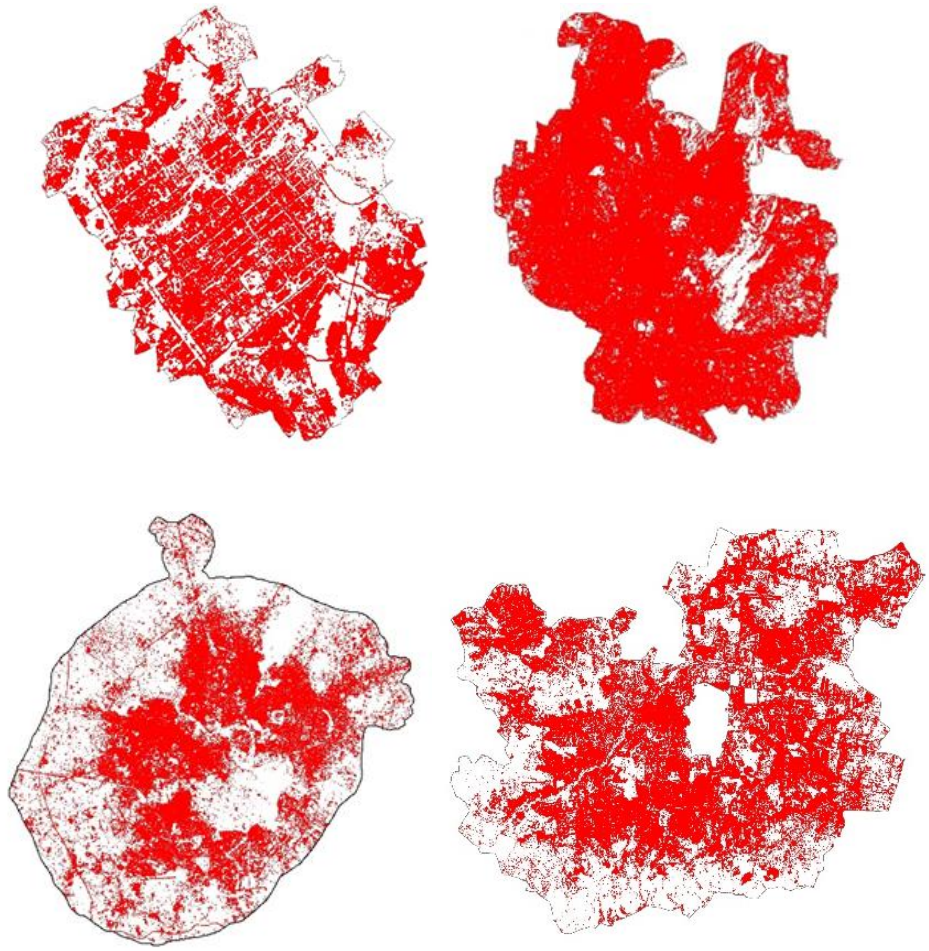
Urban Heat Stress Tracker



Smaller cities

Chandigarh, Jaipur, Lucknow and Pune

Research direction: Anumita Roychowdhury

Authors: Sharanjeet Kaur and Avikal Somvanshi

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41, Tughlakabad Institutional Area
New Delhi 110 062
Phones: 91-11-40616000
Fax: 91-11-29955879
E-mail: sales@cseinida.org
Website: www.cseindia.org

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Overview

Heatwaves have become a staple of Indian summer due to the climate change. No region of the country is immune to this worsening phenomenon. States and cities are publishing their heat action plans to safeguard their populations from the dangerous heat exposures during heatwaves. These plans, while outlining the measures for emergency response and preparedness, also define the responsibilities of stakeholder departments in the event of a heatwave. These policy interventions assume significance at a time when heat and temperature trends are expected to worsen due to climate change and growing urbanization.

The relevance of these policy actions need 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 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 daytime 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 to 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 the cities. The increasing heat is known to compromise the adaptive thermal comfort of people in cities and increase the demand for active cooling and 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 a 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 select metro cities of India to analyse the trends in heat, humidity, land surface temperature and change in land use patterns to bring out the complex nature of heat management in cities. This detailed analysis of the heat scape of four smaller metro cities namely Chandigarh, Jaipur, Lucknow and Pune considers the time frame from 2001 to 2023.

This analysis has focused on the trends in day and night time temperature, humidity levels, seasonal variations, heat trends during day and night, trend in land surface temperature and trend in built-up area in the six megacities. Analysing 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 further 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 analyse the land surface temperature, land use, land cover and Normalized Difference Vegetation Index (Green cover).

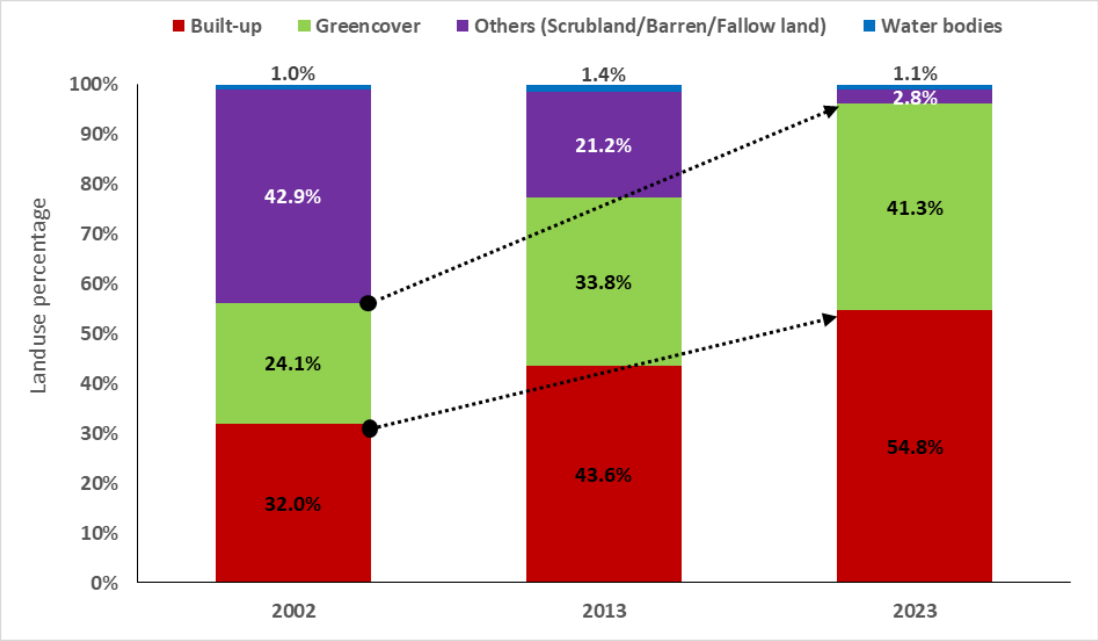
This city-level assessment focuses on changes in heat patterns over the years for the summer season, urban expansion over the years, and land surface temperature variation during the summer of 2003, 2013, and 2022.

Key findings

Chandigarh

Chandigarh has become more concertized in the last two decades, contributing to a rise in urban heat stress: Built-up area increased from 32 per cent in 2003 to 54.8 per cent in 2023. Despite the increase in the Green cover from 24.1 per cent in 2003 to 41.3 per cent in 2023, the city records the maximum surface temperature at 48.5 °C (See *Graph 1: Change in land use pattern in Chandigarh in last two decades*).

Graph 1: Change in land use pattern in Chandigarh in the last two decades



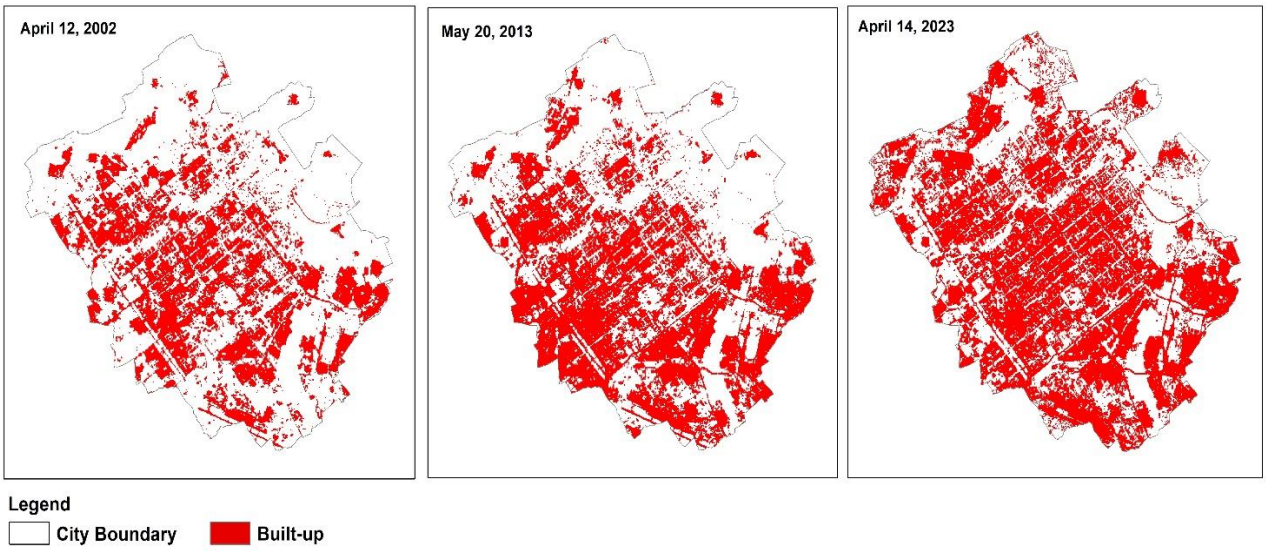
Note: Summer heat wave months (April-June) are chosen to analyse the Normalized Difference Vegetation Index (NDVI) and urban expansion for each year.
Source: CSE analysis of Landsat 7 and Landsat 8 satellite images from United States Geological Survey (USGS) Earth Explorer.

Land Use pattern change analysis: Chandigarh saw an increase in its built-up area, with an expansion from 36.6 sq. km in 2002 to 62.8 sq. km in 2023, which depicts a gradual rise in the percentage share of the city's geographical area from 32 per cent in 2002 to 54.8 per cent in 2023 (See *Map 1: Growth in Urban Built-up in Chandigarh during 2002, 2013, and 2023*). Significant and rapid urban expansion has happened especially in the city's Northwest and North East zone.

Impact of land surface changes on the distribution of land surface temperature: In 2002, the average LST of Chandigarh was 33.3 °C. The built-up area near the Chandigarh railway Station, Chandigarh Bus Stand, and Chandigarh Airport experienced much higher temperatures of 38°C-40°C. Additionally, areas along the Evening vegetable market in the southern region of the city also recorded surface temperatures above 40°C. On an extremely hot day (April 12, 2002), the highest land surface temperature at a scorching 41.5 °C was observed in the Southern part of the city. Water bodies such as Sukhna Lake and areas with dense green cover showed temperatures as low as 22.2 °C even on an extreme heat day. In 2023, the average LST of Chandigarh was 39.4 °C. The year 2023 resulted in more scorching temperatures with the maximum surface temperature recorded at 48.8 °C. On an extreme heat day (April 14, 2023), the highest temperatures were recorded in and around the Dadru Majra Garbage Dump and Landfill area in the northern part of the city where LST reached 48 °C. The

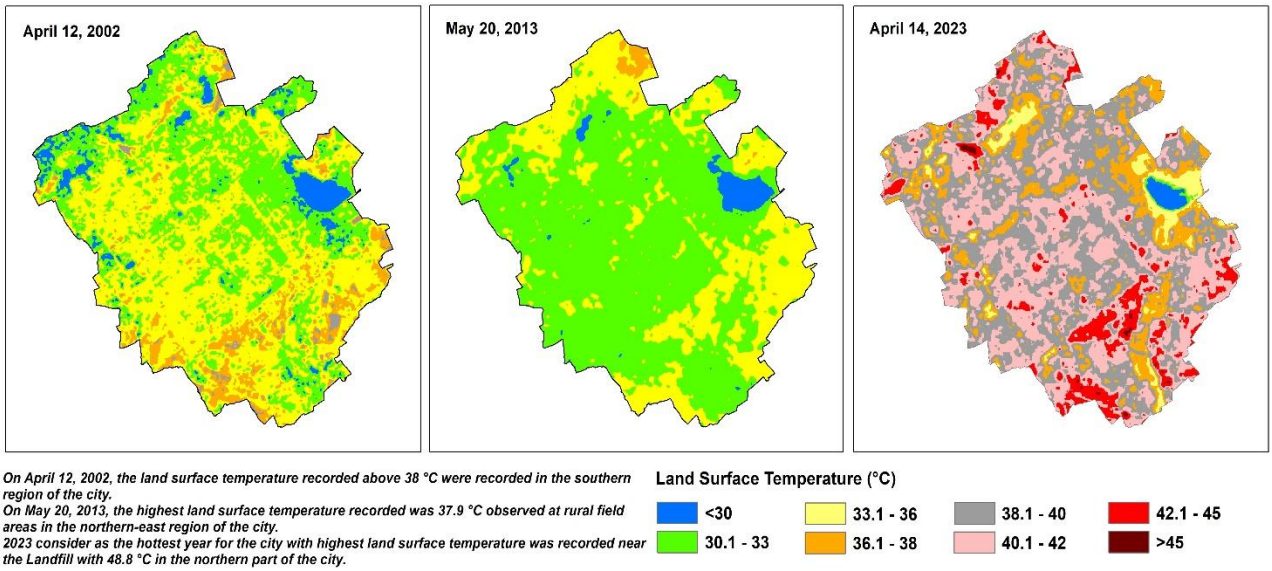
city records a temperature above 36 °C and the area especially around the Air Force School, Passport Seva Kendra, and ITBP campus in the city's southern regions was exceptionally hot with surface temperatures exceeding 42°C. The lowest temperature was recorded over water bodies and areas with dense green cover and it stood at 27.3 °C (See *Map 2: Variation in Land Surface Temperature over Chandigarh for 2002, 2013, and 2023*).

Map 1: Growth in Urban Built-up in Chandigarh during 2002, 2013, and 2023



Note: Urban expansion for each year – 2002, 2013, and 2023. The red colour depicts the urban growth in the city.
Source: CSE analysis of Landsat 7 and Landsat 8 satellite images from United States Geological Survey (USGS) Earth Explorer.

Map 2: Variation in Land Surface Temperature over Chandigarh for 2002, 2013, and 2023

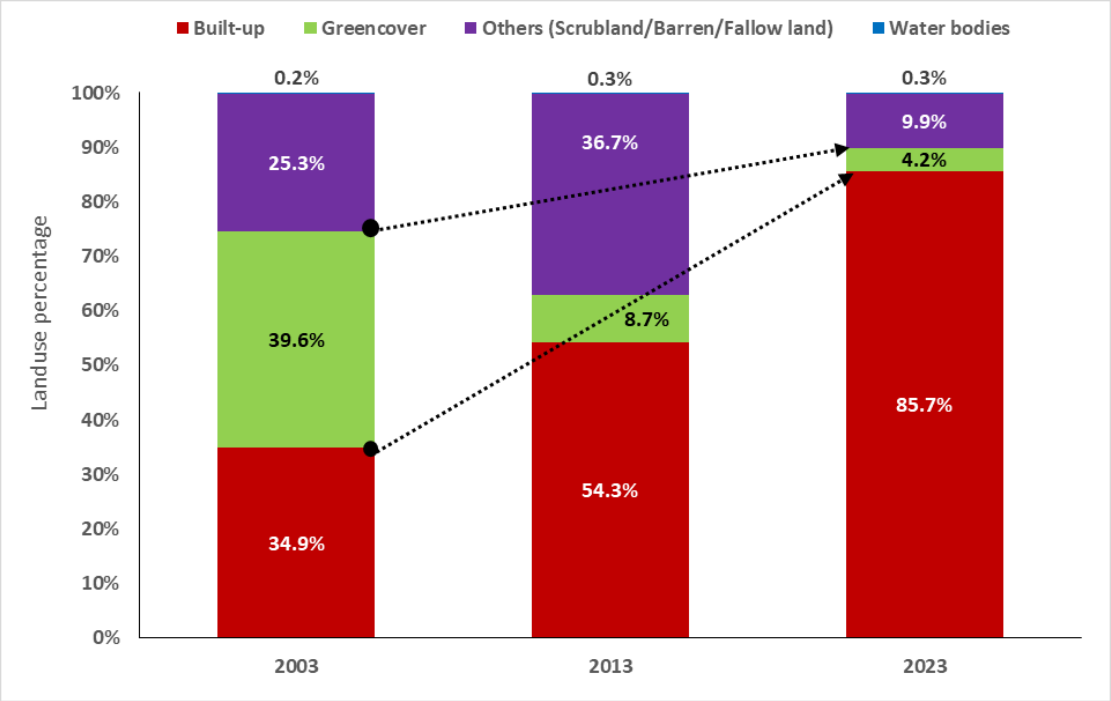


Note: Summer heat wave months (April-May) are chosen to analyse the Land Surface Temperature (LST). The respective dates of acquisition of the images are April 12, 2002, May 20, 2013, and April 14, 2023.
Source: CSE analysis of Landsat 7 and Landsat 8 satellite images from United States Geological Survey (USGS) Earth Explorer.

Jaipur

Jaipur has become more concertized in the last two decades, contributing to a rise in urban heat stress: Built-up area increased from 34.9 per cent in 2003 to 85.7 per cent in 2023. Green cover has drastically declined from 39.6 per cent in 2003 to 4.2 per cent in 2023 (See *Graph 2: Change in land use pattern in Jaipur in last two decades*).

Graph 2: Change in land use pattern in Jaipur in the last two decades



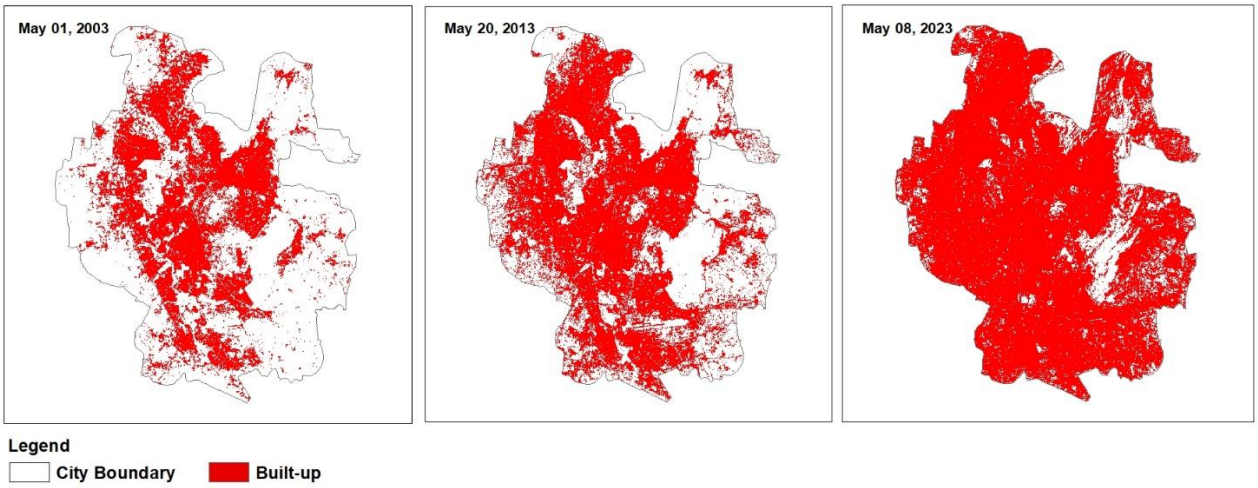
Note: Summer heat wave months (April-June) are chosen to analyse the Normalized Difference Vegetation Index (NDVI) and urban expansion for each year.
Source: CSE analysis of Landsat 7 and Landsat 8 satellite images from United States Geological Survey (USGS) Earth Explorer.

Land Use pattern change analysis: Jaipur saw an increase in its built-up area, with an expansion from 131.3 sq. km in 2003 to 322.02 sq. km in 2023, which depicts a gradual rise in the percentage share of the city's geographical area from 34.9 per cent in 2003 to 85.7 per cent in 2023 (See *Map 3: Growth in Urban Built-up in Jaipur during 2003, 2013 and 2023*). Significant and rapid urban expansion has happened across the city.

Impact of land surface changes on the distribution of land surface temperature: 2013 recorded the highest surface temperature because of the barren land and scrubland which absorbs the direct sun rays, resulting in more scorching temperatures. In 2013, the average LST of Jaipur was 45.2 °C. The densely built-up area near the Ballupura Sand Park and Sylvan Biodiversity Park in the South-east region, as well as open barren land in the Northwest region, experienced much higher temperatures above 50 °C. Additionally, areas along the outer periphery of the city also recorded surface temperatures above 45°C. On an extremely hot day (May 01, 2003), the highest land surface temperature at a scorching 45 °C was observed near Sylvan Biodiversity Forest in the eastern part of the city and isolated patches near the Jaipur National University in the southern region of the city. Water bodies and areas with dense green cover showed temperatures as low as 25.9 °C even on an extreme heat day. In 2023, the average LST of Jaipur was 40.1 °C. On an extreme heat day (May 08, 2023), the highest temperatures were recorded at Ballupura Sand Park in the southeast region and Nahargarh Sanctuary in the northern region of the city where LST reached above 48 °C. The farmland in the western regions of the city especially around JNU Main Campus, Tilak Hospital, and the areas around Jaipur

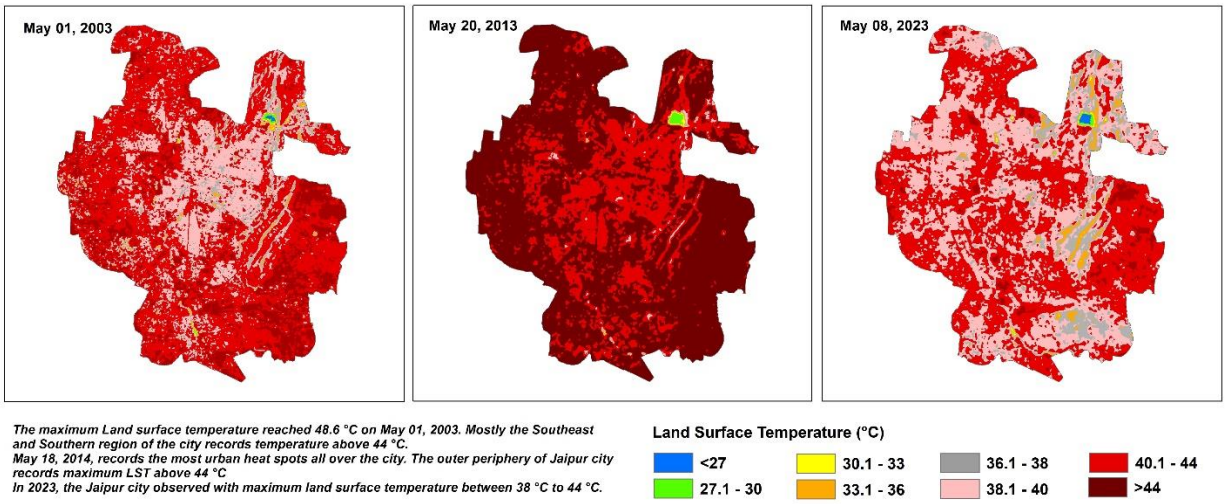
International Airport in the southern part of the city was exceptionally hot with surface temperatures exceeding 42-45 °C. The lowest temperature was recorded over water bodies and areas with dense green cover and it stood at 26 °C (See *Map 4: Variation in Land Surface Temperature over Jaipur for 2003, 2013, and 2023*).

Map 3: Growth in Urban Built-up in Jaipur during 2003, 2013, and 2023



Note: Urban expansion for each year – 2003, 2013, and 2023. The red colour depicts the urban growth in the city.
Source: CSE analysis of Landsat 7 and Landsat 8 satellite images from United States Geological Survey (USGS) Earth Explorer.

Map 4: Variation in Land Surface Temperature over Jaipur for 2003, 2013, and 2023

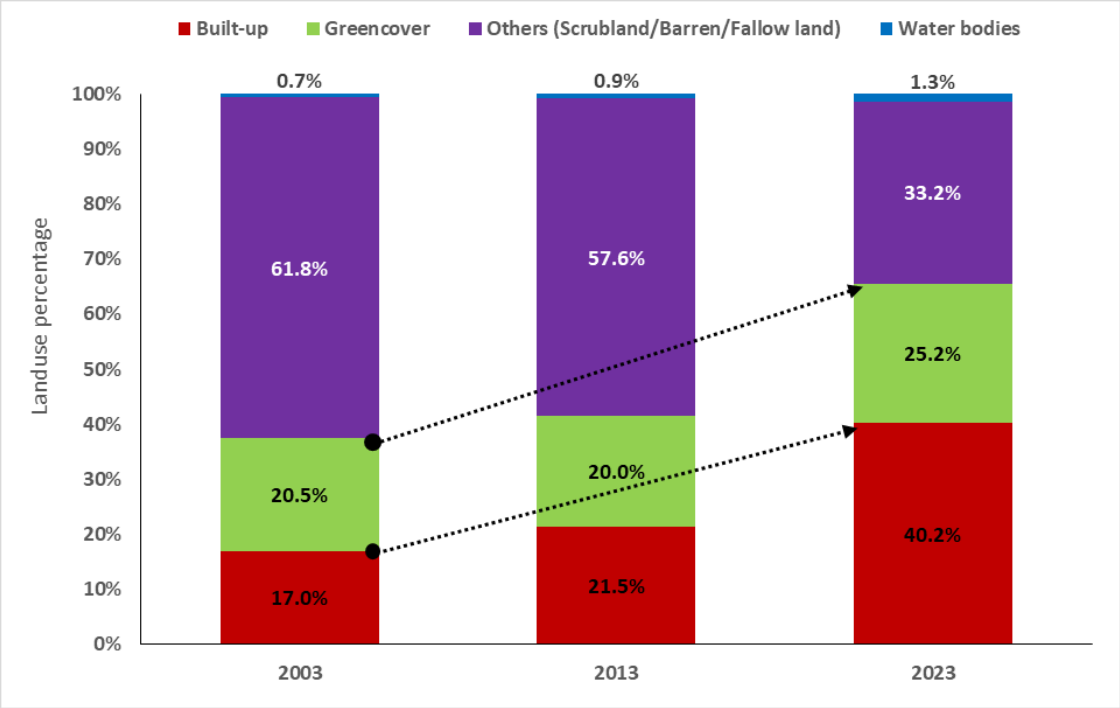


Note: Summer heat wave months (April-May) are chosen to analyse the Land Surface Temperature (LST). The respective dates of acquisition of the images are May 01, 2003, May 20, 2013, and May 08, 2023.
Source: CSE analysis of Landsat 7 and Landsat 8 satellite images from United States Geological Survey (USGS) Earth Explorer.

Lucknow

Lucknow has become more concertized in the last two decades, contributing to a rise in urban heat stress: Built-up area increased from 17 per cent in 2003 to 40.2 per cent in 2023. Green cover has increased from 20.5 per cent in 2003 to 25.2 per cent in 2023 (See *Graph 3: Change in land use pattern in Lucknow in last two decades*).

Graph 3: Change in land use pattern in Lucknow in the last two decades

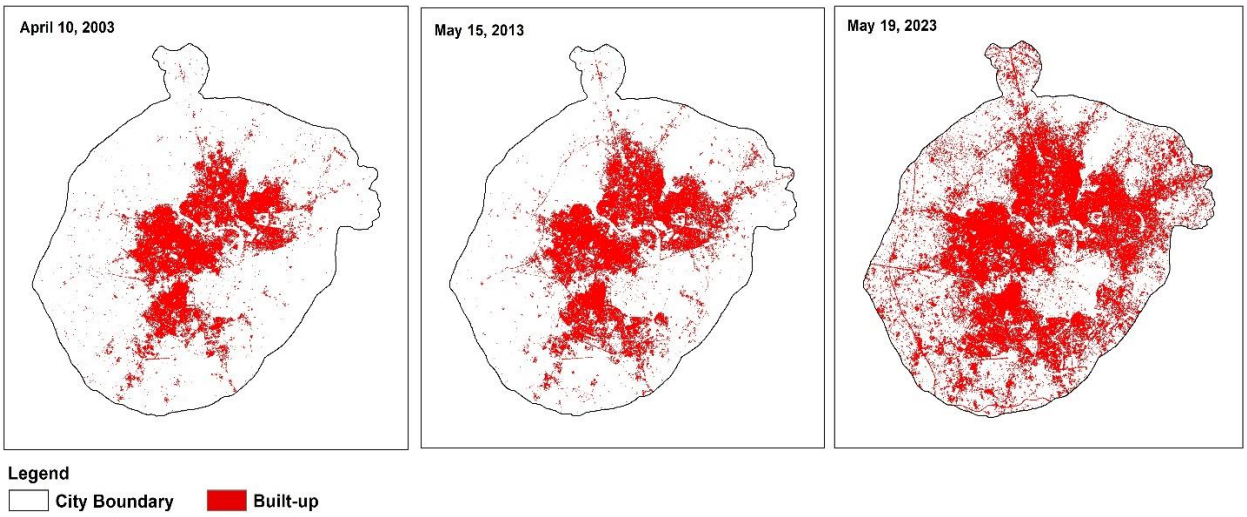


Note: Summer heat wave months (April-June) are chosen to analyse the Normalized Difference Vegetation Index (NDVI) and urban expansion for each year.
Source: CSE analysis of Landsat 7 and Landsat 8 satellite images from United States Geological Survey (USGS) Earth Explorer.

Land Use pattern change analysis: Lucknow saw an increase in its built-up area, with an expansion from 108.9 sq. km in 2003 to 257.5 sq. km in 2023, which depicts a gradual rise in the percentage share of the city's geographical area from 17 per cent in 2003 to 40.2 per cent in 2023 (See *Map 5: Growth in Urban Built-up in Lucknow during 2003, 2013 and 2023*). Significant and rapid urban expansion has happened especially in the city centre and North East zone.

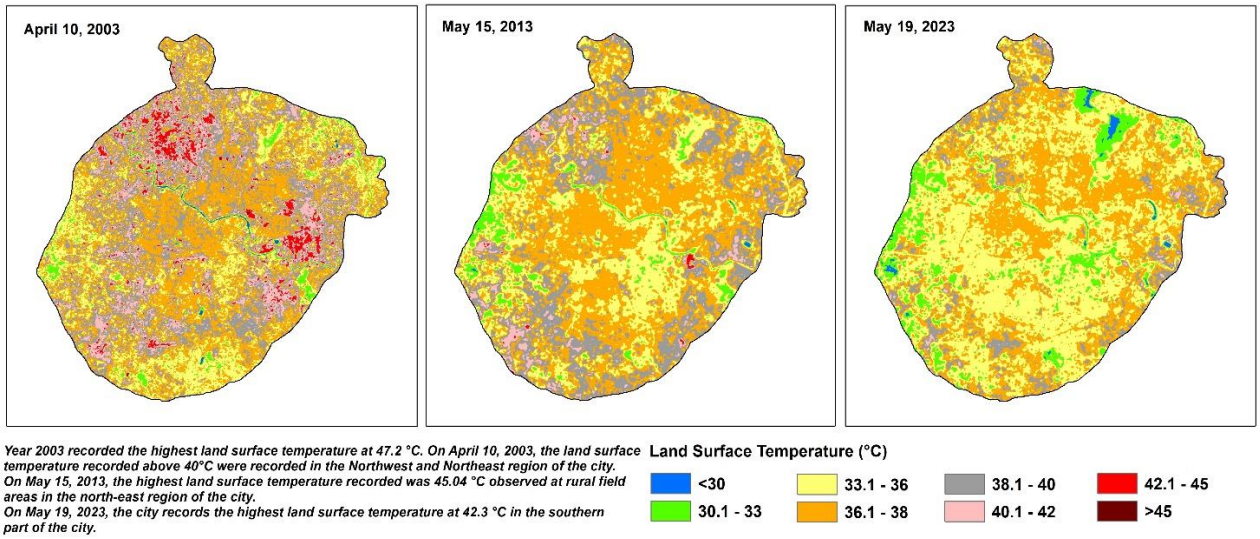
Impact of land surface changes on the distribution of land surface temperature: 2003 recorded the highest surface temperature because of the barren land and scrubland which absorbs the direct sun rays, resulting in more scorching temperatures. In 2003, the average LST of Lucknow was 37.5°C. The built-up area near the Bada Imambara and Anna market in West Lucknow experienced much higher temperatures of 40°C-45°C. Additionally, barren areas along the Badi Jugauli Forest in the north-eastern part of the city also recorded surface temperatures above 45°C. On an extremely hot day (April 10, 2003), the highest land surface temperature at a scorching 47.2 °C was observed in the barren scrublands of the North-east zone of the city. Water bodies and areas with dense green cover showed temperatures as low as 18.8 °C even on an extreme heat day. In 2023, the average LST of Lucknow was 35.5 °C. On an extreme heat day (May 19, 2023), the highest temperatures were recorded in and around the farmlands in the outer peripheries of the city where LST reached 38 - 40 °C. The lowest temperature was recorded over water bodies and areas with dense green cover and it stood at 27.7 °C (See *Map 6: Variation in Land Surface Temperature over Lucknow for 2003, 2013, and 2023*).

Map 5: Growth in Urban Built-up in the Lucknow Municipal Corporation during 2003, 2013, and 2023



Note: Urban expansion for each year – 2003, 2013, and 2023. The red colour depicts the urban growth in the city.
Source: CSE analysis of Landsat 7 and Landsat 8 satellite images from United States Geological Survey (USGS) Earth Explorer.

Map 6: Variation in Land Surface Temperature over Lucknow Municipal Corporation for 2003, 2013, and 2023

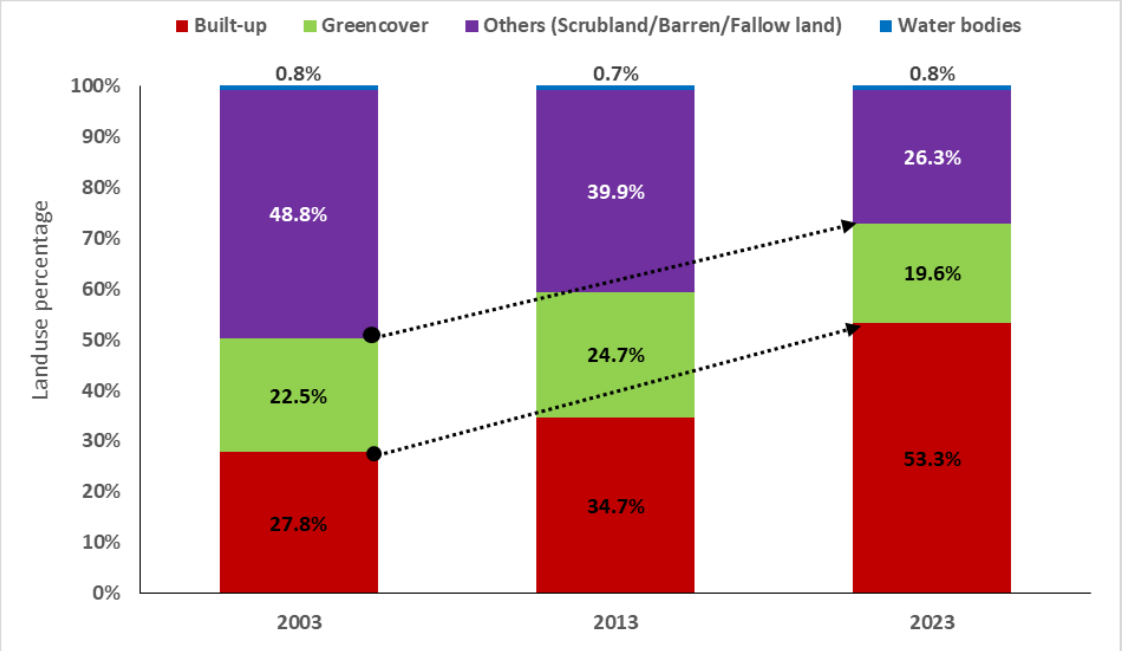


Note: Summer heat wave months (April-May) are chosen to analyse the Land Surface Temperature (LST). The respective dates of acquisition of the images are April 10, 2003, May 15, 2013, and May 19, 2023.
Source: CSE analysis of Landsat 7 and Landsat 8 satellite images from United States Geological Survey (USGS) Earth Explorer.

Pune

Pune has become more concertized in the last two decades, contributing to a rise in urban heat stress: Built-up area increased from 27.8 per cent in 2003 to 53.3 per cent in 2023. Green cover has decreased from 22.5 per cent in 2003 to 19.6 per cent in 2023 (See *Graph 4: Change in land use pattern in Pune in last two decades*).

Graph 4: Change in land use pattern in Pune in the last two decades

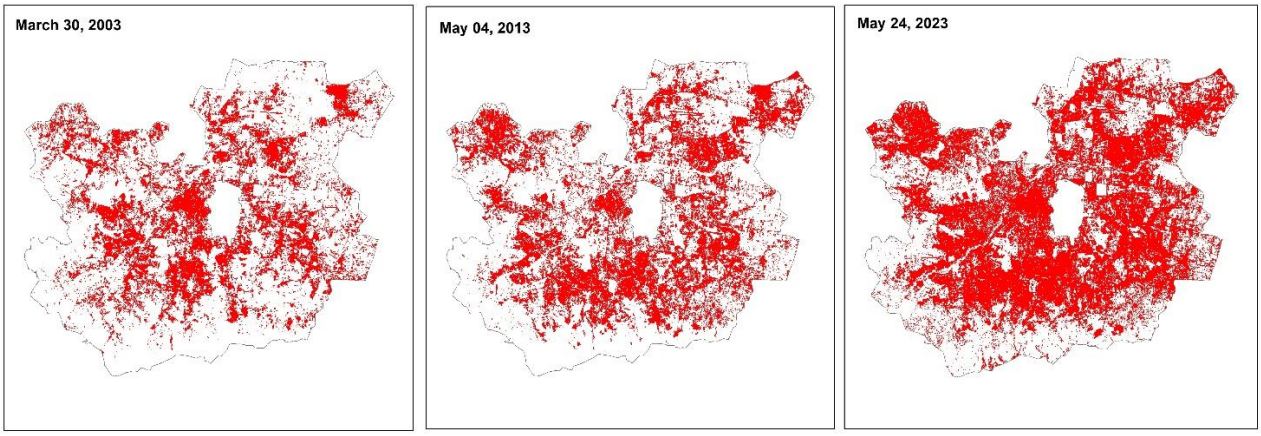


Note: Summer heat wave months (April-June) are chosen to analyse the Normalized Difference Vegetation Index (NDVI) and urban expansion for each year.
Source: CSE analysis of Landsat 7 and Landsat 8 satellite images from United States Geological Survey (USGS) Earth Explorer.

Land Use pattern change analysis: Pune saw an increase in its built-up area, with an expansion from 140.9 sq. km in 2003 to 270.4 sq. km in 2023, which depicts a gradual rise in the percentage share of the city's geographical area from 27.8 per cent in 2003 to 53.3 per cent in 2023 (See *Map 7: Growth in Urban Built-up in Pune during 2003, 2013 and 2023*). Significant and rapid urban expansion has happened especially in the city centre and North East zone.

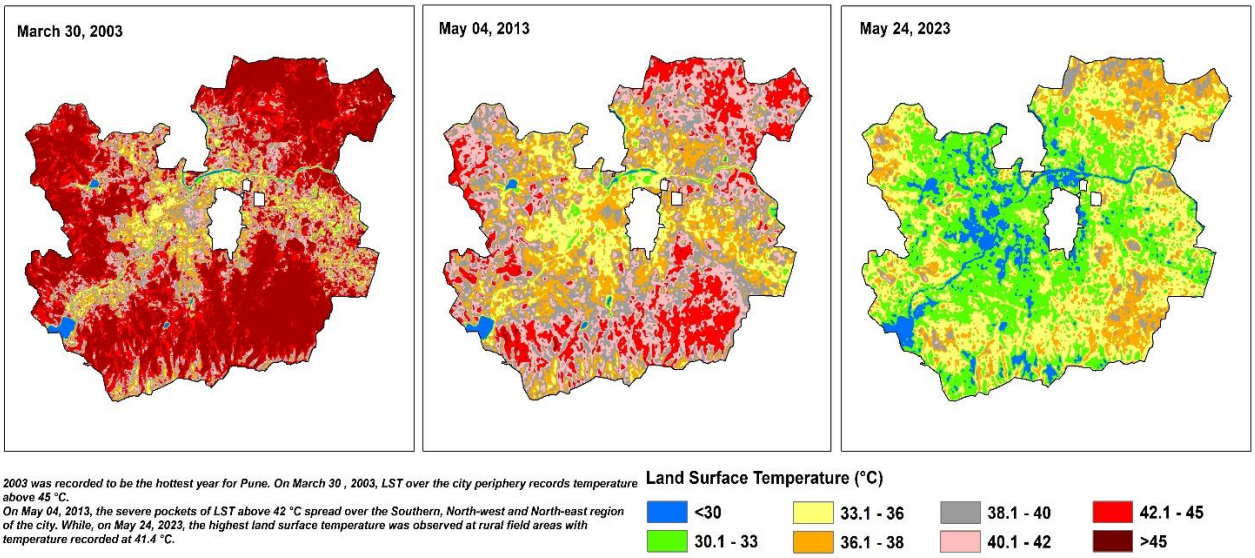
Impact of land surface changes on the distribution of land surface temperature: 2003 recorded the highest surface temperature because of the barren land and scrubland which absorbs the direct sun rays, resulting in more scorching temperatures. In 2003, the average LST of Pune was 43.2°C. The densely built-up area near the Mahatma Phule wada and Shaniwar wada experienced much higher temperatures of 38°C-42°C. Additionally, areas along the outer periphery of the city also recorded surface temperatures above 45°C. On an extremely hot day (March 30, 2003), the highest land surface temperature at a scorching 48.9 °C was observed in the Southern area, Northern-east and South-west parts of the city. Water bodies and areas with dense green cover showed temperatures as low as 24.8 °C even on an extreme heat day. In 2023, the average LST of Pune was 33.4 °C. On an extreme heat day (May 24, 2023), the highest temperatures were recorded in and around the Pune International Airport in the northeast zone where LST reached 40 °C. The farmland in the north-west and north-east regions of the city especially around Sus Gaon, Vignaharta Colony, and the areas around Mohammed Wadi in the southern part of the city was exceptionally hot with surface temperatures exceeding 36 °C. The lowest temperature was recorded over water bodies and areas with dense green cover and it stood at 24 °C (See *Map 8: Variation in Land Surface Temperature over Pune for 2003, 2013, and 2023*).

Map 7: Growth in Urban Built-up in the Pune area during 2003, 2013, and 2023



Note: Urban expansion for each year – 2003, 2013, and 2023. The red colour depicts the urban growth in the city.
Source: CSE analysis of Landsat 7 and Landsat 8 satellite images from United States Geological Survey (USGS) Earth Explorer.

Map 8: Variation in Land Surface Temperature over the Pune area for 2003, 2013, and 2023



Note: Summer heat wave months (April-May) are chosen to analyse the Land Surface Temperature (LST). The respective dates of acquisition of the images are March 30, 2003, May 04, 2013, and May 24, 2023.
Source: CSE analysis of Landsat 7 and Landsat 8 satellite images from United States Geological Survey (USGS) Earth Explorer.