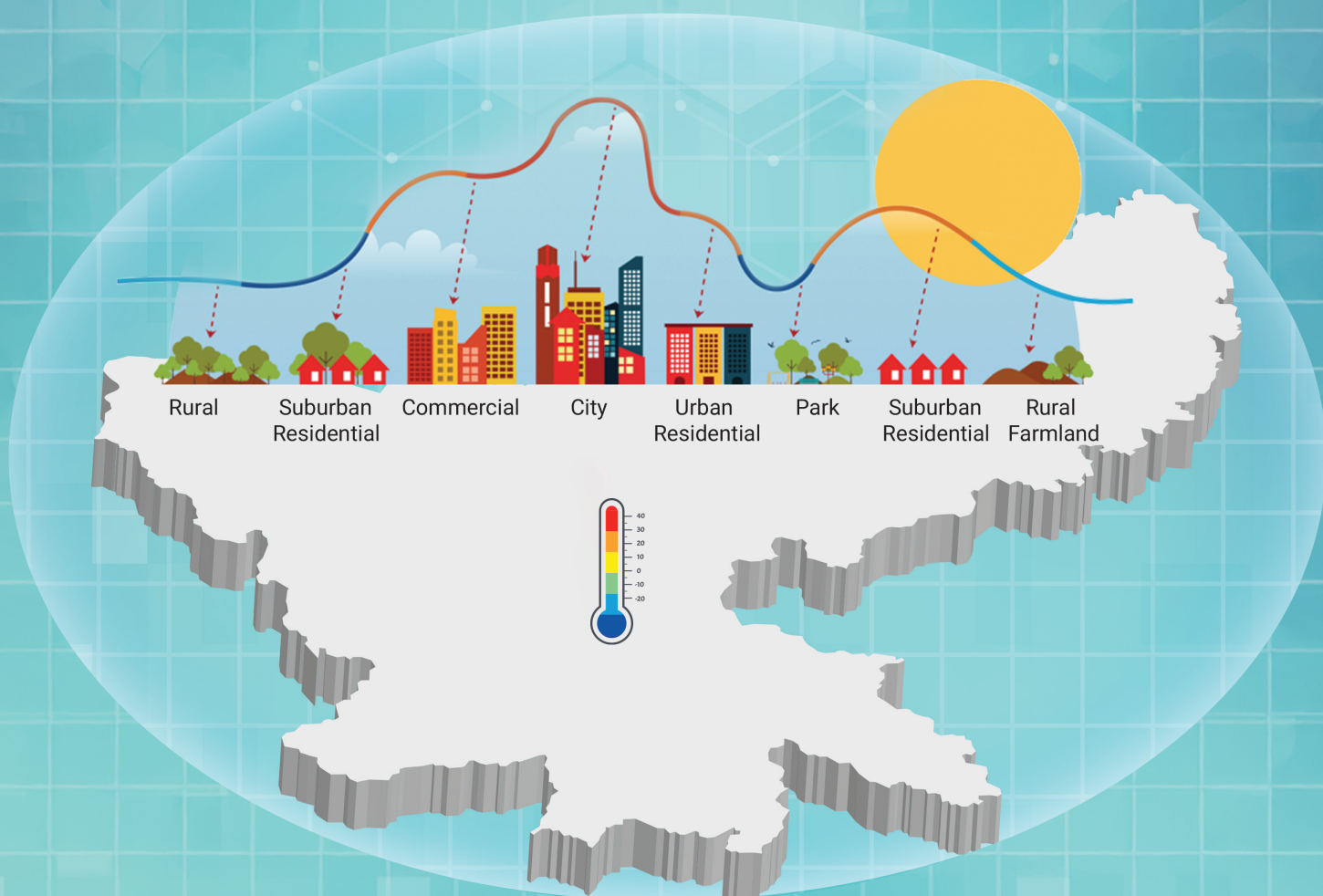




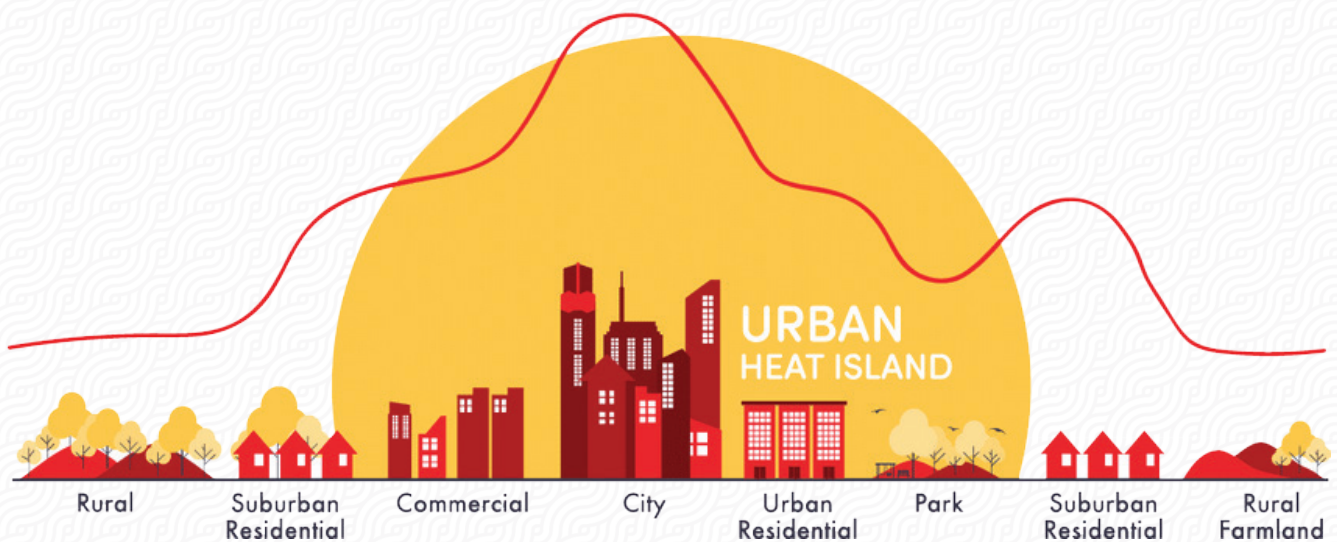
विज्ञान एवं प्रौद्योगिकी विभाग
DEPARTMENT OF
SCIENCE & TECHNOLOGY

Urban Heat Island Effect in Jharkhand



Department of Forest, Environment & Climate Change
Government of Jharkhand

Urban Heat Island Effect in Jharkhand



अबुबक्कर सिद्दीख पी, भा० प्र० से०
सचिव

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झारखण्ड सरकार

Deptt. of Forest, Environment &
Climate Change, Government of Jharkhand



Message

Though urban development is vital for progress and economic growth, it simultaneously introduces complex challenges that demand informed and proactive management. One such critical challenge is the Urban Heat Island (UHI) effect, which results in elevated temperatures across cities due to dense infrastructure, complex building geometry, limited vegetation cover, high population density, and increasing anthropogenic emissions. This phenomenon has direct and severe implications for public health, urban comfort, and sustainable planning.

This data-driven study provides critical insights into the spatial heat distribution across five key urban landscapes in Jharkhand. It is an invaluable contribution toward understanding the correlation between rapid urbanization and localized warming, identifying its main causes and impacts, and offering concrete guidance for climate-resilient city planning and urban policy development.

I am confident that the findings of this report will serve as an essential reference for, City Administration, Urban Planners, Researchers, Policymakers, State Governments officials in addressing urban heat challenges effectively. I further hope that this report will play a vital role in formulating policies, informing budget allocations, and identifying appropriate measures to address both current and future urban climate risks.

This initiative truly reflects the unwavering commitment of the Department of Forest, Environment & Climate Change toward promoting climate-resilient and sustainable urban development in Jharkhand.

I commend the efforts made by the officers of the State Forest & Climate Department, the expert Climate Modellers, Researchers, and all members of the State Climate Change Cell involved in producing this significant study.

(ABOOBACKER SIDDIQUE P.)



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Foreword



Increasing global temperature is one of the most pressing challenges of our time, and its impacts are increasingly visible at local and regional levels. While distinct from the phenomenon of global warming, the Urban Heat Island (UHI) effect has emerged as a critical warming issue for urban landscapes, particularly in rapidly growing cities where unplanned urbanization, loss of vegetation, and expanding built-up areas have intensified surface temperatures and drastically reduced thermal comfort.

I am immensely pleased to note that this comprehensive study on the Urban Heat Island Effect, focusing on five major cities of Jharkhand—Ranchi, Jamshedpur, Dhanbad, Hazaribagh, and Bokaro has been successfully conducted by the Department of Forest, Environment & Climate Change with vital support from the Department of Science and Technology (DST), Government of India.

The findings of this study clearly highlight the growing temperature differentials between urban and neighbouring semi-urban/rural areas. These results powerfully underscore the urgent need for sustainable land-use planning and climate-responsive infrastructure. I am confident that such evidence-based research will be invaluable in informed policy formulation, integrated planning, and building urban resilience.

Indeed, this report is a commendable initiative by the Department of Forest, Environment & Climate Change through its State Climate Change Cell. I trust this document will serve as a valuable reference for city administration, urban planners, and researchers in understanding the growing challenge of the Urban Heat Effect and in developing effective mitigation and adaptation strategies to address these warming risks.

I appreciate and congratulate the APCCF, CAMPA, members of the State Climate Change Cell, Independent researchers, GIS and data experts, Reviewers, and all other staff who have contributed to this landmark study and the preparation of this report. I hope that this work contributes meaningfully to the state's broader vision of climate resilience and sustainable urban development.

Date: 06.11.2025


Shri Ashok Kumar, IFS

Principal Chief Conservator of Forests (PCCF) & Head of Forest Force (HoFF)
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Acknowledgement



As we move forward, it is imperative to continue monitoring, assessing, and adapting to the ever-increasing threat of global warming, driven by rapid urbanization, land-use change, industrialization, and the increasing concentration of Greenhouse Gases in the atmosphere.

This urban heat island study is part of ongoing efforts supported by Department of Science and Technology (DST), Government of India under the National Mission on Strategic Knowledge for Climate Change (NMSKCC). The primary objective this study is to disseminate crucial knowledge on global warming and climate change among a wide set of stakeholders including policymakers, municipal corporations, urban planners, and citizens to develop effective policy measures and heat adaptation strategies.

The analysis and results presented in this report are driven by extensive research, meticulous data analysis, and reviewed by leading academicians. I am confident that the analysis, results, and recommendations presented here will serve as a valuable resource especially to city administration and urban planners and will help in formulating city-specific climate policy, enabling better urban planning, and allocating budgets for piloting and implementing long-term adaptation measures within existing urban set-ups and newly developing areas.

I extend my sincere gratitude to the **Secretary-Department of Forest, Environment & Climate Change and Principal Chief Conservator of Forests & Head of the Forest Force (HoFF)**, whose unwavering motivation and support have been the driving force behind this study. I am also grateful to the **Department of Science & Technology, Government of India**, for their essential funding support and valuable inputs.

Cordial gratitude extended to **Dr. Swagata Payra and Dr. Mili Ghosh Lala** (Associate Professors, Department of Remote Sensing & Geoinformatics, Birla Institute of Technology, Mesra, Ranchi) for reviewing the report and providing invaluable inputs and suggestions.

Finally, I sincerely appreciate the exceptional efforts of, **Vijay Shankar, Kunal Jain, Dr. Upendra Singh, Archna Singh, and Manshi Lal**. Their hard work, dedication, and commitment have been the cornerstone of this comprehensive assessment.

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IFS: APCCF, CAMPA, Govt. of Jharkhand

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In his capacity as APCCF, CAMPA, he has spearheaded several path-breaking initiatives in the Climate Change domain over the past one year, including a Block-level Vulnerability Assessment and comprehensive Climate Projection studies for the entire state, Overseeing the Urban Heat Islanding study, and training more than 2,000 grassroots forest workers and citizens on Climate Change and its associated impacts.



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He has extensive experience working closely with a wide array of prestigious national and international development agencies and multilateral institutions, including, UNICEF, UNFPA, JICA, WaterAid, GIZ and The World Bank

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Archana Singh; Manshi Lal; Shreedhar Mohan; Abhishek K. Singh

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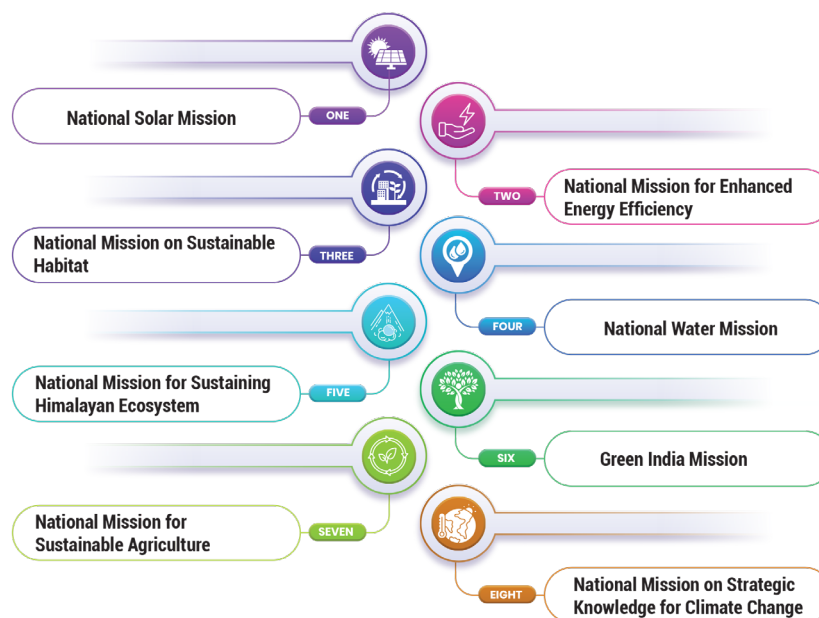
List of Abbreviations

ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
BEP/BEM	Building Effect Parameterization/Building Energy Model
DST	Department of Science & Technology, Govt of India
DN	Digital Number
GCM	Global Climate Model
EPA	Environmental Protection Agency
GHG	Greenhouse Gas
IAM	Integrated Assessment Model
ISL	Inertial sub-layer
GIS	Geographic Information System
IMD	Indian Meteorological Department
IPCC	Intergovernmental Panel on Climate Change
LST	Land Surface Temperature
MODIS	The Moderate Resolution Imaging Spectroradiometer
MRT	Mean Radiant Temperature
NAPCC	National Action Plan on Climate Change
NWP	Numerical Weather Prediction
NMSHE	National Mission for Sustaining Himalayan Ecosystem
NMSKCC	National Mission on Strategic Knowledge for Climate Change
NDVI	Normalized Difference Vegetation Index
NDBI	Normalized Difference Built-up Index
OLI	Operational Land Imager
RSL	Roughness sub-layer
RCM	Regional climate model
RH	Relative Humidity
TM	Thematic Mapper (Landsat)
TIRS	Thermal Infrared Sensor
ToA	Top of Atmosphere
SUHI	Surface Urban Heat Island
WMO	World Meteorological Organization
UHI	Urban Heat Island
UTFVI	Urban Thermal Field Variance Index
WBGT	Wet-Bulb Globe Temperature
srad	Steradian
μm	Micrometeor

This report outlines the fundamentals of the **Surface Level Urban Heat Island**, including its main causes, effects, and necessary mitigation and adaptation measures. The analysis is primarily focused on the five most urbanized cities in Jharkhand, namely **Ranchi, Jamshedpur, Dhanbad, Bokaro, and Hazaribagh**. The findings of this study provide insightful and actionable data to city administration, urban planners, and policymakers to address urban heat stress and plan for climate-resilient city development.

1.1 Project Background

Recognizing the threats of climate change to the various sectors of the economy, regions, and populations, India came up with an ambitious and comprehensive policy and planning level vision document called the “**National Action Plan on Climate Change (NAPCC)**” in **2008**. The NAPCC includes eight national missions, which are mentioned below.



Various missions were delegated to different departments for preparing the sector-specific policy, action/implementation plans, setting the goal, and starting the implementation work. The **Department of Science & Technology (DST) under the Ministry of Science & Technology** was entrusted with the responsibility of coordinating two out of these eight national missions on climate change. These are:

1. **National Mission for Sustaining Himalayan Ecosystem (NMSHE)**
2. **National Mission on Strategic Knowledge for Climate Change (NMSKCC)**

While the primary goal of NMSHE is to build the ability to scientifically assess the vulnerability of the Himalayan region to climate change and to monitor the health of the Himalayan ecosystem, NMSKCC focuses on developing strategic knowledge in key areas such as climate change science, adaptation, and mitigation. **This UHI study is a part of the National Mission on Strategic Knowledge for Climate Change (NMSKCC).**

1.2 Objective & Scope of the Study

The primary objective is to analyse the warming pattern of urban setups in the state and disseminate the knowledge, sharing results among a wide range of stakeholders, such as the city administration, urban planners, policymakers, industry associations, civil society, and citizens.

The scope of the study is to conduct a heat island study of the five most urbanized cities, using publicly available remote sensing data from various satellites, following numerical and statistical modeling methods, and to compare the heat profile of the urban setup with its neighbouring semi-urban/rural area, and to analyse the relationship between urban planning characteristics and microclimate.

The core purpose of the study is to:

1. Analyse the warming pattern of urban setups in the state.
2. Disseminate knowledge and share results among a diverse range of stakeholders.
3. Conduct a surface heat islanding study in the five most urbanized cities.
4. Compare the heat profile of urban setups with neighbouring semi-urban/rural areas.
5. Analyse relationship between urban planning characteristics and the microclimate.

2 Summary

This study represents the first systematic investigation into the Surface Urban Heat Island (SUHI) phenomenon within the state of Jharkhand, focusing on the five most populous urban landscapes, Ranchi, Jamshedpur, Bokaro, Dhanbad, and Hazaribagh. The study has utilized high-resolution remote sensing data from LANDSAT-9 and MODIS to derive radiative temperature maps and thermal imagery, effectively measuring the Land Surface Temperature (LST) and assessing the characteristics and amplitude of the Surface Urban Heat Island (SUHI) over time.

Our approach modelled and analysed daily T_{Max} , T_{Min} , T_{Mean} , Relative Humidity, and Wet-Bulb Globe Temperature in correlation mainly with the Vegetation Index and Built-up area.

Though several factors like the Normalized Difference Vegetation Index (NDVI), Normalized Difference Built-up Index (NDBI), Water Index (MNDWI), and Bare Soil Index (BSI) serve as critical indices to quantify the relationship between urbanization and the Surface Urban Heat Island (SUHI) effect, we have mainly focused on NDVI, NDBI, and Population Density (PD) to arrive at our results.

In our analysis, we found that although there is no perfect inverse correlation between LST and NDVI, when we included NDBI and Population Density in our analysis, LST showed a positive correlation with the combined index of NDBI and Population Density (PD).

Table 1 : Result Summary- SUHI data for five cities- Jharkhand

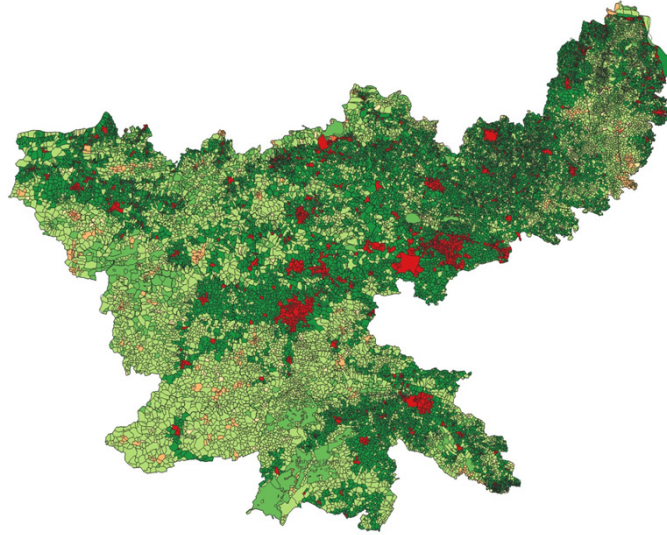
City Name	Temperature difference (Range) Rural VS Urban (2024)	Difference in WBGT 1980 VS 2024 (Hottest Day of the Year)	Decadal Growth in WBGT>32°C (1980 to 2020)
Ranchi	1.5°C-2°C	30.6 °C -30.6°C	0.00 Days/decade
Jamshedpur	1.5°C-2°C	31.5°C -33.1°C	1.88 Days/decade
Hazaribagh	0.5°C	29.7°C -30.7°C	0.10 Days/decade
Bokaro	1.0°C	31.2°C-32.7°C	0.40 Days/decade
Dhanbad	0.5°C	31.6°C -33.2°C	0.55 Days/decade

The urban–rural temperature difference has been found to be almost equal for Jamshedpur and Ranchi, which is approximately 1.5°C to 2°C (during summer), and the lowest for Hazaribagh which is approximately 0.5°C (during summer). The decadal growth of both rural versus urban temperature and WBGT are also highest for Jamshedpur while lowest for Ranchi. This suggests that Ranchi still possesses better vegetation cover and a lower impervious surface area in comparison to Jamshedpur.

While the SUHI effect is significant across all five cities, the amplitude is maximum for Jamshedpur and minimum for Hazaribagh. A comparison with publicly available data revealed that the SUHI amplitudes in all five cities considered for this study are still much lower than those in other large Indian metropolitan areas, e.g., Bengaluru, Delhi, Chennai, Mumbai, Pune, etc.

This study highlights a significant positive relationship between the urban heat island magnitude, the size of the urban area, and its ecological setting, estimated entirely from remotely sensed observations.

Figure 2 : Urban hot spots in Jharkhand- Land surface temperature across the state²



3 Concept, Definition & Discussion

3.1 Historical Background

Luke Howard, a British chemist and meteorologist, was the first to document the urban effects on air temperature. From 1806 to 1830, Howard analysed data from a small network of thermometers across London and its surroundings, and surmised that London's climate was warmer than the surrounding rural areas. He suggested that the warming of the urban setup was caused by radiation trapping and airflow interference by building walls, heat release from domestic and industrial combustion processes, and lack of evaporation from built surfaces. Studies in other cities soon followed Howard's groundbreaking work, each with a similar outcome.

Julius Ferdinand von Hann, an Austrian meteorologist, is regarded as the father of modern meteorology, who formally labelled the recurring warmth in large cities the "City Temperature" effect. Several decades later, the thermal anomaly became known as the "Urban Heat Island" effect.

The scientific understanding of UHI has been significantly advanced by modern pioneers like **T. R. Oke**. Today, the spatial and temporal patterns, and the meteorological and societal implications of heat islands are deeply understood. Assessments and predictions of UHI effects can now be made with reasonable accuracy in most global cities providing a robust framework for climate-resilient urban planning.

Intergovernmental Panel on Climate Change (IPCC), which is the world's premier research organization for such a study, had one chapter dedicated to UHI in its 2014 report. The report recognizes the presence of UHI due to the reduction in vegetation cover, changes in surface cover, urban densification, and an increase in anthropogenic activities.

3.2 Main Causes

Urbanization is a complex, and dynamic process that profoundly alters the local climate, generating unique meteorological and climatological characteristics. The dense clustering of high-rise buildings and concrete infrastructure creates intricate rain, wind, and heat patterns.

The Urban Heat Island (UHI) effect fundamentally results from the difference in the surface energy balance between urban and surrounding rural areas, driven by the way urban surfaces interact with atmospheric processes.

² Classification as per UN DEGURBA

The physical causes of the UHI are well-established. As urbanization expands, new buildings are erected, typically replacing vegetated landscapes (like pastures, forests, or fields) with three-dimensional, impervious surfaces. These changes drastically alter the surface energy exchanges in three main ways:

- **Heat Storage:** Impervious surfaces (concrete, asphalt, masonry) possess specific thermal properties that cause them to store heat efficiently during the day.
- **Heat Emission:** Urban areas generate anthropogenic heat associated with human activities, such as industrial processes, transportation, and building heating/cooling systems.
- **Altered Energy Exchange:** The lack of vegetation severely limits evapotranspiration, which is nature's primary cooling mechanism.

These urban-induced changes to the energy balance when compared to rural areas, result in distinct differences in both the heating and cooling rates between the two environments, thereby creating the persistent, elevated thermal environment characteristic of cities.

3.2.1 Reduced Vegetation Cover

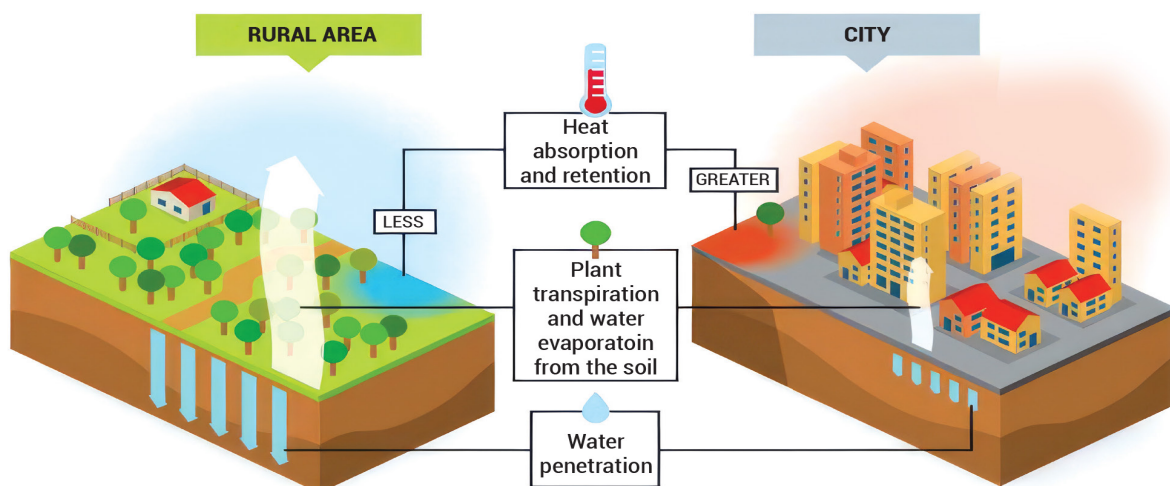
In rural areas, the landscape is dominated by vegetation and open land, which actively regulate temperature:

- **Shade:** Trees and plants provide direct shade, effectively lowering surface temperatures.
- **Evapotranspiration:** This is the key cooling process, where plants release water vapor into the air. This change of state dissipates ambient heat, acting as a natural air conditioner and directly reducing air temperatures.

In contrast, urban areas are defined by dry, impervious surfaces—conventional roofs, sidewalks, roads, and parking lots. As cities develop, the replacement of vegetation with pavement and buildings results in

- **Loss of Cooling:** The decrease in tree cover eliminates shade and moisture, making the environment prone to heating.
- **Suppressed Evaporation:** Built-up areas evaporate significantly less water. This lack of moisture and suppressed evapotranspiration is the primary contributor to the elevated surface and air temperatures characteristic of the Urban Heat Island (UHI) phenomenon.

Figure 3 Vegetating Cover and its influence on temperature



3.2.2 Thermal Properties of Urban Materials

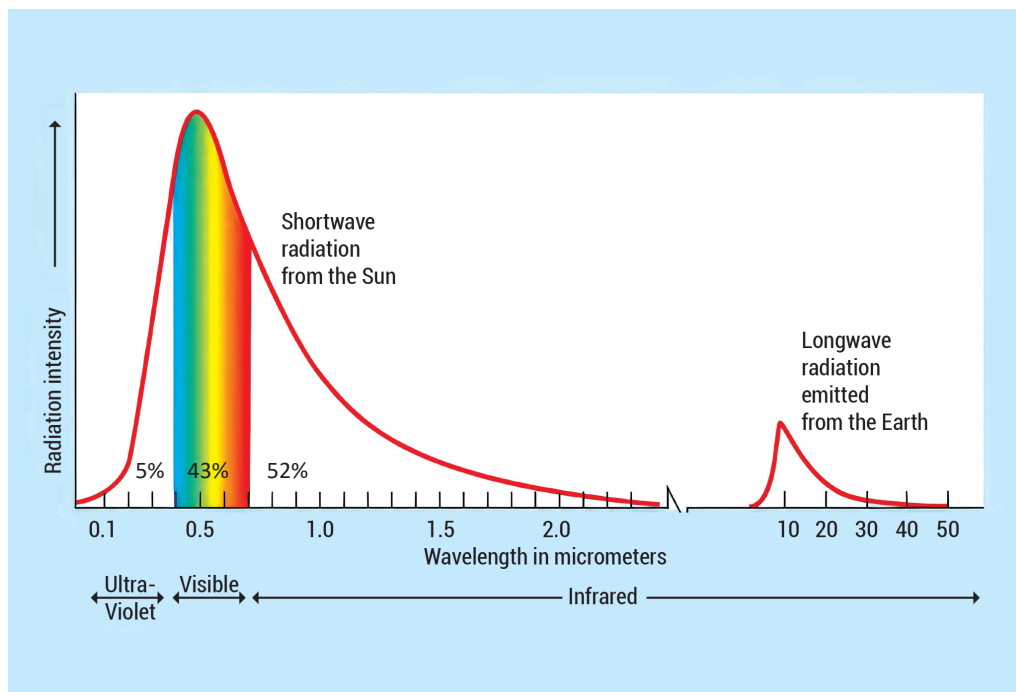
The development of the Urban Heat Island (UHI) is critically dependent on the thermal properties of the materials used in the urban environment, such as roofing and paving. These materials drastically alter how solar energy is absorbed, stored, and released compared to rural surfaces.

Urban materials stimulate UHI development through three key properties:

- **Albedo (Solar Reflectance):** Urban surfaces typically have a **lower albedo** than rural surfaces, meaning they absorb more incoming solar energy. This absorbed heat significantly increases surface temperatures and drives the formation of both the surface and atmospheric UHIs.
- **Heat Capacity:** Urban materials like concrete and asphalt have a high heat capacity, allowing them to **store a large amount of heat**. They slowly release this stored energy throughout the evening, keeping urban temperatures elevated long after sunset.
- **Thermal Emissivity (Emittance):** This measures a surface's ability to **shed heat** by emitting long-wave (infrared) radiation.
 - While solar reflectance (albedo) is the main determinant of a material's temperature, high thermal emittance helps a surface stay cooler by releasing absorbed heat more readily.
 - Most common construction materials, with the notable exception of bright metals, possess relatively high thermal emittance values.

The figure below shows the typical solar energy that reaches the Earth's surface on a clear summer day. 5% percent of solar energy is in the UV spectrum, 43% of solar energy is visible light, and the remaining 52 %of solar energy is infrared, felt as heat. Energy in all of these wavelengths contributes to urban heat island formation.

Figure 4 : Distribution of Solar radiation of wavelength reaching Earth's surface



3.2.3 Building Geometry

In an urban landscape, buildings form “urban canyons” that act as large thermal masses. Because neighbouring objects often obstruct structures and surfaces, these thermal masses cannot readily release their stored heat

due to the blockage of outgoing long-wave radiation. This obstruction effect is why the air above urban centers are typically warmer than the air over rural areas, particularly at night.

During the day, urban canyons exhibit two competing thermal effects:

- **Shading (Cooling):** Tall buildings create shade, which can reduce direct solar radiation on lower surfaces and streets, thereby helping to lower both surface and air temperatures.
- **Radiation Trapping (Warming):** When sunlight does reach surfaces within the canyon, the energy is repeatedly reflected and absorbed by building walls and the ground. This process significantly lowers the city's overall which traps more energy and contributes to temperature increases.

At night, the warming effect dominates.

- **Impeded Cooling at Night:** The physical presence of buildings and structures obstructs the long-wave radiation (heat) being released from the urban infrastructure, effectively trapping the heat within the urban boundary layer and maintaining elevated night-time temperatures.

3.2.4 Impervious Surface Area & Surface Geometry:

Impervious surfaces and the complex, corrugated form of urban geometry significantly amplify the total surface area (including horizontal, vertical, and sloped facets) relative to a flat, non-urban landscape. This amplified surface area and geometry lead to several critical changes in energy and airflow, driving the Urban Heat Island (UHI) effect:

- **Reduced Average Wind Speeds:** The dense arrangement of buildings creates friction and turbulence, significantly reducing wind flow within street canyons. This hinders the removal of heat by convection and advection, especially in sheltered areas.
- **Increased Solar Absorption and Reflection:** The multiple facets of building walls lead to multiple reflections and greater absorption of solar radiation. Energy that would typically be reflected away from a flat rural surface is repeatedly absorbed within the urban canyon, effectively lowering the overall urban albedo.
- **Increased Heat Storage:** The larger surface area allows for increased heat storage in the thermal mass of concrete and masonry, which is slowly released over time.

Altered Longwave Radiation Exchange during the day and night time

- **Daytime:** Dense built-up areas experience reduced net energy loss to the atmosphere via longwave radiation due to horizon screening (the sky view factor is limited by tall buildings).
- **Nighttime:** This same process of re-radiation and trapping between canyon walls, actually increases the heat loss to the atmosphere from the buildings themselves but slows the cooling of the street-level air, as the stored heat is continually re-radiated downward and horizontally.

3.2.5 Anthropogenic Heat

Anthropogenic emission and heat both are significant contributors to the Urban Heat Island (UHI) effect. This thermal energy is directly emitted into the urban environment from various sources within the city's infrastructure and activities, including:

- **Transportation/Vehicles:** Emission and heat from engines and exhaust systems.
- **Air-Conditioning Units:** GHG and heat expelled from cooling systems, especially on hot days when the UHI is most severe.

- **Buildings:** Heat leakage from heating systems in colder climates and heat absorbed and re-emitted by the building structure itself.
- **Industrial Facilities:** Emissions from and heat released from manufacturing and industrial operations.

Figure 5 : Main anthropogenic activities contributing to UHI and Global warming



3.2.6 Meteorological and geographic factors

Meteorological Influences: Three primary weather characteristics, wind, cloud cover and precipitation are the main suppressors of UHI development. The actual intensity of the UHI is controlled by a complex interplay of current weather, city size, and surface properties etc.

- Strong winds are inversely related to UHI intensity. As wind speeds increase, they promote the turbulent mixing of air between the urban surface and the atmosphere, which significantly increases sensible and latent heat fluxes. This mixing effectively carries heat away from the city, reducing both near-surface air temperatures and the urban–rural air temperature gradient.
- Cloud cover suppresses UHI formation by modifying the radiative exchange.
- Rainfall modifies soil moisture, directly influencing the water available for evapotranspiration. The spatial and temporal distribution of dry/wet soils across the urban-rural area profoundly influences the UHI's diurnal and seasonal patterns.

Geographic and Topographic Influences: A city's geographic location, which determines its climate and topography, significantly impacts UHI formation.

Solar Input: A city's latitude is a primary determinant of the annual and seasonal intensity of solar radiation it receives. This controls the heat stored in the urban fabric, influences energy demand for heating/cooling, and affects anthropogenic heat release.

- Tropical vs. Temperate: Tropical cities, given the greater frequency of cloud and rain (outside of arid regions), generally experience smaller UHI intensities than temperate cities. This is also partly due to different city forms in these regions (sometimes lower building heights or higher albedos).

Geographic setting (e.g., valley, basin, coastal, or mountain) induces mesoscale circulations that profoundly influence local wind fields and the surface energy budget.

- Wind Blocking/Creation: Geographic features like nearby mountains can block wind from reaching a city or create distinct wind patterns that pass through it.

- Induced Winds: Features can induce local winds like cold air currents, land–sea breezes, or downslope winds. These pre-settlement circulations are, in turn, influenced by the urban area and may either weaken or strengthen the UHI depending on their:
 - Diurnal and seasonal cycles.
 - Thermal characteristics.
 - Associated cloudiness.

The presence of water bodies (lakes, rivers) within or near the urban area impacts UHI intensity:

- Daytime: The UHI can be reduced close to a water body by the onshore advection (movement) of cool air.
- Nighttime: However, water bodies have a large thermal mass that keeps the nocturnal water temperatures more constant, potentially resulting in a higher UHI intensity at night in areas immediately adjacent to the water.

Figure 6 : Diurnal variation of temperature (Representative) at urban and rural site³

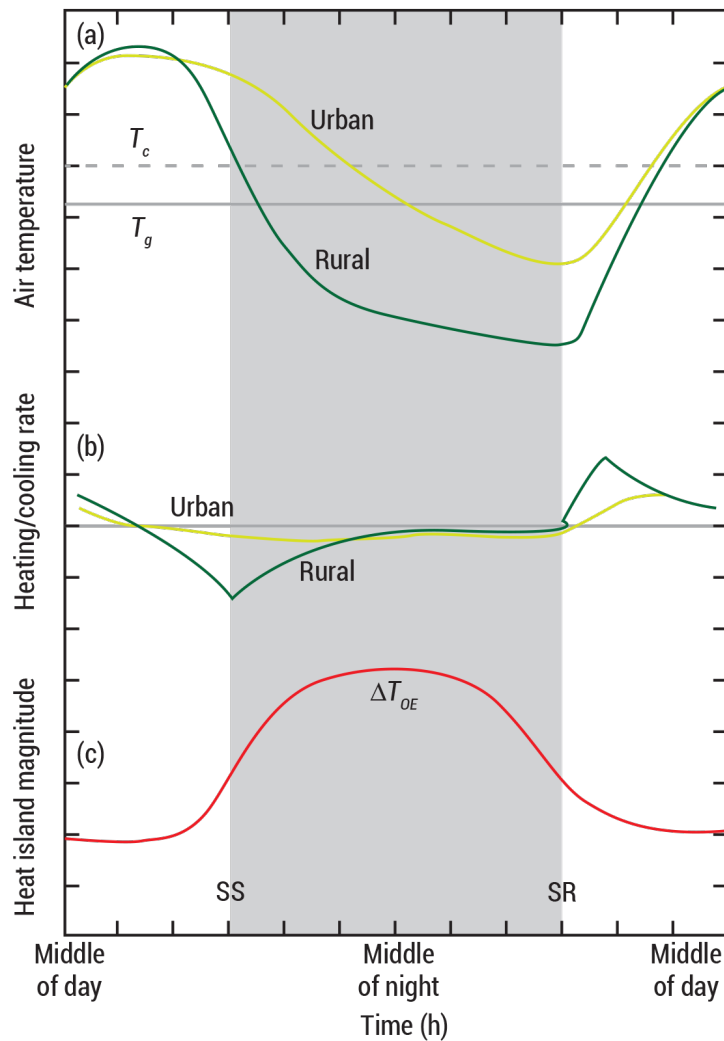
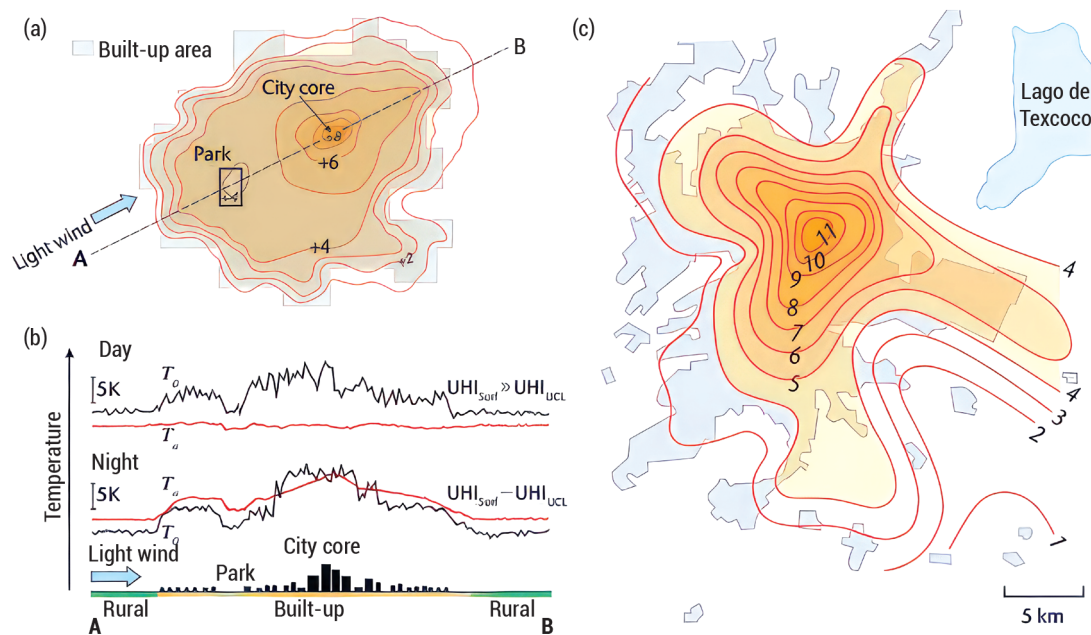


Figure 7 : Typical UHI intensity for a City (Representatives)⁴



3.3 Category of UHI

Based on the measurement of temperature at vertical, temporal, and spatial layers, as well as the measurement method and importance, the UHI can be categorized mainly into two types: **Surface UHI** and **Atmospheric UHI**. A few more categorizations are also described below.

Surface UHI (S-UHI): S-UHI is defined as the heat island resulting from the surface temperature difference between urban and rural areas. Sunlit urban surfaces (mainly ground, roofs, and walls) are typically warmer during the day than rural surfaces in the surroundings. At night, urban surfaces are in many cases warmer than rural surfaces. In cold climate cities, the S-UHI increases the number of frost-free days, and snow is less likely to remain on the ground. The S-UHI does not directly represent the near-surface air temperature⁵.

Atmospheric Urban Heat Islands: These form where there is a difference between the air temperatures of urban and rural areas. This has been further sub-divided into two types:

- **Urban Boundary Layer UHI:** The air above an urban area in the UBL is warmer compared to air at a similar height above the rural area.
- **Canopy Layer UHI:** This occurs close to the ground surface, where people and the built environment exist, extending from the ground surface to the topmost level of trees and roofs.

The different UHI types share the same fundamental energy balance origins. Each UHI type is closely linked to the vertical structure of the urban area and the atmosphere above it. Differences between the types reflect the scale and medium (air/solid) under investigation.

Canopy layer urban heat islands are the most commonly observed and are often the ones referred to in general discussions of urban heat islands. Atmospheric urban heat islands are often weak during the late morning and throughout the day and become more pronounced after sunset due to the slow release of heat from urban

⁴ Oke et.al.2017

⁵ Stewart et al., 2021

infrastructure. The timing of this peak, however, depends on the properties of urban and rural surfaces, the season, and prevailing weather conditions.

This study focuses on Surface Urban Heat Islands (SUHI). These heat island types differ in the ways they are formed, the techniques used to identify and measure them, their impacts, and, to some degree, the methods available to mitigate them. The table below summarizes the basic characteristics of each type of heat island.

Table 2 : Characteristics of Surface and Atmospheric Urban Heat Islands

Feature	Surface UHI	Atmospheric UHI
Temporal Development	Present at all times of the day and night Most intense during the day and in the summer	May be small or non-existent during the day Most intense at night or predawn and in the winter
Peak Intensity	More spatial and temporal variation: Day: 10 to 15°C Night: 5 to 10°C	Less variation: Day: 1 to 3°C Night: 7 to 12°C
Typical Identification method	Remote Sensing (Indirect Measurement)	Through fixed weather stations or mobile traverses

3.4 Impact of UHI

Elevated temperatures in an urban setup due to the formation of Urban Heat Islands, particularly during the summer, can affect the environment and the quality of life. While some heat island impacts may be positive, most impacts are negative. Among these, the two major impacts are discussed below.

3.4.1 Increased Heat Stress & Health Risk

The most severe consequence of the Urban Heat Island (UHI) effect is the significant increase in heat stress and public health risk. On a clear, calm night, a city's temperature can go up by 4 to 12 degrees centigrade due to the UHI effect. This phenomenon is particularly problematic for vulnerable groups, which include, Children, Adults with certain pre-existing medical conditions and outdoor workers. The increase in nighttime temperature due to the UHI has critical health implications:

- **Poor Sleep Quality:** Elevated temperatures disrupt sleep, preventing the body from recovering from the day's heat.
- **Compounding Risk:** Consecutive hot nights pose a greater health risk than hot days, as the lack of thermal relief leads to cumulative physiological stress.
- **Increased Mortality:** Even moderately high temperatures are strongly associated with increased all-cause population mortality, a risk significantly amplified during heat waves.

3.4.2 Increased Energy Consumption & Demand

The increased intensity of the Urban Heat Island (UHI) directly translates into a significant surge in the demand for summer cooling. This energy demand is not uniform; it varies both **vertically** (across building heights) and **horizontally** (across different land-use zones) within the city boundary.

Elevated summertime temperatures place substantial pressure on the electricity grid during peak periods, which typically occur on hot, summer weekday afternoons when both offices and homes are running cooling systems at maximum capacity.

- **Quantitative Impact:** The peak urban electric demand increases by 1.5 to 2 percent for every 1-degree Fahrenheit in summertime temperature.

- **Risk of Overload:** During extreme heat events, which are exacerbated by urban heat islands, the resulting high demand for cooling can overload power grid systems.

3.5 Measures to Minimise the Effect

While the factors influencing the UHI are well-established and have been discussed in the above section, it is equally important to formulate strategies to reduce urban heat islands. In this study, we briefly discuss a few internationally accepted measures. Detailed calculation, outcomes, evidence, and cost-benefit analysis are beyond the scope of this study. Below are a few direct and implementable measures that can lead to the reduction in the UHI effect.

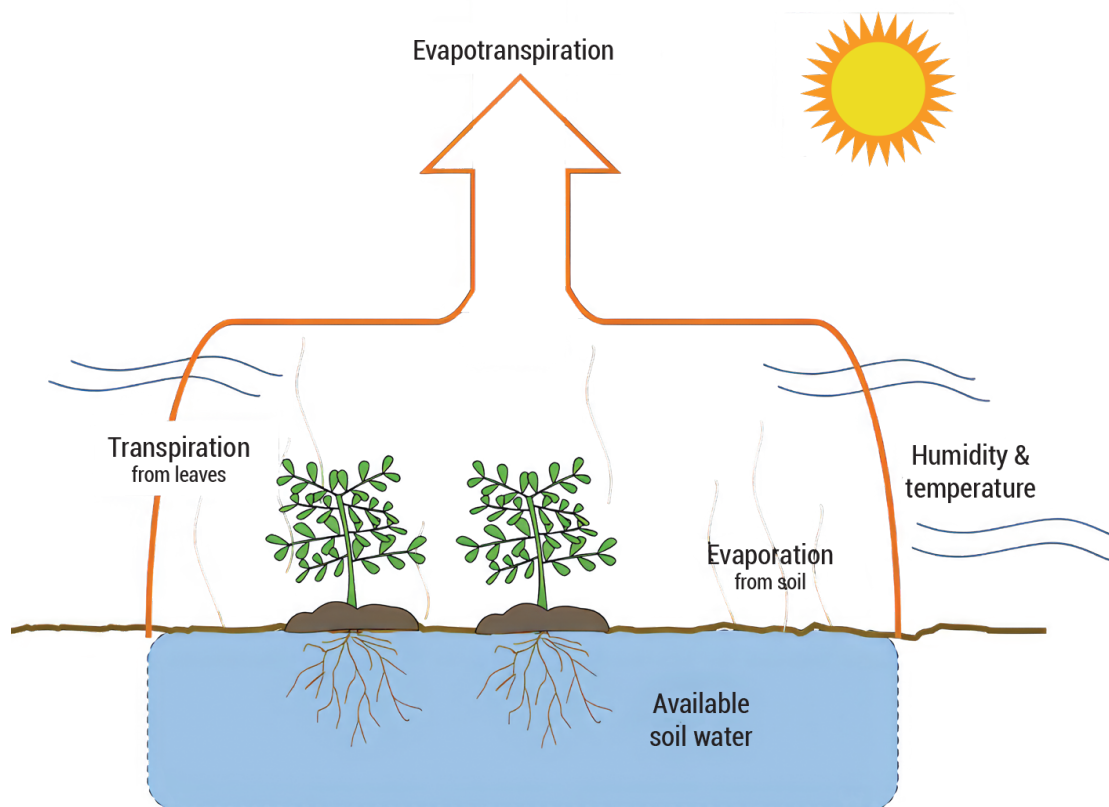
3.5.1 Increase vegetative cover:

Increasing the amount of tree and vegetation cover is one of the most effective strategies for mitigating the Urban Heat Island (UHI) effect. Trees and vegetation are most useful when planted in strategic locations across the urban landscape.

The planting of trees and increasing vegetation reduces UHI intensity through two main mechanisms:

- **Shading (Surface Cooling):** Leaves and branches create shading, which significantly reduces the amount of solar radiation that reaches the area below the canopy of a tree or plant. This keeps pavements and building surfaces cooler.
- **Evapotranspiration (Air Cooling):** Trees and vegetation absorb water through their roots and release it as vapor through their leaves (a process called transpiration). Evapotranspiration cools the surrounding air by utilizing ambient heat to evaporate the water.

Figure 8 : Evapotranspiration from a vegetative area



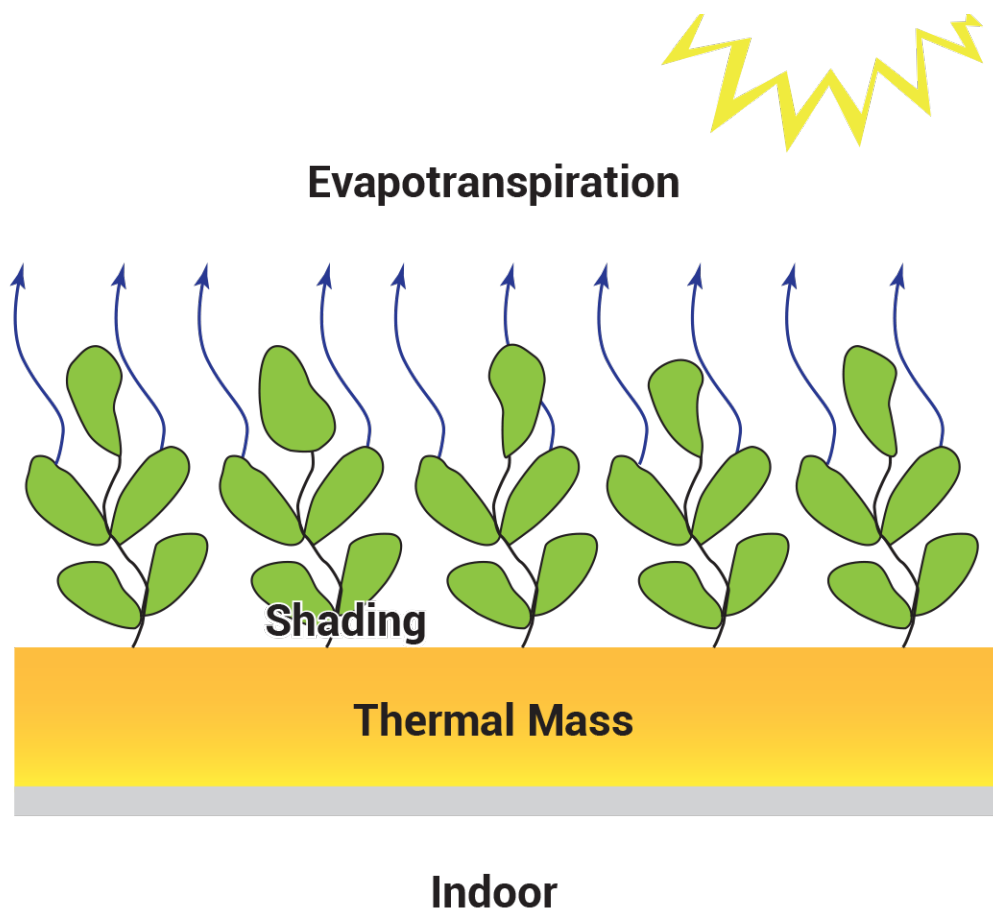
3.5.2 Green Roofs

Green roofs are an effective emerging technology for mitigating Urban Heat Islands (UHI). A green roof is essentially a vegetative layer (plants and growing medium) established directly on a rooftop. This technology helps reduce urban temperatures through the same mechanisms as natural landscapes.

1. **Shading:** The vegetation and soil provide shade to the roof surface, directly reducing the amount of solar radiation absorbed by the building material.
2. **Evapotranspiration:** The plants remove heat from the air as they release water vapor through evapotranspiration, actively cooling the immediate environment.

These two mechanisms combined significantly reduce both the roof surface temperature and the surrounding air temperature.

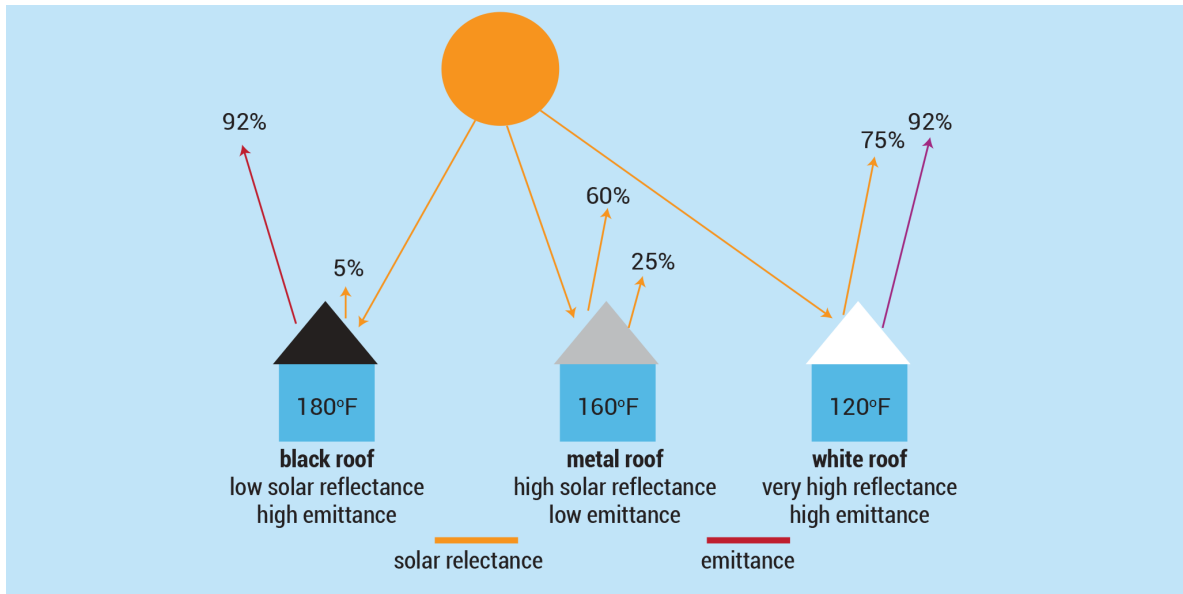
Figure 9 : Cooling effect by green roof.



3.5.3 Cool Roofs

Cool roofs are a straightforward and established technology that helps mitigate the Urban Heat Island (UHI) effect, which is partly caused by the cumulative heat from countless hot conventional roofs across a city. Cool roofing products are made of materials that are **highly reflective** (high albedo) and **highly emissive** (shed heat easily). These properties allow cool roofs to remain significantly cooler than traditional dark materials:

Figure 10 : Solar reflectance and thermal emittance for different type of roof surface.



3.6 Global Warming vs UHI

Though both **Global warming** and **UHI** are warming phenomena, they are quite different in their warming mechanisms. While the **Urban Heat Island (UHI)** is a local phenomenon where a city is significantly warmer than its surrounding rural areas due to factors like paved surfaces and lack of vegetation, **Global warming** is the long-term rise in Earth's average temperature, mainly due to the increase in the concentration of **GHG gases** in the atmosphere.

Urban heat islands are caused by development and the changes in the radiative and thermal properties of urban infrastructure, as well as the impacts buildings can have on the local microclimate (for example, tall buildings can slow the rate at which cities cool off at night). Heat islands are influenced by a city's geographic location and by local weather patterns, and their intensity changes on a daily and seasonal basis.

Local climate changes resulting from urban heat islands fundamentally differ from global climate changes in that their effects are **limited to the local scale** and decrease with distance from their source. Global climate changes, such as those caused by increases in the sun's intensity or greenhouse gas concentrations, **are not locally or regionally confined**.

Global warming is an average increase in the temperature of the atmosphere near the Earth's surface and in the lowest layer of the atmosphere, which can contribute to changes in global climate patterns. Global warming can occur from a variety of causes, both natural and human-induced. In common usage, "**global warming**" often refers to the warming that can occur as a result of increased emissions of greenhouse gases from human activities. Global warming can be considered part of global climate change, along with changes in precipitation, sea level, etc.

Global warming **can exacerbate the UHI** effect by making heat waves more intense and frequent. This creates a feedback loop where cities become hotter due to global warming, and the UHI effect, in turn, contributes to further local warming and can worsen climate change impacts.

3.7 UHI Study in India

Various UHI studies have been carried out for many of India's largest cities. The list is given below in the table. In most of these studies, rapidly changing land-use patterns and increasing urban density are the main causes leading to the Urban Heat Island effect.

Table 3 : A review of various UHI Studies carried out in different cities of India⁶

Sr. No.	Study Location	Focus of the Study	Methods	Issues	Findings	Authors
1	Delhi NCR	Study of temperature trends in four cities of the NCR region	Study of seasonal and annual temperature trends and anomalies through trend analysis	Urbanization patterns affecting annual and seasonal temperatures of various cities	Increased night time temperature that indicate contribution of changing land-use pattern and anthropogenic heat	(22)
2	New Delhi	Summertime UHI over Delhi and its relationship with aerosols	Remote sensing and GIS to measure surface temperature	Thermal contrast between central and surrounding parts of Delhi	Thermal contrast varies from 4-7°C in April to 7-10°C in May-June.	(23)
3	Mumbai	Analysis of UHI in relation to NDVI, comparison between Delhi and Mumbai	Thermal Mapping through LANDSAT Images	Changing land-use patterns and green cover	UHI was found to be strong in Mumbai compared to that in Delhi	(24)
4	Pune	Structure of heat and moisture islands	Mobile Survey for 170 locations in the City	Influence of topography and morphological variation and katabatic winds	Strong heat and moisture islands at night	(25)
5	Bangalore	Urban Growth pattern in Bangalore and its impact on UHI	Remote Sensing and Field data through GIS	Increase in built-up area affecting water-bodies and green-cover	Increase of 2-2.5 during the last decade, 76% decline in vegetation cover and 79% decline in water bodies.	(2)
6	Bangalore	Minimizing UHI and Imperviousness factor	Field measurements and simulation	Effect of urban geometry, water bodies and green cover	0.8-2°C rise in mean air temperature, higher night temperatures observed in dense commercial areas. Cool roofs and green roofs facilitate 16.9% and 11.8% saving in cooling load	(1)
7	Guwahati	Summertime UHI in urban and sub-urban pockets	Half-hourly temperature data measurements through fixed weather stations, mobile measurements	Urban sprawl	Urban Heat island intensity of 2.12°C during day-time and 2.29°C during night-time was found	(26)
8.	Chennai	Impact of built geometry and urbanization	Air temperature and relative humidity measurements	Urban density correlation between urban and rural environments	3.6°C in summer and 4.1°C in winter	(27)
11	Vishakhapatnam	UHI Intensities and negative impacts	Field Surveys, Measurement of Surface Temperature	Topography and urban morphology	Intensity of heat island varies from 2°C to 4°C and intensity is high during winter season compared to Summer and monsoon seasons.	(28)
12	Jaipur	Temporal and Spatial variations of UHI	Satellite Data and GIS Technique for assessment of Surface UHI	Changes in Land-use/Land-cover	13.12% of the city is under moderate UHI potential area and 0.97% is under high UHI potential area	(29)
13	Bhopal	Mitigation of thermal pollution to enhance urban air quality	Identification of UHI through Landsat TM Band	Increased built up area, reducing green cover.	Old city has very prominent UHI due to heavy pollution and emission of hot gasses	(30)

4 Approach & Methodology

This study uses high-resolution remote sensing data to evaluate the UHI effect in relation to landscape dynamics and to assess the spatial interrelationships in heterogeneous urban landscapes at micro-levels. In this study, we have followed the approach provided in the below figure. Details on the data source, equations, and modeling approach have been discussed subsequently in this section.

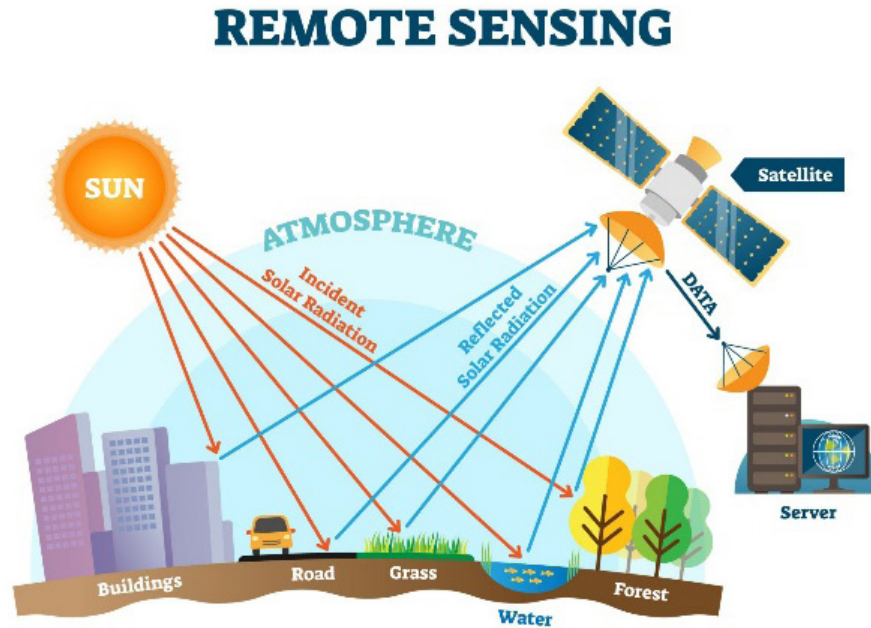
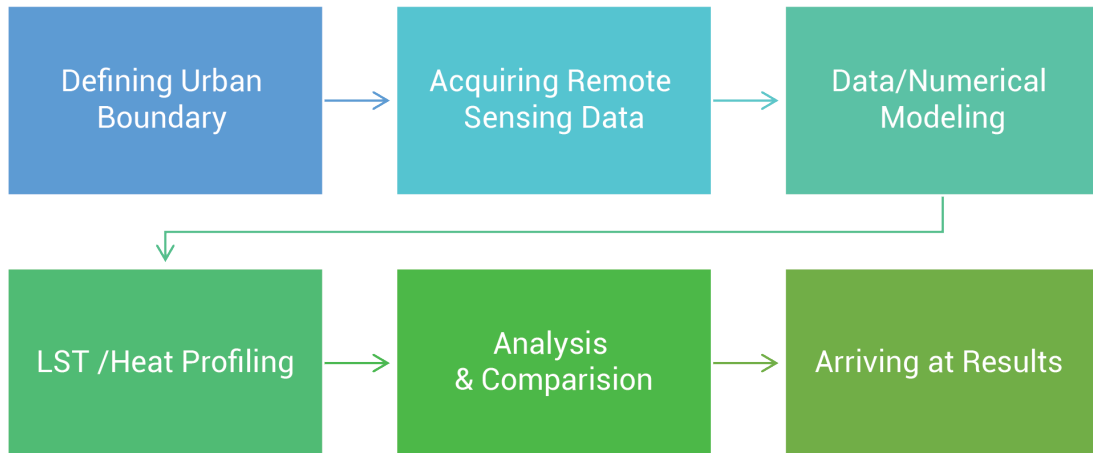


Figure 11 : Approach & Methodology



4.1 Defining Urban Boundary

Though local city governments (Municipal Corporations) define the municipal boundary, which mainly dictates the urban-rural divide, unorganized growth is always a problem that keeps expanding the city boundary continuously, and sometimes it is very difficult to demarcate the urban-rural boundary.

For the purpose of this study, we have considered PIN codes (sourced from Census 2011 data) as the main indicator for defining the urban boundary. We also considered the UN DEGURBA Method, which uses high-resolution satellite imagery and population density to define categories such as cities, towns, and rural areas.

Figure 12 : The UN DEGURBA method of classification⁷.

THE UN DEGURBA METHOD OF CLASSIFICATION

		Minimum population size of the cluster of cells (settlement size)			No minimum population size criterion (not an entity)
		≥ 50,000	50,000 -5,000	5,000 -500	
Population density of cells, inhabitations per km ²	≥ 1,500	Urban Centre	Dense Urban Cluster	Rural Cluster	
	300-1,500		Semi-Dense Urban Cluster		Suburban or Peri Urban grid cells
	300-50				Low Density Rural grid cells
	<50				Very Low Density Rural grid cells

Source : Applying the Degree of Urbanisation - A methodological manual to define cities, towns and rural areas for international companies - 2021 edition

4.2 Remote Sensing Data

UHI can be quantified with outdoor ambient air and Land Surface Temperature (LST) from data obtained from meteorological stations, in situ campaigns with portable thermal cameras, and remote sensing data. Though the lack of meteorological stations at disaggregated levels makes it difficult to estimate the UHI with air temperature. In this context, thermal spatial data acquired through space-borne sensors at regular intervals provides an effective way to monitor LST, as it indicates the surface energy balance, which directly affects the urban environment.

From the remote sensing data, it is possible to compute the Land Surface Temperature (LST), a relevant variable that can be used to determine the radiative load of the earth's surface. It conducts longwave radiation and turbulent heat fluxes between the earth and the atmosphere; that is, it is a variable in the physics of local and global surface processes, linked to radiative, latent, and sensible heat fluxes.

The LST, also known as radiometric or "skin" temperature, refers to the direct measurement of the earth's surface temperature. Unlike the measurements taken by meteorological stations that record the temperature near the surface, the LST allows for a more detailed scale of analysis. In areas of dense vegetation, it will represent the temperature of the leaves of the canopy; in areas of sparse vegetation, the temperature will correspond to the whole canopy, subsurface (limbs, branches, etc.), and the ground surface; and on bare ground, it will correspond to the temperature of the top (few micrometres) from the ground surface.

The most applied satellites/sensors to study LST are Moderate-resolution sensors (ASTER, MODIS, etc.) and high-resolution sensors (Sentinel-2, Landsat-8/9, etc.). Spatial data from different satellites comes with a trade-off between spatial and temporal resolution. While MODIS and AVHRR data, with low spatial and high temporal resolution thermal bands, are appropriate for studying large areas, data from **LANDSAT** and **ASTER** are appropriate for estimating the UHI at a regional scale.

Some studies adopt more than one of the above-mentioned data sources to complement the information, both at the atmospheric and surface levels (UHI and SUHI), respectively. While selecting relevant data sources, we also analysed 579 relevant research papers that were published between the year 2000 and 2020 across the globe. We found that 317 (approximately 55%) out of the 579 research papers have used **LANDSAT exclusively**, and 396 (approximately 68%) have used a **combination of LANDSAT and MODIS** for UHI study, analysis, and arriving at results.

⁷ Applying the Degree of Urbanisation-A methodological manual to define cities, towns and rural areas for international comparisons, 2021 edition

In this study, we have used **LANDSAT-9** and **MODIS** data as the thermal sensor source for temporal and spatial analysis, respectively.

Table 4 : Most used Satellite/ Sensors to obtain LST data.

Satellite	Exclusive use		Combination	
	No of Papers	Percentage (%)	No of Papers	Percentage (%)
Landsat	317	54.75%	396	68.39%
MODIS	103	17.79%	185	31.95%
ASTER	15	2.59%	36	6.22%
NOAA/AVHRR	1	0.17%	7	1.21%
METEOSAT	-	-	3	0.52%

4.3 Data/Numerical Modeling

LST can be used to retrieve relevant climate variables, as evapotranspiration, water-stress vegetation, soil moisture, and thermal inertia. Its application is vast, being effective in UHI research and global warming.

In remote sensing, the LST is recovered by estimating the emitted surface radiance, obtained by the atmospheric correction in the radiance sensor, and inverting the Planck function, considering the effects of emissivity variation. To compute the LST, it is necessary to process the two levels of data: NIR and RED bands from level 1 and the thermal band from level 2. The standard processing has been presented below.

The conversion from Digital Number (DN) to Top of Atmosphere (ToA) spectral radiance ($L\lambda$)—physical quantity defined as the radiant flux in each direction, considering a surface normalized concerning surface area and unit solid angle. It has been calculated according to Equation (1) using the thermal band.

$$L\lambda = MLQ_{cal} + AL$$

Where

$L\lambda$ is the ToA spectral radiance (Watts/(m² * srad * μm));

ML is the band-specific multiplicative rescaling factor from the metadata

AL is the band-specific additive rescaling factor from the metadata

and the quantized and calibrated standard product pixel values (DN) is Q_{cal} , i.e., the thermal band.

ToA spectral radiance ($L\lambda$) is converted to Top of Atmosphere brightness temperature (Kelvin) using the below equation.

$$TK = K_2 / (\ln(K_1 / L\lambda) + 1) \dots \dots \dots 2$$

Where

TK is the Top of Atmosphere brightness temperature (K);

$L\lambda$ is TOA spectral radiance (Watts/(m² * srad * μm));

K_1 and K_2 are band-specific thermal conversion constants from the metadata (K_1 or $K_2_constant_band_x$, where x is the thermal band number).

Subsequently, the result is converted into Temperature in Celsius TC , according to the below equation.

$$TC = TK - 273.15 \dots \dots \dots 3$$

Where

TC is Top of Atmosphere brightness temperature ($^{\circ}C$).

The thermal band includes the Emissivity (E) of the soil and vegetation.

Although it is possible to deduce radiance and temperature values, it is necessary to include emissivity in the computation for the generation of the LST, using the NIR and RED bands. For this purpose, first, the Normalized Difference Vegetation Index ($NDVI$) is calculated according to the below equation.

$$NDVI = (NIR - RED) / (NIR + RED) \dots\dots\dots 4$$

Where

NIR is the near-infrared satellite band and RED is the red satellite band.

This result is used to obtain the Proportion of Vegetation (PV) as below.

$$PV = ((NDVI - NDVI_{min}) / (NDVI_{max} - NDVI_{min}))^{1/2} \dots\dots\dots 5$$

Where

$NDVI_{min}$ and $NDVI_{max}$ are the minimum and maximum values obtained in the $NDVI$ calculation, respectively.

The emissivity (E) is estimated by below equation

$$E = 0.004 * PV + 0.986 \dots\dots\dots 6$$

Finally, the LST was computed according to the below equation

$$LST = (TC / (1 + (\lambda * TC / \rho) * \ln(E))) \dots\dots\dots 7$$

Where

LST is the temperature, with correction by emissivity ($^{\circ}C$)

TC is the temperature of the brightness at the sensor ($^{\circ}C$)

λ is the wavelength of the emitted radiance

E is the emissivity

ρ is which is deduced from below equation

$$\rho = h * c / \sigma = (1.438 \times 10^{-2} \text{ } mk) \dots\dots\dots 8$$

Where

σ is the Boltzmann constant ($1.38 \times 10^{-23} \text{ } J/K$),

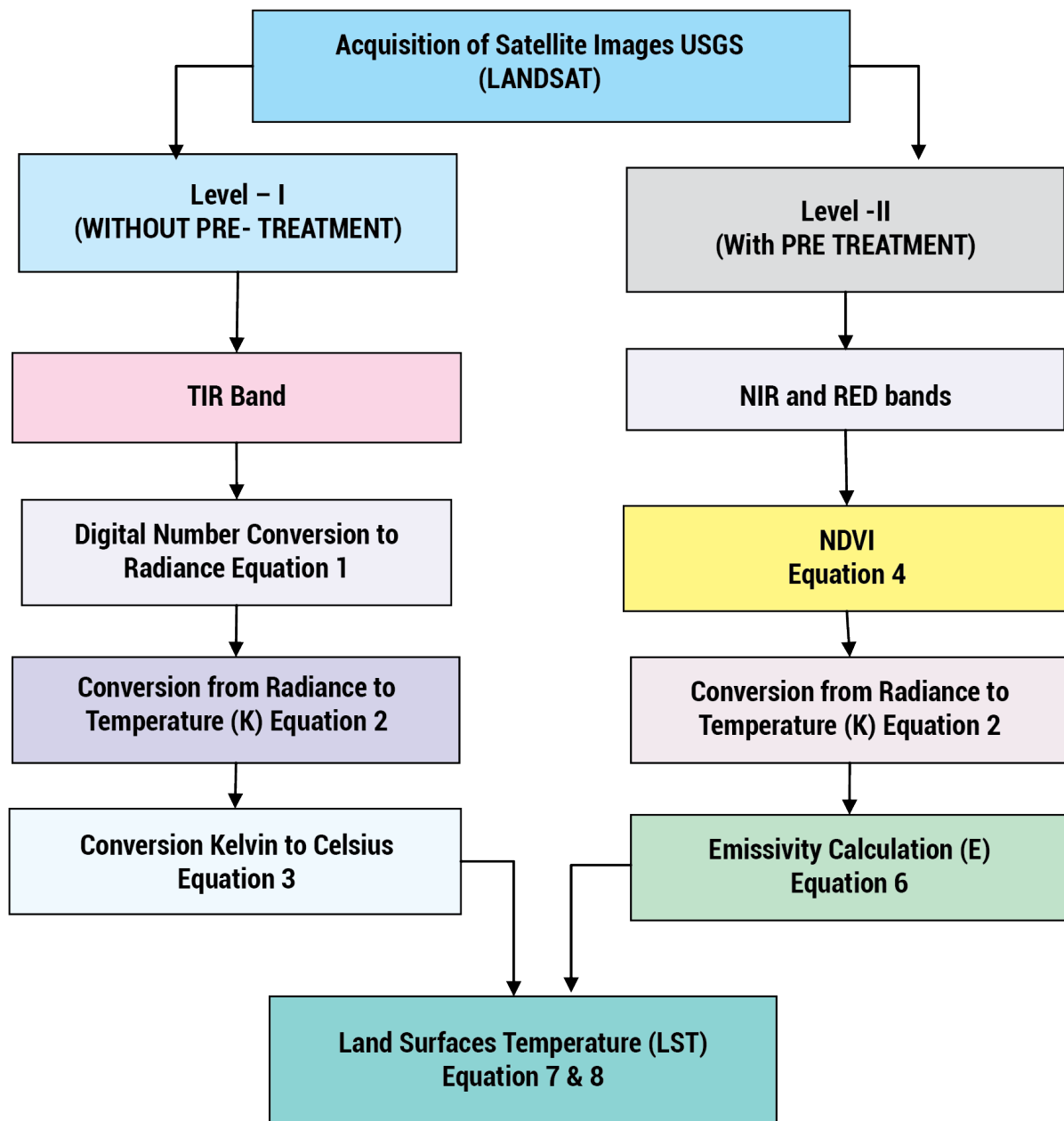
h is Planck's constant ($6.626 \times 10^{-34} \text{ } Js$),

c is the speed of light ($2998 \times 10^8 \text{ } m/s$).

NDBI value has been calculated as a ratio between the shortwave infrared (SWIR) and near-infrared (NIR).

$$NDBI = (SWIR - NIR) / (SWIR + NIR)$$

Figure 13 : Steps for preparing surface temperature map



5 Analysis & Results

To accurately measure the SUHI's amplitude, our study utilized high-resolution thermal data from **Landsat-9** and **MODIS**. The Land Surface Temperature (LST) values were derived using a robust methodology to ensure quality and confidence:

The study employed Land Surface Temperature (LST) data to characterize the horizontal temperature gradient across each urban area in correlation with the NDBIx (NDVI) and Population Density.

Spatio-Temporal Data Coverage

- **Temporal Range:** A comprehensive period from **1980 to 2024** analysed for each city.
- **Data Profiled:** LST profiling was conducted for the below parameters:
 - Maximum Temperature- T_{max}
 - Minimum Temperature- T_{min}
 - Mean Temperature- T_{mean}
 - Relative Humidity-RH
 - Wet-Bulb Globe Temperature-WBGT
- **Spatial Resolution:** All data parameters has been analysed and modelled on a consistent grid size of **5km*5 km**.

5.1 Results & Visualization

Our analysis clearly illustrates the concerning trend of escalating heat risk within the city boundaries over the years. This change is characterized by two critical observations.

- **Significant Increase in WBGT:** There is a clear and substantial rise in the Wet Bulb Globe Temperature (WBGT) over the study period. Since WBGT is the most accurate measure of human heat stress, this increase signals a direct and growing risk to public health and outdoor worker safety.
- **Urban vs. Rural Temperature Differential:** The analysis shows a significant difference between urban and rural temperatures. This means that the urban core is becoming disproportionately warmer relative to its surroundings over time.

The collective result of **SUHI** is **presented** below in the table and graphs. Our analysis **shows** that the urban–rural temperature difference has been found in almost all cities **that** have been considered for this study. The amplitude, **i.e., the** difference in urban vs. rural **LST**, is **maximum for Jamshedpur** and **minimum for Hazaribagh and Dhanbad**. The decadal growth of both rural versus urban temperature and **WBGT** is highest for Jamshedpur while lowest for Ranchi.

Table 5 : SUHI data for five cities- Jharkhand

City Name	Temperature difference (Range) Rural VS Urban (2024)	Difference in WBGT 1980 VS 2024 (Hottest Day of the Year)	Decadal Growth in WBGT>32°C (1980 to 2020)
Ranchi	1.5°C-2°C	30.6 °C -30.6°C	0.00 Days/decade
Jamshedpur	1.5°C-2°C	31.5°C -33.1°C	1.88 Days/decade
Hazaribagh	0.5°C	29.7°C -30.7°C	0.10 Days/decade

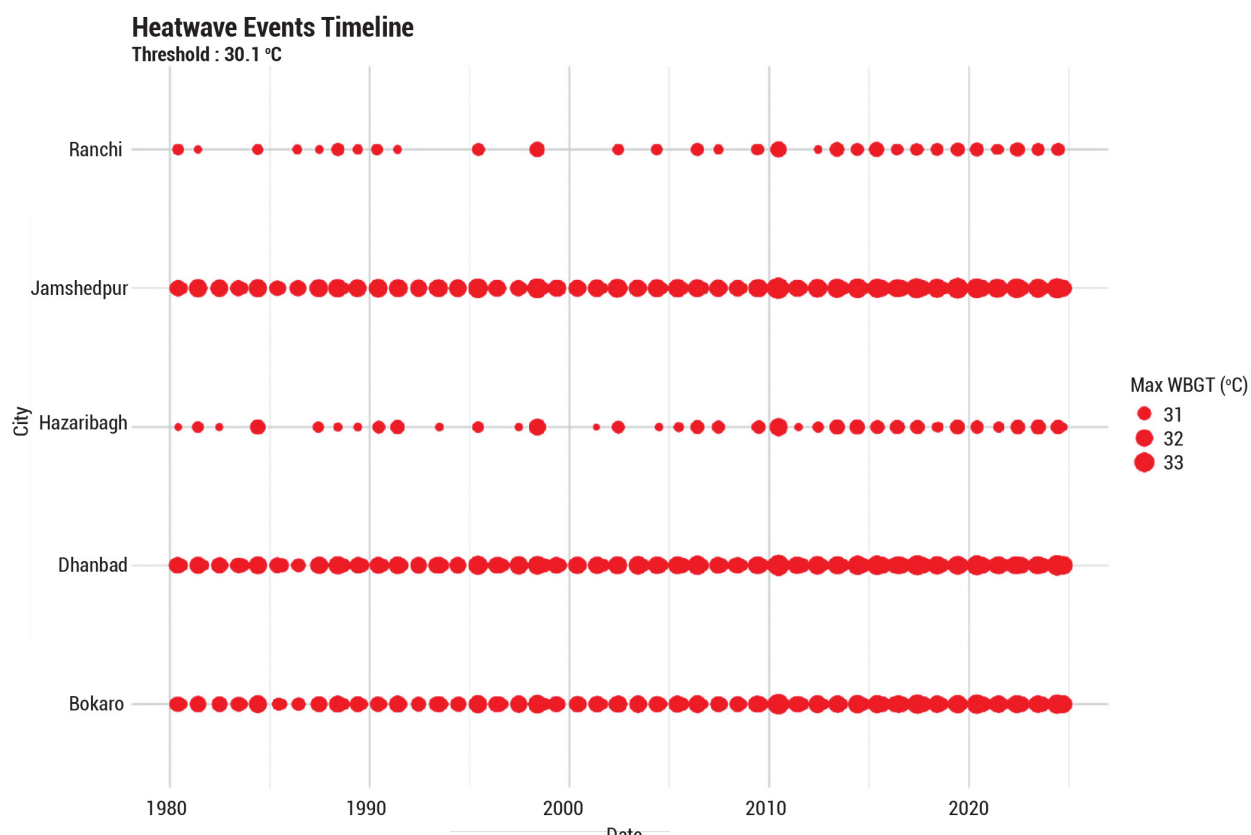
Bokaro	1.0°C	31.2°C-32.7°C	0.40 Days/decade
Dhanbad	0.5°C	31.6°C -33.2°C	0.55 Days/decade

The actual LST map derived from MODIS, with features overlaid isotherms (lines of equal land temperature), exhibits a crucial characteristic of the Urban SUHI phenomenon. The isotherm map captures the temperature gradient from the urban core out to the rural surroundings. The detailed results for each city (Ranchi, Jamshedpur, Hazaribagh, Bokaro, Dhanbad) have been presented in the below sections.

Along with the difference in LST, other thermal parameters like heatwave intensity and WBGT have been analysed for all five cities for the last 40 years. Our analysis shows that across all cities, there is a positive increase in extreme heat days per decade, indicating that urban landscapes in Jharkhand are experiencing a clear warming trend. This trend aligns with data for the entire state, which has already been analysed in our climate projection study.

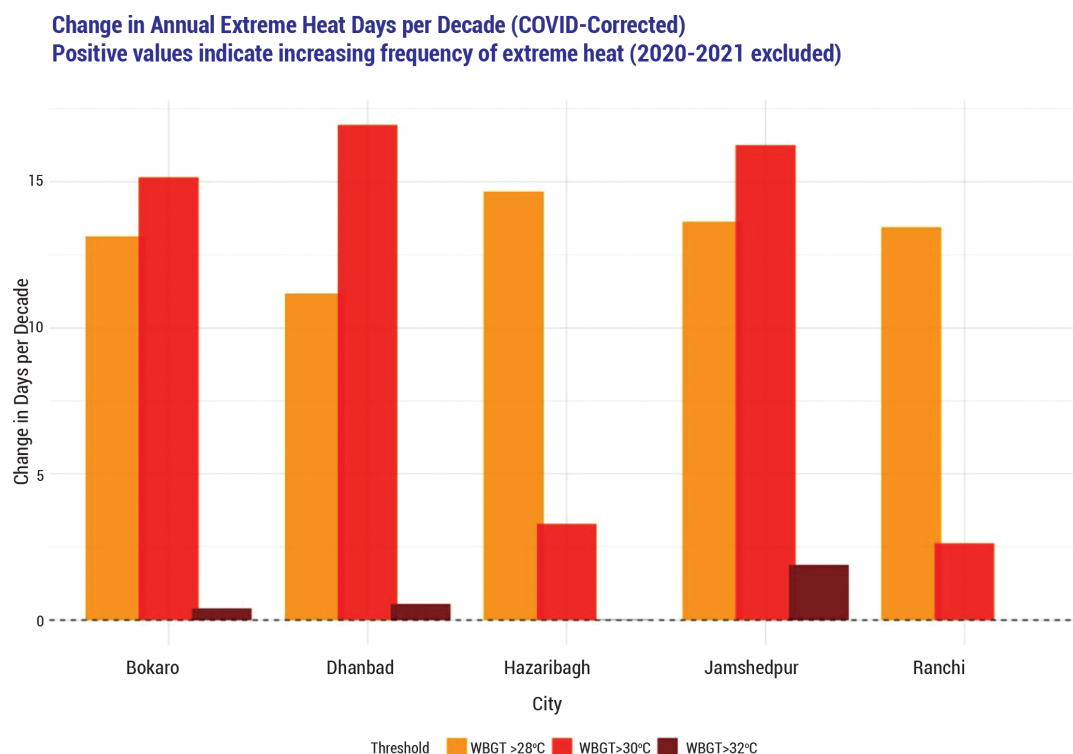
The below graph illustrates the decadal change in annual extreme heatwave events across five cities of Jharkhand—Bokaro, Dhanbad, Hazaribagh, Jamshedpur, and Ranchi. The changes are analysed using WBGT 30.1°C which represents levels of combined heat and humidity that can impact human comfort and health. The extreme heatwave event has increased most for Jamshedpur while least for Ranchi and Hazaribagh.

Figure 14 : Heatwave event timeline -All five cities



Jamshedpur and Bokaro exhibit the highest increase, with approximately 15 to 17 additional extreme-heat days per decade at WBGT > 30°C. Dhanbad follows closely with a rise of about 12 to 16 days, while Hazaribagh and Ranchi show moderate but still significant increases of 10 to 14 days per decade for WBGT > 28°C.. Even though the rise in WBGT > 32°C is lower, its increasing presence indicates an emerging risk of dangerously high heat levels during the peak summer season across all cities.

vFigure 15 : Change in extreme heat days per decade-all five cities.



5.2 Ranchi

Ranchi is the capital city of Jharkhand. Its average elevation is 651 m above sea level. The figure below shows the temperature profile of the city over the years. Our analysis provides a clear quantitative measure of the Surface Urban Heat Island (SUHI) intensity for Ranchi. On average, there is a temperature difference of approximately **1.5°C** between the dense urban setup and the rural area within the city boundary.

Table 6 :Result- SUHI -Ranchi

City Name	Temperature difference (Range) Rural VS Urban (2024)	Difference in WBGT 1980 VS 2024 (Hottest Day of the Year)	Decadal Growth in WBGT>32°C (1980 to 2020)
Ranchi	1.5°C-2°C	30.6 °C -30.6°C	0.00 Days/decade

Figure 16 : LST Profile map- Ranchi

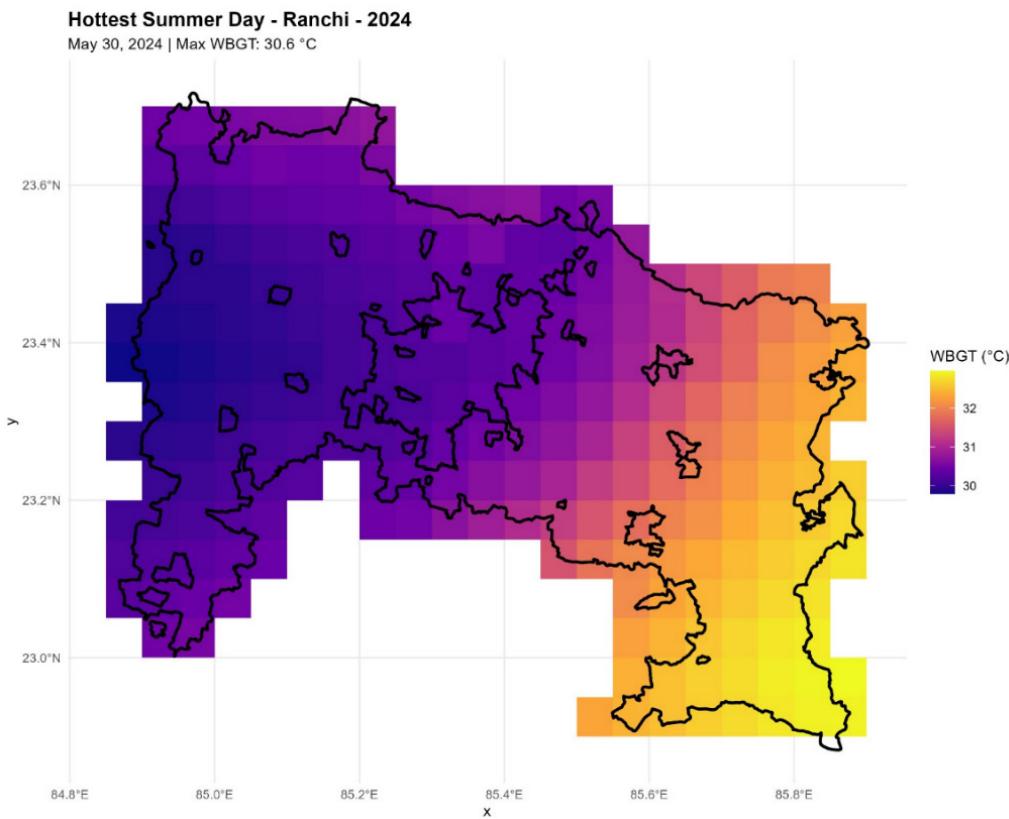
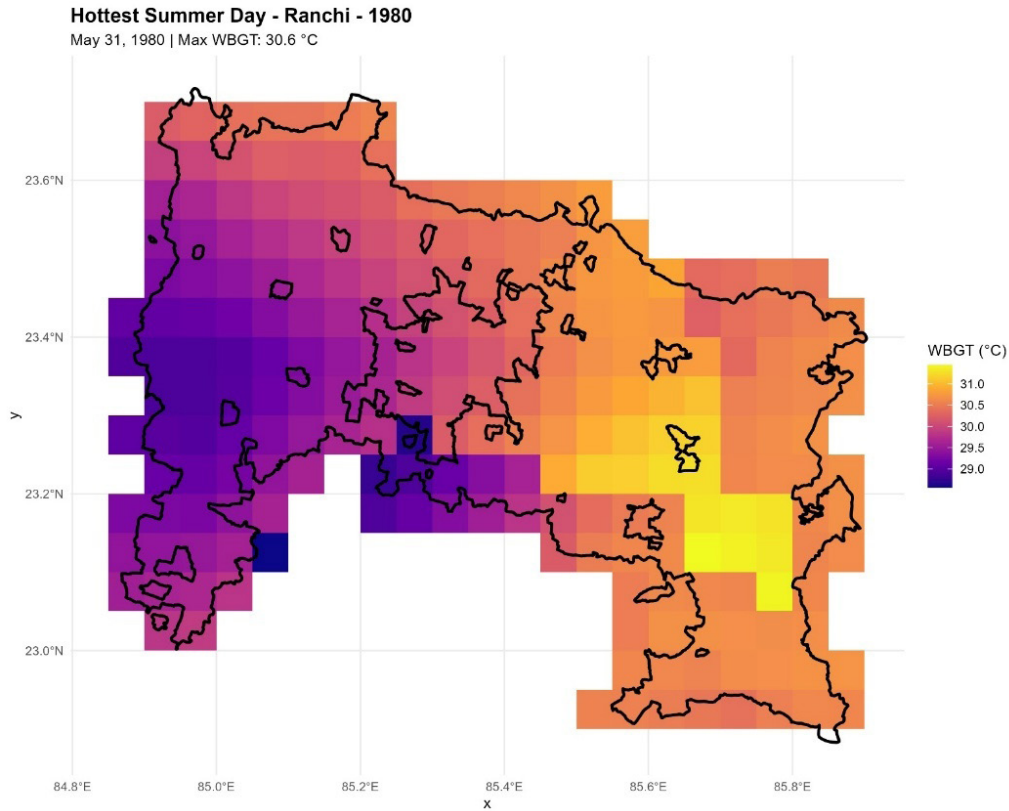
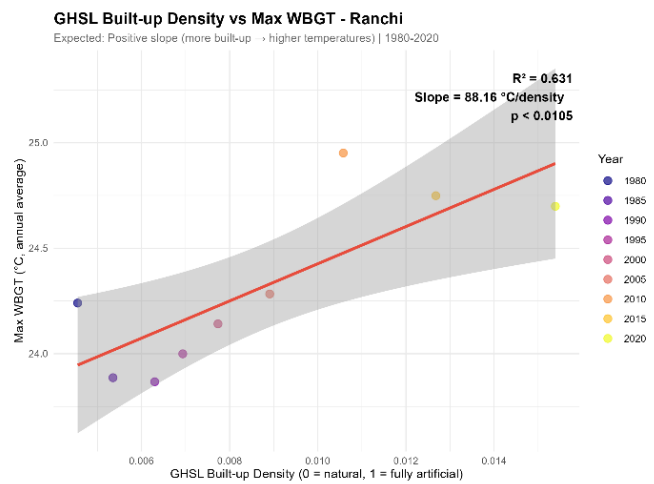
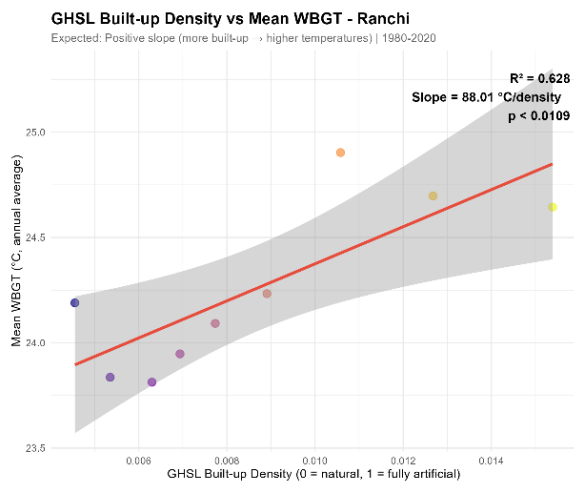
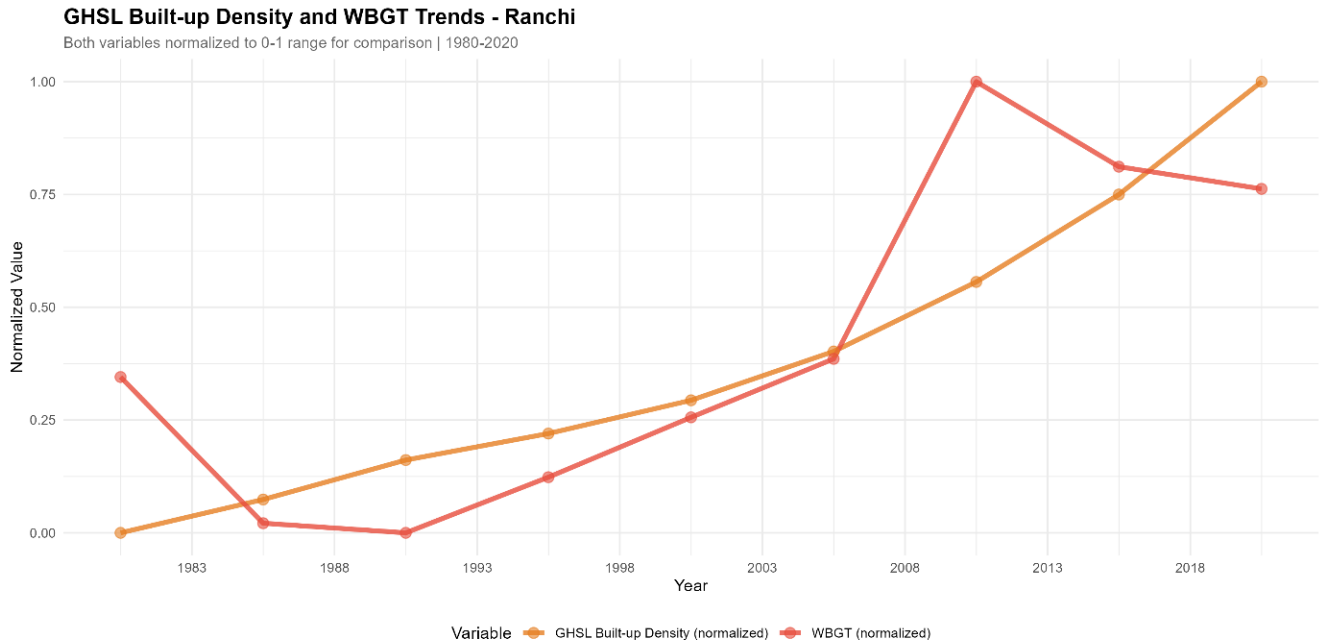


Figure 17 : Correlation and regression chart- Built-up area vs LST-Ranchi

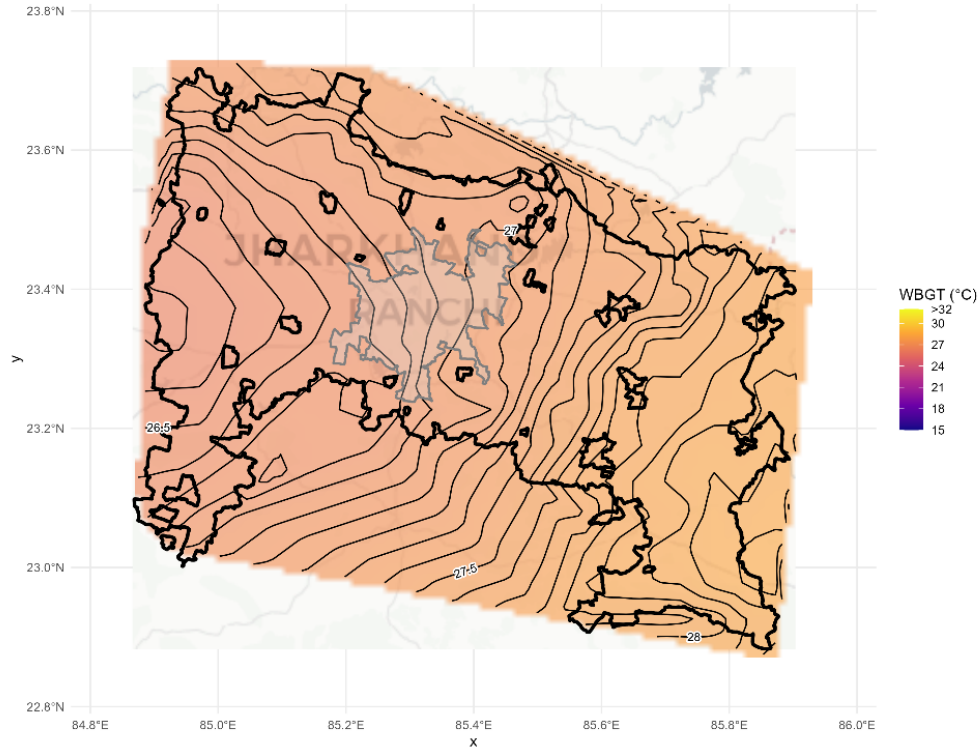


The analysis presented in the graphs clearly confirms a proportional relationship between the NDBI and LST. This confirms that as the built-up area within the city has increased over the last 40 years, the LST has increased correspondingly. The finding reinforces the core reason driving the SUHI effect, i.e., the replacement of natural cooling surfaces with dry, impervious, heat-absorbing materials.

Figure 18 : WBGT Isotherm- Summer- 1980 vs 2024-Ranchi

WBGT Isotherm Map - Ranchi - Summer 1980

Based on 92 days | Urban + Rural Areas | Seasonal Avg Mean WBGT: 26.1 °C



WBGT Isotherm Map - Ranchi - Summer 2024

Based on 92 days | Urban + Rural Areas | Seasonal Avg Mean WBGT: 26.2 °C

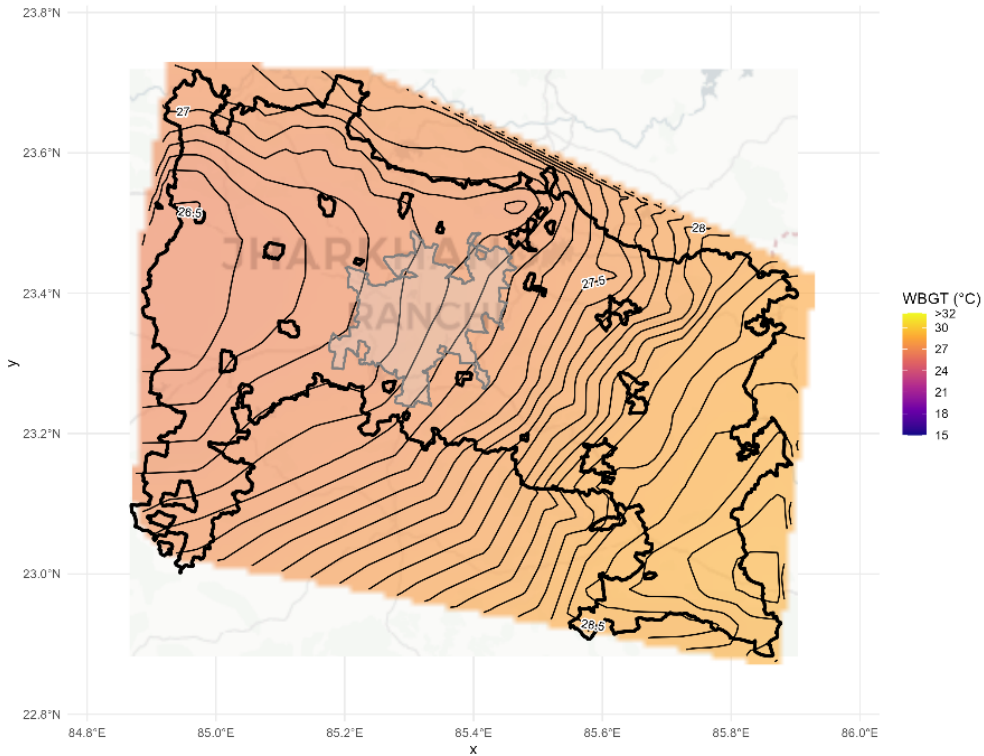
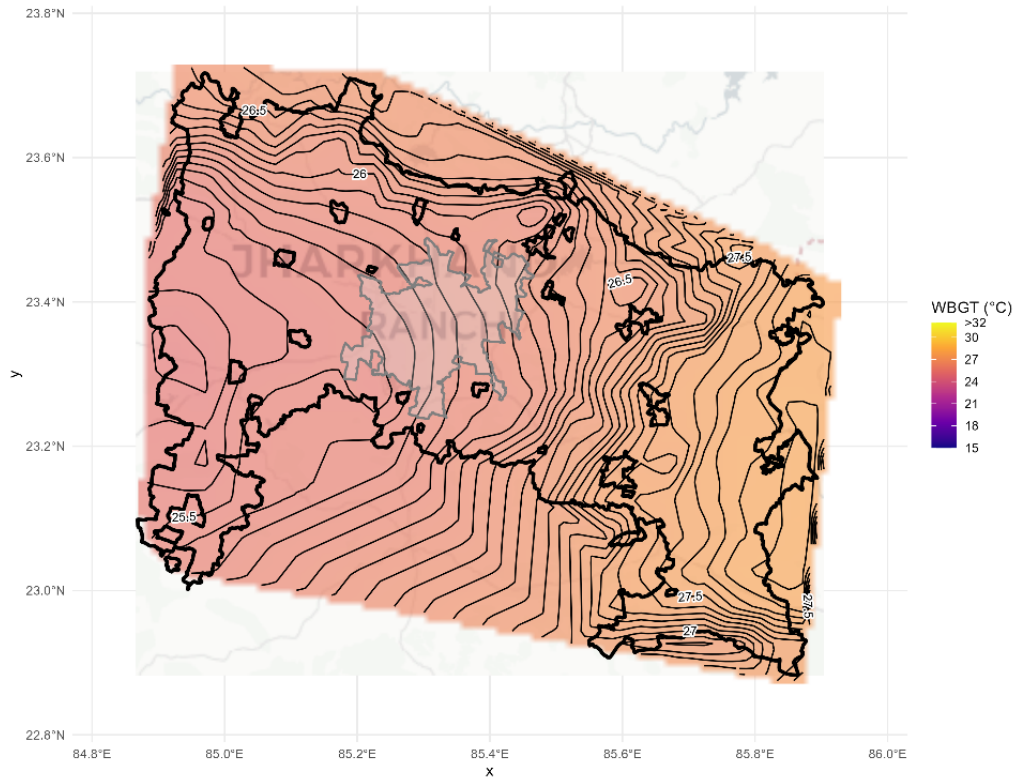


Figure 19 : WBGT Isotherm- Monsoon- 1980 vs 2024-Ranchi

WBGT Isotherm Map - Ranchi - Monsoon 1980

Based on 122 days | Urban + Rural Areas | Seasonal Avg Mean WBGT: 26 °C



WBGT Isotherm Map - Ranchi - Monsoon 2024

Based on 122 days | Urban + Rural Areas | Seasonal Avg Mean WBGT: 27.6 °C

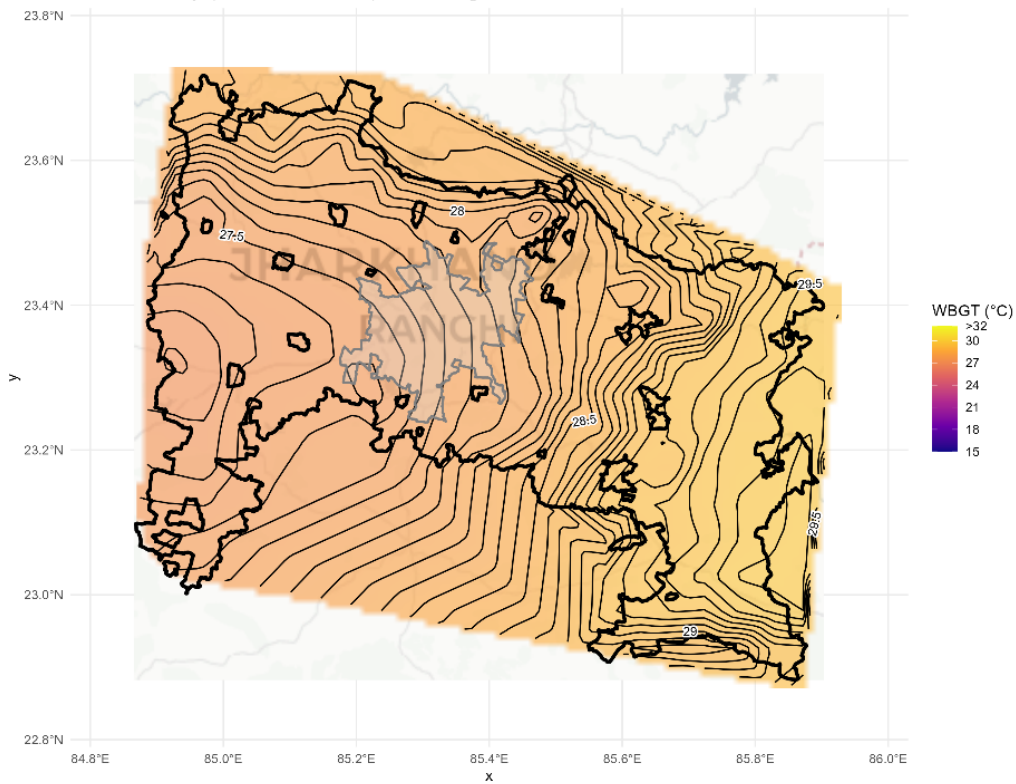
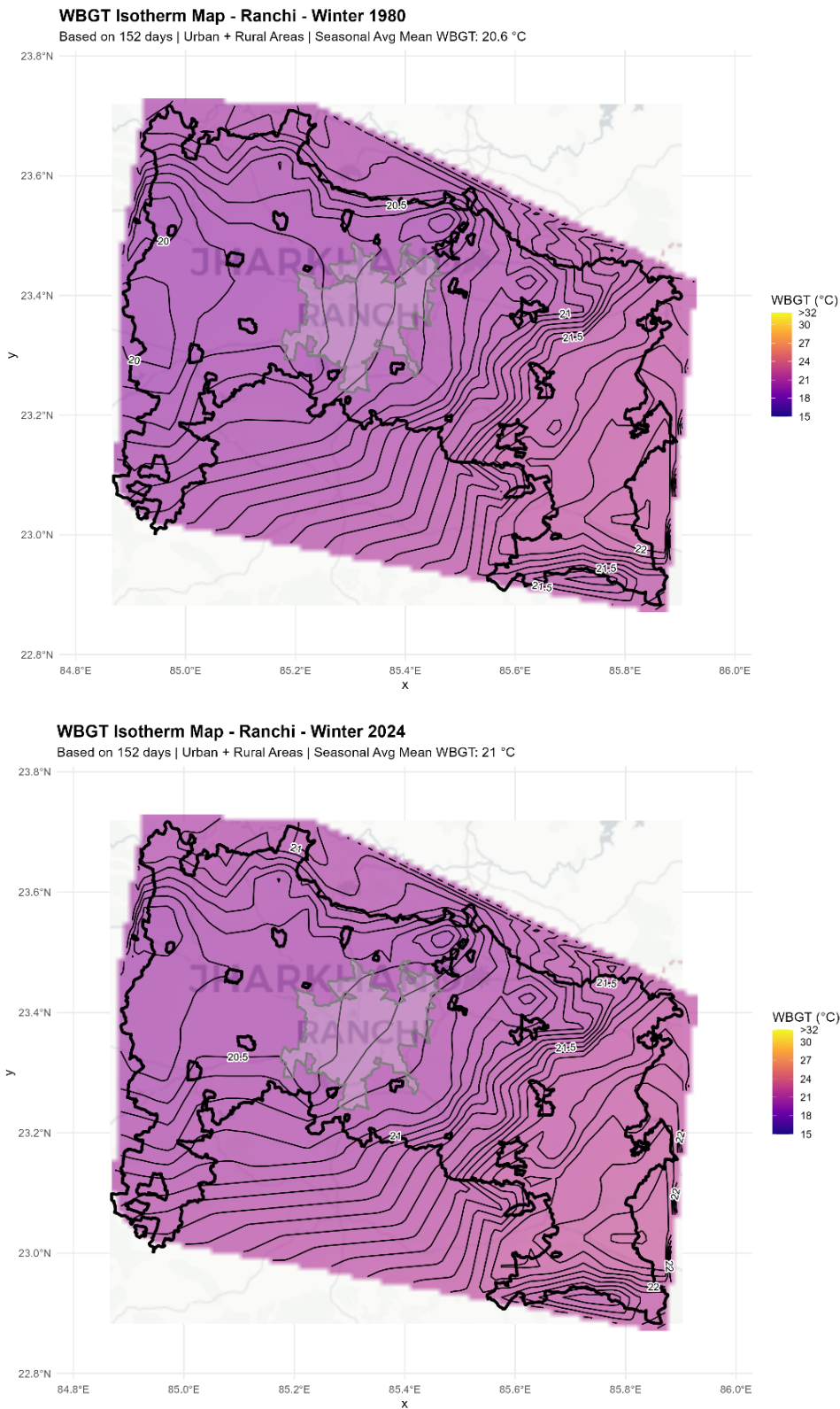
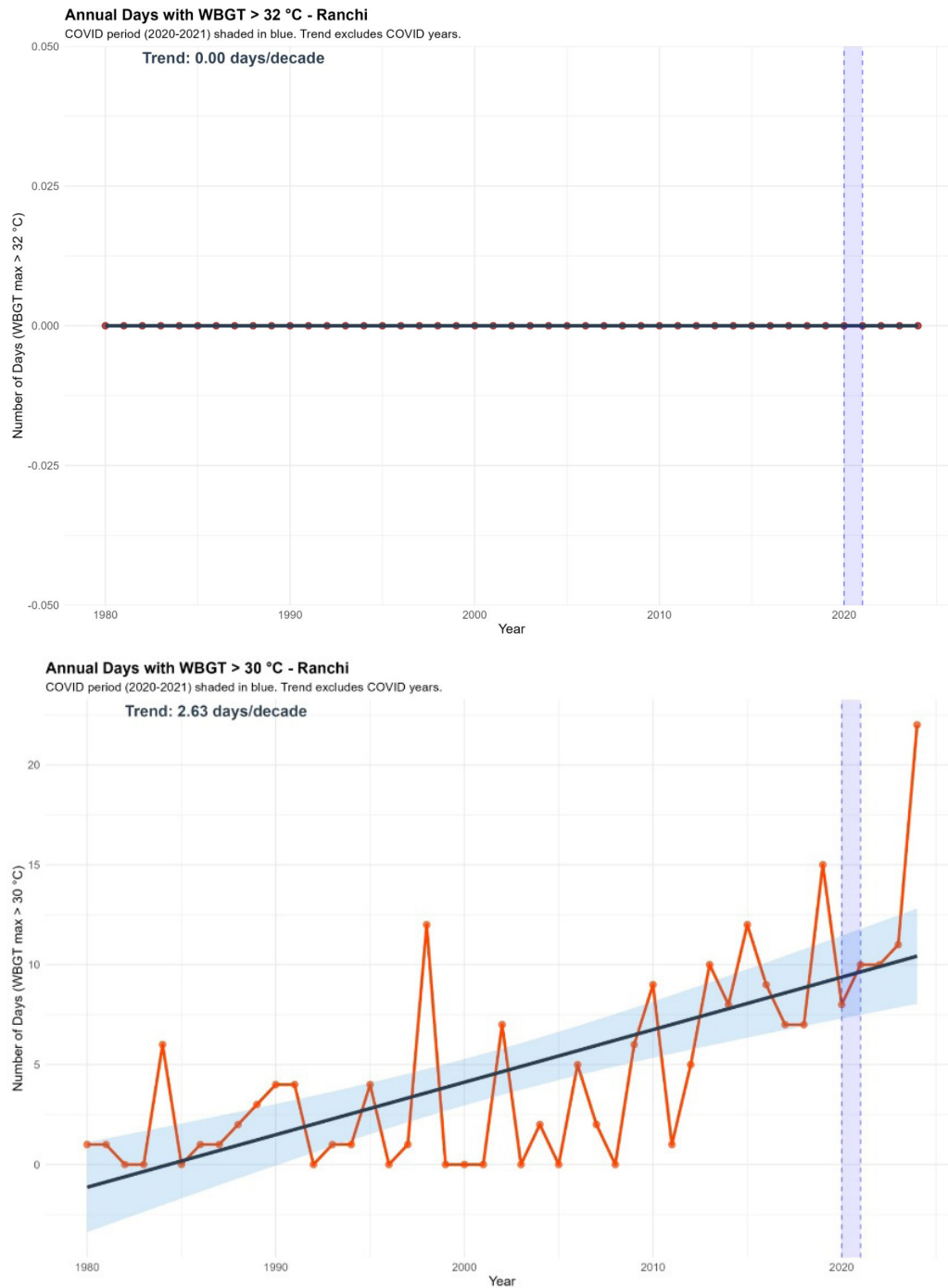


Figure 20 : WBGT Isotherm- Winter- 1980 vs 2024-Ranchi



The above figures clearly show how the temperature profile of the city is changing over the years. It can be observed that there is a significant increase in WBGT in all three seasons of the year, as well as a difference in urban versus rural temperature.

Figure 21 : WBGT trend between 1980 to 2024 for Ranchi



The above graph shows the trend of WBGT for Ranchi between 1980 and 2024. It can be observed that WBGT has never crossed 32°C while there is a decadal growth of 2.63 days per decade for 30°C.

5.3 Jamshedpur

Jamshedpur is situated at the southern end of the state of Jharkhand. The average elevation of the city is 135 meters from sea level. This city is the industrial hub of Jharkhand. Our analysis provides a clear quantitative measure of the Surface Urban Heat Island (SUHI) intensity for Jamshedpur. On average, there is a temperature difference of approximately **1.5°C between** the dense urban setup and the rural area within the city boundary.

Table 7 :Result- SUHI -Jamshedpur

City Name	Temperature difference (Range) Rural VS Urban (2024)	Difference in WGBT 1980 VS 2024 (Hottest Day of the Year)	Decadal Growth in WGBT(Summer)>32°C (1980 to 2024)
Jamshedpur	1.5°C to 2°C	31.5°C -33.1°C	1.88 Days/decade

Figure 22 : LST Profile map- Jamshedpur

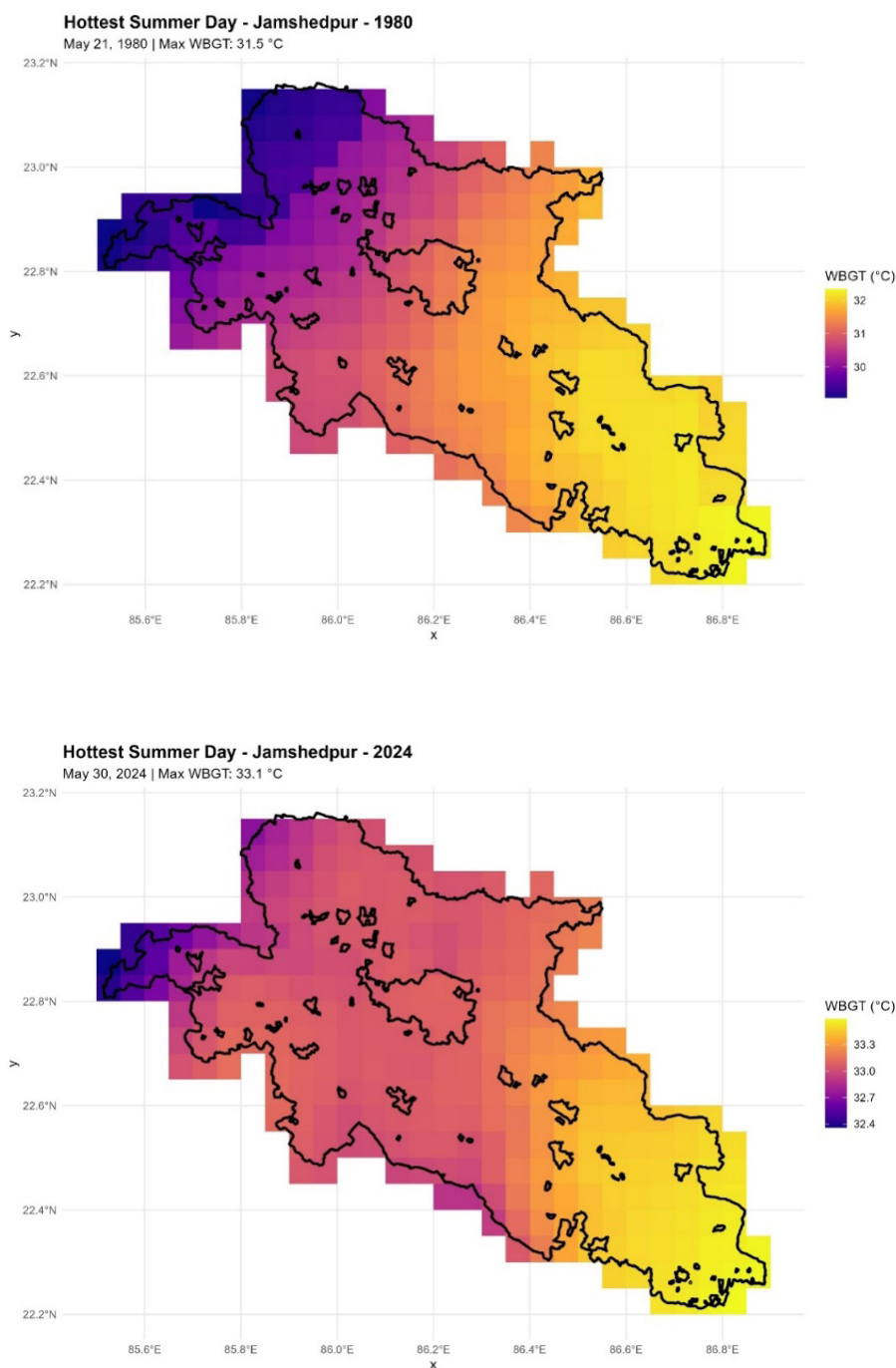
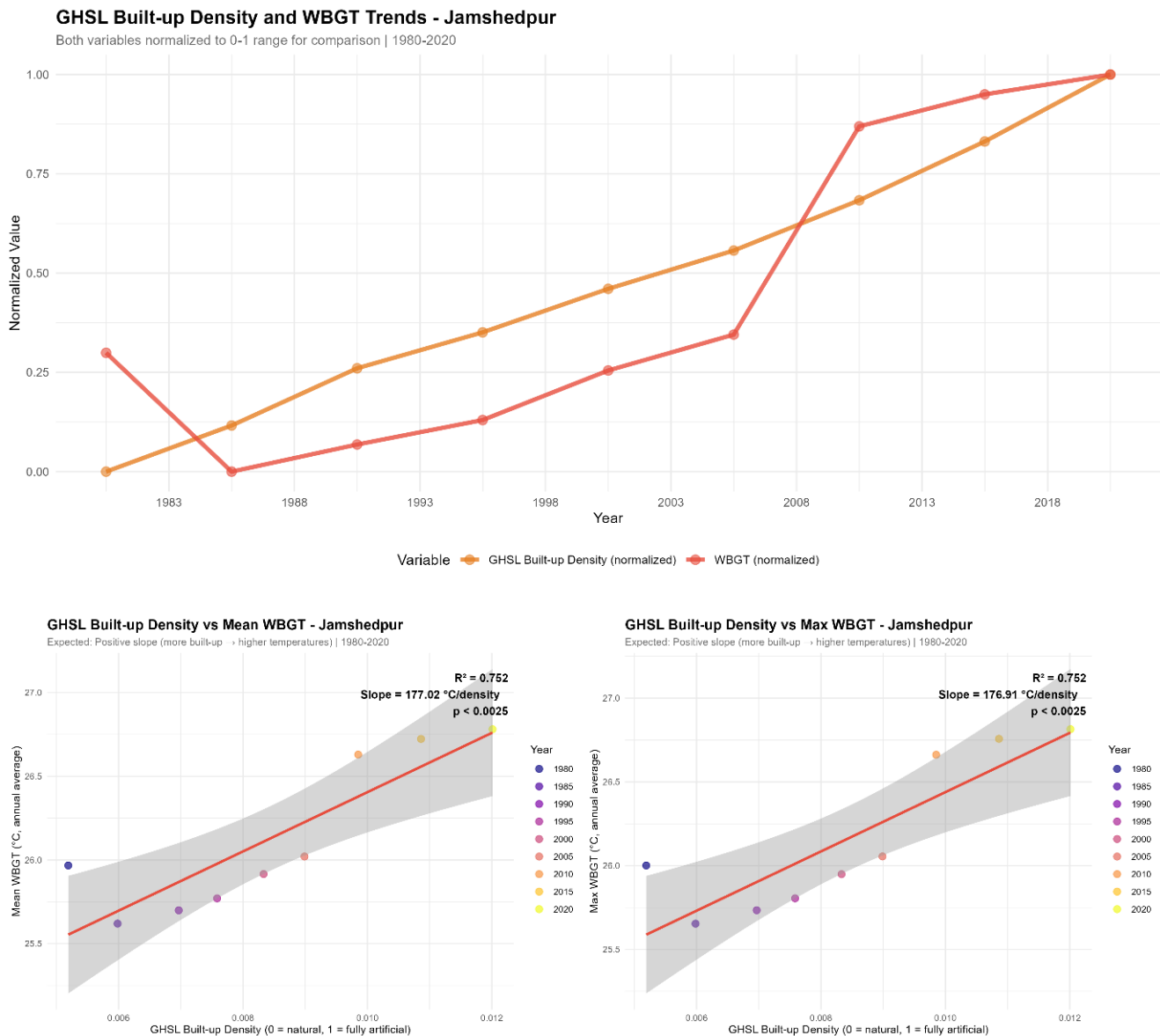


Figure 23 Correlation and regression chart- Built-up area vs LST-Jamshedpur



The analysis presented in the graphs clearly confirms a proportional relationship between the NDBI and LST. This confirms that as the built-up area within the city has increased over the last 40 years, the LST has increased correspondingly. The finding reinforces the core reason driving the SUHI effect, i.e., the replacement of natural cooling surfaces with dry, impervious, heat-absorbing materials.

Figure 24 : WBGT Isotherm- Summer- 1980 vs 2024-Jamshedpur

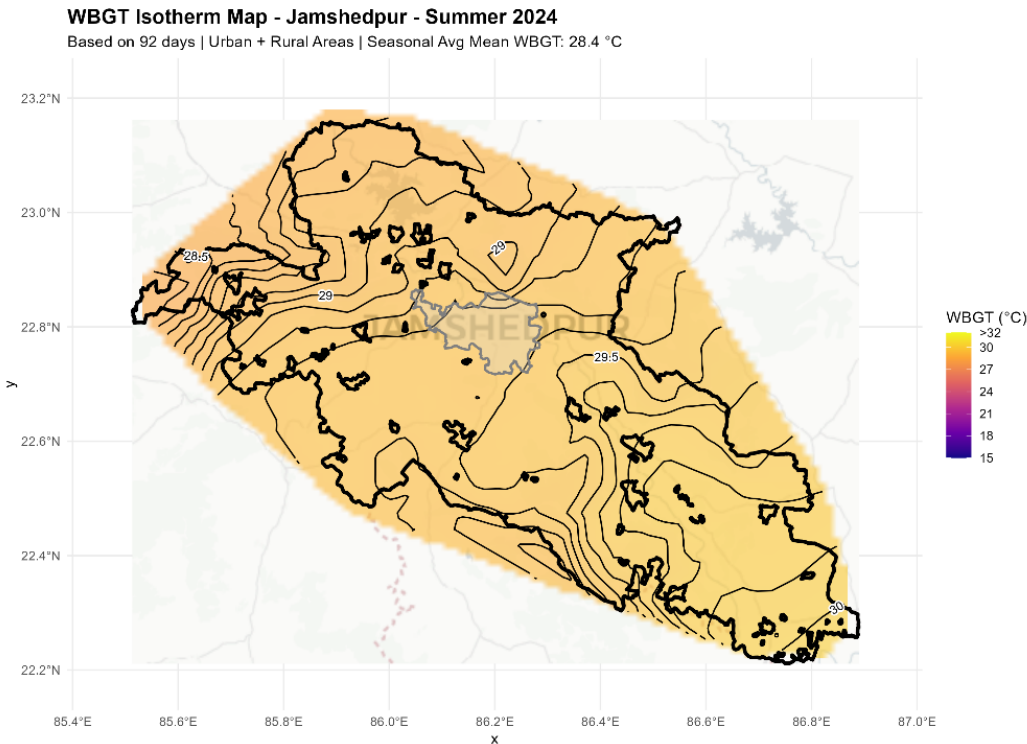
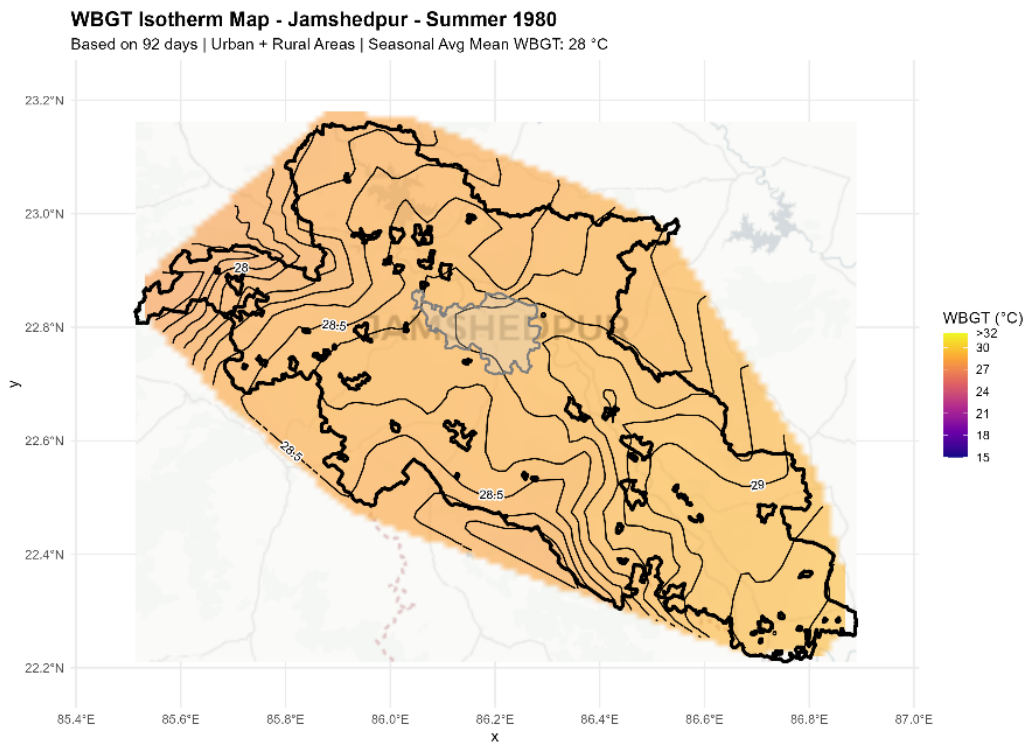


Figure 25: WBGT Isotherm- Monsoon- 1980 vs 2024-Jamshedpur

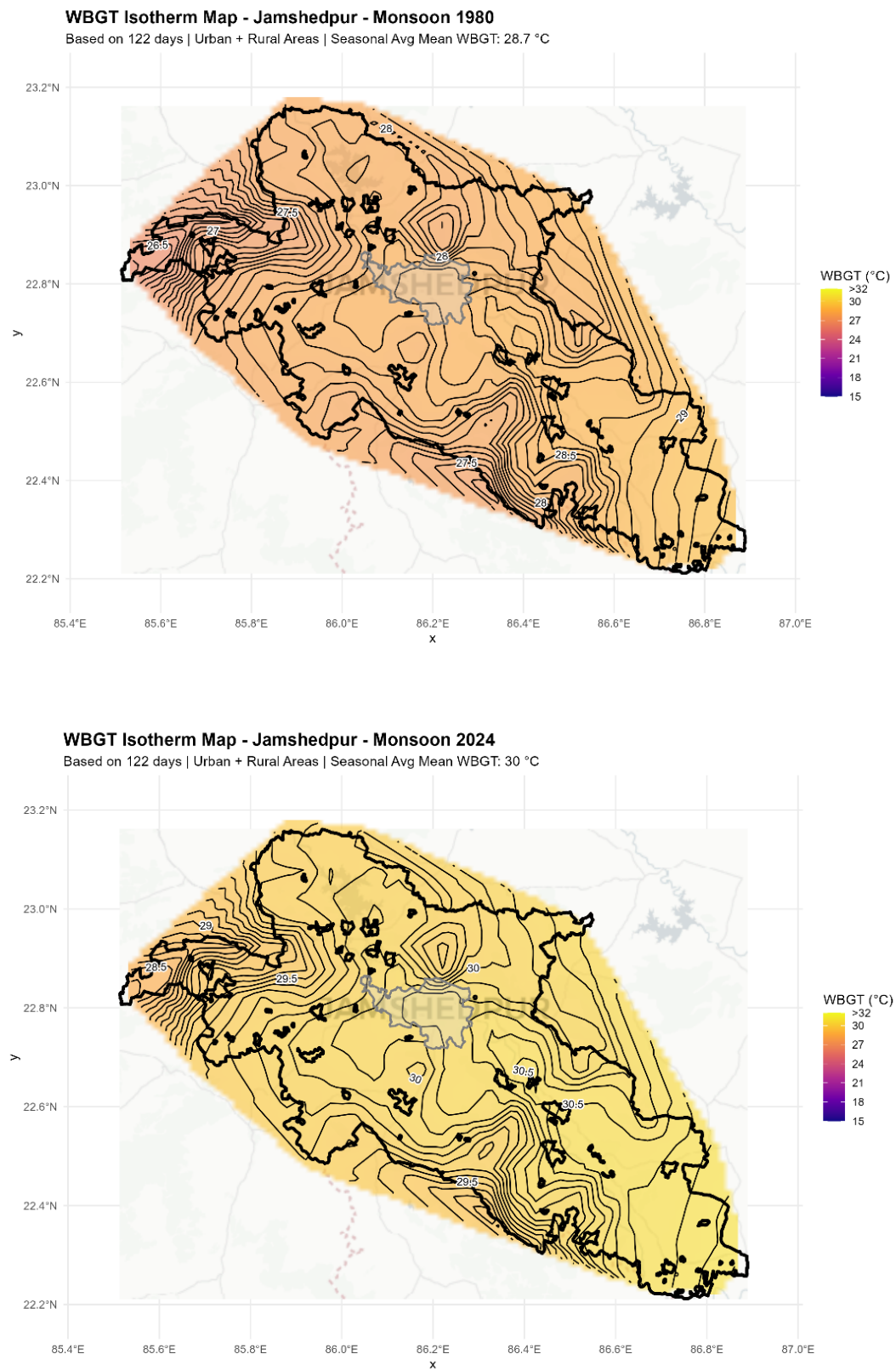
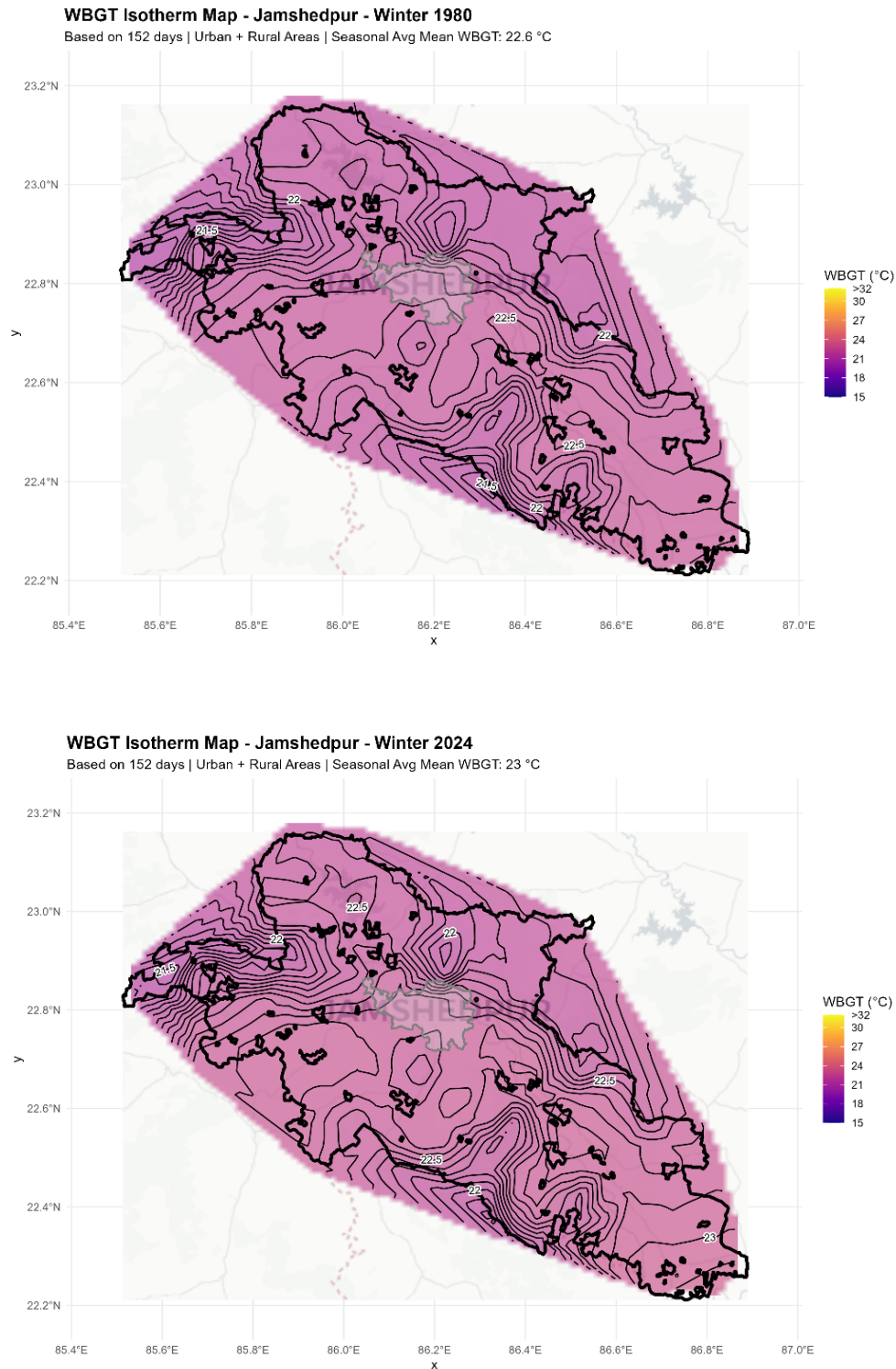
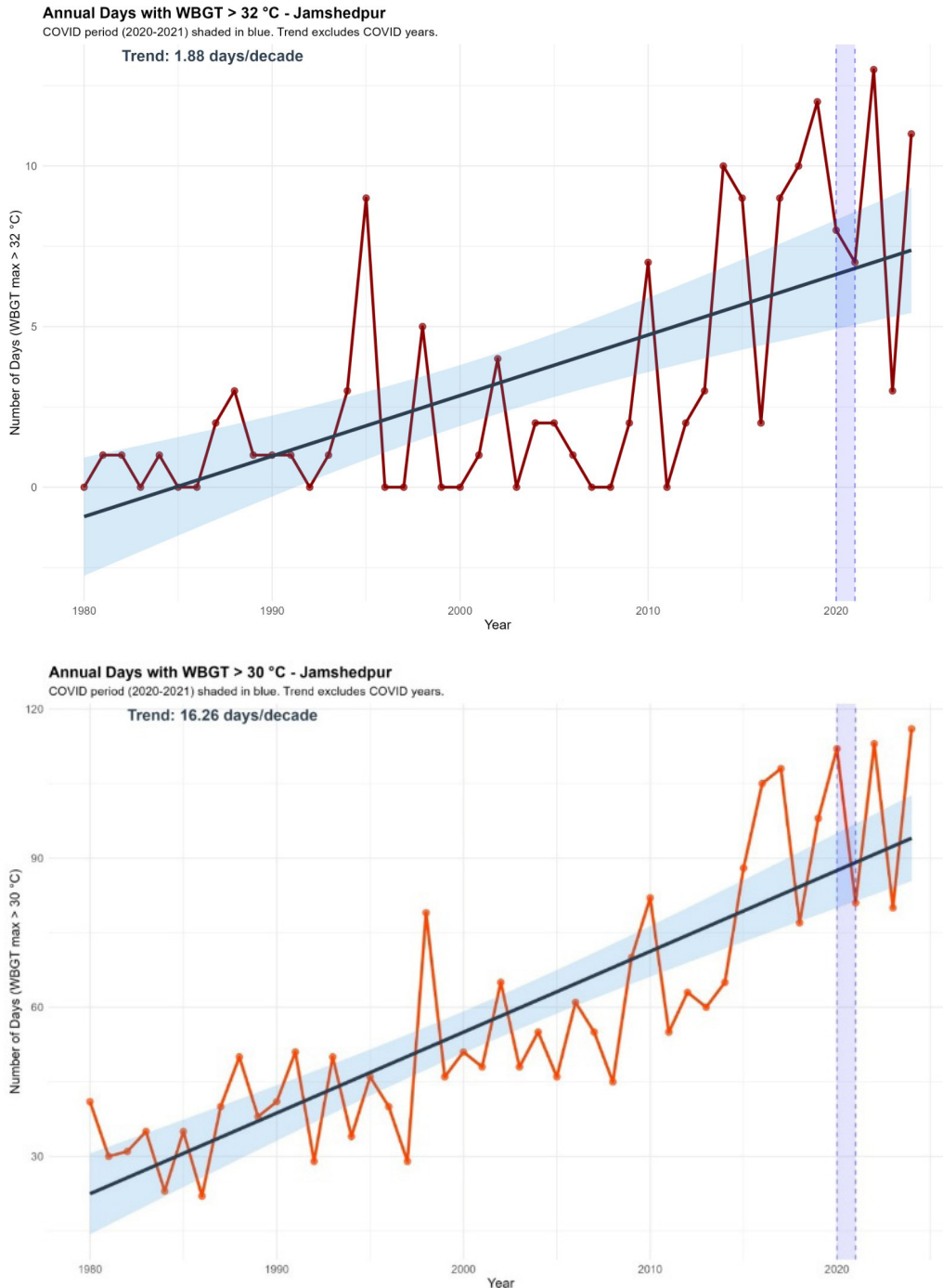


Figure 26: WBGT Isotherm- Winter- 1980 vs 2024-Jamshedpur



The above figures clearly show how the temperature profile of the city is changing over the years. It can be observed that there is a significant increase in WBGT in all three seasons of the year, as well as a difference in urban versus rural temperature.

Figure 27 : WBGT trend between 1980 to 2024 for Jamshedpur



The above graph shows the trend of WBGT for Jamshedpur between 1980 and 2024. It can be observed that WBGT started crossing above 32°C frequently after 1990 (1.88 days per decade), while there is a decadal growth of 16.26 days per decade for WBGT 30°C.

5.4 Hazaribagh

Hazaribagh is a district town in Jharkhand with an average elevation of the city of 610 m from sea level. Our analysis provides a clear quantitative measure of the Surface Urban Heat Island (SUHI) intensity for Hazaribagh. On average, there is a temperature difference of approximately **0.5°C** between the dense urban setup and the rural area within the city boundary.

Table 8 :Result- SUHI - Hazaribagh

City Name	Temperature difference (Range) Rural VS Urban (2024)	Difference in WBGT 1980 VS 2024 (Hottest Day of the Year)	Decadal Growth in WBGT>32°C (1980 to 2020)
Hazaribagh	0.5°C	29.7°C -30.7°C	0.10 Days/decade

Figure 28 : LST Profile map- Hazaribagh

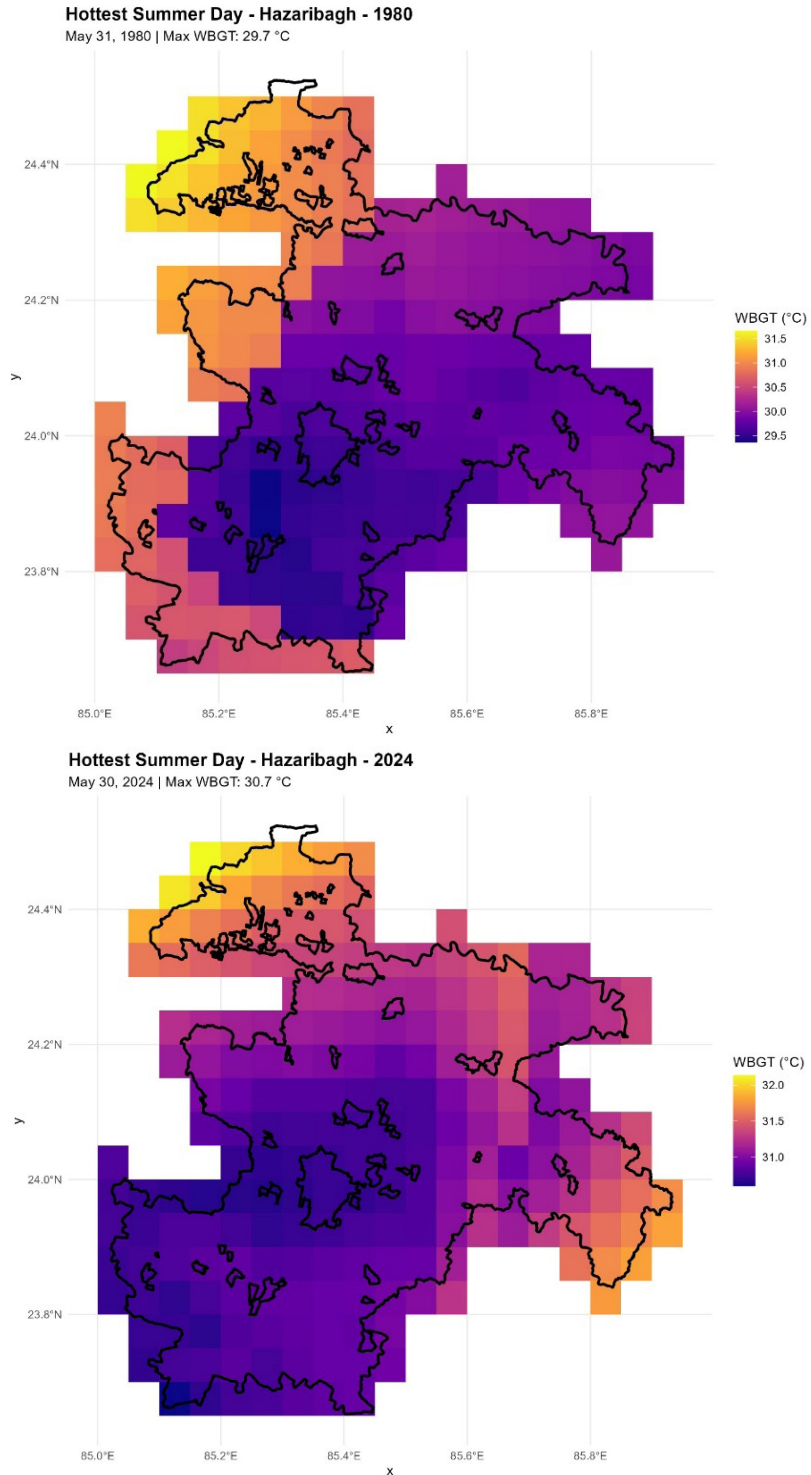
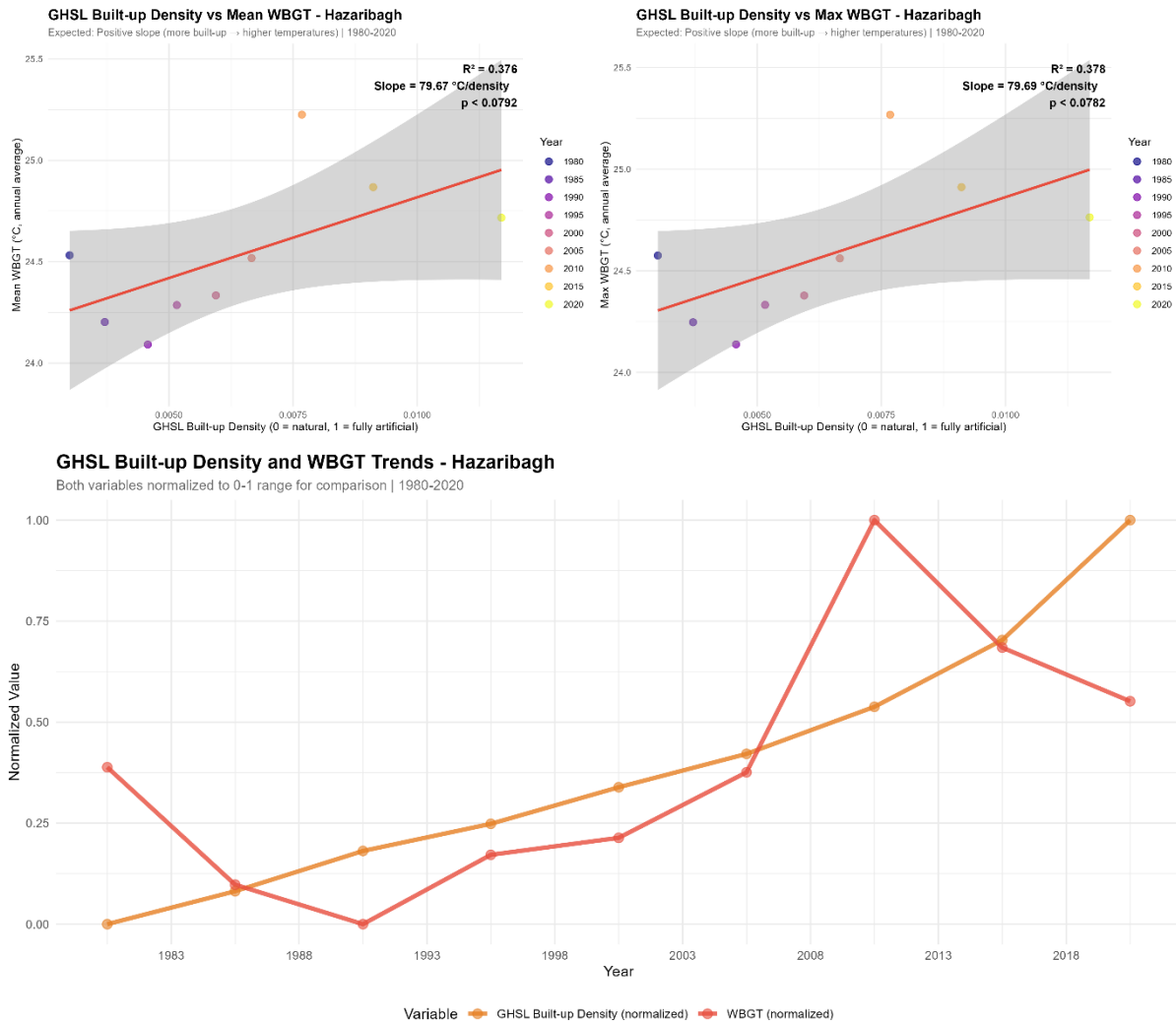


Figure 29 : Correlation and regression chart- Built-up area vs LST-Hazaribagh

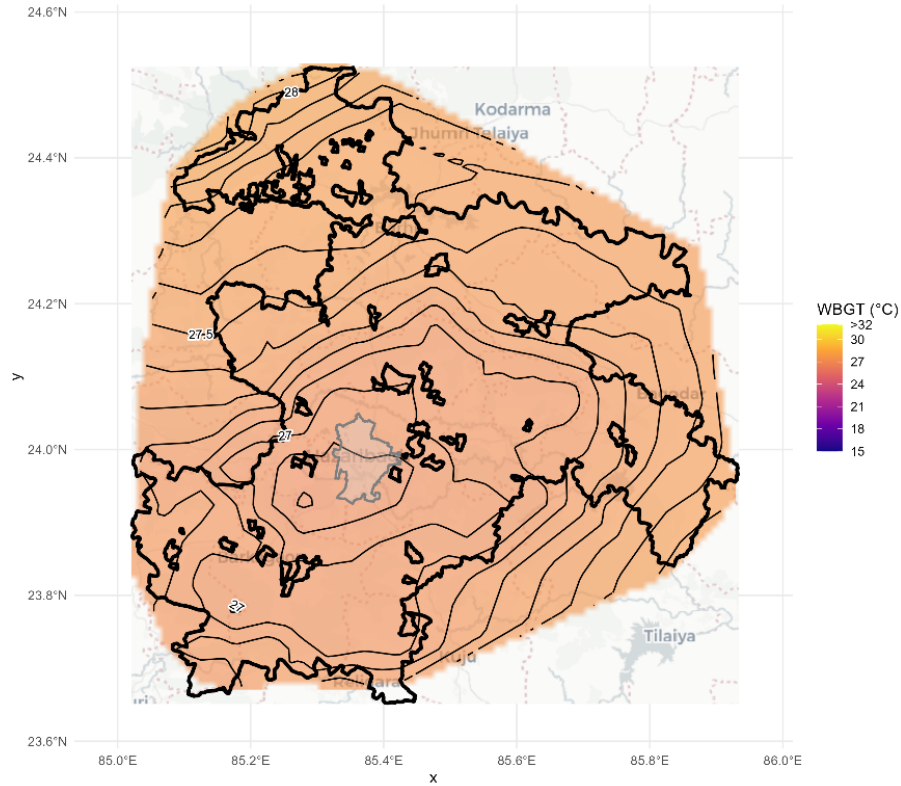


The analysis presented in the graphs clearly confirms a proportional relationship between the NDBI and LST. This confirms that as the built-up area within the city has increased over the last 40 years, the LST has increased correspondingly. The finding reinforces the core reason driving the SUHI effect, i.e., the replacement of natural cooling surfaces with dry, impervious, heat-absorbing materials.

Figure 30 : WBGT Isotherm- Summer- 1980 vs 2024-Hazaribagh

WBGT Isotherm Map - Hazaribagh - Summer 1980

Based on 92 days | Urban + Rural Areas | Seasonal Avg Mean WBGT: 26.1 °C



WBGT Isotherm Map - Hazaribagh - Summer 2024

Based on 92 days | Urban + Rural Areas | Seasonal Avg Mean WBGT: 26.2 °C

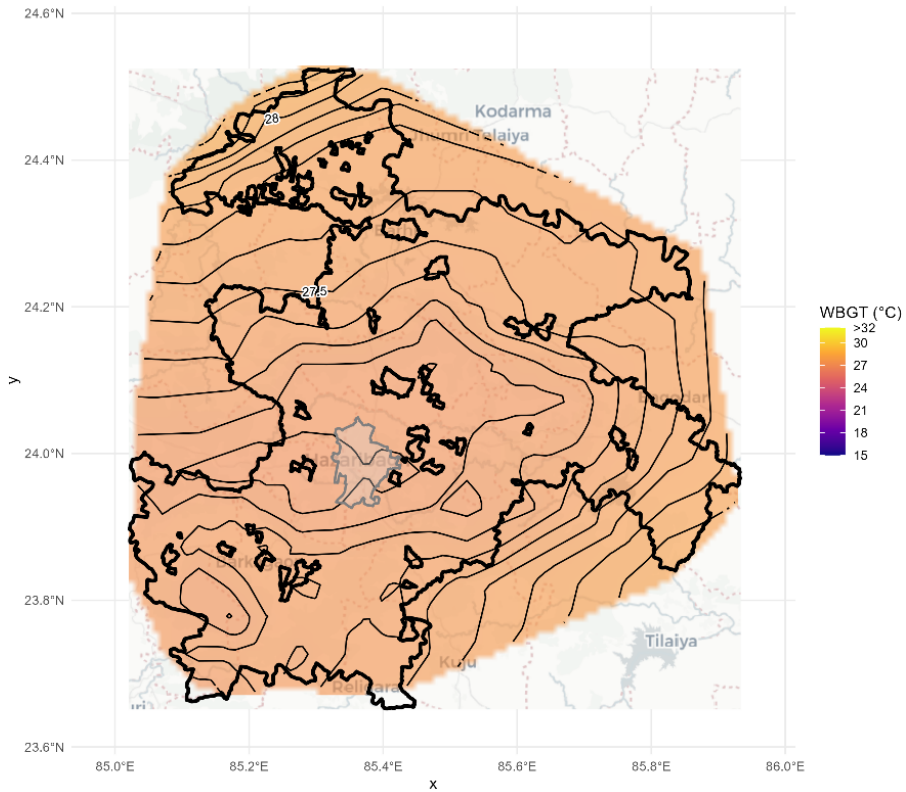


Figure 31 : WBGT Isotherm- Monsoon- 1980 vs 2024-Hazaribagh

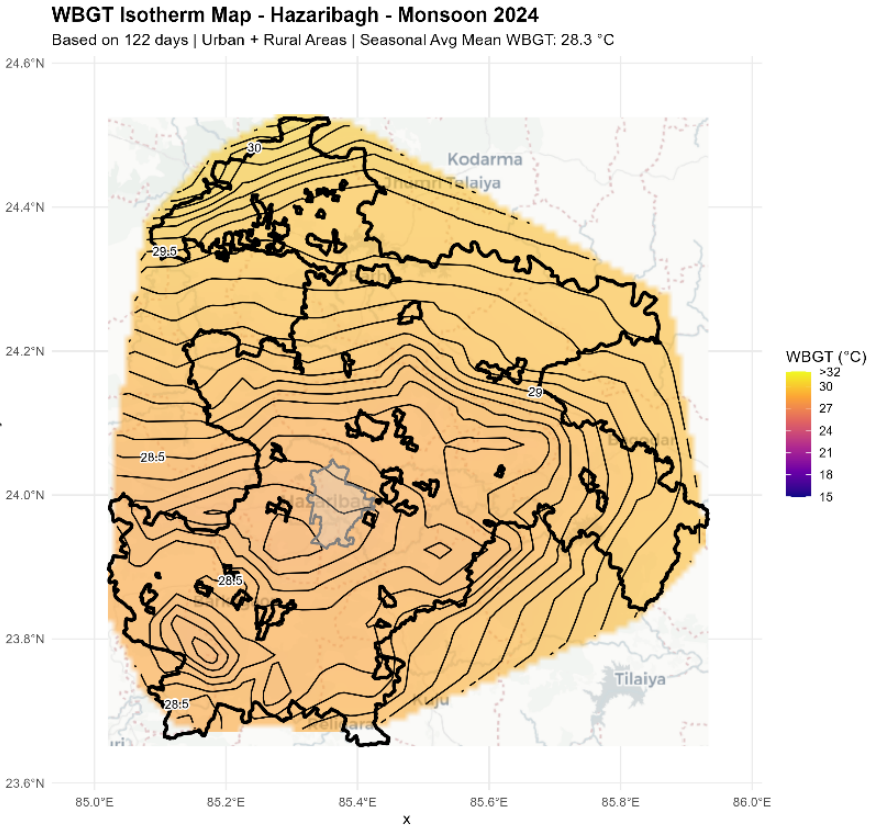
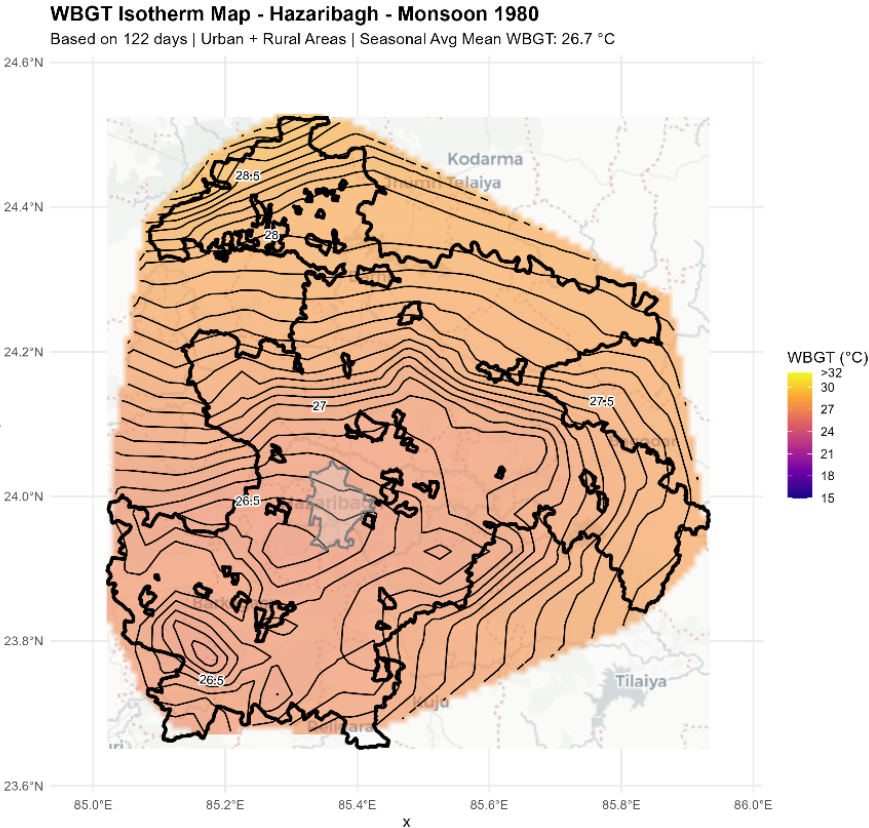
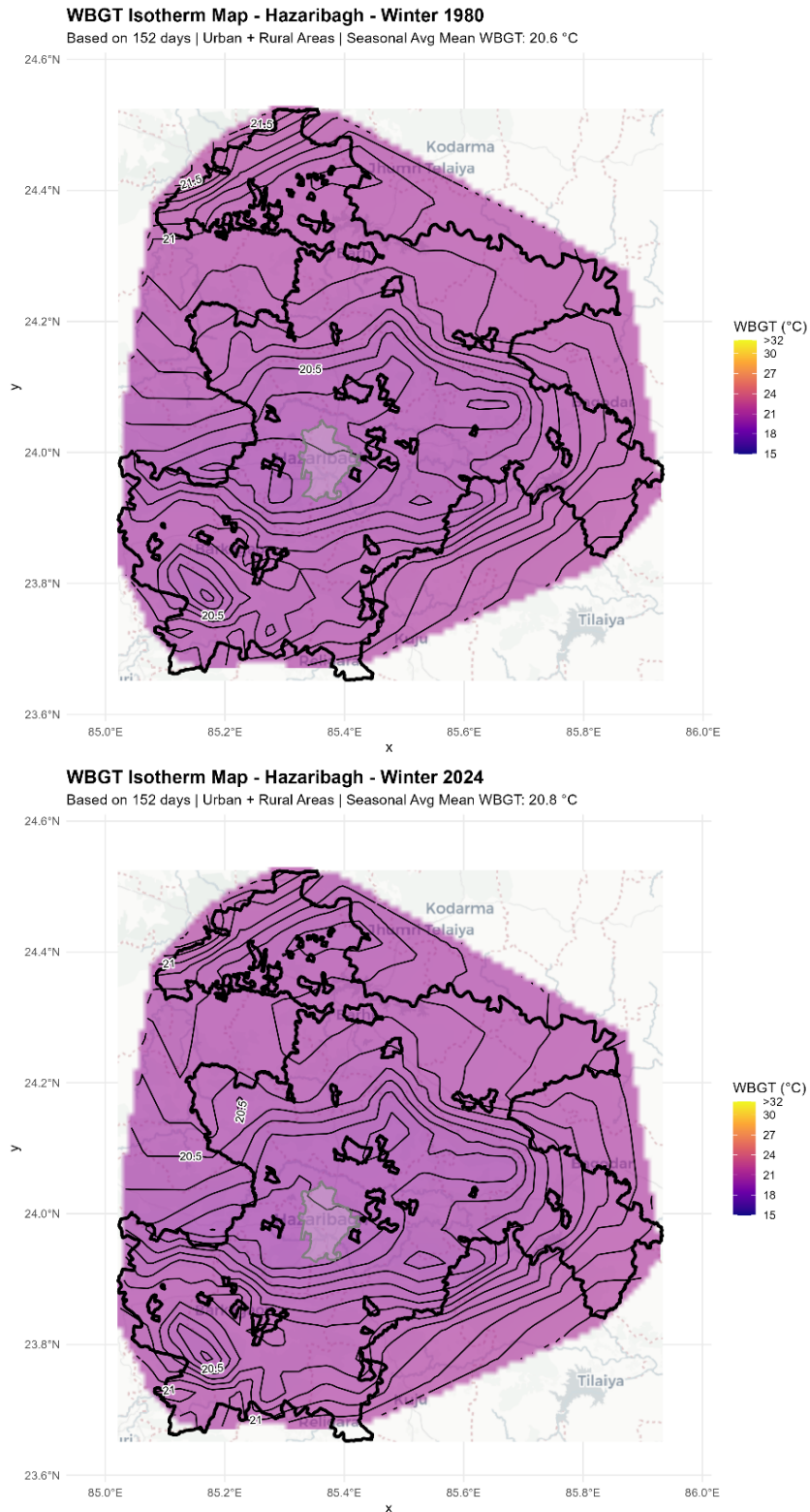
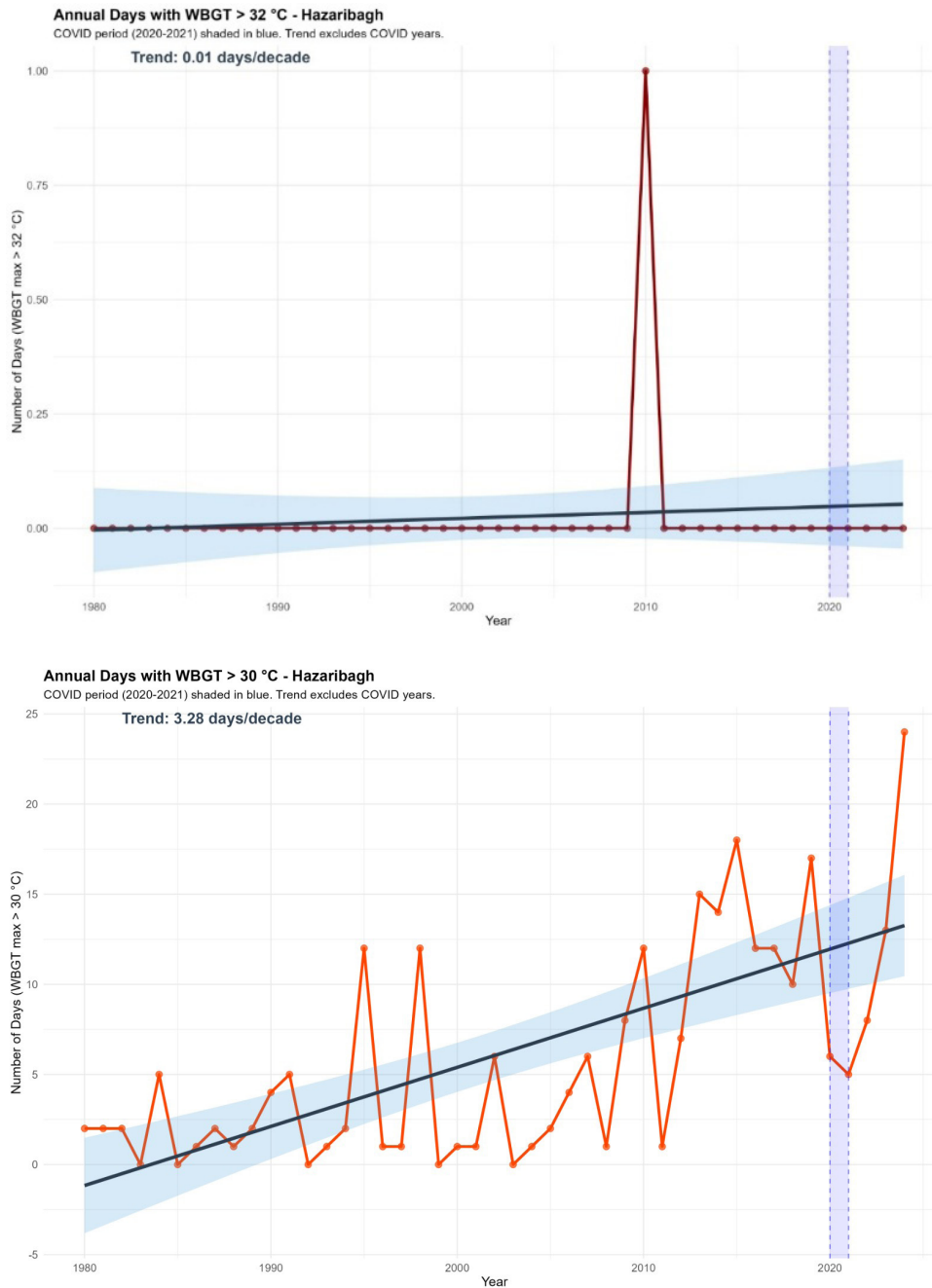


Figure 32 : WBGT Isotherm- Winter- 1980 vs 2024-Hazaribagh



The above figures clearly show how the temperature profile of the city is changing over the years. It can be observed that there is a significant increase in WBGT in all three seasons of the year, as well as a difference in urban versus rural temperature.

Figure 33 : WBGT trend between 1980 to 2024 for Hazaribagh



The above graph shows the trend of WBGT for Hazaribagh between 1980 and 2024. It can be observed that WBGT almost never crossed above 32°C between 1980 and 2023, while there is a decadal growth of 3.28 days per decade for WBGT 30°C. Though there is a clear trend of warming, Hazaribagh is still relatively cooler than other cities that have been considered for the study.

5.5 Bokaro

Bokaro, officially known as Bokaro Steel City, is a large and planned city in Jharkhand. It is the fourth most populous city in the state. The average elevation of the city is 210 meters above mean sea level. Our analysis provides a clear quantitative measure of the Surface Urban Heat Island (SUHI) intensity for Bokaro. On average, there is a temperature difference of approximately 1°C between the dense urban setup and the rural area within the city boundary.

Table 9 : Result- SUHI -Bokaro

City Name	Temperature difference (Range) Rural VS Urban (2024)	Difference in WBGT 1980 VS 2024 (Hottest Day of the Year)	Decadal Growth in WBGT>32°C (1980 to 2020)
Bokaro	1.0°C	31.2°C-32.7°C	0.40 Days/decade

Figure 34 : LST Profile map- Bokaro

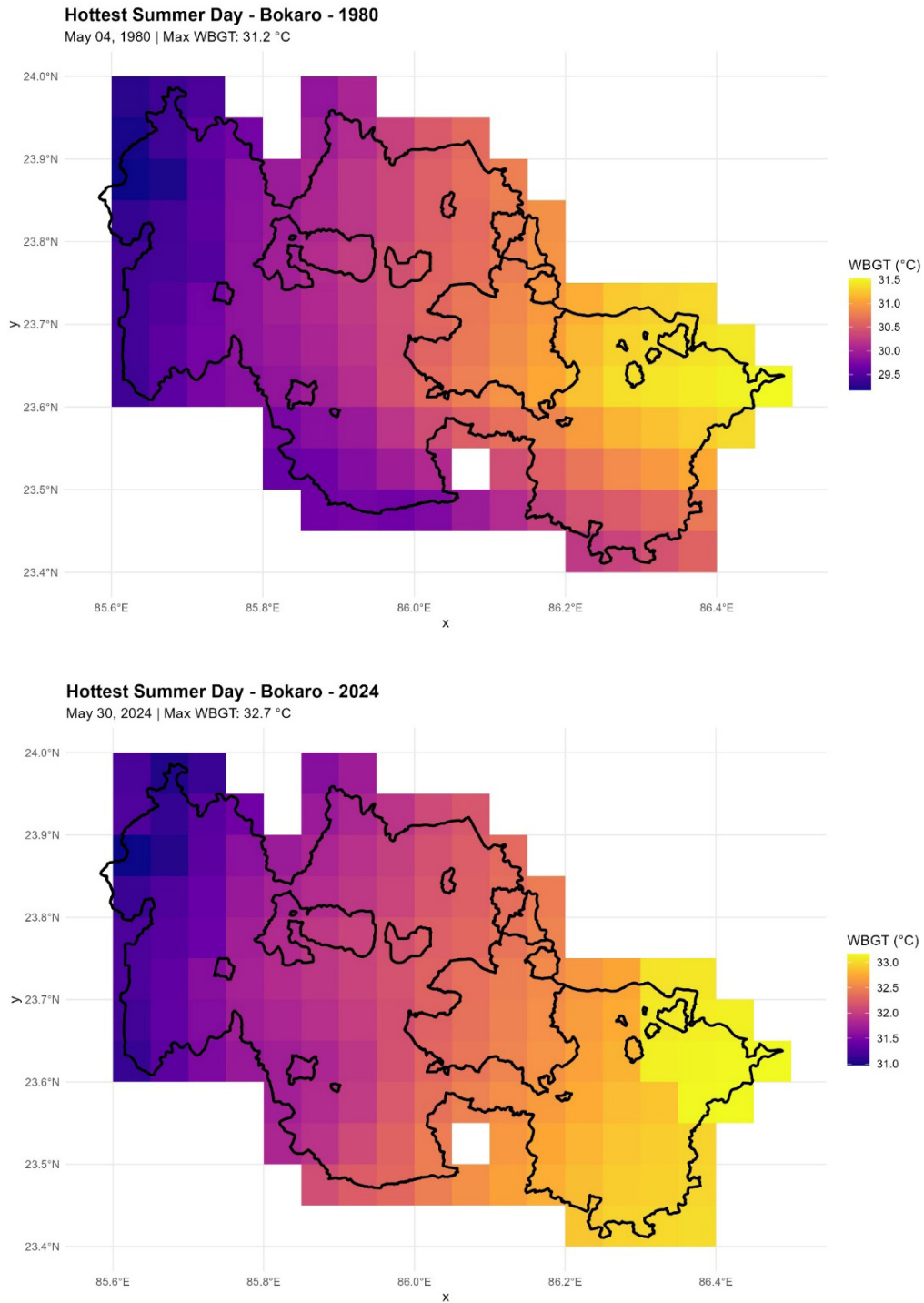


Figure 35 : Correlation and regression chart- Built-up area vs LST-Bokaro



The analysis presented in the graphs clearly confirms a proportional relationship between the NDBI and LST. This confirms that as the built-up area within the city has increased over the last 40 years, the LST has increased correspondingly. The finding reinforces the core reason driving the SUHI effect, i.e., the replacement of natural cooling surfaces with dry, impervious, heat-absorbing materials.

Figure 36 : WBGT Isotherm- Summer- 1980 vs 2024-Bokaro

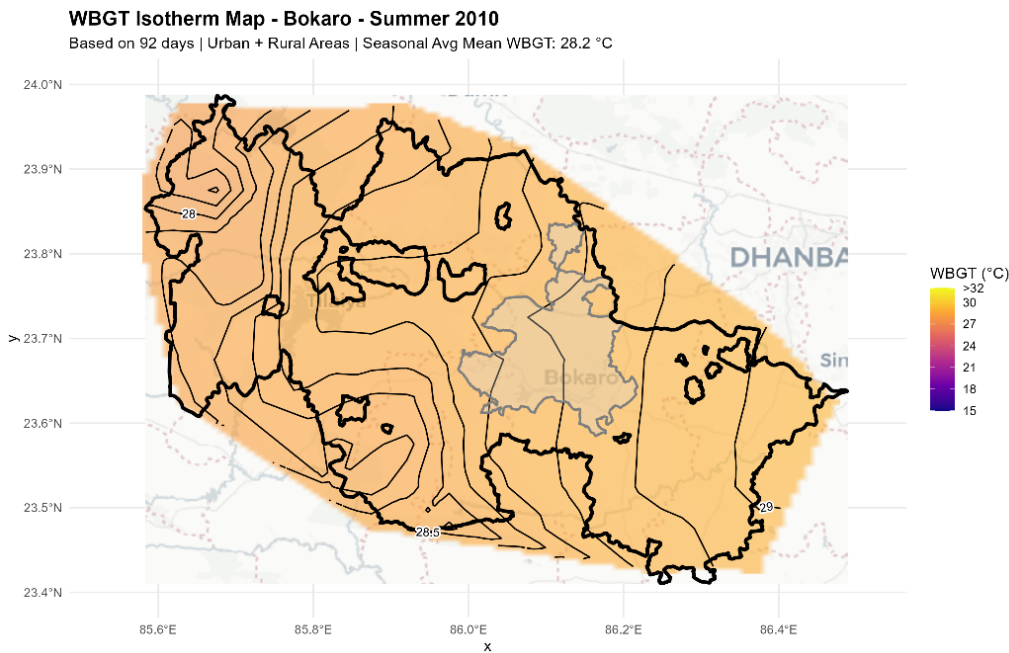
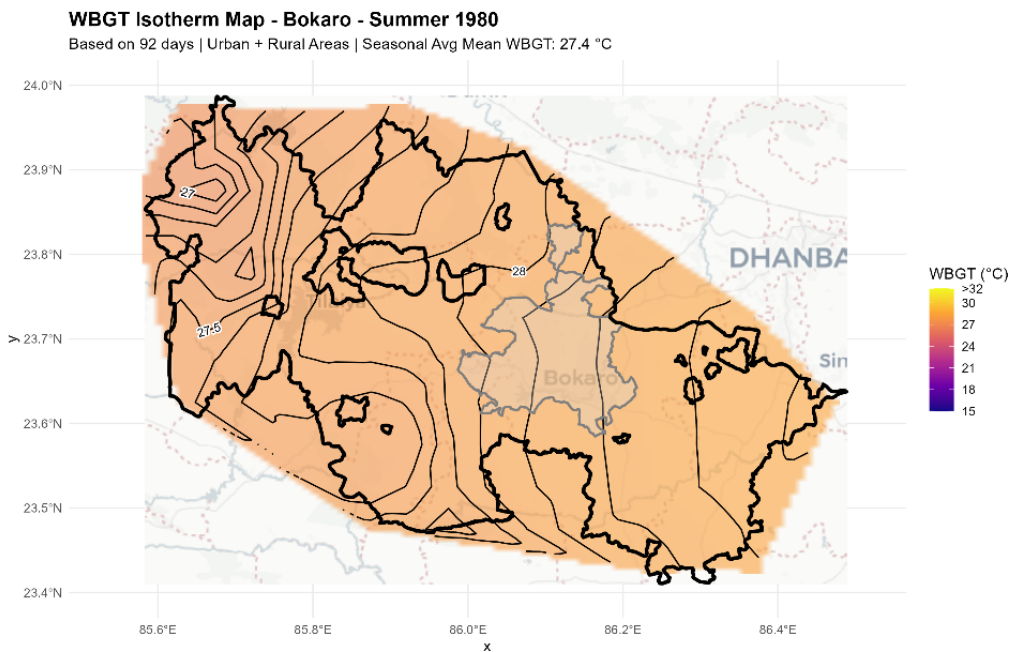


Figure 37 : WBGT Isotherm- Monsoon - 1980 vs 2024-Bokaro

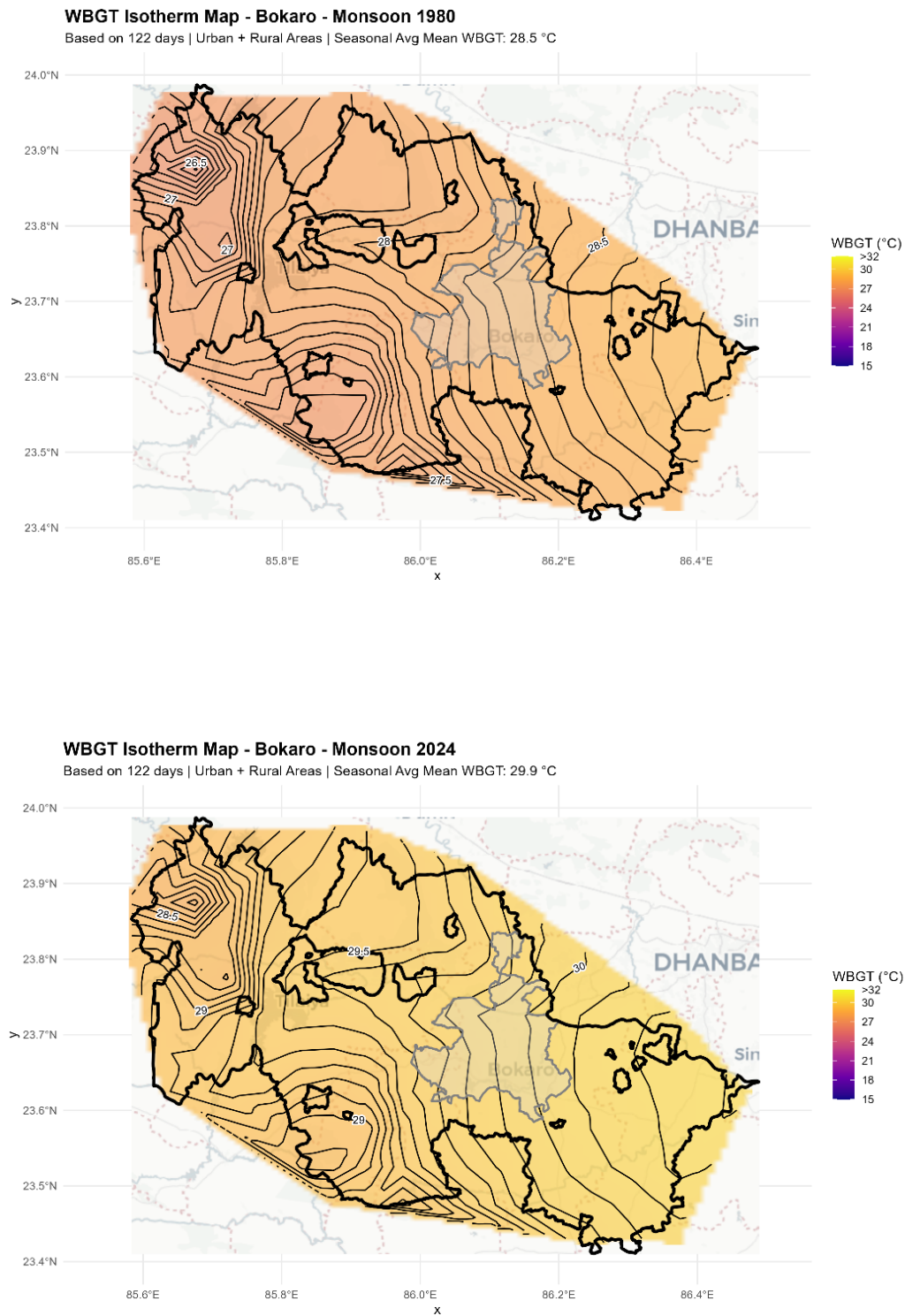
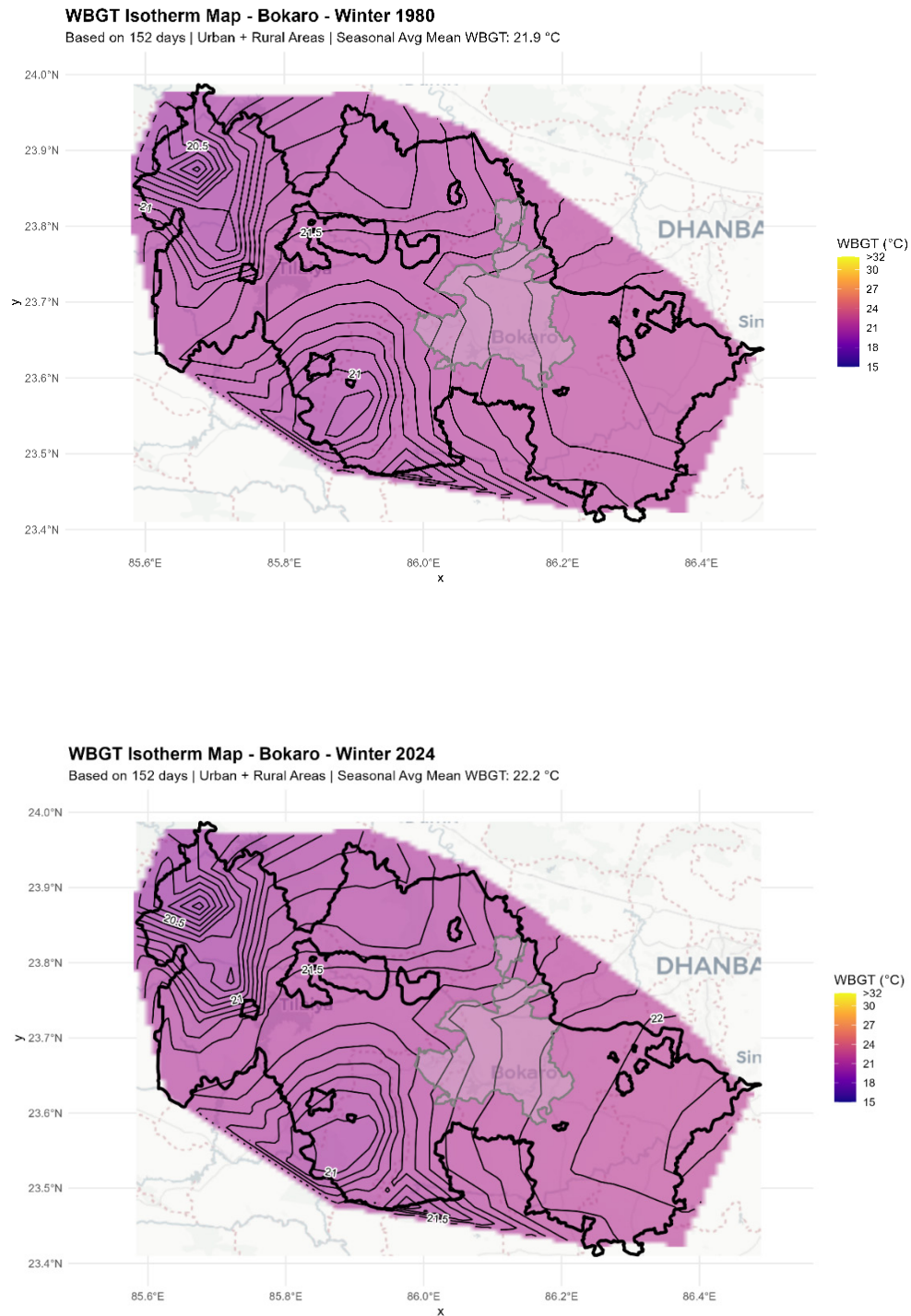
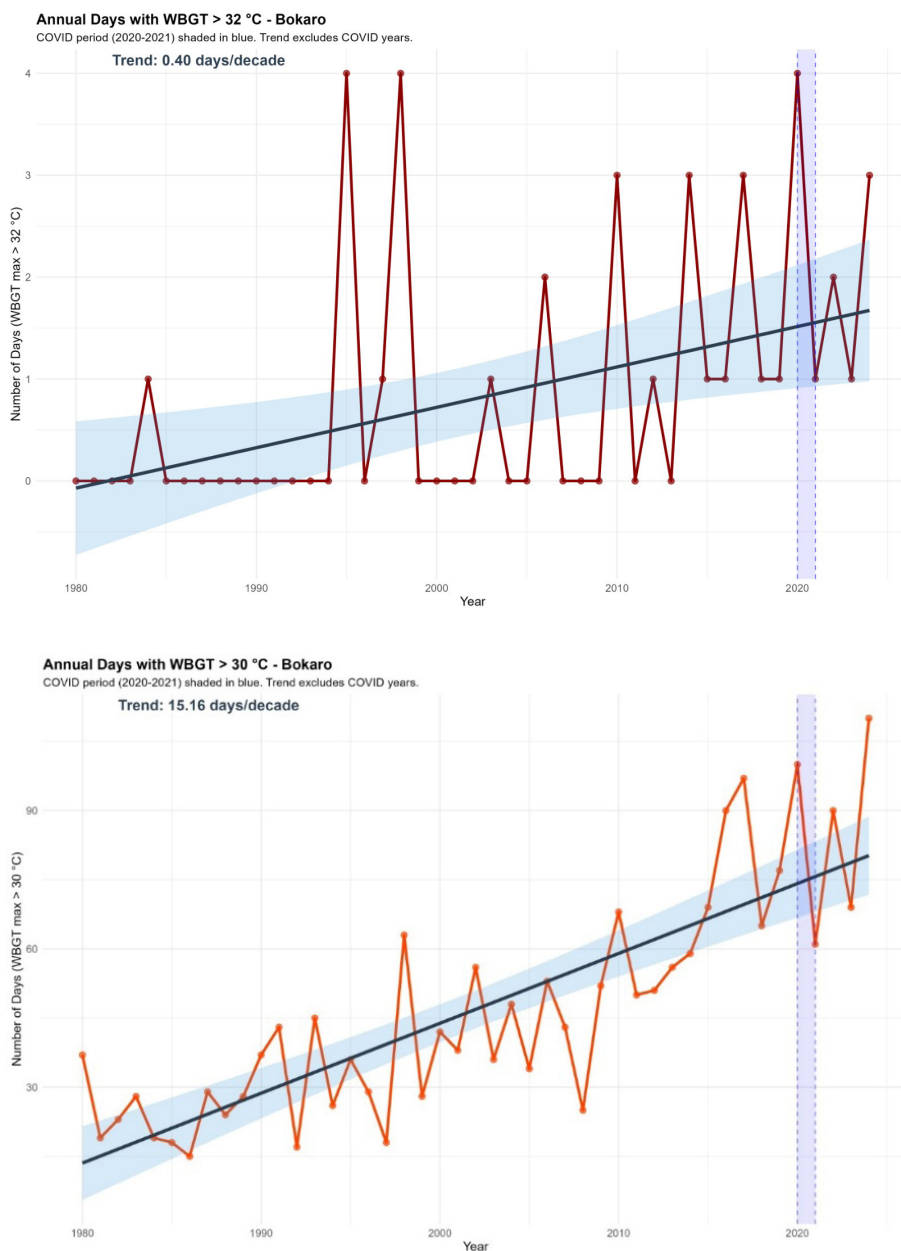


Figure 38 : WBGT Isotherm- Winter - 1980 vs 2024-Bokaro



The above figures clearly show how the temperature profile of the city is changing over the years. It can be observed that there is a significant increase in WBGT in all three seasons of the year, as well as a difference in urban versus rural temperature.

Figure 39 : WBGT trend between 1980 to 2024 for Bokaro



The above graph shows the trend of WBGT for Bokaro between 1980 and 2024. It can be observed that WBGT started crossing above 32°C frequently after 2000, while there is a decadal growth of 15.16 days per decade for WBGT 30°C. Though there is a clear trend of warming, Bokaro is cooler than Jamshedpur but warmer than Ranchi.

5.6 Dhanbad

Dhanbad is the second-most populated city after Jamshedpur and a major financial hub of Jharkhand. Dhanbad is often referred to as the Economic Capital of Jharkhand'. Dhanbad has an average elevation of 227 m from the sea level. Our analysis provides a clear quantitative measure of the Surface Urban Heat Island (SUHI) intensity for Dhanbad. On average, there is a temperature difference of approximately 0.5°C centigrade between the dense urban setup and the rural area within the city boundary.

Dhanbad is the second-most populated city after Jamshedpur and a major financial hub of Jharkhand. Dhanbad is often referred to as the Economic Capital of Jharkhand'. Dhanbad has an average elevation of 227 m from the

sea level. Our analysis provides a clear quantitative measure of the Surface Urban Heat Island (SUHI) intensity for Dhanbad. On average, there is a temperature difference of approximately 0.5°C centigrade between the dense urban setup and the rural area within the city boundary.

Dhanbad is the second-most populated city after Jamshedpur and a major financial hub of Jharkhand. Dhanbad is often referred to as the ‘Economic Capital of Jharkhand’. Dhanbad has an average elevation of 227 m from sea level. Our analysis provides a clear quantitative measure of the Surface Urban Heat Island (SUHI) intensity for Dhanbad. On average, there is a temperature difference of approximately **0.50C** between the dense urban setup and the rural area within the city boundary.

Table 10 : Result- SUHI -Dhanbad

City Name	Temperature difference (Range) Rural VS Urban (2024)	Difference in WBGT 1980 VS 2024 (Hottest Day of the Year)	Decadal Growth in WBGT>32°C (1980 to 2020)
Dhanbad	0.5°C	31.6°C -33.2°C	0.55 Days/decade

Figure 40 : LST Profile map- Dhanbad

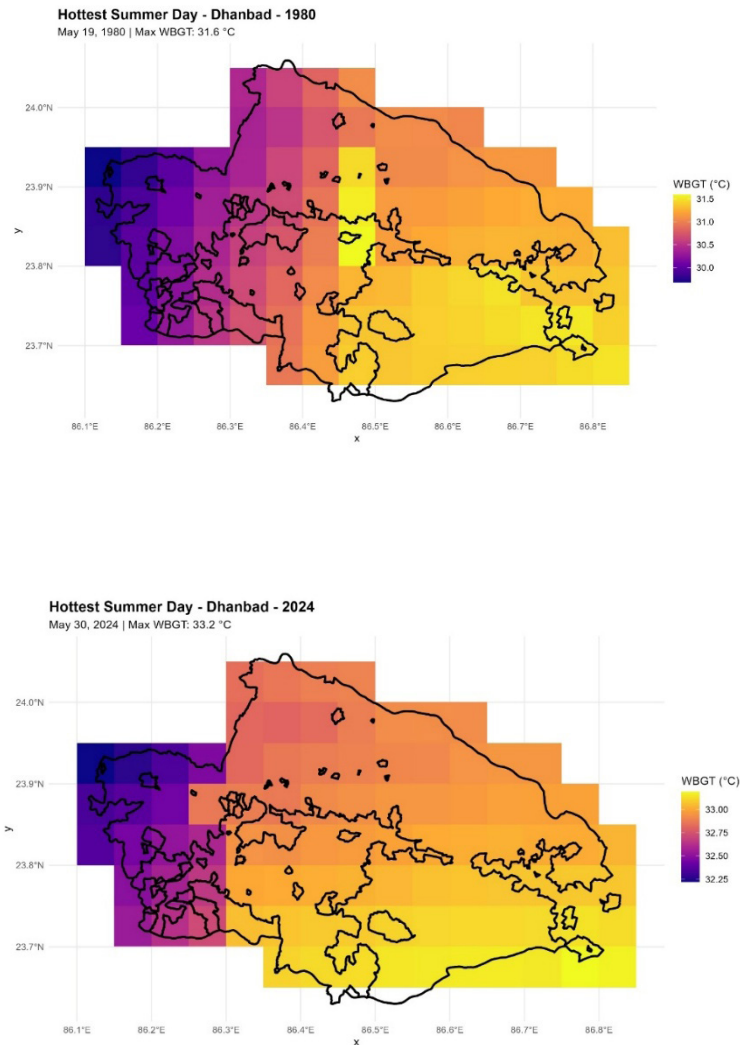
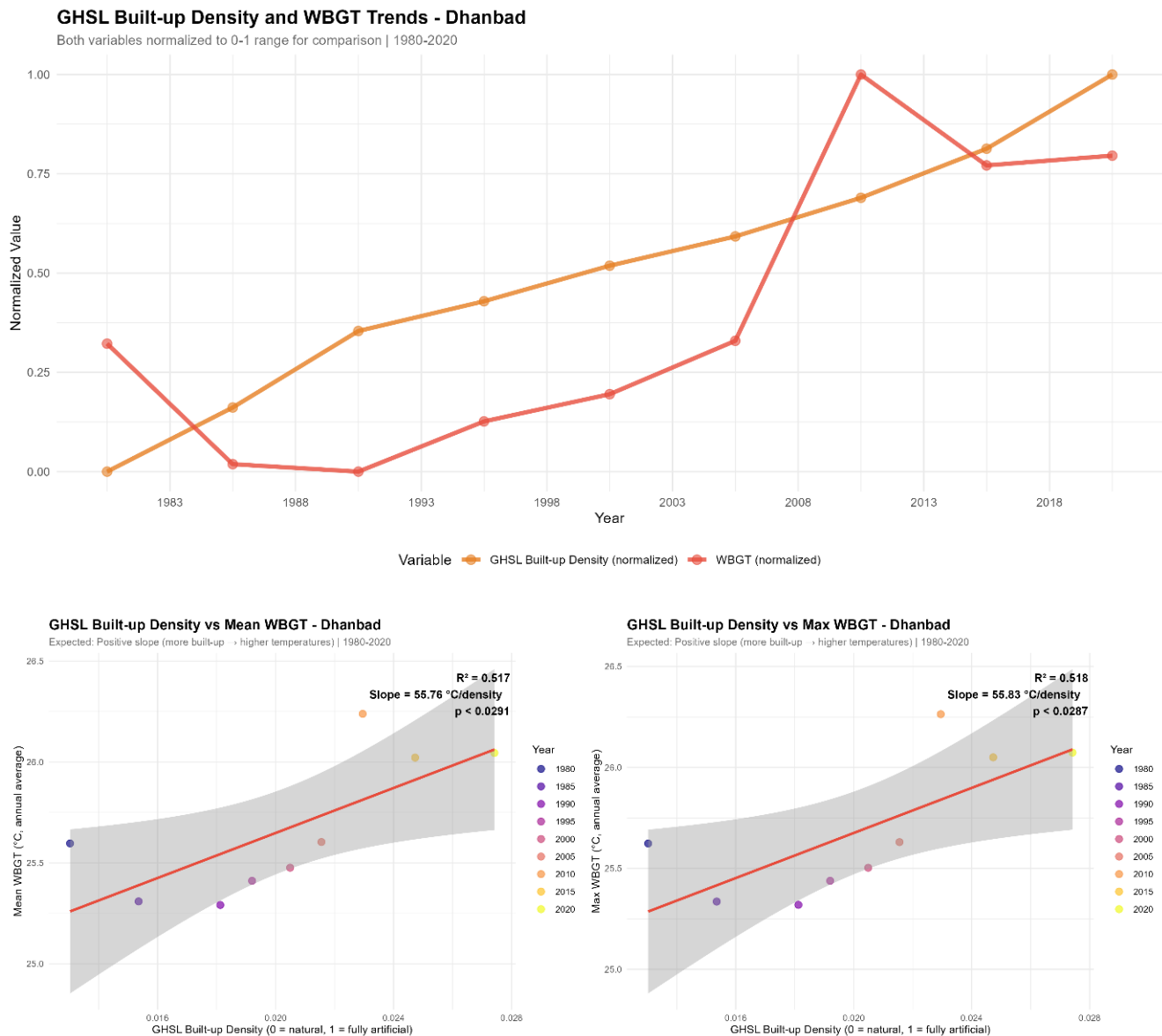


Figure 41 : Correlation and regression chart- Built-up area vs LST-Dhanbad



The analysis presented in the above graphs clearly confirms a proportional relationship between the NDBI and LST. This confirms that as the built-up area within the city has increased over the last 40 years the LST has increased correspondingly. The finding reinforces the core reason driving the SUHI effect i.e. the replacement of natural cooling surfaces with dry, impervious, heat-absorbing materials.

Figure 42 : WBGT Isotherm- Summer- 1980 vs 2024-Dhanbad

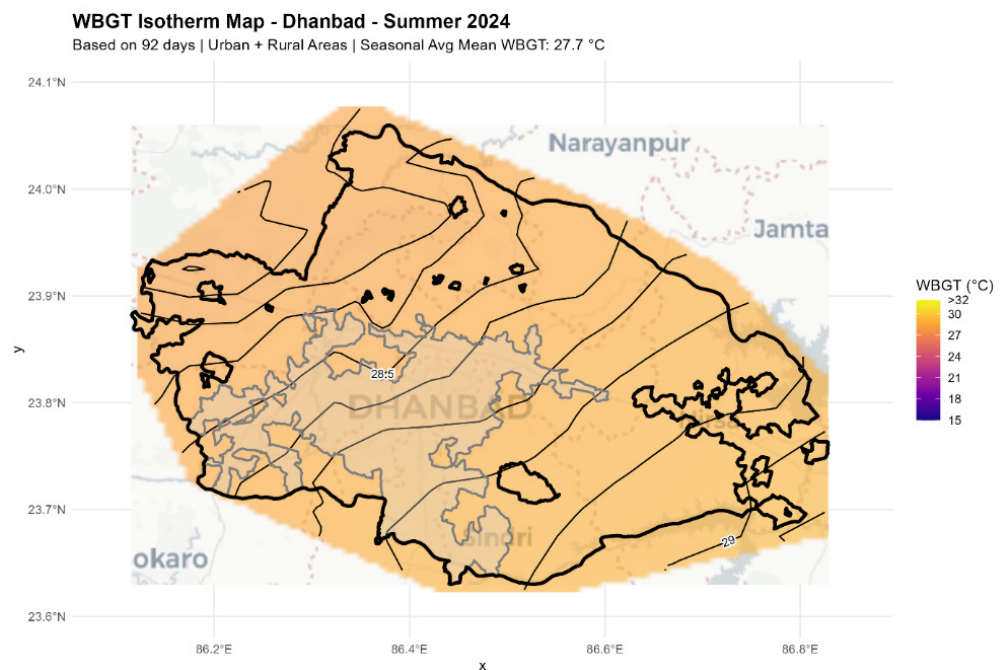
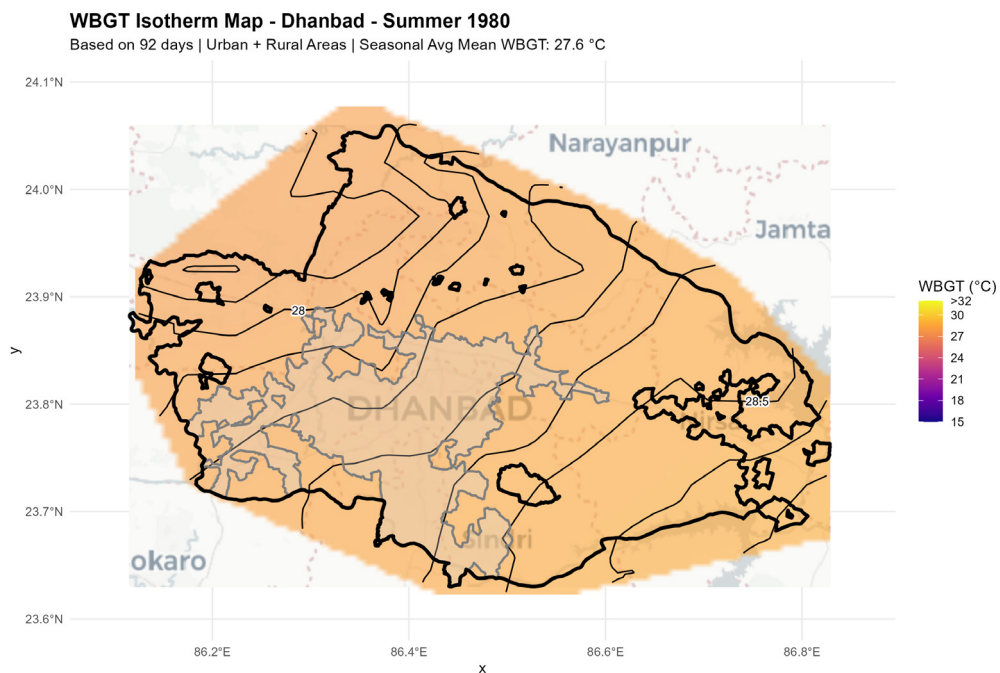


Figure 43 : WBGT Isotherm- Monsoon - 1980 vs 2024-Dhanbad

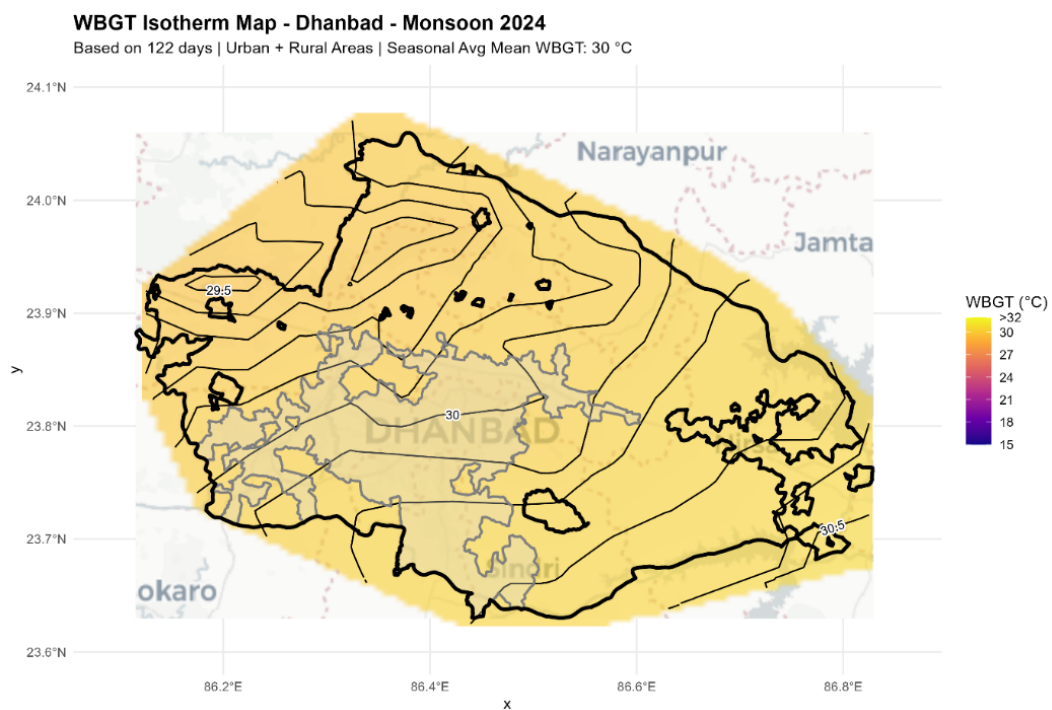
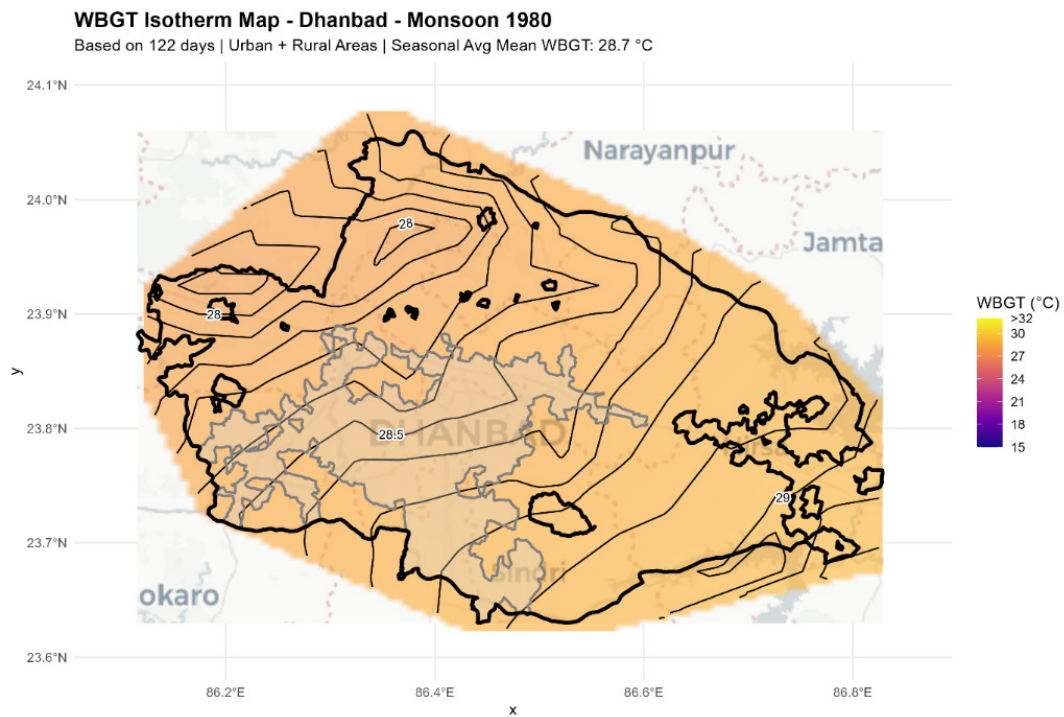
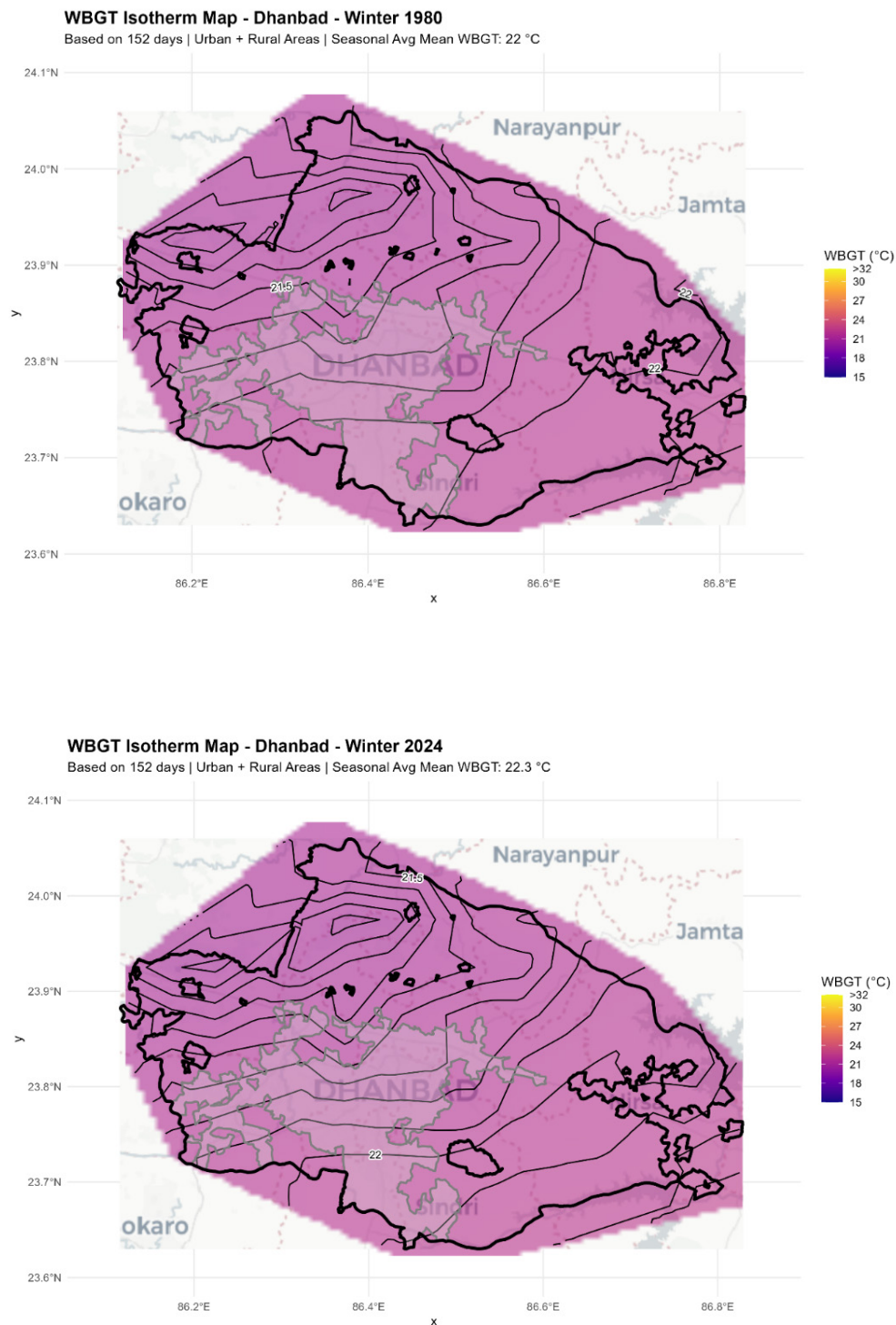
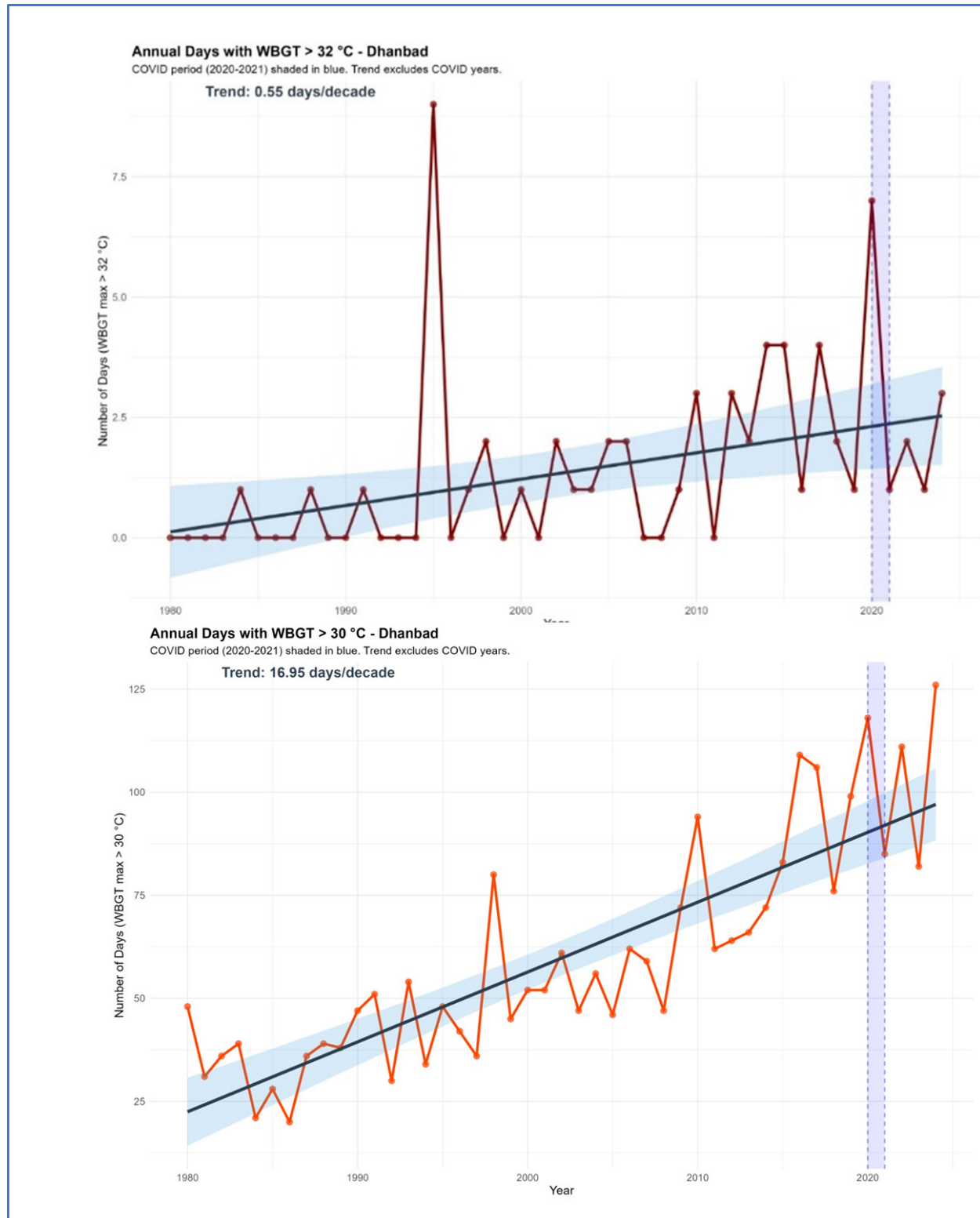


Figure 44 : WBGT Isotherm- Winter - 1980 vs 2024-Dhanbad



The above figures clearly show how the temperature profile of the city is changing over the years. It can be observed that there is a significant increase in WBGT in all three seasons of the year, as well as a difference in urban versus rural temperature.

Figure 45 : WBGT trend between 1980 to 2024 for Dhanbad



The above graph shows the trend of WBGT for Dhanbad between 1980 and 2024. It can be observed that WBGT started crossing above 32°C frequently after 1990 (0.55 days per decade), while there is a decadal growth of 16.95 days per decade for WBGT 30°C. The COVID period (2020–2021) is shaded in blue.

6 Conclusion

This UHI study of five major cities in Jharkhand shows that all five urban landscapes exhibit a significant Surface Urban Heat Island (SUHI) effect. Our analysis established a positive correlation between the intensity of the SUHI and NDBI. This conclusively demonstrates that the increase in built-up area and corresponding decline of vegetation cover is a main contributor to the spatial variations in Land Surface Temperature (LST). The loss of natural cooling mechanisms, such as evapotranspiration, due to the replacement of vegetation cover with impervious surfaces, is making the urban core intensely hotter.

This study finds that the Land Surface Temperature (LST) amplitude is maximum for Jamshedpur and minimum for Hazaribagh and Dhanbad. The Wet-Bulb Globe Temperature (WBGT), which is a measure that accounts for temperature, humidity, wind speed, and solar radiation, and is the most relevant index for human heat stress, is continuously increasing beyond the dangerous mark in Jamshedpur. Consequently, the population living in Jamshedpur is the most susceptible to heat strokes and other heat-related morbidities during the summer months.

With rapid urbanization, more people will be moving towards these cities, which will further intensify both the SUHI and UHI effect. The combined effect of global warming and the SUHI/UHI will result in more intense and frequent heat waves during the summer season, which will make the urban population acutely vulnerable to heat-related illnesses and heat strokes.³ It will lead to a dramatically higher demand for cooling and energy consumption. These findings highlight an urgent need for interventions to mitigate the escalating risks to public health and the power infrastructure.

Conclusively, our overall analysis shows that among the five cities, the amplitude of SUHI is maximum for Jamshedpur, while minimum for Hazaribagh and Dhanbad. Decadal growth of WBGT exceeding 32°C is maximum for Jamshedpur, followed by Dhanbad, Bokaro, Hazaribagh, and Ranchi.

7 Recommendation

The study provides vital, data-driven insights confirming a clear pattern that urban areas are getting warmer than their rural and semi-urban surroundings. The escalating amplitude of the Surface Urban Heat Island (SUHI) poses a serious threat to the cities' socio-economic well-being, leading to negative impacts such as thermal discomfort, increased morbidity rates, stress on public health infrastructure, changes in hydrological behavior, and increased energy consumption.

We recommend two categories of measures that may help to minimize the UHI effect. These policy and program-level interventions will create awareness among a diverse range of stakeholders and help in mitigating the impact of the UHI.

7.1 Policy Instruments

Urban forestry programs: The State Forest Department and City Administration/Municipal Corporations should jointly formulate and implement robust Urban Forestry Programs. The primary objective must be to significantly increase the vegetation cover within the city boundaries through planned afforestation, park development, and street-tree planting initiatives.

Mandatory Green building standard: International and domestic green building codes, such as LEED, ECBC (Energy Conservation Building Code), and GRIHA, should be made mandatory for designated classes of new and large-scale construction projects. Municipal Corporations must develop a clear manual and robust monitoring mechanism to ensure compliance.

Incentivising eco-home concepts: Establish an incentive mechanism to encourage existing and new building owners to adopt green measures. A key financial incentive could be a rebate in the property tax rate for building owners who implement codes like ECBC or GRIHA, or utilize alternative, green/low-albedo building materials (e.g., cool roofs, porous pavements).

Moving to cleaner transport: Formulate a city level Clean Transport Policy to accelerate the transition to electric vehicles (EVs) and other sustainable modes. This policy should consist of financial incentives such as:

- Reduction in registration fees for EVs.
- Waiver or reduction of parking fees within the municipal boundary.
- Proposing subsidized electricity tariffs for EV charging infrastructure.

7.2 Demonstration Project

Green Roof Implementation:

- **Concept:** The green roof concept is a well-established mechanism to reduce the cooling load on buildings through insulation and evapotranspiration.
- **Pilot:** Apply the concept on a few select, high-visibility buildings (e.g., Municipal Corporation or Forest Department offices) and rigorously monitor the results (e.g., indoor temperature, energy savings).
- **Wider Drive:** After satisfactory results are achieved, a wider implementation drive can be promoted through various incentives, leveraging the success of the pilot.

Cool Roof Implementation:

- **Concept:** It is scientifically proven that a reflective coating on the roof surface significantly reduces the heat load, making the surface relatively cooler than a normal/ dark surface.
- **Pilot:** Apply the concept of the cool roof to a few selected buildings (e.g., Municipal Corporation or Forest Department offices) and rigorously monitor the results.

- **Wider Drive:** Upon confirming satisfactory results, a wider implementation drive should be promoted through targeted incentives, focusing on high-impact areas (e.g., large commercial buildings, industrial facilities, and low-income housing).

Outcomes of these pilot projects must be shared with wider stakeholders, specifically with Industrial Association, Builder Association, Resident Welfare Association (RWA) etc.

8 Limitations of the current study

The study is primarily based on remote sensing data, which was used to map Land Surface Temperatures (LST) for measuring the amplitude of the SUHI effect.

The lack of sufficient on-the-ground (in-situ) data for LST validation is one of the limitations of this study. LST derived from satellite imagery introduces a probable source of error. Blending actual land-based measurements with remote sensing data is necessary to significantly improve the accuracy level of the UHI amplitude calculation in future studies.

Also, the current analysis mainly focused on LST mapping, which captures the surface thermal pattern but ignores air temperature above ground level and does not fully represent the heat experienced by people. A more holistic understanding of UHI dynamics requires considering air temperature alongside LST and other factors such as building geometry, water surfaces, etc.

The current study may serve as a foundation for subsequent, more detailed, micro-level, proportion-based investigations. Future research should integrate multiple data sources and indices to fully characterize the UHI and guide precise, site-specific mitigation planning

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