formula. Delhi´s weather data is based on average of the two IMD weather stations at Palam and Safdarjung. * Data uptill 30 August, 2023.

Source: CSE analysis of climatological data from IMD

The ambient air temperature used to come down by 14.3°C (on an average) from the daytime peak to nighttime low in pre-monsoon season (March–May) during the 2001–10 period. It only cooled down by 12.3°C this pre-monsoon season *(see Graph 9: Trend in pre-monsoon ambient air temperature 2018-2023)*. The same phenomenon is noted with land surface temperature. During the 2001–10 period, nighttime LST used to be lower than the daytime LST by an average of 15°C. However, it cooled down by just 12.2°C this pre-monsoon season *(see Graph 10: Trend in pre-monsoon land surface temperature 2018–2023)*. This is a 14–19 per cent loss in cooling effect of night on the city this year.

The situation worsened during the monsoon season (June–August). Ambient temperature and LST cooled down by just about 7.5°C each this monsoon compared to the 2001–10 average of 8.5°C and 9.6°C respectively *(see Graph 11: Trend in monsoon ambient air temperature 2018–2023* and *Graph 12: Trend in monsoon land surface temperature 2018–2023)*. It is a 12–21 per cent loss in the city´s daily self-cooling ability.

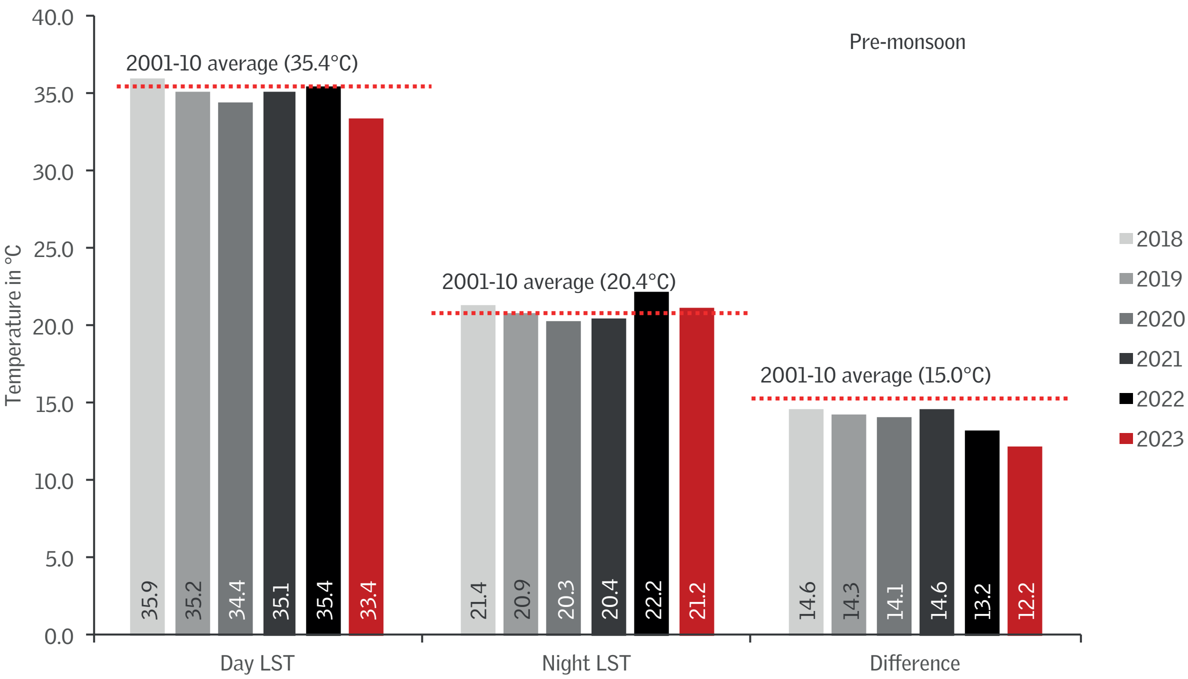
Graph 9: Trend in pre-monsoon ambient air temperature 2018–2023



Note: Pre-monsoon refers to the months of March, April and June. Monsoon falls within June, July and August. Delhi´s weather data is based on average of the two IMD weather stations at Palam and Safdarjung. * Data uptill 30 August, 2023.

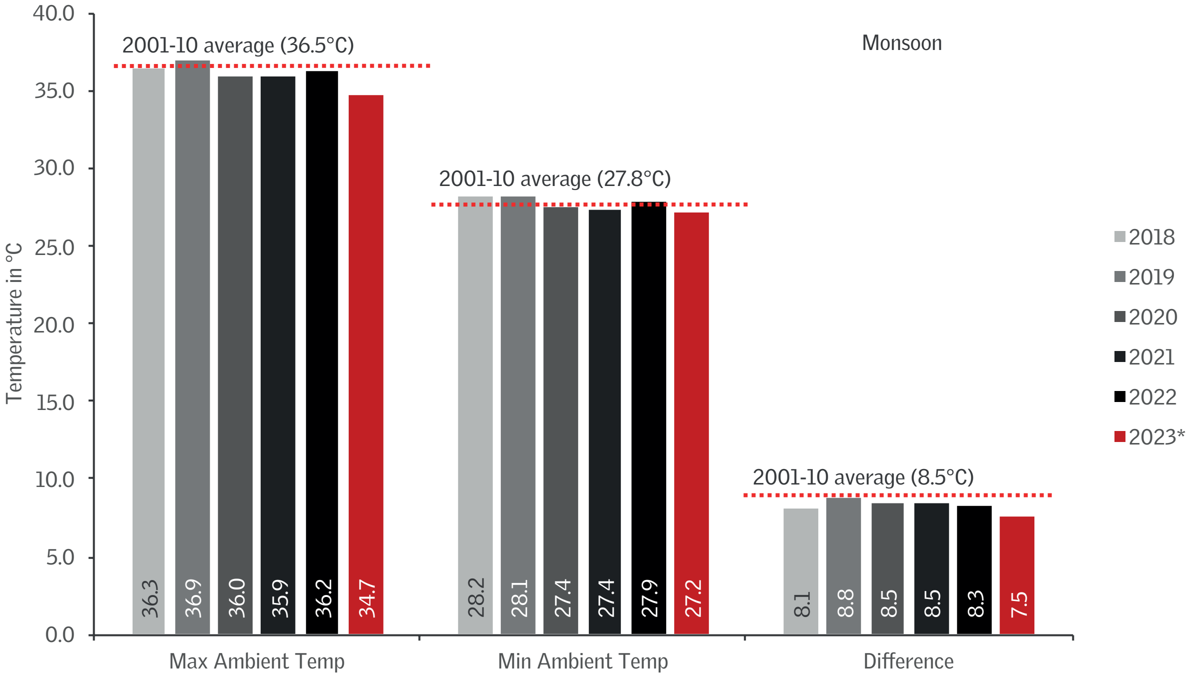
Source: CSE analysis of climatological data from IMD

Graph 10: Trend in pre-monsoon land surface temperature 2018–2023



Note: Pre-monsoon refers to the months of March, April and June. Monsoon falls within June, July and August. * Data uptill 30 August 2023.
Source: CSE analysis of monthly MODIS Land Science data from NASA Earth Observations.

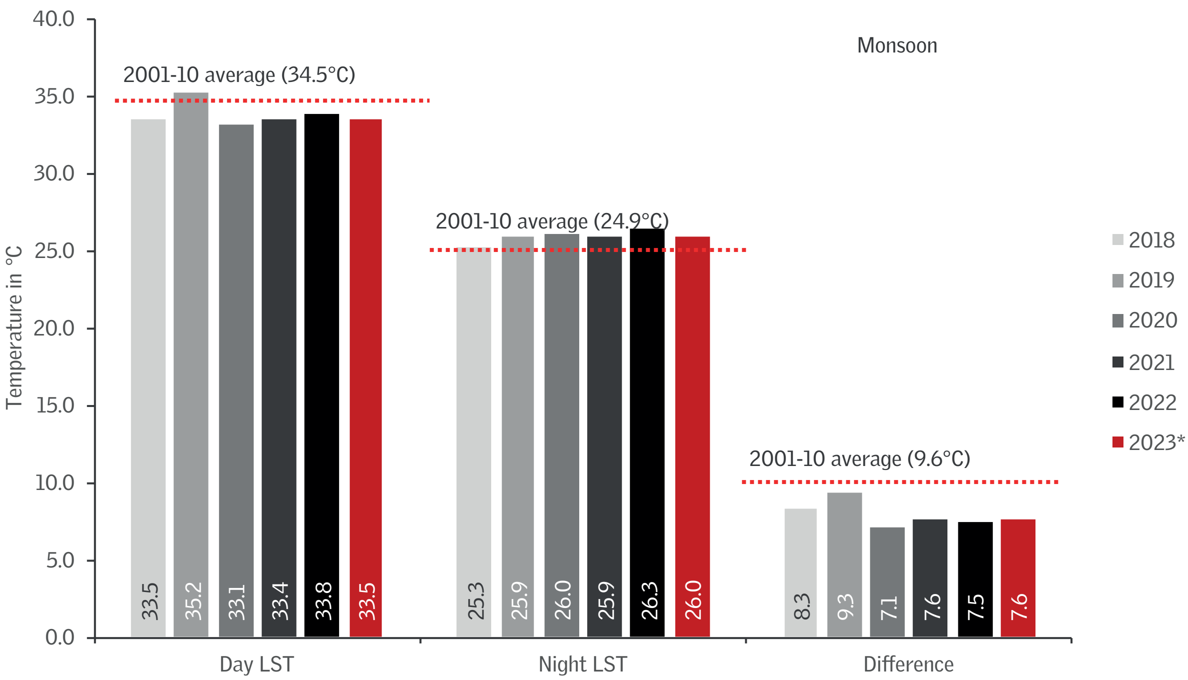
Graph 11: Trend in monsoon ambient air temperature 2018–2023



Note: Pre-monsoon refers to the months of March, April and June. Monsoon falls within June, July and August. Delhi´s weather data is based on average of the two IMD weather stations at Palam and Safdarjung. * Data uptill 30 August 2023.

Source: CSE analysis of climatological data from IMD

Graph 12: Trend in monsoon land surface temperature 2018–2023



Note: Pre-monsoon refers to the months of March, April and June. Monsoon falls within June, July and August. * Data uptill 30 August 2023.

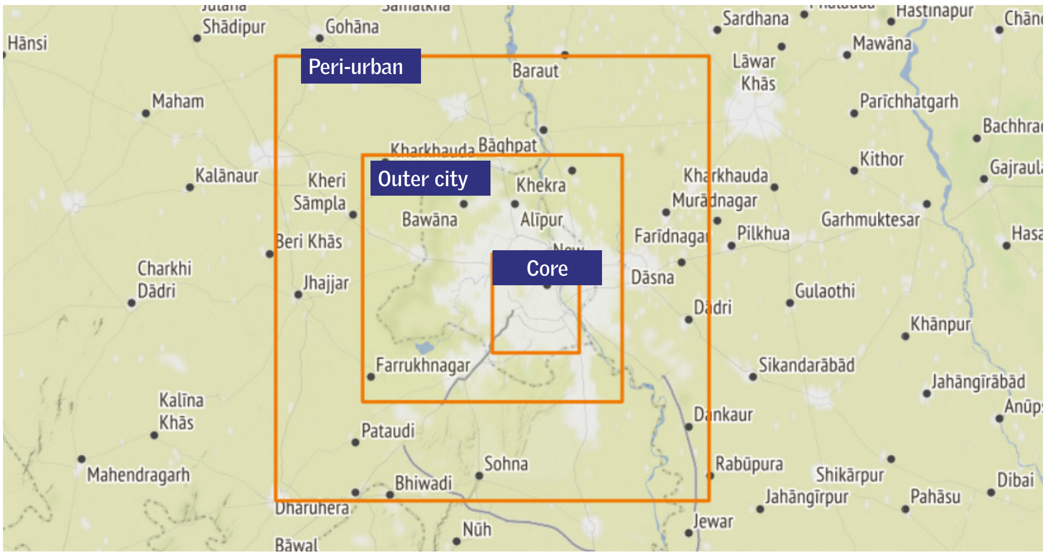
Source: CSE analysis of monthly MODIS Land Science data from NASA Earth Observations.

This lowering in the city's ability to cool down at night compared to its 2001–10 capacity, especially the LST, has been observed throughout the study period of this analysis, starting from 2018.

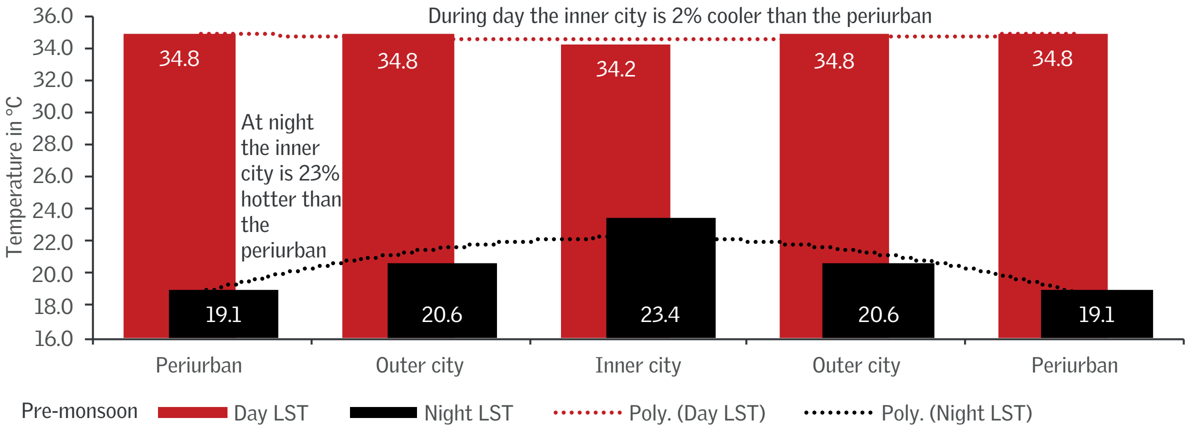
Analysis of Delhi's spatial heatscape shows that its core is not cooling down at night at the same rate as its peri-urban region; high green cover in the city's core has helped keep it cooler during the day but is not helpful in cooling it down at night: During the daytime, the core of Delhi is 0.6–1.1°C cooler than its peripheries and peri-urban areas, both during per-monsoon and monsoon seasons. This is the opposite of the urban heat island effect and quite unique to Delhi *(see Graph 13: Spatial variation in land surface temperature among the core city, outer city and peri-urban region of Delhi; i. Pre-monsoon season 2018-23).* This is possibly due to the high green cover and low built-up density in the core of the city but the actual reasons need to be further investigated and is out of the scope of this analysis.

However, the picture reverses at night and the city core is 2.8–4.3°C hotter during pre-monsoon and 0.9–1.5°C hotter during monsoon *(see Graph 9: Spatial variation in land surface temperature among the core city, outer city and peri-urban region of Delhi; ii. Monsoon season 2018–23).* In other words, at night, the peri-urban area gets cooler by 5°C during pre-monsoon and by 2.5°C during monsoon than the city's core from its daytime peak.

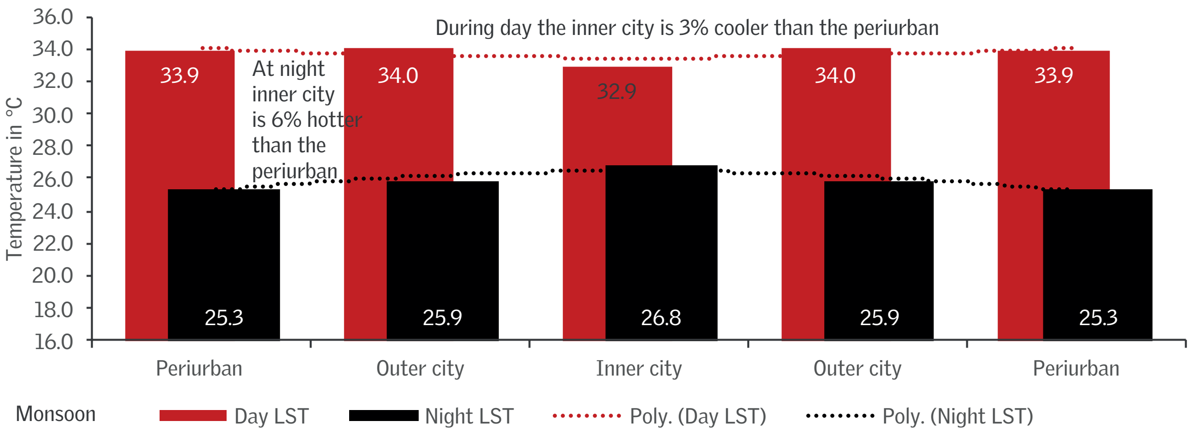
Graph 13: Spatial variation in LST among the core city, outer city and peri-urban region of Delhi



i. Pre-monsoon season 2018–23



ii. Monsoon season 2018–23

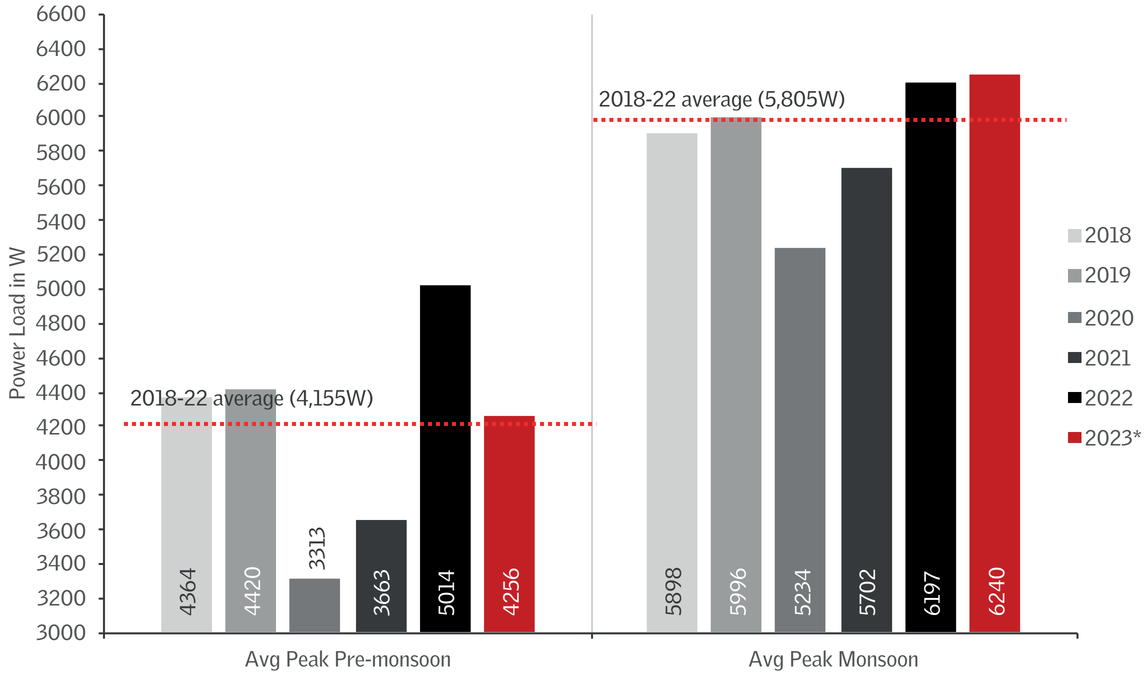


Note: Based on average of 2018, 2019, 2020, 2021, 2022 and 2023 data. Pre-monsoon refers to the months of March, April and June. Monsoon falls within June, July and August. * Data uptill 30 August 2023.

Source: CSE analysis of monthly MODIS Land Science data from NASA Earth Observations.

High heat and humidity is driving up the electricity consumption in the city: Monsoon discomfort is reflected in the city's demand for electricity. On an average, in the last six years, the daily peak electricity demand during monsoon has been over 40 per cent higher than the peak demand during pre-monsoon season. This year the average daily peak demand during monsoon has been 47 per cent or about 2000 kW higher than the pre-monsoon average *(see Graph 14: Trend in pre-monsoon and monsoon average daily peak power demand 2018-2023)*. In fact, the average daily peak demand this monsoon has been the highest since real-time load monitoring started in the city in 2018.

Graph 14: Trend in pre-monsoon and monsoon average daily peak power demand 2018–2023

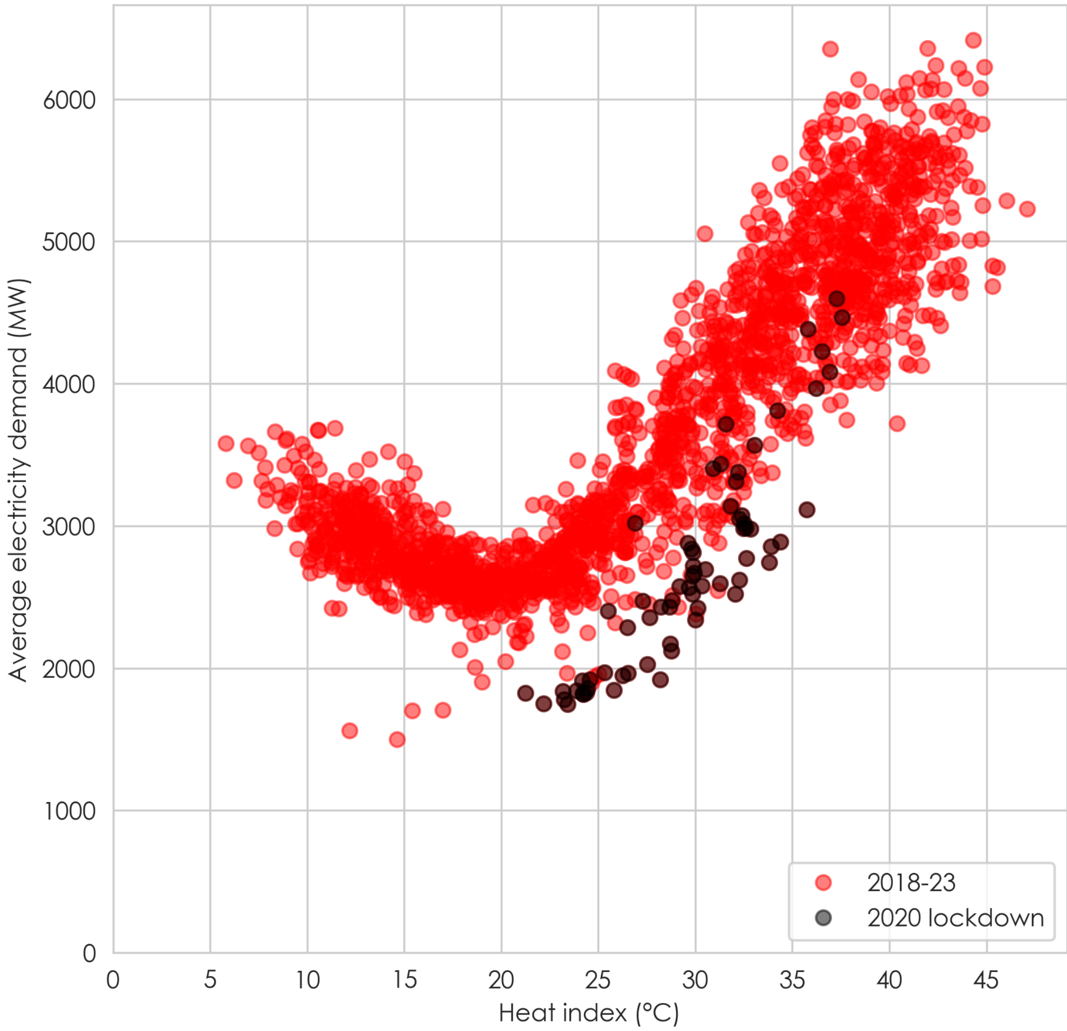


Note: Pre-monsoon refers to the months of March, April and June. Monsoon falls within June, July and August. Morning = 0500hr-1200hr; Afternoon = 1200hr–1700hr; Evening = 1700hr-2100hr; Night = 2100hr-0500hr. * Data uptill 30 August, 2023.

Source: CSE analysis of real-time power demand data from State Load Dispatch Centre, Delhi.

Every one-degree rise in heat index increases city power demand by 140–150 MW: The city's power demand is closely linked to its outdoor temperature and humidity conditions. Power demand is at its minimum when the outdoor heat index is between 17.5–22.5°C (daily mean), which is commonly observed in the months of February and October. The demand for power increases if the heat index increases or decreases from that comfort spot. The demand for power is significantly higher when it gets hotter than when it gets colder *(see Graph 15: Correlation between daily average heat index and average daily power demand 2018-2023)*. Every degree of increase in the heat index beyond 22.5°C adds 140–150 MW to the city's electricity demand. The majority of this additional demand can be attributed to space cooling.

Graph 15: Correlation between daily average heat index and average daily power demand 2018–2023



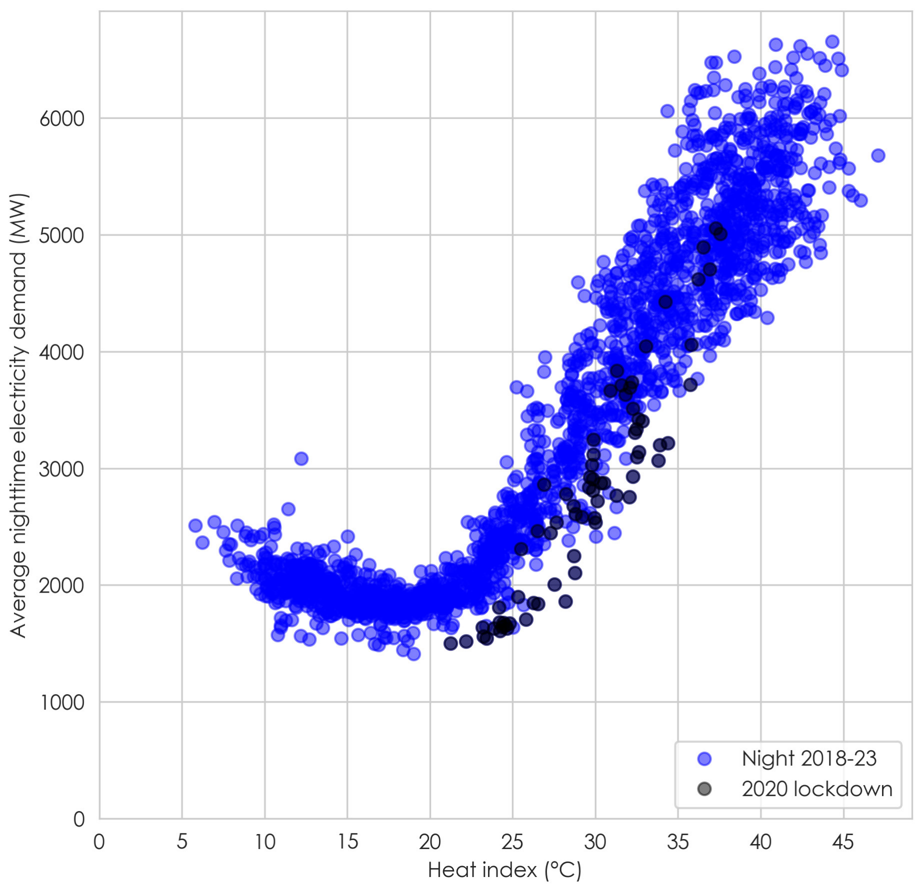
Note: Heat index has been calculated using th U.S. National Oceanic and Atmospheric Administration formula. * Data uptill 30 August 2023.

Source: CSE analysis of real-time power demand data from State Load Dispatch Centre, Delhi and climatological data from IMD

Delhi is consuming more electricity at night due to the changing nature of heat in the city: Nighttime power demand is similar to whole day power demand but has a starker relationship with outdoor temperature and humidity conditions. The nighttime demand increases by a staggering 190–200 MW for every degree of increase in outdoor heat index beyond 22.5°C; almost one-third higher than the day rate *(see Graph 16: Correlation between daily average heat index and average* *night power demand 2018-2023)*. Unlike the whole day demand, nighttime demand does not significantly increase if the heat index drops below the threshold of 17.5°C, implying that people are not using electricity to keep warm during cold nights.

In the last six years the daily peak electricity demand was recorded at night for 194 days and 363 days during pre-monsoon and monsoon seasons respectively *(see Graph 17: Trend in daily peak demand timing during pre-monsoon season 2018-2023)*. In comparison, the daily peak happened in the afternoon only on 118 days and 173 days during pre-monsoon and monsoon seasons respectively *(see Graph 18: Trend in daily peak demand timing during monsoon season 2018-2023)*.

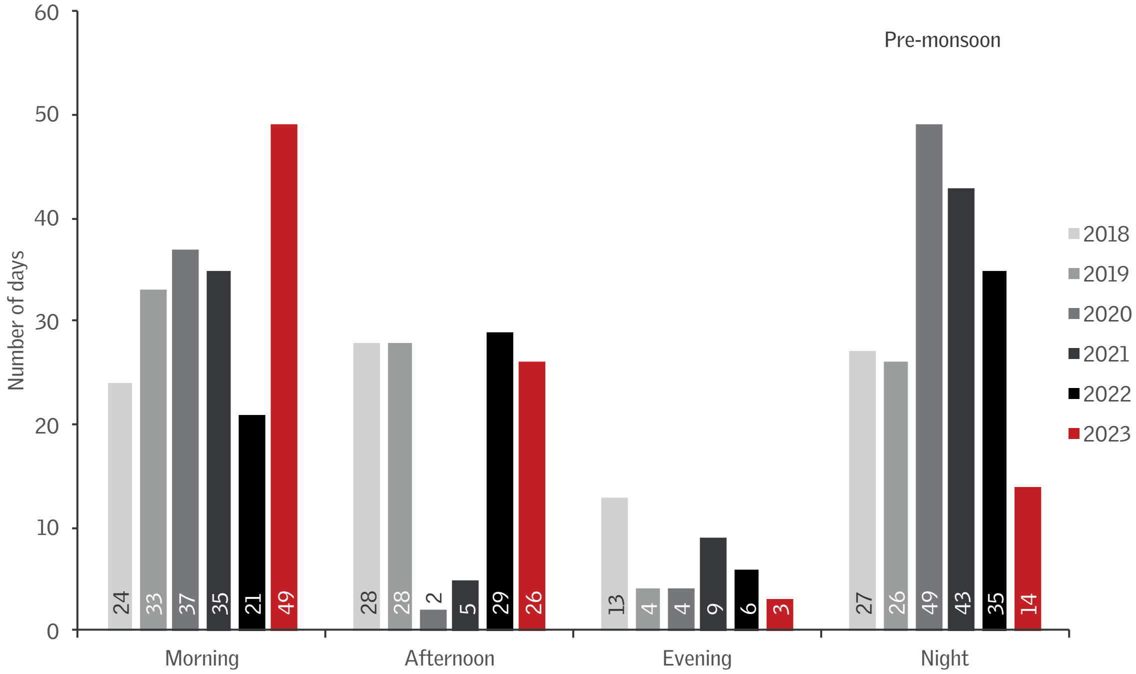
Graph 16: Correlation between daily average heat index and average night power demand, 2018–2023



Note: Heat index has been calculated using th U.S. National Oceanic and Atmospheric Administration formula. Nighttime = 2100hr-0500hr. * Data uptill 30 August 2023.

Source: CSE analysis of real-time power demand data from State Load Dispatch Centre, Delhi and climatological data from IMD

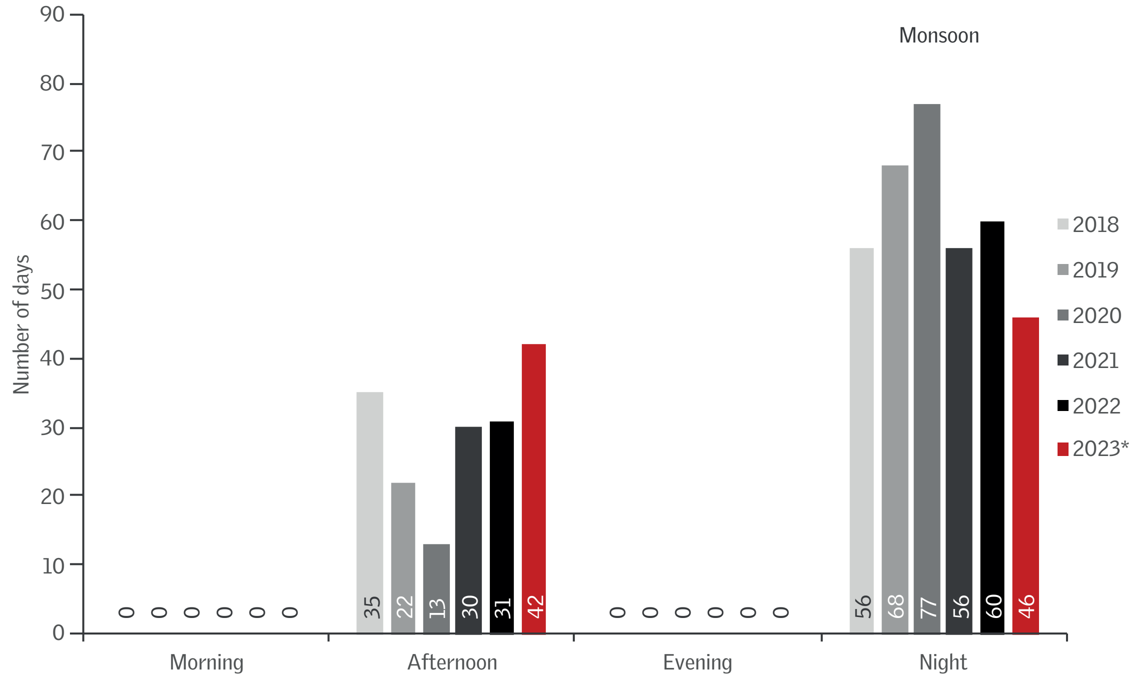
Graph 17: Trend in daily peak demand timing during pre-monsoon season, 2018–2023



Note: Pre-monsoon is defined as March, April and June. Monsoon is defined as June, July and August. Morning = 0500hr-1200hr; Afternoon = 1200hr-1700hr; Evening = 1700hr-2100hr; Night = 2100hr-0500hr. * Data uptill 30 August, 2023.

Source: CSE analysis of real-time power demand data from State Load Dispatch Centre, Delhi.

Graph 18: Trend in daily peak demand timing during monsoon season, 2018–2023



Note: Pre-monsoon is defined as March, April and June. Monsoon is defined as June, July and August. Morning = 0500hr-1200hr; Afternoon = 1200hr-1700hr; Evening = 1700hr-2100hr; Night = 2100hr-0500hr. * Data uptill 30 August, 2023.

Source: CSE analysis of real-time power demand data from State Load Dispatch Centre, Delhi.

Delhi is both greener and more concretized compared to two decades ago: Delhi saw a significant increase in its green cover area, with an expansion from 196 sq. km in 2003 to 359 sq. km in 2022, which depicts a gradual rise in the percentage share of the state's geographical area from 32.6 per cent in 2003 to 44.2 per cent in 2022. The growth in green cover encompassing forests, recreational parks, sparse vegetation, and agriculture, signifies a decline in the land surface temperature in the respective regions *(See Graph 19: Change in land use pattern in Delhi from 2003 to 2013 to 2022 & Map 1: Green Cover of Delhi over three decades 2003, 2013, and 2022)*.

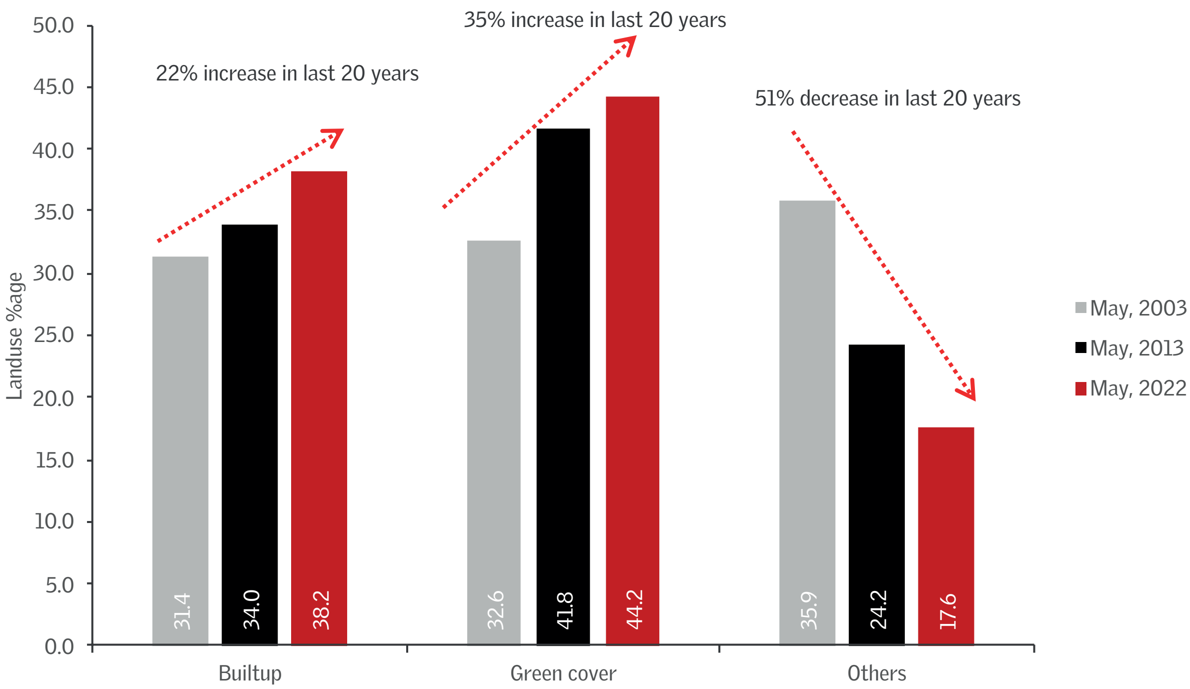
The central part of the city (comprising the northern region of the South, Southeast, and Northeast areas of New Delhi), has a higher proportion of green cover than other regions, which records the lower surface temperature values in the city (30 °C to–38 °C on exceptionally hot days).

On the other hand, over the past three decades, Delhi has experienced significant and rapid urban expansion in all directions, especially in the East, South, Southwest, and Southeast zones. The total heat absorbing built-up area has risen dramatically, from 467.8 sq. km to 568.9 sq. km, during 2003–2022 *(See Map 2: Growth in Urban Built-up in Delhi during 2003, 2013 and 2022).*

Land surface changes have a significant impact on the distribution of land surface temperature. In general, water bodies and green cover tend to have lower surface temperature values, whereas built-up areas, soil, and open bare lands have higher surface temperatures. Delhi shows distinct patterns of land surface temperature and heat island expansion during the years 2003, 2013, and 2012.

In 2003, the central part of Delhi had low temperature, ranging from 30.1°C to 36 °C, while the northern and southwestern suburban areas, covered by rock and new growth settlements, recorded temperatures above 36°C. The middle part of Delhi, which was covered by enough density of vegetation and tree cover, showed moderately lower temperature values. Conversely, densely populated built-up areas in the Southwest, Northwest, North, New Delhi, and Southern parts of Delhi recorded temperatures above 40°C. However, in 2022, there was a dramatic rise in land surface temperature inside the city, exceeding 40°C and covering almost all regions, except the vegetation or green cover area was observed, with temperatures that ranged from 38°C to 40°C—a significant increase from the earlier 30–33°C *(See Map 3: Variation in Land Surface Temperature over Delhi during 2003, 2013 and 2022).*

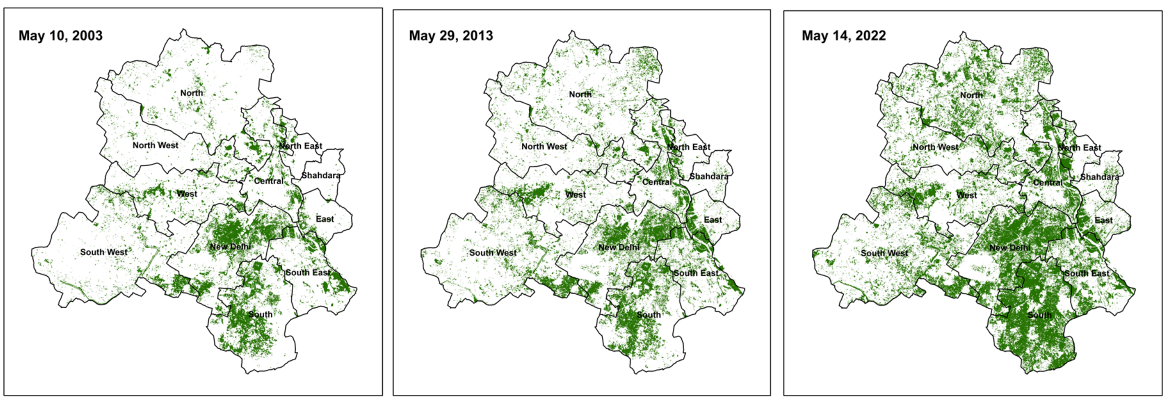
Graph 19: Change in land use pattern in Delhi from 2003 to 2013 to 2022



Note: Summer heat wave months (May-June) are chosen to analyze the Normalized Difference Vegetation Index (NDVI) and urban expansion for each year – 2003, 2013, and 2022.

Source: CSE analysis of Landsat 7 and Landsat 8 satellite images from United States Geological Survey (USGS) Earth Explorer.

Map 1: Green Cover of Delhi over three decades—2003, 2013 and 2022

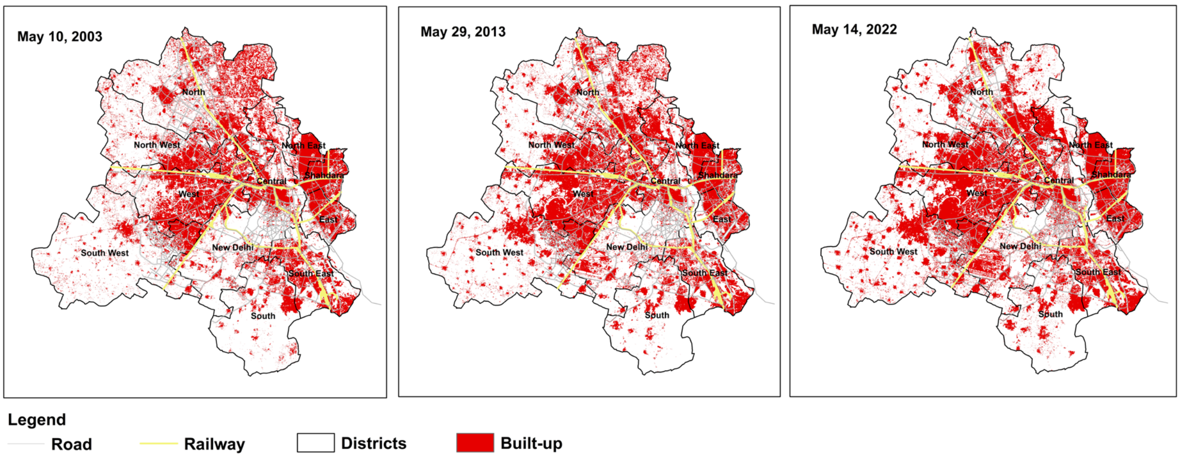


Normalized Difference Vegetation Index (NDVI) is calculated using Band 5 and 4 of Landsat 8 satellite imagery and Band 4 and 3 of Landsat 7 satellite imagery. NDVI values ranges from +1.0 to -1.0. The green cover of the city is calculated using NDVI values greater than 0.2 that includes Sparse vegetation (Shrubs, grasslands or senescing crops), dense vegetation, agriculture and recreation parks.

Note: Summer heat wave months (May-June) are chosen to analyze the Normalized Difference Vegetation Index (NDVI) for each year – 2003, 2013, and 2022.

Source: CSE analysis of Landsat 7 and Landsat 8 satellite images from United States Geological Survey (USGS) Earth Explorer.

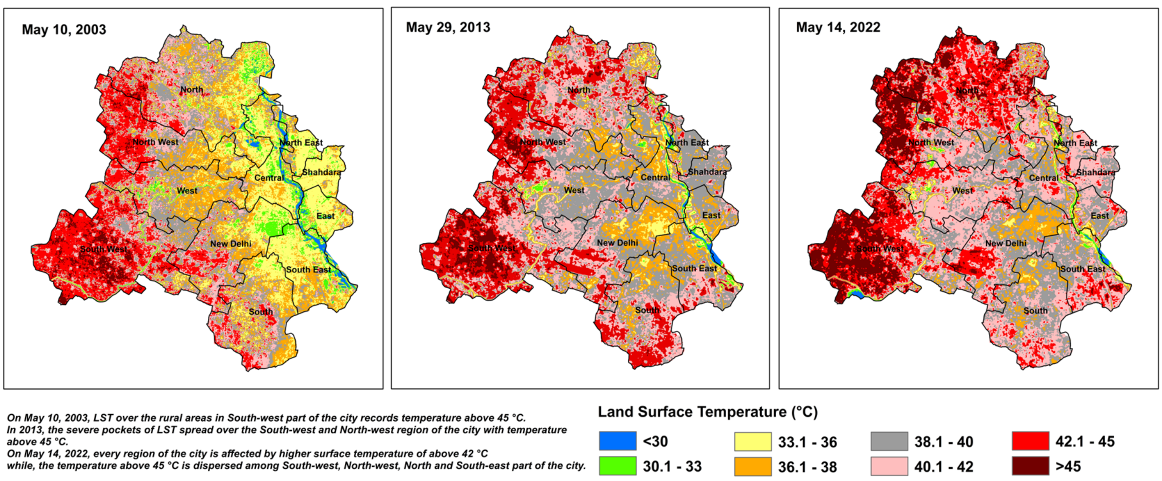
Map 2: Growth in urban built-up in Delhi during 2003, 2013 and 2022



Note: Urban expansion for each year—2003, 2013, and 2022.

Source: CSE analysis of Landsat 7 and Landsat 8 satellite images from United States Geological Survey (USGS) Earth Explorer.

Map 3: Variation in land surface temperature in Delhi during 2003, 2013 and 2022



Note: Summer heat wave months (May-June) are chosen to analyze the Land Surface Temperature (LST). The respective date of acquisition of the images are May 10, 2003, May 29, 2013, and May 14, 2022.

Source: CSE analysis of Landsat 7 and Landsat 8 satellite images from United States Geological Survey (USGS) Earth Explorer.

Way forward

Delh's Heat Wave Action Plan is an emergency plan; needs stronger long-term solutions to mitigate heat: The Delhi government has unveiled the Heat Wave Action Plan which may be implemented next summer, subject to approval from NDMA. The plan has included the measures for emergency response and preparedness as laid out in NDMA's 2019 National Guidelines for Preparation of Action Plan–Prevention and Management of Heat Wave *(see Box: Heat Action Plans (HAPs))*.

It has defined the responsibilities and work of every stakeholder in handling the public health impact of a heatwave. The current plan is focused on protecting people from midday peak ambient temperatures, which is one aspect of heat stress management. On structural aspects, it underscores a cool roof programme for buildings. Most of its implementation strategy has been labelled as "a future recommendation" without providing adequate details on specific strategies for implementation in the short and long-term. The plan does provide funding strategies for the cooling strategy either.

Delhi needs a Heat Resilience Plan that not only provides for emergency health services to victims of heatwaves but also helps to reduce the heat in the city by eliminating waste heat accumulation. The scope of the plan requires expansion to include more comprehensive long-term measures for heat management. Address all heat generators in the action plan.

Heat-proof cities: At a city scale, make inventories of water bodies and existing and potential green areas (district/city forests, riverine stretches, parks and other green areas) for protection and augmentation. New development must require adherence to a minimum level of greening requirements per hectare of development as well as vertical greening. It also needs to:

i) rationalize clustering of buildings and layout for climate proofing.
ii) reduce traffic volume by improving accessibility, connectivity, non-motorized transport, and fleet electrification.
iii) address location of industries and use of waste heat.
iv) cool down concrete with shading and cool surfaces.

Each of these strategies require detailed roadmap, timeline and mandate for implementation.

Cool down buildings to improve adaptive thermal comfort: Implement the thermal comfort requirements outlined in India's Cooling Action Plan. A binding mandate to enable the widespread adoption of passive architectural measures is needed, including features such as day lighting, ventilation, orientation, shading, and appropriate material for improving thermal comfort. Hours of air-conditioner usage should be reduced, along with electricity consumption, and protecting public health should be prioritized. This is essential to address the additional stress due to rising humidity and nighttime temperatures in the city. Such interventions need detailed strategies and targets for new buildings, as well as for the retrofitment of existing buildings.

Institutionalize data analytics and science for tracking climatic and meteorological variables for heat management.

Improve citizen's access to climate data, early warning systems and awareness to build support for wide-ranging interventions.

HEAT ACTION PLANS IN CITIES/STATES

The National Guidelines for Preparation of Action Plan–Prevention and Management of Heat Wave was published in October 2019 by National Disaster Management Authority (NDMA) to inform state-and city-level heat action plans (HAP). So far, 15 states have already formally published their Heat Action Plan (HAP), and Delhi has recently submitted its plan to NDMA for approval. The plan may come into effect next year. All the plans are linked to IMDs heatwave forecasting system and completely rely on it for activating any kind of heat alert or warming.

A rapid review of all the plans show the basic features of HAP as:

i) defining the institutional mechanism
ii) setting the roles and responsibilities of stakeholders (government departments/civil societies/ other organizations)
iii) outlining mitigation measures

All state HAPs are near identical in their design of institutional mechanisms and roles and responsibilities of stakeholders. The mitigation measures are also similar with some minor deviation in the stringency of proposed actions. For instance, most HAPs advice the education department to revise school timings in the event of a heatwave but Delhi plan instructs its education department to "ensure schools do not function during peak hours (12 noon–4pm) when a heat wave is declared."

Similarly, the advisory to industries to restrict working hours for outdoor labour varies significantly. For instance, Haryana plans to issue "directives for flexible working hours to restrict heat exposure", while Delhi and Telangana plan to "encourage employers to shift outdoor workers' schedules away from peak afternoon hours." Bihar HAP has no mitigation measures listed for general labour but has clearly instructed its rural development department that no MGNREGA work will be scheduled between 11.30 am to 3.30 pm during a heatwave alert.

Funding is another grey area as most HAPs have not indicated how the actions listed in the plans will be funded. CSE has reviewed 8 HAPs (Delhi, Haryana, Bihar, Uttar Pradesh, Andhra Pradesh, Karnataka, Telengana and Himachal Pradesh) but only Haryana and Telangana have detailed the funding mechanism for their plans.

Key short-term / emergency measures in HAPs

- Issue a sate/district wide heat alert when extreme heat events are forecasted by the IMD. Display posters and distribute pamphlets on the prevention of heat-related illnesses.

- Keep adequate stocks and ensure availability of medical supplies like ORS in all hospitals/ PHCS/UHCs. Deploy additional staff in hospitals and PHCs/UHCs to attend to the influx of patients during a heat alert. Ensure the availability of ambulances for emergency purposes.

- Build and activate cooling centers, such as temples, public buildings, malls etc., during a heat alert.

- Provide access to shaded areas for outdoor workers, slum communities and other vulnerable populations at a large scale. For example, keep parks and night shelters open all day during a heat alert.

- Hold regular (daily, if necessary) conferences to discuss reports and fresh developments during a heat alert and ensure that communication channels are functional and operating.

- All non-essential uses of water (other than drinking, keeping cool) may be suspended.

- Increase efforts to distribute fresh drinking water to the public by opening "Piaau" or "water ATMs".

- Inform power supply companies to prioritize maintaining power in critical facilities (such as hospitals and dispensaries).

- Availability of water, ORS and cool/shaded space in open construction sites, bus stands and other public places during processions and political and other rallies during summer.

- Restrict school hours and prohibit open-air classes when a heat wave is declared.

- Encourage employers to shift outdoor workers' schedules away from peak afternoon hours during a heat alert.

- Ensure that public buses do not run during peak hours when a heat wave is declared. If necessary, only AC buses should operate.

Key long-term measures in HAPs

- Heat alerts, emergency response plans and delineation of high-risk areas need to target vulnerable groups. This should also be incorporated in the City Development Plan.

- Insulation in buildings should be increased and building standards raised alongside improving building bye-laws. The heat tolerance in new infrastructure should also be increased and existing building should be retrofitted accordingly. Building bye-laws can have components of passive ventilation and cool roof technologies to increase thermal comfort and these should be made mandatory in more vulnerable areas.

- Identifying locations for building shelters and shades in urban areas. Shelter locations for the urban poor and slum dwellers must be identified and constructed.

- Incorporation and documentation of indigenous knowledge to develop protective measures at the regional and community level to generate awareness and sensitize people. Local culture and physical exposure of populations to warmer climate conditions need to be improvised to reduce the impact of heat on health and physical wellbeing.

- Capacity building at the community level, through awareness campaigns and outreach programmes. The risks associated with heat and its impact on health, livelihood and productivity, and ways to mitigate these impacts should be clearly communicated.

- Research on micro-climate should be initiated and the need to monitor temperatures in urban areas corroborated. There should be policy-level intervention to retrieve natural eco-systems and natural shelters.

- Greening infrastructure by installing vertical and roof gardens can be an effective method to cope with heat.

- Initiating early warning systems, advisories and alerts on extreme heat for communities and urban local bodies (ULB). Building communication networks through local bodies, health officers, healthcare centers, hospitals, communities and media.

- Encouraging investing in water bodies, installing fountains in areas of mass presence and promoting greeneries in urban areas along with improving green transport and energy systems.

- Other strategies such as promoting green/heat resilient infrastructure, improving urban planning to enhance natural shading and developing green spacing, energy efficient practice etc. will also be included to reduce heat impacts.

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Indian summers are increasingly becoming unbearable due to climate change-induced heatwaves. Many states and cities have published heat action plans to safeguard their populations from dangerous heat exposures. But these well-intentioned plans are blind to the changing nature of heat in our cities. CSE has carried out a detailed analysis of heat stress in Delhi and its impact on human behaviour vis-a-vis electricity consumption to understand how things have changed since 2001. Analysis shows that, apart from daytime peak temperature, increasing humidity and nighttime temperatures are also the driving factors of heat discomfort in the city.

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