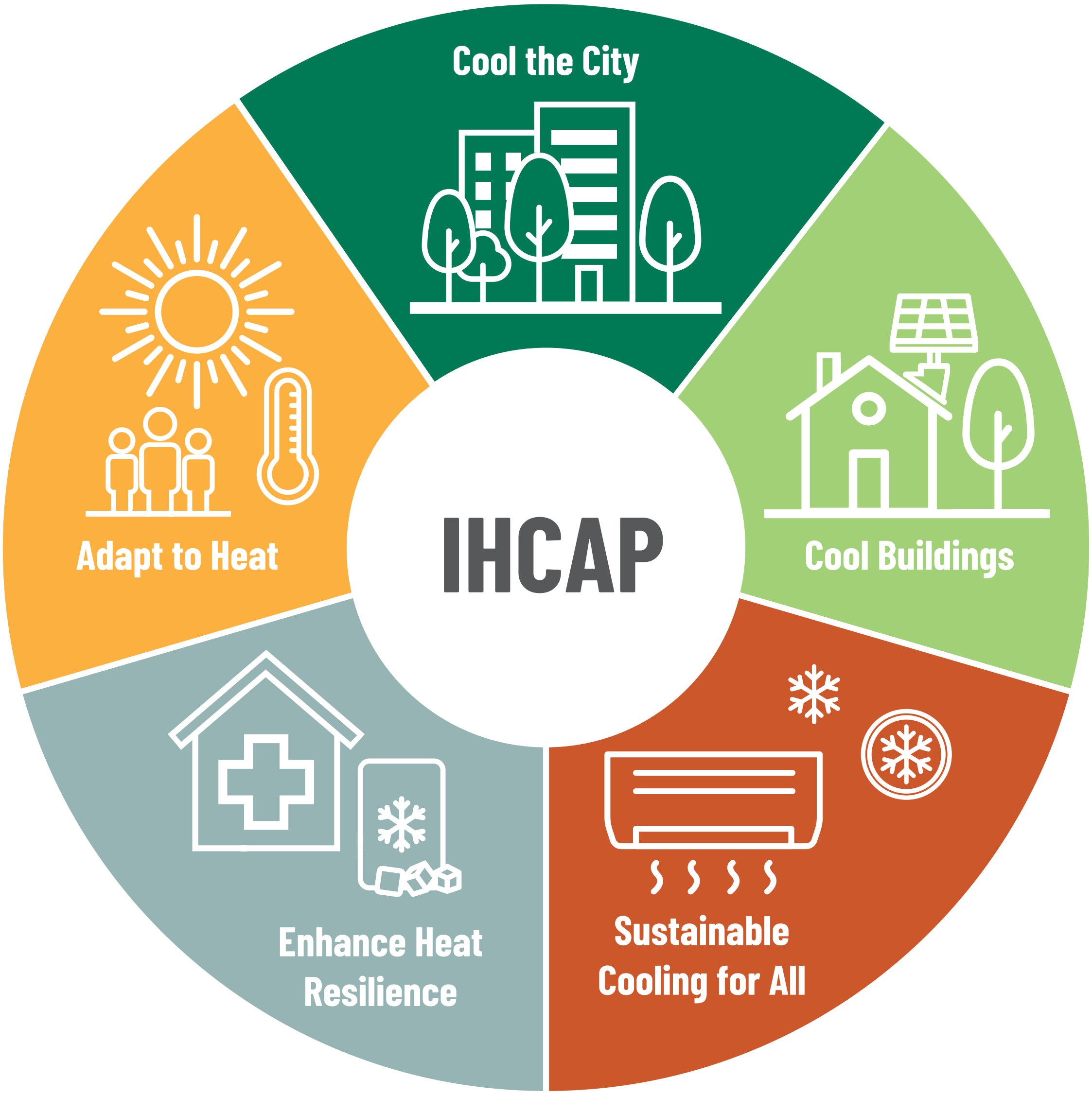

INTEGRATED HEAT AND COOLING ACTION PLAN FOR BHUBANESWAR

iFOREST
INTERNATIONAL FORUM FOR ENVIRONMENT, SUSTAINABILITY & TECHNOLOGY

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International Forum for Environment, Sustainability & Technology (iFOREST) is an independent non-profit environmental research and innovation organisation. It seeks to find, promote and scale-up solutions for some of the most pressing environment–development challenges. It also endeavours to make environmental protection a peoples' movement by informing and engaging the citizenry in important issues and programs.

The Singapore-ETH Centre (SEC) was established in 2010 by ETH Zurich and Singapore's National Research Foundation as part of its CREATE campus. Located in Asia, a rapidly urbanising region, the SEC aims to advance research and innovation, foster cross-disciplinary collaborations, and translate cutting-edge Swiss technology and expertise into practical solutions for some of the most pressing challenges in urban sustainability, resilience, and health through its programmes: Future Cities Lab Global (FCL Global), Future Resilient Systems (FRS), and Future Health Technologies (FHT). SEC also leads the Cooling Singapore initiative, a multi-disciplinary project focused on mitigating urban heat through advanced modelling and collaboration with government agencies to improve urban design and thermal comfort across the city-state.

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List of Abbreviations

AC	Air Conditioner
AMRUT	Atal Mission for Rejuvenation and Urban Transformation
AoI	Area of Interest
BAU	Business as Usual
BDA	Bhubaneswar Development Authority
BEE	Bureau of Energy Efficiency
BMC	Bhubaneswar Municipal Corporation
BESS	Battery Energy Storage System
CEA	City Energy Analyst
CMIP6	Coupled Model Intercomparison Project Phase 6
CPWD	Central Public Works Department
CSR	Corporate Social Responsibility
DAY	Deendayal Antyodaya Yojana
DBT	Dry Bulb Temperature
ECBC	Energy Conservation Building Code
ECSBC	Energy Conservation & Sustainable Building Code
ENS	Eco-Niwas Samhita
FAR	Floor Area Ratio
GI	Galvanised Iron
GWP	Global Warming Potential
HAP	Heat Action Plan
HI	Heat Index
HRI	Heat Risk Index
HVAC	Heating, Ventilation and Air Conditioning
ICAP	India Cooling Action Plan
IEC	Information, Education and Communication
IHCAP	Integrated Heat and Cooling Action Plan
IMD	India Meteorological Department
INCCA	Indian Network on Climate Change Assessment
IPCC	Intergovernmental Panel on Climate Change
ISEER	Indian Seasonal Energy Efficiency Ratio
IST	Indian Standard Time
IT	Information Technology
ITeS	Information Technology enabled Services
LST	Land Surface Temperature
LULC	Land Use Land Cover
MC	Municipal Corporation
MBE	Mean Bias Error
MEPS	Minimum Energy Performance Standards
MHT	Mahila Housing Trust
MoEFCC	Ministry of Environment, Forest & Climate Change
MoSPI	Ministry of Statistics and Programme Implementation
NbS	Nature-based Solutions
NDMA	National Disaster Management Authority
NDVI	Normalised Difference Vegetation Index
NGO	Non-Governmental Organization
NULM	National Urban Livelihood Mission
OECBC	Odisha Energy Conservation Building Code
ORS	Oral Rehydration Solution
OSDMA	Odisha State Disaster Management Authority
OSHB	Odisha State Housing Board
PALM-4U	Parallelized Large-Eddy Simulation Model for Urban Applications
PHC	Primary Health Centre
PLFS	Periodic Labour Force Survey
PPH	Persons per Hectare
PV	Photovoltaic
PWD	Public Works Department
RAC	Room Air Conditioner
RETV	Residential Envelope Transmittance Value
RH	Relative Humidity
RMSE	Root Mean Square Error
ROW	Right-of-Way
RWA	Resident Welfare Associations
SEC	Singapore-ETH Centre
SEZ	Special Economic Zone
SOP	Standard Operating Procedure
SSP	Shared Socioeconomic Pathway
SUJOG	Sustainable Urban Services in a Jiffy by Odisha Government
TPCODL	Tata Power Central Odisha Distribution Limited
UCHC	Urban Community Health Centre
UGS	Urban Green Space
UHI	Urban Heat Island
ULB	Urban Local Body
UPHC	Urban Primary Health Centre
URDPFI	Urban and Regional Development Plans Formulation and Implementation Guidelines
U_{roof}	Thermal Transmittance of Roof
WBGT	Wet Bulb Globe Temperature
WRF	Weather Research Forecasting

Foreword

Bhubaneswar has long been recognised as one of India's leading smart cities, blending heritage with innovation and people-centric planning. However, like many rapidly growing urban centres, our city faces the escalating challenges of rising temperatures, heat stress, and increasing demand for cooling, all exacerbated by climate change and rapid urbanisation.

It gives me great pride to present the Integrated Heat and Cooling Action Plan (IHCAP) for Bhubaneswar, a pioneering step towards making our city more climate-resilient, sustainable, and liveable for generations to come. This plan marks a proactive effort to address these challenges, ensuring that our growth is not only inclusive and modern but also climate-responsive.

The IHCAP represents more than just a document; it is a vision for safeguarding the health and productivity of our citizens, protecting vulnerable communities, and ensuring that every household, workplace, and public space in Bhubaneswar is prepared for the realities of a warming world. Through a combination of urban greening, cool roof interventions, water-sensitive planning, sustainable cooling measures, and resilient public health systems, the plan provides a comprehensive roadmap to tackle urban heat and manage cooling demand sustainably.

As the Mayor of Bhubaneswar, I am deeply committed to steering the city towards a future where development and environmental responsibility go hand in hand. This plan is a reflection of our resolve to set benchmarks for other cities in India and globally. It is also a testament to the collaborative spirit of our citizens, experts, and institutions who contributed to shaping this mission.

I call upon all stakeholders, government agencies, private sector, academic institutions, and civil society to work together in implementing this plan. With collective effort, we can ensure that Bhubaneswar continues to shine as a resilient, inclusive, and climate-smart city, leading the way in adapting to the challenges of the 21st century.

Sulochana Das
Mayor, Bhubaneswar Municipal Corporation

Foreword

The idea of an Integrated Heat and Cooling Action Plan (IHCAP) has been a journey of more than seven years. It began in 2018, when I was a member of the committee that drafted the India Cooling Action Plan (ICAP). The ICAP aimed to achieve "sustainable cooling and thermal comfort for all" by improving the energy efficiency of appliances and buildings, and by promoting eco-friendly refrigerants. While it was envisioned as a national program, it was evident to me that its goals could only be realised if translated into city-level action plans. During this period, I was also writing extensively about the rising threat of heatwaves and the urgent need for cities to build resilience against extreme heat.

In March 2019, the ICAP was released, followed later that year by the National Disaster Management Authority's guidelines for preparing Heat Action Plans (HAPs) for cities. The guidelines were primarily focused on adaptation—heat warnings, awareness campaigns, and basic measures to prevent mortality and morbidity during extreme heat. However, they did not address the critical need for sustainable cooling and thermal comfort. As a result, HAPs remained disconnected from the ICAP, leaving a major gap in India's strategy to deal with rising heat. That disconnect stayed with me.

In October 2019, iFOREST was established, and the task of institution-building demanded most of my time. As a result, I had to set aside the idea of IHCAP for nearly four years. But the idea never left me. In 2023, I felt it was time to bring the pieces together—to integrate ICAP and HAP into a comprehensive framework that could simultaneously address rising temperatures and surging cooling demands.

That year, I wrote the first concept note on IHCAP and presented it at the Montreal Protocol meeting in Montreal, Canada. The response was encouraging: the concept was widely appreciated, and the Ozone Secretariat of the UN Environment Programme recognised it as a key strategy to tackle global ozone and climate challenges. This affirmation strengthened my resolve to make IHCAP a reality.

In 2024, we at iFOREST began developing the IHCAP for Bhubaneswar, in partnership with the Singapore ETH-Zurich Centre (SEC). SEC provided vital modelling support, while the iFOREST team worked on the ground to collect and analyse data, engage with stakeholders, and shape the plan. The result is the country's first IHCAP—a product of months of rigorous research, collaboration, and innovation—that fills a critical gap in India's approach to heat resilience.

It is fitting that Bhubaneswar, one of the most heat-stressed cities in the country, is the first to adopt such a framework. The city has consistently shown foresight and ambition in embracing innovative urban solutions. With this plan, it reinforces its position as a climate leader, while also setting an example for other Indian cities to follow. By adopting the IHCAP, Bhubaneswar is not only protecting its citizens from escalating heat risks but also demonstrating how cities can proactively shape a sustainable and resilient cooling future.

I am grateful to my colleagues at iFOREST and our partners at SEC for their dedication and expertise in making India's first IHCAP a reality. I believe this pioneering effort will inspire many other cities across the country to adopt and adapt the IHCAP framework, ultimately contributing to a cooler, healthier, and more climate-resilient future for millions of urban citizens.

Dr. Chandra Bhushan
President & CEO, iFOREST

The Heat Lexicon

- **Land Surface temperature:** Surface temperature or Land surface temperature (LST) refers to the temperature of the land or surface measured at the interface between the Earth's surface and the atmosphere. It indicates how hot the surface of an object, such as soil, pavement, rooftops, or vegetation, feels to touch or through remote sensing instruments.
- **Dry-bulb temperature:** The dry-bulb temperature indicates the measurement by a thermometer that is not influenced by the moisture present in the air. This is why it is commonly referred to as air temperature or ambient air temperature and can be expressed in degrees Celsius (°C), degrees Fahrenheit (°F), or Kelvin (K).
- **Wet-bulb temperature:** The wet-bulb temperature indicates the temperature measured by a moistened thermometer bulb exposed to airflow. This measurement reflects the combined effects of heat and humidity. A wet-bulb temperature of 35°C (95°F) represents the point at which the human body can no longer effectively cool itself through perspiration, potentially leading to heat stroke or even death with prolonged exposure.
- **Heat Index:** The Heat Index is the perceived temperature that the human body experiences when both air temperature and relative humidity are considered. Also known as the "feels like temperature," the heat index accounts for the fact that high humidity diminishes the effectiveness of sweating in cooling the body, causing it to feel hotter than the actual air temperature. The heat index is calculated using the formula:

  $\text{Heat Index} = -42.379 + 2.04901523T + 10.14333127R - 0.22475541TR - 6.83783 \times 10^{-3}T^2 - 5.481717 \times 10^{-2}R^2 + 1.22874 \times 10^{-3}T^2R + 8.5282 \times 10^{-4}TR^2 - 1.99 \times 10^{-6}T^2R^2$

  T - Air Temperature (F)

  R - Relative Humidity (%)
- **Wet-bulb Globe Temperature:** Wet-Bulb Globe Temperature (WBGT) is a composite temperature index used to estimate the effect of temperature, humidity, wind speed, and solar radiation. It provides a more comprehensive measure of heat stress than air temperature or heat index alone, making it particularly useful for assessing occupational and athletic heat exposure in outdoor and indoor environments.
- **Physiological Equivalent Temperature:** Physiological Equivalent Temperature (PET) is defined as the temperature at which the thermal conditions of an outdoor environment (including solar radiation, wind, humidity, and temperature) would cause the same physiological response in a person as they would in a standard indoor environment at rest, without wind and solar radiation.

  PET enables a comparison of the integral effects of complex outdoor thermal conditions on a human body by converting these conditions into an equivalent temperature that would elicit the same physiological response in a typical indoor environment.

Table 1: Heat Index, Wet-Bulb Globe and Physiological Equivalent Temperature

Aspect	Heat Index	Wet-Bulb Globe Temperature	Physiological Equivalent Temperature
Definition	Perceived temperature which combines air temperature and relative humidity.	The lowest temperature achievable by evaporative cooling of a wet surface.	A thermal comfort index reflecting human physiological response to outdoor conditions.
What it measures	How hot it feels to humans in hot and humid conditions. Temperature + Humidity	Evaporative cooling potential and physiological stress on the body. Temperature + Humidity + Evaporation rate	• Air temperature • Humidity • Wind speed • Solar radiation • Human metabolism and clothing
Assumes	Still air, shady conditions (no direct sunlight).	Evaporative environment regardless of solar exposure.	Simulates an individual's thermal state, assuming specific clothing and metabolic rate.
Used for	Public weather forecasts, heat advisories, general comfort.	Occupational safety, climate modelling, and health risk assessments.	Designed to assess thermal comfort and human heat perception in urban/ public spaces, such as in urban planning, landscape designs, heat comfort studies, and so on.

Note: Since PET values vary at the individual level, the PET index used in this report is derived from literature studies conducted in India for regions with similar climatic conditions.[1]

Table 2: Categorisation of thermal sensation and physiological stress used for the study

Thermal sensation	Physiological stress level	PET range in °C
Very Cold	Extreme Cold Stress	≤ 9
Cold	Strong Cold Stress	9 – 11
Cool	Moderate Cold Stress	11.1 – 14
Slightly Cool	Slight Cold Stress	14.1 – 18
Neutral	No Thermal Stress	18.1 – 26
Slightly Warm	Slight Thermal Stress	26.1 – 28
Warm	Moderate Heat Stress	28.1 – 33
Hot	Strong Heat Stress	33.1 – 36
Very Hot	Extreme Heat Stress	36.1 – 40

Source: iFOREST and SEC Analysis

Executive Summary

India's cities face a dual challenge: intensifying warming from both climate change and the urban heat island (UHI) effect, and a rapid surge in cooling demand. This creates a dangerous feedback loop—rising cooling needs drive higher energy use, intensifying UHI and greenhouse gas emissions, which in turn worsen heat stress and increase cooling demand. Without integrated action, this cycle will deepen public health risks, erode productivity, raise energy demand, and escalate emissions.

The Integrated Heat and Cooling Action Plan (IHCAP) for Bhubaneswar—the first of its kind in India—offers a unified framework to break this cycle. It aims to:

- Reduce Urban Heat Island (UHI) effect through urban planning, building design interventions and climate-sensitive infrastructure.
- Improve indoor thermal comfort through building design and construction practices that reduce heat absorption.
- Provide access to cooling for all residents by promoting affordable, energy-efficient, and low-emission cooling solutions.
- Strengthen Bhubaneswar's ability to prepare for, respond to, and recover from extreme heat events through proactive planning, early warning systems, and targeted adaptation measures.
- Create a unified, actionable city-wide framework that brings together various departments and stakeholders to address heat stress and cooling needs, reducing policy fragmentation and implementation gaps.

The city

Bhubaneswar, a rapidly growing city on India's eastern coast, is particularly vulnerable to climate hazards. Governed by Bhubaneswar Municipal Corporation (BMC) across 186 km² and 67 wards, the city faces high exposure to cyclones, heat waves, and other climate risks. Its population has increased from 8.4 lakh in 2011 to the current projected population of 11.5 lakh.

Bhubaneswar developed its Heat Action Plan (HAP) in 2020, which was revised in 2025. It features threshold-based heat alerts, awareness campaigns, and emergency response protocols.

Present and Future Heat Stress

Bhubaneswar experiences a warm and humid climate. In recent years, Bhubaneshwar has endured scorching summer temperatures, frequently surpassing 40°C for several consecutive days. Studies have confirmed a rising trend in both temperature levels and the frequency of heatwave events, with particularly severe occurrences recorded in 2012, 2014, and 2016.

Climate projections under SSP2-4.5 indicate alarming trends. By 2050, summer maximum temperatures will rise by 1.5°C on an average with extreme heat event temperatures increasing by 2 to 2.5°C. A typical summer day in 2050 will experience heat stress equivalent to current heatwave conditions. Heat stress duration will extend to 7-9 hours daily, significantly increasing health risks and reducing productivity.

In recent years, the city has also witnessed major changes in its land use pattern. From 2018 to 2024, built-up areas expanded 23% while vegetation fell 9.8% and water bodies declined 75%, intensifying the UHI effect. Surface temperatures now vary by up to 20°C across the city, with built-up areas reaching 45°C compared to 38-39°C in vegetated areas. Northern wards (Ward 1 to 11) consistently experience higher temperatures (+0.8-1.9°C) due to heat advection, while high-density areas like Salia Sahi (Wards 20-21, 26) face the greatest heat exposure.

The consequences are already severe and multifaceted:

- **Health:** All-cause mortality is higher in hot-humid months (August-October) rather than peak summer, reflecting the complex relationship between heat, humidity, and health outcomes.
- **Economic:** About 30% of Bhubaneswar's workforce faces notable productivity losses—10-15% for medium-intensity outdoor jobs and 20-25% for physically intensive roles. This translates to cumulative annual earning loss of 8.6% due to extreme heat.
- **Energy:** Cooling now accounts for 34-37% of total city electricity consumption. Between 2021-2023, residential AC ownership surged from 6% to 15%, while commercial sector penetration increased from 71% to 89%. Under business-as-usual scenarios, cooling energy demand could increase 7.6 times by 2050.

Modelling impacts and outcomes

The study employed comprehensive modelling across two representative clusters—Salia Sahi (slum and low-rise buildings) and Janpath (commercial corridor with taller buildings)—to assess the effectiveness of various heat mitigation strategies. Both areas currently experience similar heat stress levels with summer Physiological Equivalent Temperature (PET) of 34-35°C, projected to rise by 3.0-3.5°C by 2050.

City-Scale Interventions: Nature-based solutions demonstrated significant cooling potential. Urban greening (parks, forests and corridors) achieved the greatest impact, reducing average surface temperatures by 6.6°C with daytime peaks dropping by 16.1°C. Green road medians lowered surface temperatures by 2.4°C and reduced PET by 3.6°C when properly aligned with wind patterns. Water bodies provided cooling effects of 3.3°C in PET reduction, while strategic building densification with improved shading and airflow reduced daytime PET by 2.2°C.

Building-Level Measures: Roof interventions also are highly effective in reducing temperatures. Green roofs delivered the greatest cooling benefits, reducing daytime surface temperatures by 5-22°C depending on time of day, with 24-hour average reductions of 9.5°C for residential buildings and 8.15°C for institutional buildings. White-painted roofs also offered substantial cooling, lowering surface temperatures up to 8.7°C in low-rise areas and 4.9°C in slums. However, solar photovoltaic roofs showed mixed results—providing 3.5°C daytime cooling but increasing nighttime temperatures by 2°C.

Upgraded building construction following Energy Conservation and Sustainable Building Code/Eco-Niwas Samhita 2024 reduces annual electricity intensity by 10.1% through improved insulation, reflective coatings, and high-performance materials.

Appliance efficiency: Efficient cooling appliances deliver substantial savings: replacing current 3-star with 5-star split ACs cuts residential energy consumption by 8.5-11.6%, while water-based chiller systems in commercial buildings achieve 13.5-17.3% savings and reduce refrigerant-related emissions.

Integrated City-Level Interventions

To understand the cumulative impact of building design and construction practices along with the use of efficient appliances on energy and GHG emissions from cooling, three scenarios were modelled. The results of the modelling study are as follows:

- **Business-as-Usual:** In BAU Scenario, cooling electricity demand increases 7.6 times by and GHG emissions from cooling by around 4 times by 2050.
- **Intervention Scenario:** Moderate compliance with energy efficiency building code cuts electricity use and GHG emissions by 44%, with 6.5-year payback periods for typical 2BHK homes.
- **Deep-Cut Scenario:** Aggressive efficiency measures reduce energy consumption and emissions by up to 67%, with 8.5-year payback periods that will likely shorten as technology costs decline.

Implementing the above interventions can transform Bhubaneswar's heat resilience, cutting projected cooling energy demand and emissions, reducing peak temperatures by several degrees, and safeguarding public health and economic productivity—ensuring the city's continued growth remains both liveable and climate-smart.

An Integrated Action Plan

Bhubaneswar's rising heat stress demands a shift from the existing HAP to a comprehensive IHCAP. However, a transition to IHCAP requires policy and practice shifts at the city, state and national levels.

A. Bhuwaneshwar Action Plan

1. Cool the City

- **Urban Greening** – Rapidly expand green cover in heat-vulnerable wards to meet WHO's benchmark of 9 m^2 urban green space per person.
- **Water Body Restoration** – Develop and enforce a Water Body Conservation & Restoration Policy, mapping and reviving degraded ponds, lakes, and streams.
- **Cool Roofs** – Launch a citywide cool roof programme prioritising informal settlements; estimated cost for all slum roofs ≈ ₹33.3 crore.
- **Climate-Sensitive Streets** – Update design guidelines to include shaded walkways, permeable pavements, green medians, and high-albedo surfaces.

2. Sustainable Cooling & Energy Efficiency

- **Promote energy-efficient appliances** – Incentivise high star-rated cooling devices and pilot new sustainable cooling technologies.
- **District Cooling** – Identify high-development zones for district cooling, conduct feasibility studies, and integrate in planned IT and commercial areas.

3. Heat-Resilient Infrastructure

- **Health** – Add PHCs/CHCs in underserved wards; introduce mobile clinics and ice-pack dispensaries in vulnerable areas.
- **Homeless Shelters** – Conduct survey to assess needs, close 60% capacity gap, design shelters with cooling features.
- **Cooling Centers** – Repurpose existing public buildings, introduce mobile cooling units for outdoor workers.
- **Water Kiosks** – Improve maintenance, expand in underserved wards, ensure reliable supply.
- **Cool Bus Stops** – Retrofit with shading, ventilation, reflective materials, and greenery.

4. Heat Adaptation Measures

- **Revise Heat Thresholds** – Use maximum temperature, heat index, and night-time heat index.
- **Parametric Insurance** – Pilot schemes for vulnerable workers, triggered by heat thresholds, with quick payouts.
- **Strengthen Sectors** – Digitise health appointments and records; improve waste and animal welfare systems.
- **Finance & Capacity** – Build municipal capacity, allocate funds, define departmental roles.

5. Build Capacity

- **Adopt the IHCAP Framework** – Integrate mitigation and sustainable cooling in HAP; revise every 5 years.
- **Modelling & Data** – Institutionalise climate modelling, enhance data collection, improve monitoring.
- **Capacity Development** – Undertake capacity building programmes for all stakeholders, especially critical departments like health, water, electricity, disaster management etc.

B. Odisha's Action Plan

- **Urban Cooling Policy** – A policy to support long-term greening, blue infrastructure, and cool roof integration in planning.
- **Energy Efficiency Building Codes** –
  - » Revise OECBC 2022: lower compliance threshold from 1000 m^2 to 500 m^2; raise AC efficiency to 4–5 star.
  - » Develop residential codes (ENS 2024) with stricter envelope standards, lower thresholds, and mandatory cool roofs.
  - » Strengthen enforcement via integration with approvals, capacity building, and incentives.
- **Electricity Policy** – Develop a heat-season electricity supply strategy with grid resilience measures.

C. National Policy Support

- **Revise NDMA HAP Guidelines** – Incorporate humidity and night-time heat; mandate spatial heat risk mapping; integrate cross-sectoral impacts; include future heat projections; expand scope to mitigation and sustainable cooling.
- **URDPFI Guidelines** – Add ward-level green space standards, heat assessment tools, and modelling into urban planning for proactive mitigation.

CITY LEVEL EFFORTS

Cool the city

- Expand green cover across wards with low green cover
- Prioritise restoration and rejuvenation of water bodies as 32 wards have seen a decline of over 50% in surface water levels across 5 years
- Adopt a dedicated Water Body Conservation Policy to provide a long-term framework for water bodies restoration and rejuvenation work
- Develop a Cool Roof Programme for improving thermal comfort, especially focusing on low-income and informal settlements
- Revise Street Design Guidelines for Bhubaneswar to integrate heat mitigation strategies
- Identify priority roads for better traffic management and design

Sustainable Cooling for All

- Incentivise the shift from 3-star to 5-star cooling appliances
- Pilot and incentivise emerging sustainable cooling technologies
- Identify sites and develop district cooling in the city

Enhance Heat Resilience

- Adopt digitalisation for appointments and patient records
- Conduct a homelessness survey to identify high-priority areas and develop new homeless shelters
- Repurpose existing government infrastructure as public cooling shelters and establish new public cooling shelters in heat risk wards
- Improve O&M system for water kiosk facilities
- Upgrade the current bus infrastructure to cool bus stops

Heat Adaptation Measures

- Add Heat Index and night-time indices to the current heat threshold
- Introduce parametric insurance for vulnerable groups based on relevant thresholds for protection against extreme heat
- Incorporate Waste Management Measures into city Heat Action Plan
- Develop a comprehensive capacity-building program and earmark financial resources to strengthen the capabilities of departments

Policy Recommendation

- Adopt IHCAP Framework and focus on capacity building and improve data collection processes to institutionalise the framework

STATE LEVEL EFFORTS

Urban Cooling Policy

- A dedicated policy focusing on nature-based solutions, cool roofs, and cooling centers to improve heat-resilience of the cities

Sustainable and Energy Efficient Building Codes

- Revise Existing OECBC 2022 and Adopt Residential Building Code to match latest national standards while incorporating local requirements and strengthen implementation of building codes

Heat Season Electricity Policy

- Develop a specific heat season electricity policy to manage load demand and reduce power cuts

NATIONAL LEVEL EFFORTS

Guidelines for Preparation of Heat Action Plan - NDMA

- Convert HAP guidelines to IHCAP. Key changes required include:
- Revision of Heat Wave Definition and Guidance on Incorporating Humidity and Night-time Temperatures for Heat Thresholds
- Strengthening the Spatial Risk Assessment and Response to UHI
- Integrate Cross-Sectoral Impacts of Heat
- Integrate Future Heat Stress Projections
- Expand the scope of HAPs to include heat mitigation and sustainable cooling measures

Urban and Regional Development Plans Formulation and Implementation - MoHUA

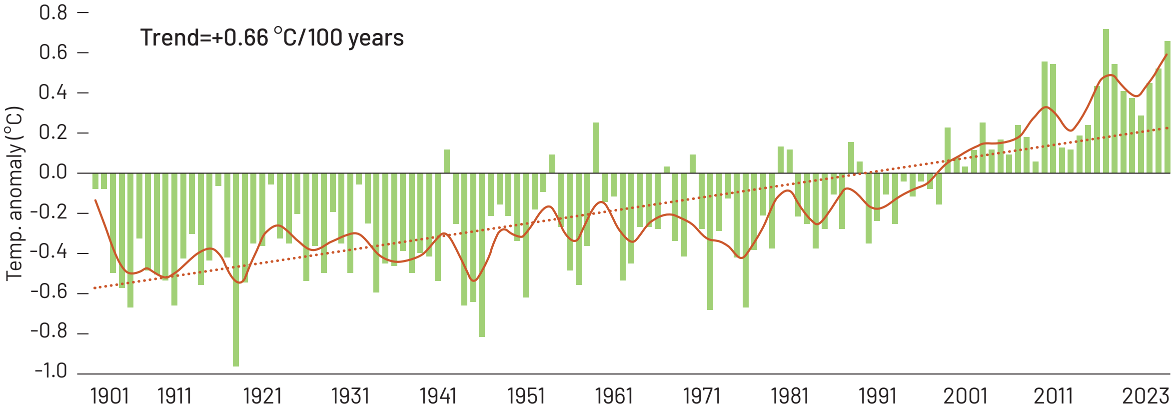
- Include Heat Assessment into the Urban Planning processes to tackle the UHI Effect

01

Introduction

India, like many parts of the world, is warming. The year 2024 was noted as the hottest on record, with the annual mean being 0.65°C higher than the long-term average for the period 1991-2020.[2] Heatwaves have increased in intensity, frequency, duration, and even geographic spread, with more regions experiencing extreme heat for longer periods.[3] Urban areas are often affected more severely than their surroundings due to the Urban Heat Island (UHI) effect, where human activities and land modifications cause cities to absorb, retain and release more heat, leading to temperature differences of up to 5°C compared to nearby rural areas.[4]

Figure 1.1: Annual mean land surface air temperature anomalies over India for 1901-2023



Source: Annual Climate Summary 2023, IMD Pune

In response, India has been proactively working to mitigate heat effects and ensure more sustainable cooling solutions. The National Disaster Management Authority (NDMA) has initiated the development of Heat Action Plans (HAPs) to combat heat stress. So far, more than 120 districts/cities in 14 states have developed HAPs.[5] The Ministry of Environment, Forest and Climate Change (MoEFCC) has also launched the India Cooling Action Plan (ICAP) as a roadmap for sustainable cooling with a 2037-38 target to reduce cooling demand across sectors by 20-25%, cooling energy requirements by 25-40% and refrigerant demand by 25-30%. The ICAP's overarching goal is to "achieve sustainable cooling and thermal comfort for all while securing environmental and socio-economic benefits for the society". It prioritises energy-efficient and climate-friendly cooling in appliances, buildings, cold chain, and transport sectors.[6]

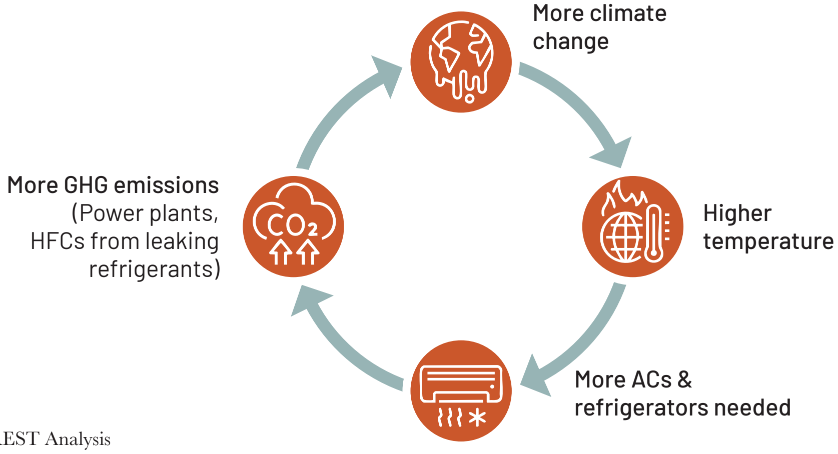
Sustainable cooling is crucial as the widespread adoption of existing air conditioning technology is creating a vicious cycle, driving increased energy consumption and greenhouse gas emissions, further intensifying UHI effect and climate change and resulting in more heat stress and even higher demand for cooling.

While India's heat and cooling actions appears comprehensive, several gaps need to be addressed:

- Both HAP and ICAP share common goals, but they singularly focus on only one aspect – either heat or cooling. With the HAPs only focusing on heat management and developing strategies to protect people from heat stress, they miss out on mitigating the effects of increasing cooling demand. Conversely, while the ICAP addresses sustainable cooling, it's focus is cooling appliances and refrigerants and thus overlooks the essential aspect of reducing heat, which can be as critical as providing sustainable cooling technologies.
- Both action plans fail to adequately address heat mitigation strategies of reducing heat within the city and buildings.
- The existence of two separate plans for an interconnected issue – HAPs at city level and ICAP at the national level – each with distinct goals, implementation strategies and monitoring mechanisms, creates a fundamental disconnect when it comes to on-ground delivery. As access to cooling becomes critical for protecting public health, food security, and economic stability, addressing sustainable cooling at the city level is critical.

To overcome these gaps, integrating heat and cooling plans into a unified framework at the city-level – an Integrated Heat and Cooling Action Plan – with clear mandates is necessary to ensure a coordinated response to challenges posed by extreme heat and cooling needs.

Figure 1.2: Vicious heat and cooling cycle

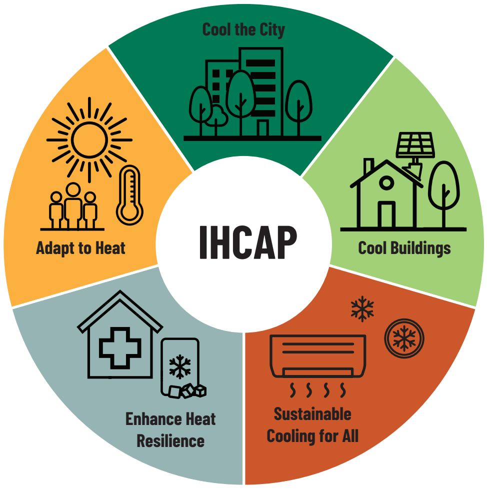


Source: iFOREST Analysis

1.1 Integrated Heat and Cooling Action Plan

An Integrated Heat and Cooling Action Plan (IHCAP) is built on five integrated strategic pillars:

Figure 1.3: Pillars of Integrated Heat and Cooling Action Plan



Source: iFOREST Analysis

Pillar 1: Cool the City

Reduce the Urban Heat Island (UHI) effect and improve outdoor thermal comfort through:

- **Nature-based solutions** – expanding urban green cover, developing tree-lined medians, and restoring or creating water bodies.
- **Albedo enhancement** – promoting cool roofs, cool pavements, and reflective building façades.
- **Climate-sensitive urban design** – improving city morphology to enhance ventilation and minimise local heat build-up.

Pillar 2: Cool Buildings

Promote building design and construction practices that reduce heat absorption and improve indoor comfort through:

- Passive cooling strategies (orientation, shading, ventilation).
- Use of high-reflectance and insulating materials.
- Climate-responsive architecture tailored to local weather conditions.

Pillar 3: Sustainable Cooling for All

Ensure access to affordable, efficient, and climate-friendly cooling solutions by:

- Promoting super-efficient cooling appliances.
- Deploying centralised systems such as district cooling in high-density areas.
- Providing targeted cooling solutions for low-income and vulnerable communities.

Pillar 4: Enhance Heat Resilience

Safeguard communities from rising temperatures and frequent heatwaves by:

- Strengthening critical infrastructure (electricity, water, transport) to withstand extreme heat.
- Establishing cooling shelters in high-risk zones.
- Designing cool public spaces and infrastructure such as shaded bus stops and railway stations.

Pillar 5: Adapt to Heat

Build long-term capacity to manage extreme heat events through:

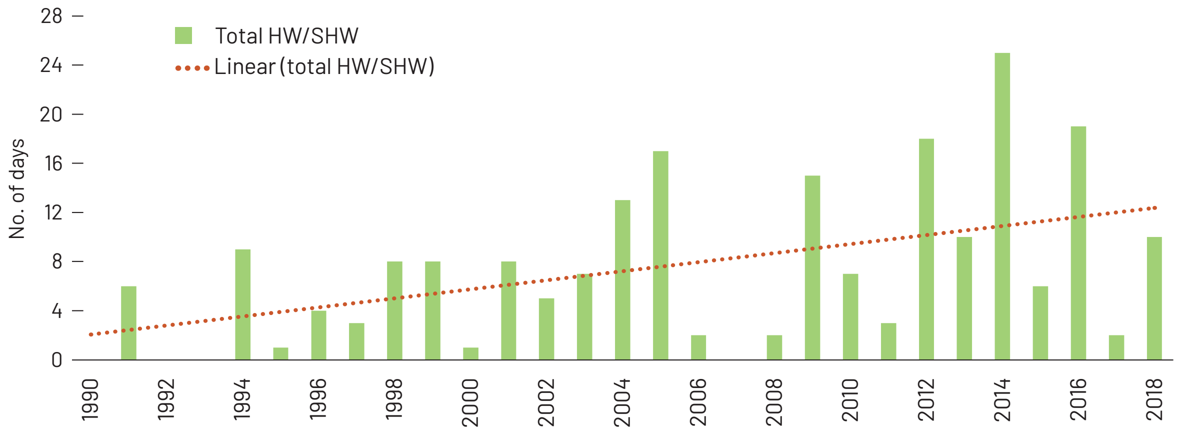
- Setting local heat thresholds based on temperature, humidity, and night-time heat stress.
- Implementing Heat SOPs (Standard Operating Procedures) for extreme heat days, including work-hour adjustments and public amenities.
- Introducing parametric insurance for vulnerable groups such as outdoor workers and street vendors.
- Establishing dedicated heat wards in healthcare centres and training medical staff on heat illness management.

1.2 Heat Action Plans in Odisha and Bhubaneswar

Odisha and its capital city, Bhubaneswar, have a long history of experiencing extreme heat conditions that pose serious threats to public health and well-being. In recent years, Bhubaneshwar has endured scorching summer temperatures, frequently surpassing 40°C for several consecutive days. Studies have confirmed a rising trend in both temperature levels and the frequency of heatwave events, with particularly severe occurrences recorded in 2012, 2014, and 2016. These devastating heat waves have served as a wake-up call to the growing dangers of heat stress.[7]

In response to these escalating challenges, the Government of Odisha and the Bhubaneswar Municipal Corporation have proactively initiated a range of measures aimed at reducing heat-related risks:

Figure 1.4: Number of heat wave days in Bhubaneswar



Source: Bhubaneswar Heat Action Plan 2020

- **Declaring heat waves as a local disaster:** Heatwaves are not recognised as a disaster at the national level under the existing disaster relief policies. Odisha stands out as one of the few states that has classified heatwaves as a local disaster. This classification enables the state government to utilise up to 10% of the State Disaster Response Fund (SDRF) for heat actions.[8]
- **Adoption of the state heat wave action plan:** Odisha is one of the early adopters of a state-specific heat wave action plan.[9] Since 2014, the state has regularly updated the HAP document, with the latest revision happening in 2023.[10]
- **Adoption of the city heat wave action plan:** In line with the actions taken by the state government, Bhubaneswar also conducted scientific studies to determine heat threshold temperatures for the city.[11] In 2020, this led to the development of a HAP, which was recently revised in 2025. However, the HAP is focused only on adaptive strategies and needs to be transformed into an Integrated Heat and Cooling Action Plan to provide long-term, sustainable solutions for heat and cooling.

1.3 IHCAP for Bhubaneswar

An Integrated Heat and Cooling Action Plan for the city of Bhubaneswar is being developed to meet the following key objectives:

- **Develop a Scalable, Data-Driven IHCAP Framework for the City:** Develop and establish a robust, evidence-based framework that can inform future planning and monitoring to address heat and cooling challenges.
- **Integrate Heat Mitigation into Bhubaneswar Urban Planning:** Embed heat risk reduction strategies into the city's land use, infrastructure, and housing policies, including expanding green cover, enhancing albedo, and improving building design.
- **Promote Sustainable and Equitable Access to Cooling:** Ensure thermal comfort for all residents, particularly for vulnerable and low-income communities, by promoting affordable, energy-efficient, and low-emission cooling solutions.
- **Enhance City's Resilience to Urban Heat:** Strengthen Bhubaneswar's ability to prepare for, respond to, and recover from extreme heat events through proactive planning, early warning systems, and targeted adaptation measures.
- **Facilitate coordinated action:** Creation of a unified, actionable city-wide framework that brings together various departments and stakeholders to address heat stress and cooling needs, reducing policy fragmentation and implementation gaps.

The IHCAP for Bhubaneswar should therefore serve to deliver on the following interconnected outcomes:

- Reduction in Urban Heat Island (UHI) effect through strategic urban planning, building design interventions and climate-sensitive infrastructure.
- Improved Thermal Comfort in Housing, with better-designed buildings that reduce cooling demand.
- Lower Emissions from Cooling through widespread adoption of passive cooling techniques, energy-efficient appliances, and adoption of newer technologies.
- Enhanced Public Health, driven by reduced heat stress and improved critical infrastructure, enabling better well-being and economic performance, especially for outdoor workers.

02

City Profile

SUMMARY

Governance and Climate Vulnerability

Bhubaneswar, a fast-growing IT and education hub on India's eastern coast, is governed by Bhubaneswar Municipal Corporation (BMC) covering 186 km^2. Positioned between coastal plains and Eastern Ghats, Bhubaneswar faces high exposure to cyclones, floods, heat waves, strong winds, occasional earthquakes, and other climate-related hazards.

Land-Use Composition

Bhubaneswar has around 16% built-up, 12% roads, 30% open/fallow/paved spaces, and 42% vegetation/water bodies. Residential use dominates built-up areas, alongside key industrial hubs, such as Chandrasekharpur, Rasulgarh, Mancheswar, etc. and a growing IT sector at Infocity SEZ.

Population Growth & Change

BMC's population doubled from 4.1 lakh (1991) to 8.4 lakh (2011); projected at around 11.5 lakh by 2025. Household sizes are declining (from 4.8 in 1991 to 4.0 in 2025), reflecting increasing nuclearisation and changing social dynamics.

Density and Ward-level Variation

Despite BMC's area growing from 124.7 to 186 km^2, population density increased from 3,300 to 6,175 persons/km^2, between 1991 and 2025, indicating rising urban pressure. Wards 21 and 26 (Salia Sahi) have the highest population density – over 700 persons per hectare (PPH), while 40% of wards are 'Small Town' category (<100 PPH), indicating uneven infrastructure pressure.

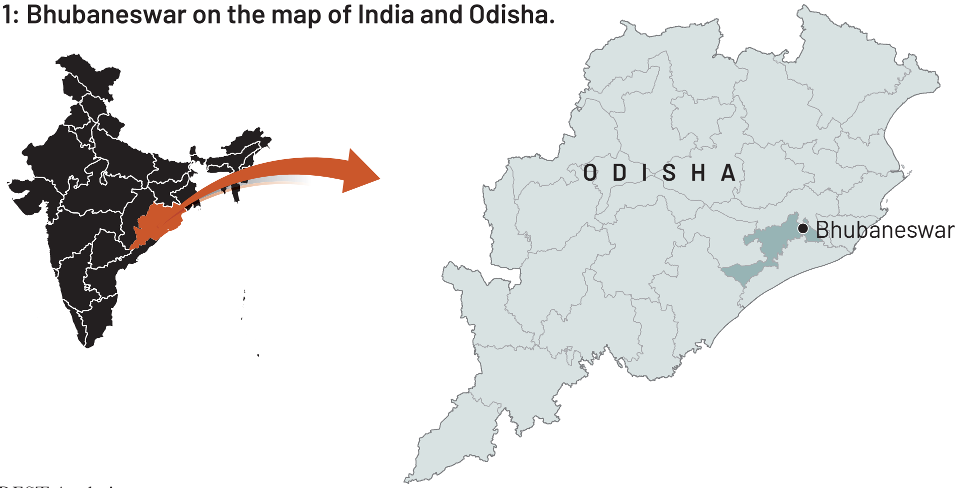
Economy & Workforce Trends

Economy is diversified across government services, education, IT, tourism, real estate, and industry. Odisha's workforce share in agriculture fell from 56% (2011–12) to 49% (2023–24), with industry (26%) and services (25%) rising; urban jobs in construction, transport gig work, and street vending are expanding, reflecting the transition from agricultural to industrial and service sectors.

Bhubaneswar is located on the eastern coast of India. It is emerging into a prominent hub for information technology (IT) and education, positioning itself among the country's fastest-growing cities.

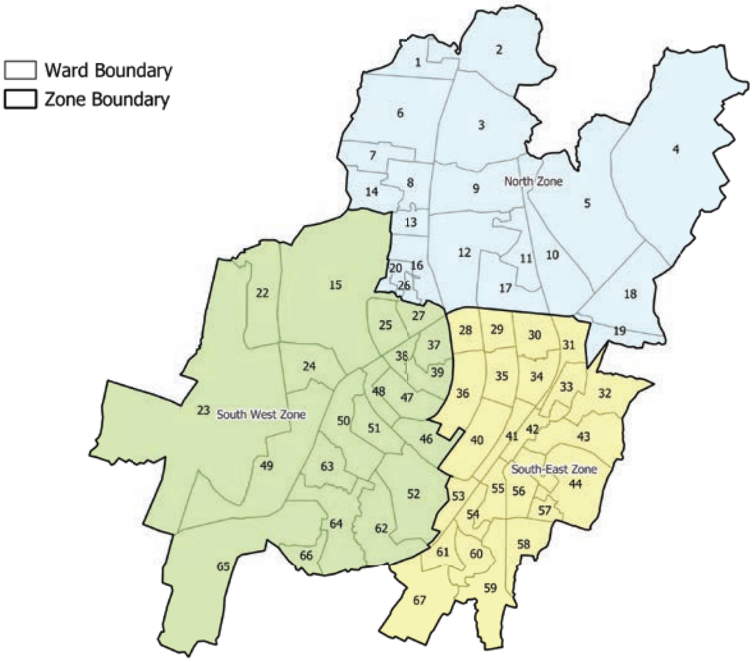
The city is administered by the Bhubaneswar Municipal Corporation (BMC), which governs an area of approximately 186 square kilometres. BMC is divided into three administrative zones and 67 wards: North (21 wards), South-East (25 wards), and South-West (21 wards).

Figure 2.1: Bhubaneswar on the map of India and Odisha.



Source: iFOREST Analysis

Figure 2.2: Administrative zones and wards within BMC



Source: iFOREST Analysis

The city falls in the Khurda district, positioned between 20°12' and 20°25' N latitude and 85°44' E longitude, within the eastern coastal plains and along the axis of the Eastern Ghats mountains, with an average altitude of 45 m (148 ft) above sea level.

Lying on the western fringe of Odisha's mid-coastal plain, it lies on a low laterite plateau shaped by continuous erosion into valleys and ridges. The rivers Kuakhai, Bhargavi, and Daya flow along the city's south-eastern edge. Vast hillocks and forests are spread across the northern, western, and southern regions.

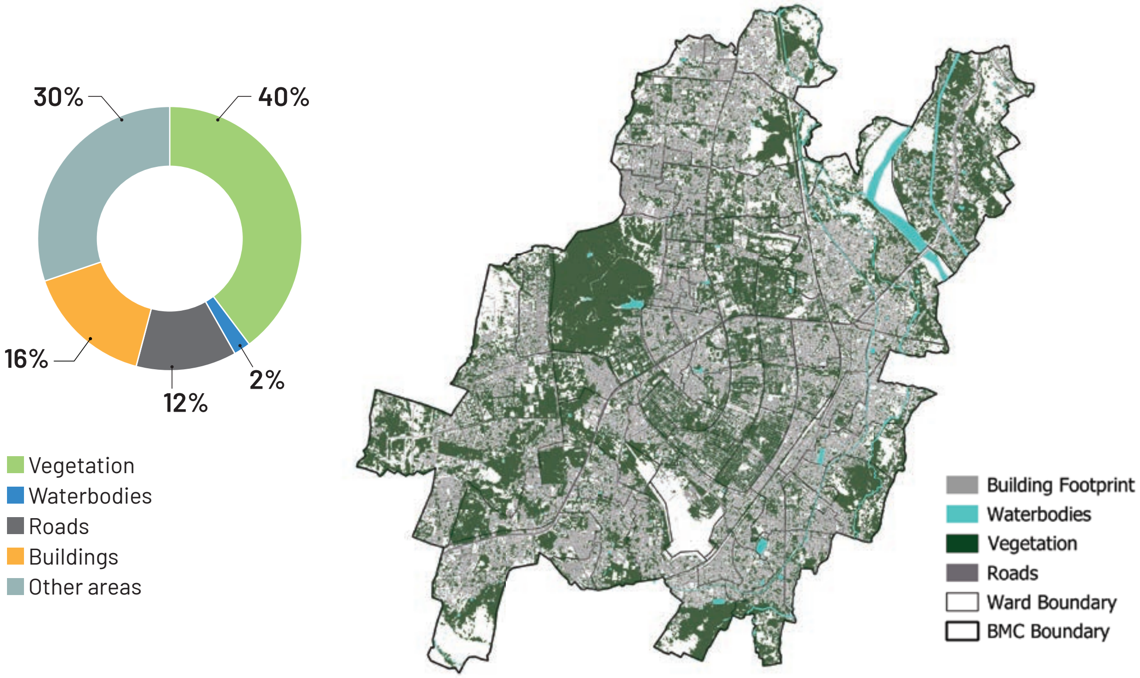
Topographically, the city can be divided into two major parts: the western uplands and the eastern lowlands, with the South-Eastern Railway forming the primary divide between these two broad units. As the ground slopes from west to east, the city benefits from a natural drainage advantage. Kanjia Lake, located on the northern outskirts, offers rich biodiversity and is a wetland of national importance.

Bhubaneswar's unique location in the eastern coastal plains, combined with its climatic and geographic features, also makes it highly vulnerable to natural hazards, including cyclones, floods, heat waves, strong winds, and occasional earthquakes. From 1991 to 2021, the state saw nine cyclones, typically experiencing one cyclone every 1-2 years, with a growing trend towards intense storms. This vulnerability underscores the importance of climate-resilient urban planning and infrastructure development.

2.1 Land-use

In Bhubaneswar, approximately 16% of the land is built, with an additional 12% covered by roads. Around 30% consists of fallow plots, playgrounds, paved open spaces, or concrete surfaces, while the remaining 42% is occupied by vegetation and water bodies. Within the built-up areas, residential structures dominate, with smaller portions allocated to commercial, industrial, and mixed-use developments.

Figure 2.3: Existing land cover in Bhubaneswar



Source: iFOREST Analysis

Despite the city's predominantly residential character, Bhubaneswar hosts several significant industrial hubs, including the Chandrasekharpur, Rasulgarh, and Mancheswar Industrial Zones, as well as the Khurda and Chandaka Industrial Estates. The city's rapidly expanding IT sector is centred around the Infocity Special Economic Zone (SEZ), a dedicated technology and innovation park.

2.2 Demography and Workforce

BMC has witnessed a steady and significant demographic transformation over the last three decades. This can be attributed to in-migration, natural growth, and an increase in administrative boundaries over the years.

Table 2.1: Demographic trend in Bhubaneswar

Years	Population	Households	Household size	Growth Rate (%)	Population density (persons per km^2)	BMC area (km^2)
1991	4,11,542	85,973	4.8	-	3,300	124.7
2001	6,48,032	1,39,769	4.6	57.5	4,815	134.6
2011	8,40,834	1,96,496	4.3	29.8	6,247	134.6
2025 (Projected)	11,48,620	2,90,187	4.0	-	6,175	186

Source: iFOREST Analysis

Between 1991 and 2011, the population of BMC more than doubled, increasing from 4.1 lakh to 8.4 lakh[12]. Based on these trends, the projected population using the linear forecast method for 2025 is expected to be around 11.5 lakh.

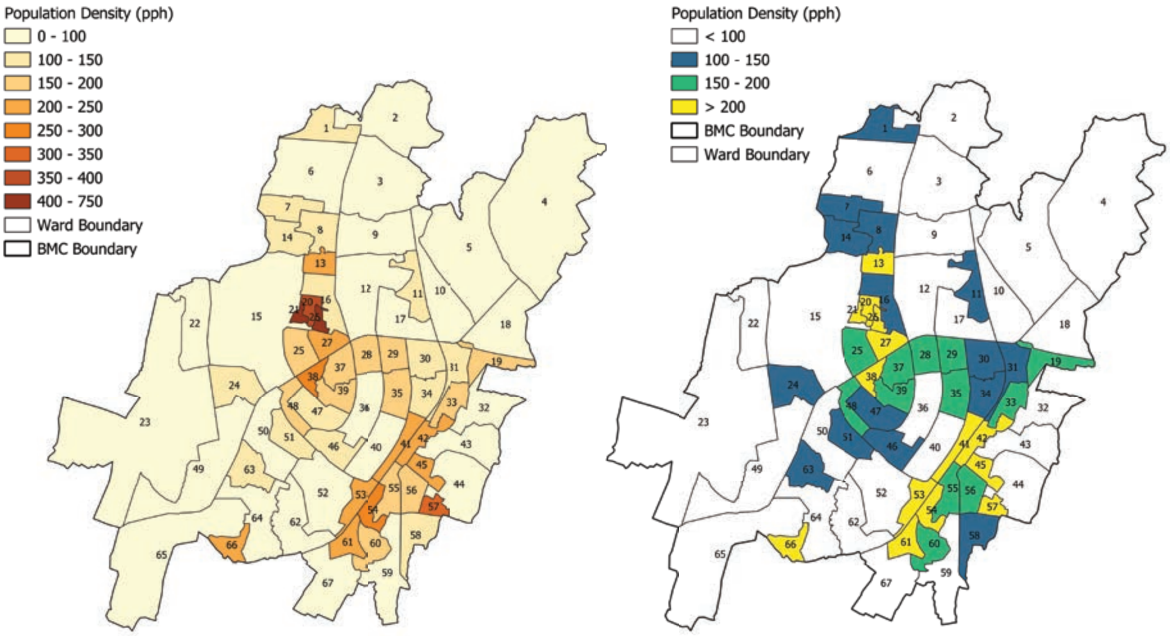
Population density in Bhubaneswar witnessed a significant increase between 1991 and 2011, rising from 3,300 persons per km^2 to 6,247 persons per km^2. Notably, this rise occurred despite the expansion of the BMC boundary from 124.7 km^2 in 2011 to 134.6 km^2 in 2011. The increase in density, even with a larger administrative area, underscores the growing pressure on urban infrastructure and services.

The number of households in Bhubaneswar has increased significantly, from approximately 86,000 in 1991 to nearly 2.9 lakh in the 2025 projection. Alongside this growth, there has been a steady decline in average household size, falling from 4.8 in 1991 to 4.0 in 2025. This trend reflects broader changes in social structure due to nuclearisation of families. These shifts have implications for housing typologies, service delivery models, and resource distribution within the city.

Ward-wise Population Density

Population distribution in Bhubaneswar varies significantly across wards. Wards 21 and 26 (Salia Sahi) are the most densely populated, each recording densities of over 700 persons per hectare (PPH). As per the Urban and Regional Development Plans Formulation and Implementation (URDPFI) guidelines of Government of India (GoI), around 21% of the city's wards fall into the 'Megapolis' category (densities above 200 PPH), while approximately 40% fall under the 'Small Town' category (0 to 100 PPH). This highlights a pronounced disparity in population density across the city.

Figure 2.4: Ward-wise population density

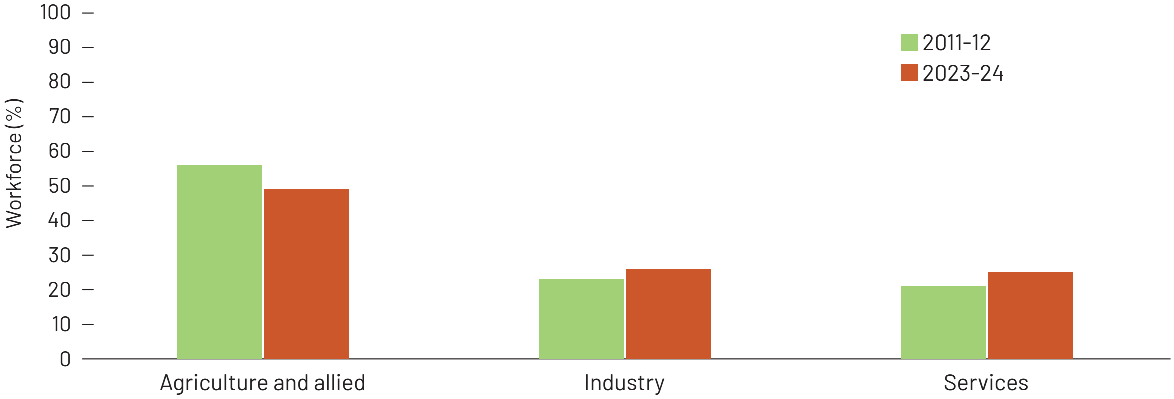


Source: iFOREST Analysis

Economy and Workforce

Bhubaneswar is emerging as a rapidly growing urban centre with a diversified economy driven by government services, education, IT/ITeS, tourism, and real estate. It hosts several IT parks and industrial estates, making it a key emerging tech and business hub in eastern India.

Figure 2.5: Workforce participation in Odisha



Source: Odisha Economic Survey 2024–25

While city-specific data on workforce distribution in Bhubaneswar not available, the Odisha Economic Survey 2024–25 provides useful context. Over the past decade, Odisha's workforce has gradually shifted from agriculture to industrial and service sectors. According to the survey, the share of the workforce engaged in agriculture and allied activities declined from 56% in 2011–12 to 49% in 2023–24. Meanwhile, employment in the industry and service sectors rose to 26% and 25%, respectively. This structural shift reflects broader economic diversification trends and signals evolving employment patterns in urban centres like Bhubaneswar, where construction, services, and informal trade are gaining prominence. Accordingly, outdoor occupations such as construction workers, transport gig workers and street vendors have grown in the city.

03

Bhubaneswar's Heat Profile

3.1 Climate and Weather Profile

3.2 Urban Heat Island Effect

3.3 Future Heat Stress

SUMMARY

Climate Profile

Bhubaneswar falls in the warm and humid climate zone, experiencing high temperatures and humidity from March to October. The annual mean temperature is 27.5°C and monthly averages range from 22°C to 32°C. During the summer months (March to June), average maximum daily temperatures often exceed 35°C, with peaks above 40°C in May and June.

Climate Trends

Long-term climate trends show rising heat and humidity levels in Bhubaneswar, making summers both hotter and more humid, and extending heat stress well into October. Even winters are becoming more humid, intensifying thermal discomfort throughout the year.

Heat Stress Pattern

Median summer and 10th-percentile hot-humid days have similar 24-hour average temperature and heat index. But summer days are hotter by 3.68°C during the day, while hot-humid days have higher night-time temperatures by 1.7°C, exhibiting varying heat stress pattern.

Land Use Change and Increasing UHI

From 2018 to 2024, Bhubaneswar's built-up area expanded by 23%, while vegetation fell by 9.8% and water bodies by 75%. This loss of green and blue spaces has intensified the Urban Heat Island effect, with built-up areas reaching 45°C, barren/paved land ~41.5–42°C, and tree-covered or water areas staying cooler at ~38–39°C.

UHI Pattern

Intra-city surface temperatures can vary by up to 20°C, with hotspots in industrial zones, the airport area, riverbanks, and slums. Northern wards (1–9) remain consistently hotter (+0.8–1.9°C) due to heat advection from southern and central zones. At night, urban areas stay up to 2°C warmer than rural surroundings as built materials release stored heat, with the effect strongest on typical summer nights and weaker during heatwaves or hot-humid days.

Future Projections

By 2050, under the SSP2-4.5 scenario, summer maximum temperatures are projected to rise by 1.5°C on average and by 2–2.5°C during extreme heat days. Heat stress is expected to persist for 7–9 hours daily, increasing health risks and reducing productivity, particularly among vulnerable groups.

Understanding the heat profile of Bhubaneswar requires analysing the city's climatic conditions, the intensity of the urban heat island (UHI) effect, the factors influencing urban heat dynamics and the sectors most affected by heat. Understanding these localised factors enables the development of targeted strategies to address the unique heat-related challenges faced by the city.

3.1 Climate and Weather Profile

Bhubaneswar falls under the warm and humid climate category.[13] The city experiences high temperatures and humidity throughout the year, with an annual mean temperature of 27.5°C and monthly averages ranging from 22°C to 32°C. During the summer months (March to June), average maximum daily temperatures often exceed 35°C, with peaks above 40°C in May and June.

The monsoon season, from June to October, brings most of the city's annual rainfall of 1,657.8 mm, driven by winds from the Bay of Bengal. August typically records the highest monthly rainfall of 374.6 mm. Humidity during these months rises above 80%, while temperatures remain between 27°C and 28°C. As a result, the city experiences prolonged heat stress for nearly eight months (March to October), with average wet bulb temperature ranging from 24°C to 27°C. Winters are brief, lasting around ten weeks in December and January, with temperatures dipping to seasonal lows of 15°C to 18°C during these months.

3.1.1 Climate Trends

The Climatological Tables published by the India Meteorological Department (IMD), Pune, provide normal values for various meteorological parameters, such as humidity, wind, cloud cover, and visibility, recorded at 08:30 and 17:30 hours IST across 416 observatories in India for the period 1981–2010. Previous editions of this publication, covering the periods 1931–1960, 1951–1980, 1961–1990, and 1971–2000, are also available. This data serves as a comprehensive reference for understanding the climate characteristics of different regions in India. The climatological tables of Bhubaneshwar are given in Annexure 2.

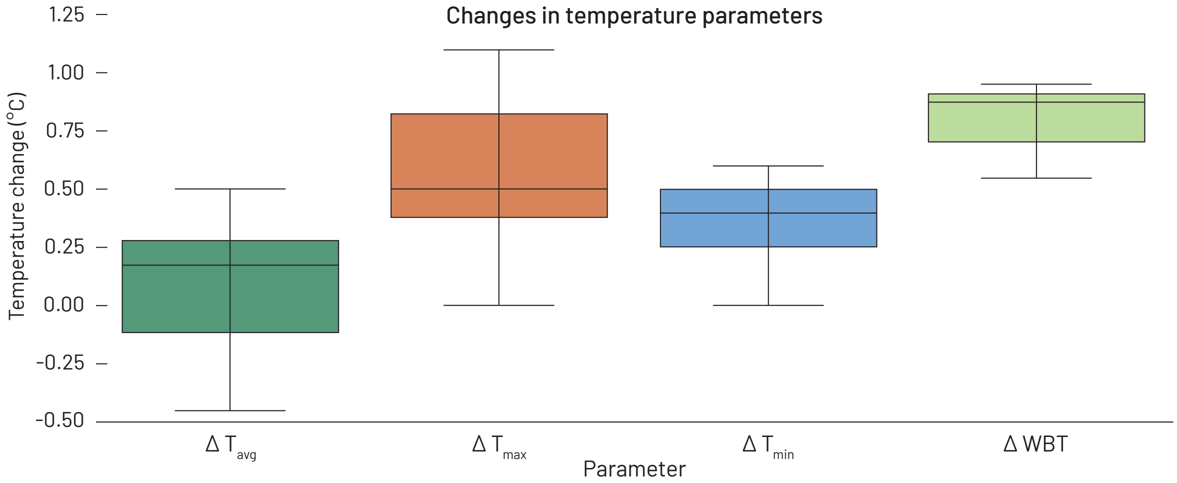
To examine the long-term climate trends and changes in Bhubaneswar, the climate during 1961-1990 was compared to those of 1991-2020. The assessment focused on the following parameters: average monthly mean temperature, average daily maximum temperature, average daily minimum temperature, mean wet bulb temperature, and relative humidity.

Table 3.1: Month-wise variation in climatic conditions between 1961-1990 and 1991-2020

Month	Δ T_{avg}	Δ T_{max}	Δ Month High	Δ T_{min}	Δ Month Low	Δ WBT	Δ RH
January	-0.4	0.9	1.1	0	-0.4	0.55	6
February	0.25	1.1	1.3	0	-0.4	0.7	3
March	0.5	1	0.9	0.6	0.4	1.25	4.5
April	0.35	0.8	0.2	0.4	0.4	0.95	3.5
May	0.05	0.3	0.2	0.5	0.5	0.95	4.5
June	0.15	0	-0.3	0.4	0.5	0.9	5
July	0.5	0.4	0.6	0.5	0.6	0.85	3
August	0.25	0.4	0.9	0.4	0.7	0.7	4
September	0.2	0.4	0.7	0.5	0.7	0.7	3.5
October	-0.05	0.1	0.2	0.6	0.4	0.9	6
November	-0.3	0.6	0.5	0.3	0.2	0.9	7.5
December	-0.45	0.7	1.2	0.1	-0.2	0.7	8

Source: iFOREST Analysis

Figure 3.1: Overall variation in climatic conditions between 1961-1990 and 1991-2020



Source: iFOREST Analysis

- Overall, the long-term climate trend indicates a steady rise in temperature and humidity levels in Bhubaneswar. Consequently, summers have become not only hotter but also more humid, significantly heightening the risk of heat stress.
- Heat risk now extends well beyond summer months, with elevated humidity from July to October contributing to prolonged periods of thermal discomfort. Winters, though slightly cooler, are also becoming more humid, making the cold feel more intense and further adding to worsening thermal discomfort.

However, certain variations are observed across different seasons:

- From February to September, the mean temperatures have increased, while they have reduced from October to January. March and July has witnessed highest increase in temperature, while December has experienced the largest reduction. This trend indicates that summer and hot-humid months are becoming warmer, whereas winter months are becoming colder.
- There are discernible differences between the early summer months (March and April) and the late summer months (May and June)
  - » In March and April, the average daily maximum temperature has increased by 1°C and 0.8°C, respectively. The daily minimum temperatures also increase by 0.6°C and 0.4°, indicating higher daytime and night-time temperatures. Furthermore, the trends show the early summer season is becoming progressively hotter.
  - » In the late summer months of May and June, the rise in mean temperature is notably lower, at 0.05°C and 0.15°C, respectively. During this period, the average daily maximum temperatures remain stable or only slightly increase, suggesting that days are not becoming hotter. However, a rise is observed in the average minimum temperature of 0.4-0.5°C, pointing to warmer nights.
- During the hot-humid months, both average maximum and minimum temperatures have increased each month. Nights have grown warmer overall, but daytime temperatures showed a more significant rise in July, August, and September, with only a slight increase in October.
- While the mean temperatures for the winter months are decreasing, the average maximum temperatures have notably risen by 0.6-0.9°C, suggesting warmer daytime conditions. Similarly, the average minimum temperatures have also seen either a slight increase or remains unchanged.
- February has turned a bit warmer, likely due to a notable rise in maximum daytime temperatures by 1.1°C, the highest increase among all months. This indicates that days are getting hotter, while nighttime temperatures have stayed consistent.
- The wet bulb temperature (WBT) in Bhubaneshwar has consistently increases throughout the months, reflecting increased heat stress.

3.1.2 Heat Stress Pattern

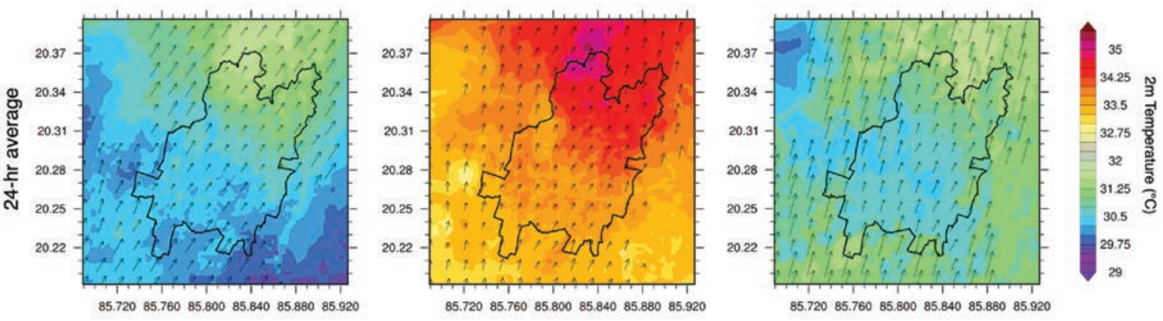
To further understand the city's micro-climate and the patterns of different heat stress conditions, three representative days – a heat wave day, a median summer day, and a hot-humid day – were analysed using the Weather Research Forecasting (WRF) model.[14]

Representative dates were selected by analysing daily meteorological data for Bhubaneswar from 2020 to 2024, focusing on the summer and hot-humid months (March to October). Average dry bulb temperature and relative humidity at 2 meters were used as key indicators.

- **Heat wave day:** The top 5th percentile date, April 25, 2024, was selected based on the average dry bulb temperature.
- **Median summer day:** The 50th percentile date, March 28, 2024, was selected based on the average dry bulb temperature.
- **Hot-humid day:** The Heat Index (HI) values for each day were calculated, and the date corresponding to the 10th percentile, June 02, 2024, was selected.

The key observations from analysing the heat stress across the three dates are as follows:

Figure 3.2: 24-hour average temperature on three representative days



Source: iFOREST and SEC Analysis

Table 3.2: Heat characteristics in Bhubaneswar on three representative days

Scenario	24-Average Temperature (°C)	Day-time Average Temperature (°C)	Night-time Average Temperature (°C)	24-Average Heat Index (°C)
Median Summer Day	30.6	38.5	27.1	42.8
Heat Wave Day	33.6	41.00	29.7	49.8
Hot-Humid Day	30.7	34.9	28.8	43.1

Source: iFOREST and SEC Analysis

Median Summer Day vs. Hot-Humid Day

- The temperature on median summer day and hot-humid day is similar, ranging around 30.6 - 30.7°C.
- On median summer day, daytime temperature is notably higher, at about 38.5°C, which exceeds hot-humid day by about 3.68°C.
- At night, temperature on a hot-humid day is elevated, with temperatures approximately 1.7°C higher than the median summer day.
- The Heat Index are similar for both dates, reflecting similar heat stress over a 24-hour period.

Heat Wave Day vs. Median Summer and Hot-Humid Day

- The average temperature on a heat wave day is around 3°C higher than that of both hot-humid and median summer days.

- During the heat wave day, the daytime temperature is high, ranging at 41.0 °C, around 2.45°C higher than the average summer day.
- At night, during a heat wave, the level of heat stress is again higher to both median and hot-humid day, with the temperature ranging around 29.7°C.

Hourly Heat Characteristics

The hourly temperatures on the three representative days shows that:

- On a typical summer day, temperatures exceed the thresholds set by the current Bhubaneswar HAP between 11:30 AM and 3:30 PM, resulting in five hours of heat stress.
- On a heatwave day, extreme heat exposure lasts for approximately eight hours, from 9:30 AM to 4:30 PM, increasing the period of heat stress to seven hours.
- However, on hot and humid days, temperature levels remain below the thresholds defined in the current HAP of Bhubaneshwar.

Table 3.3: Average hourly temperatures on three representative days

Legend: Current heat thresholds in Bhubaneswar HAP

36.2	Hot day advisory	39.1	Heat alert day	> 41.4	Extreme heat alert day

Hour	Median Summer Day (Present)	Heat Wave Day (Present)	Hot-Humid Day (Present)
0:30	27.07	29.98	28.56
1:30	26.79	29.65	28.86
2:30	26.62	29.36	28.76
3:30	26.46	29.36	28.83
4:30	25.96	28.56	28.73
5:30	25.57	28.25	28.54
6:30	25.37	28.29	28.55
7:30	26.39	30.76	28.90
8:30	28.80	33.92	29.53
9:30	31.91	36.64	31.18
10:30	34.46	39.01	33.41
11:30	36.64	40.54	34.95
12:30	38.23	41.41	35.56
13:30	39.03	41.93	35.48
14:30	39.52	41.80	34.76
15:30	39.29	39.31	33.56
16:30	35.53	37.88	32.27
17:30	31.81	35.69	31.15
18:30	29.77	33.25	29.93
19:30	28.58	31.47	29.36
20:30	28.05	30.64	29.52
21:30	27.94	29.80	29.53
22:30	27.69	29.80	29.30
23:30	27.51	29.57	27.28

Source: iFOREST and SEC Analysis

Overall, the analysis reveals that the current heat thresholds, based solely on maximum dry bulb temperatures, primarily captures heat stress during the daytime and in summer months. However, this method overlooks the heat stress experienced during hot-humid months, where elevated Heat Index and night-time temperatures significantly contribute to sustained stress. These findings highlight the need to re-define heat thresholds.

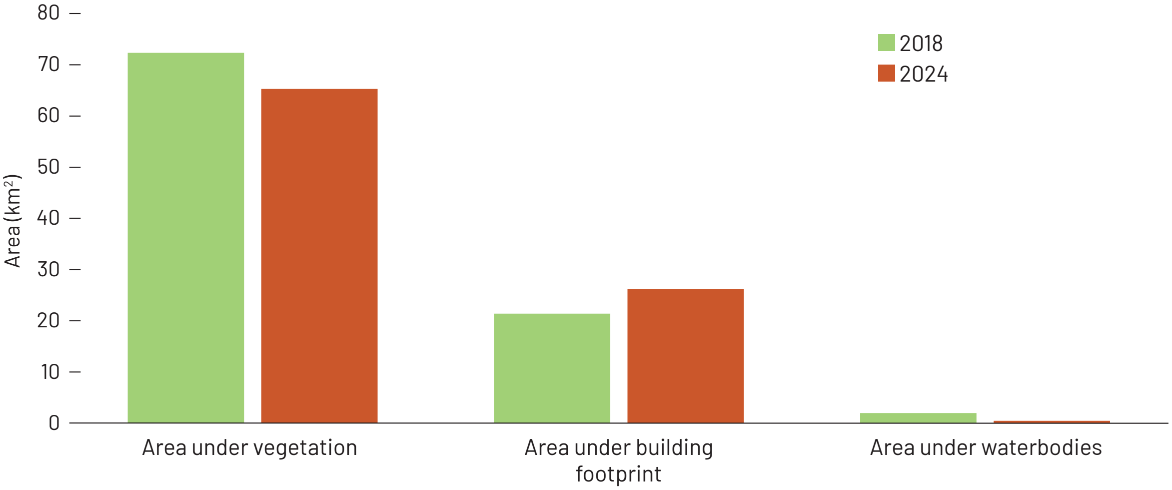
3.2 Urban Heat Island Effect

Heat stress in urban areas arises not only from climate change but also from factors such as high building density, extensive concrete surfaces, and limited vegetation, along with air pollution and traffic congestion. This segment of the research aimed to investigate the various underlying causes of the Urban Heat Island (UHI) effect in Bhubaneswar and to identify specific areas within the city that experience elevated UHI.

3.2.1 Land use and land cover

The land use and land cover (LULC) assessment offers valuable insights into the long-term macro trends of a city's built environment, vegetation, and water bodies. It aids in analysing urbanisation rates and patterns, along with trends concerning natural resources. For Bhubaneswar, a comprehensive evaluation was conducted by analysing Sentinel-2 satellite data to monitor changes from 2018 to 2024. This analysis revealed significant transformations in the city's landscape. Built-up areas have expanded substantially, while agricultural land and vegetation cover experienced a decline.

Figure 3.3: Land-use changes in Bhubaneswar from 2018 to 2024

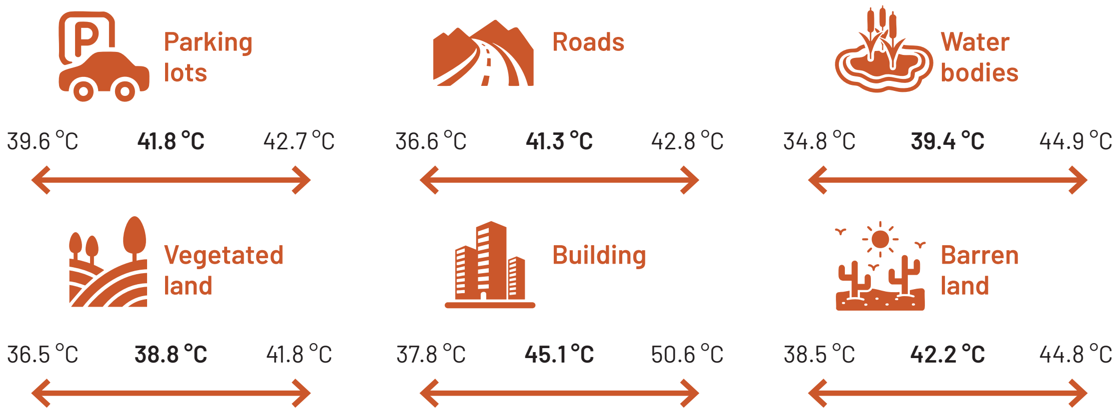


Source: iFOREST Analysis

Over this period, the city's built-up area has expanded by 23%, underscoring its status as one of India's fastest-growing cities. However, this growth has come at the cost of natural ecosystems, with a 9.8% decline in vegetation cover and an alarming 75% reduction in water body areas.

The shrinking of green and blue spaces in Bhubaneswar has direct and serious implications for the city's thermal profile and overall liveability. Surface temperatures[15] in built-up areas now regularly reach as high as 45°C, while barren land and paved surfaces such as roads and parking lots register between 41.5°C and 42°C. Low-income housing and industrial zones, with asbestos-cement or galvanised iron roofs, experience the highest surface temperatures within the built environment. In stark contrast, areas with dense tree cover and water bodies remain significantly cooler, maintaining surface temperatures around 38–39°C and providing crucial natural relief from heat stress.

Figure 3.4: Surface temperatures measured across different urban land covers in Bhubaneswar



Key Finding: Surface temperature analysis reveals that vegetated areas exhibit the lowest temperatures, followed by water bodies, paved or asphalt surfaces, barren land, and rooftops, which record the highest temperature levels.

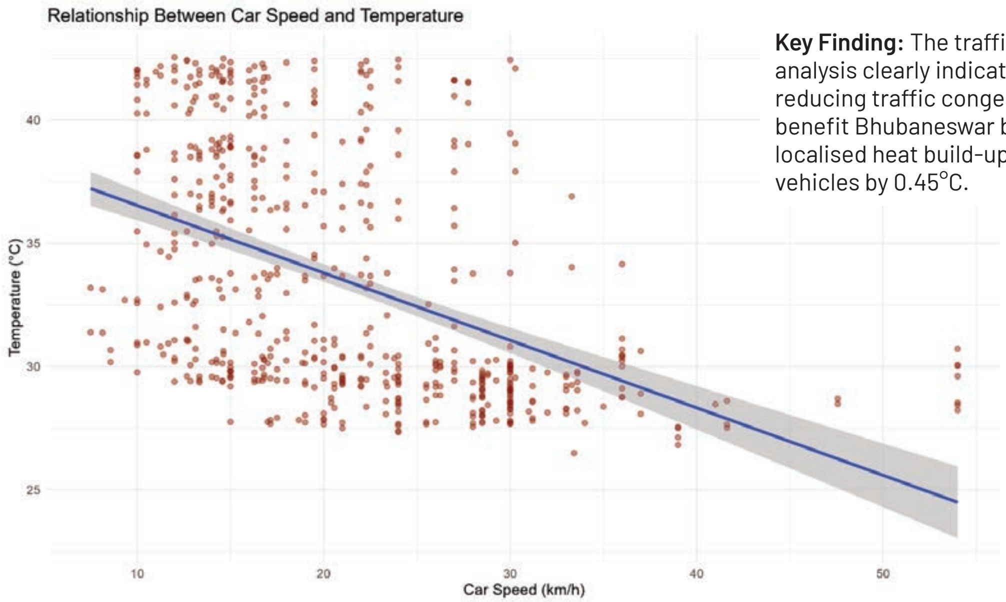
Source: iFOREST and SEC Analysis

The loss of vegetation removes vital shade, leading to greater exposure to solar radiation. Additionally, replacing natural land cover with heat-absorbing materials like asphalt and concrete, which have low albedo and high heat retention, has contributed to an increase in UHI in Bhubaneshwar.

3.2.2 Traffic and Congestion

Traffic congestion and vehicular emissions also impact UHI. To understand the impact of traffic congestion and vehicular emissions on urban heat stress, an analysis was conducted to examine the relationship between vehicle speed and ambient temperatures across different road stretches in Bhubaneswar.

Figure 3.5: Relationship between traffic speed and ambient temperature



Key Finding: The traffic congestion analysis clearly indicates that reducing traffic congestion can benefit Bhubaneswar by lowering localised heat build-up from idling vehicles by 0.45°C.

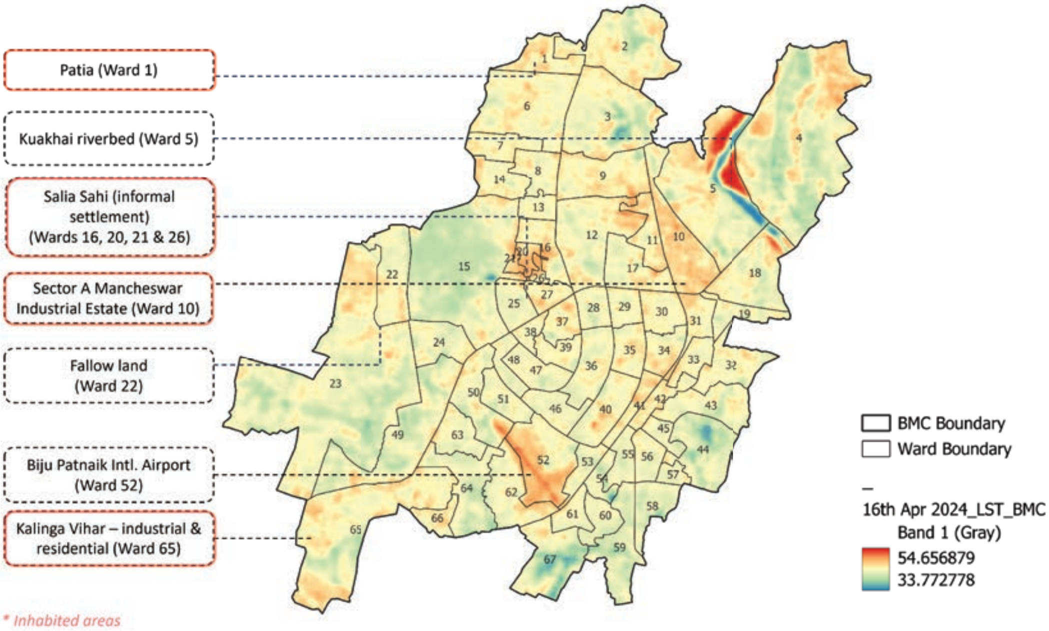
Source: iFOREST Analysis

This issue is especially prevalent in Indian cities where congestion is common and vehicles often idle for extended periods. In Bhubaneswar, over 72,000 vehicles were registered in 2020–2021 alone[16], highlighting the city's heavy reliance on motor vehicles and the growing congestion challenge. The study found that by reducing traffic congestion in the city can help lower ambient temperatures by around 0.45°C by minimising localised heat buildup from idling vehicles. Additionally, it contributes to reduced greenhouse gas emissions, improved air quality, and enhanced economic productivity through shorter travel times.

3.3.3 Land Surface Temperatures

Surface temperatures in the city is affected by LULC, building characteristics, traffic and urban morphology. In Bhubaneshwar, these factors have led to significant surface temperature differences.

Figure 3.6: Surface temperature recorded on 16th April 2024 for Bhubaneswar



Source: iFOREST Analysis

- **High intra-city temperature variation**

  Surface temperatures across different parts of Bhubaneswar vary by as much as 20°C during summer months. Industrial areas, regions with fallow land or dense concrete surfaces, and low-income neighbourhoods are emerging as urban heat hotspots.

  Some emerging heat hotspots include industrial zones such as Mancheswar, Kalinga Vihar, and Patia. Similarly, areas with fallow land, including riverbanks and Ward 52 (Biju Patnaik International Airport), as well as regions with extensive asphalt and concrete coverage, are also particularly warm. Furthermore, low-income neighborhoods like Salia Sahi using heat-absorbing building materials, such as GI roofs, are especially vulnerable.

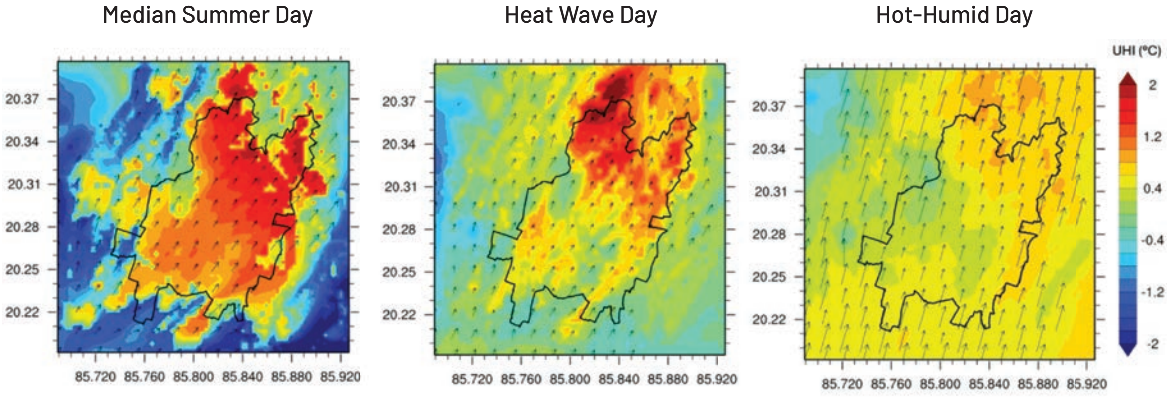
- **Higher Temperatures in the North**

  The northern part of Bhubaneswar consistently experiences elevated ambient temperatures due to the strong advection of heat by prevailing southerly winds. These winds carry warmer air from the southern and central parts of the city toward the north, intensifying the UHI effect in that region. Consequently, Wards 1 to 9 regularly record higher temperatures compared to the rest of the city, with daily ambient temperature differences ranging from 0.8°C to 1.9°C.

- **Pronounced Night-time UHI Effect**

  In contrast to daytime conditions that are mainly influenced by direct solar heating, the UHI phenomenon is particularly pronounced at night. At night, ambient temperatures in Bhubaneswar can go up to 2°C higher than in surrounding rural areas. This is primarily due to the high thermal mass and heat-retaining properties of materials, which absorb solar radiation during the day and slowly release it after sunset. Consequently, urban areas remain significantly warmer than their rural surroundings well into the night.

Figure 3.7: Night-time temperature in Bhubaneswar during the three representative days



Source: iFOREST and SEC Analysis

However, the intensity and distribution of night-time UHI in Bhubaneswar vary significantly across different weather conditions:

- **Heat wave day:** During a heat wave day the contrast between urban and rural areas is reduced due to region-wide warming caused by large-scale meteorological conditions such as dry air advection and high-pressure systems. These elevate temperatures uniformly across both urban and rural areas, diminishing the relative UHI effect. UHI effects are more localised, with the highest intensities concentrated in the northern part of the city. Central and southern zones exhibit much weaker UHI (around 0.4°C).
- **Typical Summer Day:** UHI is more widespread and intense during these periods. Night-time temperature differences between urban and rural areas range from 0.8°C to 1.2°C, with peaks up to 2°C in northern areas. These effects are driven by the greater heat retention of urban building materials compared to vegetated rural landscapes. The pronounced temperature contrast results in a stronger and more spatially extensive UHI effect.
- **Hot-Humid Days:** UHI effects are comparatively weaker, likely due to lower peak air temperatures. While humidity levels are high, the absence of extreme heat leads to a subdued temperature contrast between urban and rural areas.

The findings from Bhubaneswar clearly highlight the multifaceted and interconnected causes of the UHI effect. The thermal disparity observed across the city stems from a combination of surface and atmospheric factors, including the widespread use of materials with high thermal mass, reduced vegetative cover and evapotranspiration, and heat emissions from traffic, industrial activity, and buildings.

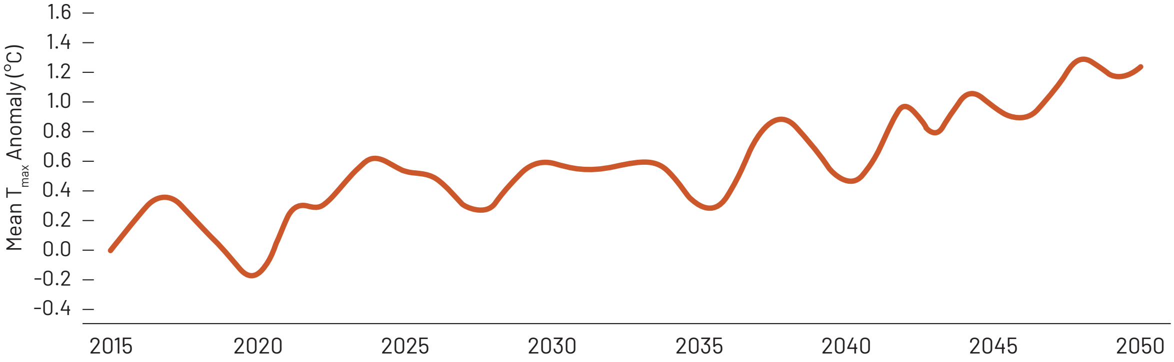
The UHI effect is particularly pronounced during night-time hours. Unlike daytime heating, which is primarily influenced by solar radiation, night-time UHI is governed by longwave radiative cooling and the delayed release of heat from built surfaces, resulting in slower cooling in urban areas compared to their rural surroundings. Special attention is needed for the northern parts of the city, that experience consistently higher temperatures.

3.3 Future Heat Stress

To assess future heat stress in Bhubaneswar, multiple models from the Coupled Model Intercomparison Project Phase 6 (CMIP6) were analysed under the Shared Socioeconomic Pathways (SSP)2 - 4.5 scenario[17]. Shared socio-economic pathways – a set of scenarios exploring different possible trajectories for global socio-economic development – are widely used in climate modelling to project future emissions and climate change impacts. SSP 2-4.5 scenario was chosen as it reflects a middle-of-the-road development pathway, with carbon dioxide (CO_2) emissions remaining near current levels until mid-century.

To simulate future climate conditions, summer temperatures till 2014 were used as a baseline, with projected changes derived from CMIP6 models. The projections focused on average summertime conditions and incorporated variations in the diurnal temperature profile to minimise day-to-day fluctuations. Based on this approach, representative dates reflecting both typical and extreme summer conditions in 2050 were identified.

Figure 3.8: Mean of maximum temperature under the SSP2-4.5 scenario till 2050

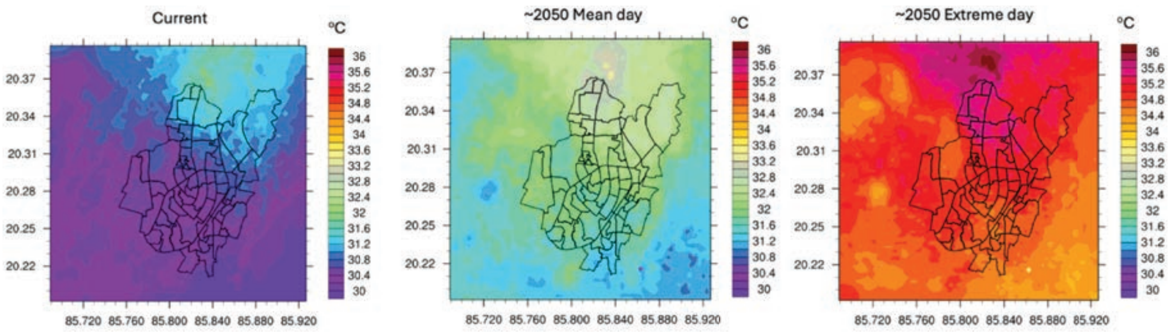


Source: iFOREST and SEC Analysis

Climate projections indicate a clear warming trend for Bhubaneswar during the summer months. Maximum daily temperatures are expected to rise by 1.5°C on an average, while during extreme heat events, increases of 2 to 2.5°C are anticipated by 2050 relative to the baseline.

To further assess future heat stress, representative dates were selected for a median summer day and a heatwave day for 2050 based on historical and projected temperature data. The modelling results are as follows:

Figure 3.9: 24-hour average temperatures under present and future scenarios



Source: iFOREST and SEC Analysis

Table 3.4: Summer temperatures in Bhubaneswar in present and future scenarios

Scenario	24-Average Temperature (°C)	Day-time Average Temperature (°C)	Night-time Average Temperature (°C)
Current Median Summer Day	30.6	38.5	27.1
Current Heat Wave Day	33.6	41.0	29.7
Median Summer Day: 2050	32.1	40.0	27.7
Heat Wave Day: 2050	35.1	43.1	30.9

Source: iFOREST and SEC Analysis

- A typical heat wave day in 2050 is expected to be 1.5-2.0°C warmer than a typical heat wave day currently. Likewise, compared to the present median summer day, the average daily temperature on the median summer day in 2050 is expected to rise by 1.5°C.
- The most significant increase is observed during daytime hours. The daytime temperatures on a typical summer day in 2050 are expected to rise by 1.5°C and by 0.63°C at night, compared to current median summer conditions.

- In case of heat wave days, the temperature increase is much higher. A typical heatwave day in 2050 will be 2.1 °C warmer during the day and 1.2°C warmer in night compared to a typical heatwave day currently.
- In 2050, during the summer season, the hours exceeding the heat thresholds defined by the current Bhubaneswar HAP are projected to expand, lasting from 9:30 AM to 5:30 PM on a heatwave day and from 10:30 AM to 4:30 PM on a mean summer day. This results in prolonged daily exposure of approximately 7 to 9 hours. Such extended periods of extreme heat significantly increase risks to public health and worker productivity, especially among vulnerable populations.
- Overall, by 2050, a typical summer day in Bhubaneswar is projected to experience heat stress levels equivalent to those of a current heatwave day, particularly during peak heat hours.

Table 3.5: Average hourly temperatures on a median summer day and a heat wave day in 2050

Legend: Current heat thresholds in Bhubaneswar HAP

36.2	Hot day advisory	39.1	Heat alert day	> 41.4	Extreme heat alert day

Hour	Mean Summer Day (2050)	Heat Wave Day (2050)
0:30	27.05	31.96
1:30	26.85	31.29
2:30	26.56	30.71
3:30	26.49	30.16
4:30	26.27	29.70
5:30	25.83	29.49
6:30	26.13	30.10
7:30	28.58	31.97
8:30	31.96	34.74
9:30	35.13	38.35
10:30	37.72	41.42
11:30	39.35	43.64
12:30	40.28	44.72
13:30	40.77	43.10
14:30	40.50	42.37
15:30	38.96	41.51
16:30	37.61	39.01
17:30	35.43	36.63
18:30	32.90	34.08
19:30	31.07	32.46
20:30	29.72	31.63
21:30	28.98	31.12
22:30	28.35	30.76
23:30	28.00	30.43

Source: iFOREST and SEC Analysis

04

Mapping Spatial Risks

SUMMARY

High Heat Wards

Wards 1 to 11, in the northern part of the city along with Wards 20, 21, and 26 (Salia Sahi), exhibit the highest heat risk in the city, determined by a combination of high surface temperatures, ambient air temperatures, and humidity levels.

High Exposure Wards

Wards 20, 21 & 26 (Salia Sahi) record the highest population and building densities and limited open spaces, intensifying heat retention. Ward 41 (Railway Station) and Ward 14 (Defence Colony) have high road surface coverage, increasing impermeable surfaces and local heat absorption.

High Sensitivity Wards

Wards 22 (Bharatpur), 65 (Raghunath Nagar), and 67 (Sundarpada) top the list. Key drivers include overcrowded housing, large slum populations, and higher shares of women and children.

Adaptive Capacity Gaps

43 of 67 wards fall into the highest risk category for adaptive capacity, lacking adequate green spaces, water bodies, water access, or nearby healthcare facilities. This leaves more than half of the city underserved in heat resilience infrastructure.

High Risk Wards

Bhubaneswar's heat risk varies significantly across wards due to differences in urban form, land use, and socio-economic conditions.

- Highest Risk: Wards 20, 21 & 26 (Salia Sahi), Ward 27 (Nayapalli), Ward 41 (Railway Station), Ward 22 (Bharatpur), and Ward 66 (Raghunath Nagar).
- Lowest Risk: Ward 15 (Bharatpur Reserve Forest) benefits from dense vegetation and negligible population; Ward 23 (Kalinga Nagar) combines low density with good housing space; Wards 59 & 67 retain agricultural land and water bodies; Ward 44 (Badagada Village North) has a large wetland and minimal urbanisation.

The urban form, land use patterns, and socio-economic disparities across different parts of a city result in uneven exposure and sensitivity to extreme heat. Understanding where and to what extent these risks manifest is essential for designing effective and equitable heat action plans.

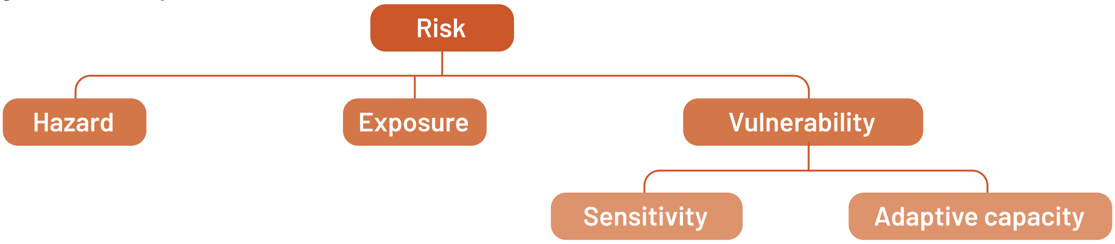
Wards, the smallest administrative units within the city, serve as the foundation for local governance, service delivery, and community-level planning. A ward-level assessment allows for a more granular understanding of how heat risks vary across neighbourhoods, enabling tailored interventions that directly address the needs of the most vulnerable populations.

This analysis presents a detailed, ward-wise assessment of heat risk in Bhubaneswar. By mapping spatial patterns of vulnerability, it identifies the most at-risk areas that require urgent and targeted adaptation measures—informing policy, planning, and resource allocation at the local level.

4.1 Heat Risk Index

A Heat Risk Index (HRI), in line with the IPCC's risk framework, has been used to map heat risk in Bhubaneshwar. IPCC defines risk as a function of hazard, exposure and vulnerability. Vulnerability in turn is dependent on the sensitivity and adaptive capacity of a population.

Figure 4.1: Components of the Heat Risk Index



Source: AR5 Report, IPCC

Each of the components of the Heat Risk Index is estimated on a set of indicators that reflect a mix of socioeconomic, physiological, climatic, and behavioural factors. Changes in the value of these indicators can either heighten or reduce the severity of heat-related impacts. For developing the heat risk index of Bhubaneshwar, a total of 12 indicators was utilized, and the values for each indicator was normalized according to their positive or negative impact on heat risk.

- For indicators that are positively correlated with risk (e.g., heat index, surface temperature, population density), higher raw values were given higher scores.
- For indicators that are negatively correlated with risk (e.g., green cover, water access, healthcare access), higher raw values were given lower scores, reflecting their risk-reduction role.

Scores on all indicators were aggregated for each ward to generate a cumulative risk score, with higher scores signifying greater levels of heat-related risk.

Table 4.1: Ward-level heat risk assessment indicators

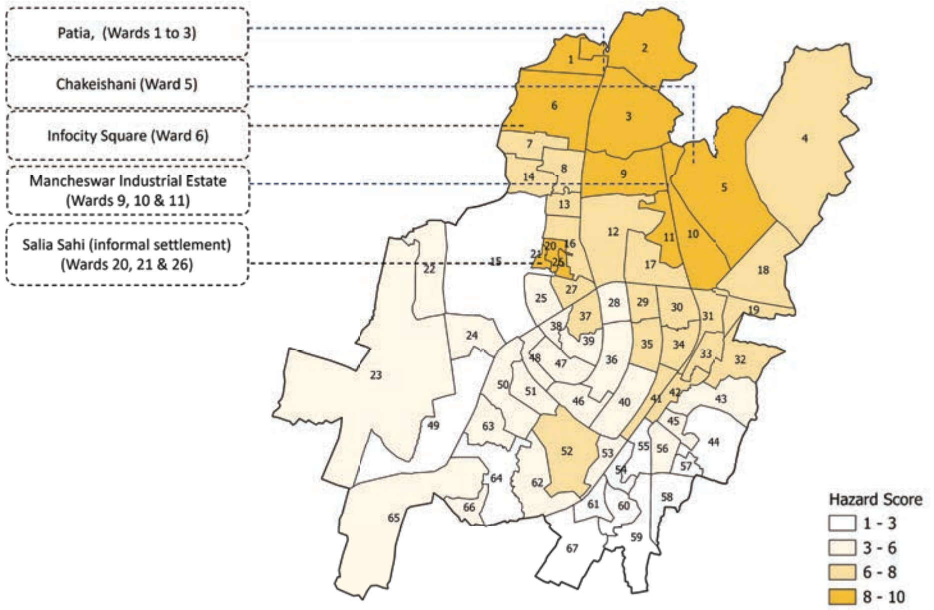
Hazard	Exposure	Vulnerability	
		Sensitivity	Adaptive Capacity
1. Heat Index (°C) 2. Surface Temperature (°C)	3. Population density (PPH) 4. Building density (%) 5. Area under roads (%)	6. Per capita housing space (m^2/p) 7. Homeless & Slum population (%) 8. Women & children population (%)	9. Urban Green Spaces (m^2 per capita) 10. Area under water bodies (%) 11. Access to water: a) Water supply line density (km/km^2) b) Storage capacity of water reservoirs 12. Access to healthcare (%)

Source: iFOREST Analysis

4.2 Hazard

Hazard refers to the magnitude and climatic intensity of heat stress, encompassing the temperature extremes and atmospheric conditions that drive thermal discomfort. The spatial analysis of heat hazard indicators highlights specific areas in Bhubaneswar that experience increased heat stress.

Figure 4.2: Ward-level hazard assessment



Source: iFOREST Analysis

- **Heat Index:** Notably, Wards 2 and 1 (Patia) and Wards 3, 4, and 6 (Chandrasekharpur), located in the northern part of the city, have emerged as the highest-risk areas based on the Heat Index, reflecting elevated thermal discomfort due to the combined effects of temperature and humidity.
- **Surface Temperature:** Wards 20, 21, and 26 (Salia Sahi), as well as Wards 52 (Airport) and 10 (Mancheswar Industrial Estate), stand out as key urban heat hotspots based on Surface Temperature, driven by a higher concentration of impermeable surfaces such as roads and dense built-up areas

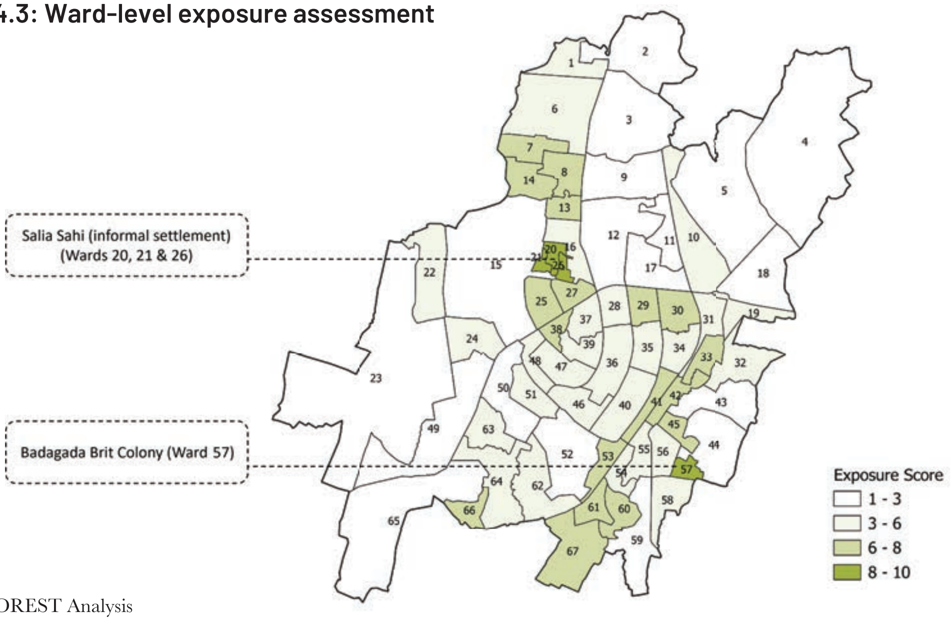
Overall, the northern part of the city along with Wards 20, 21, and 26 (Salia Sahi), exhibit the highest heat risk in the city.

4.3 Exposure

Exposure refers to the presence of people and heat-retaining built environments in areas affected by heat, encompassing the concentration and spatial distribution of human activity and infrastructure. The analysis of exposure shows the following:

- **Population Density:** Wards 21, 26 and 20 (Salia Sahi) exhibit the highest population densities, indicating a greater number of people exposed to heat stress in compact urban environments.
- **Building Density:** The same wards 20, 21, and 26 (Salia Sahi) record the highest proportion of built area, reflecting dense built environments that contribute to heat retention and limit natural cooling.
- **Area under Roads:** Wards 41 (Bhubaneswar Railway Station), 14 (Defence Colony) and 21 (Salia Sahi) register the highest share of area under roads, suggesting an increased surface impermeability and heat absorption, which intensifies local thermal conditions.

Figure 4.3: Ward-level exposure assessment



Source: iFOREST Analysis

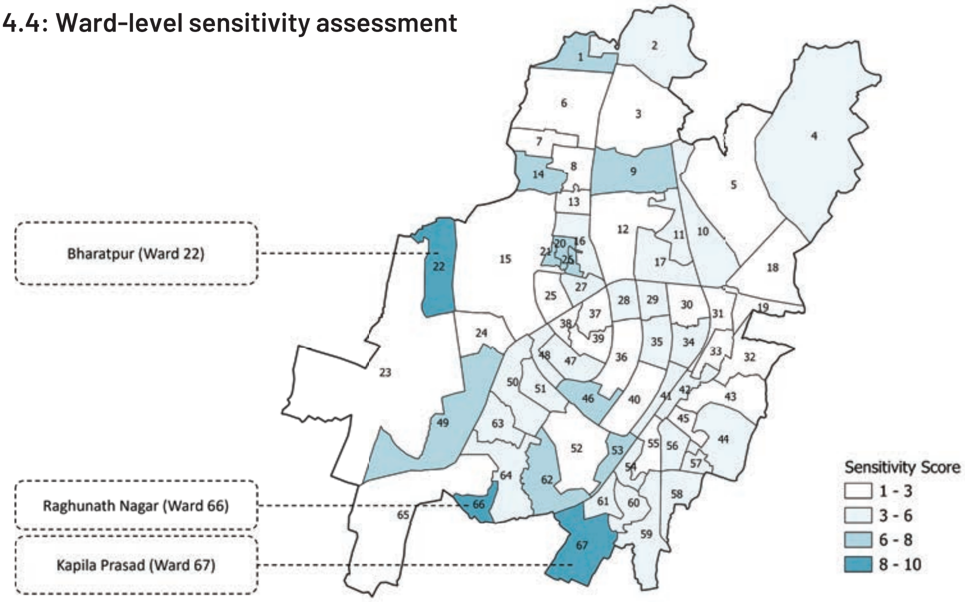
Overall, wards 20, 21, and 26, which include the informal settlement of Salia Sahi, along with Ward 57 (Badagada), have higher exposure.

4.4 Vulnerability

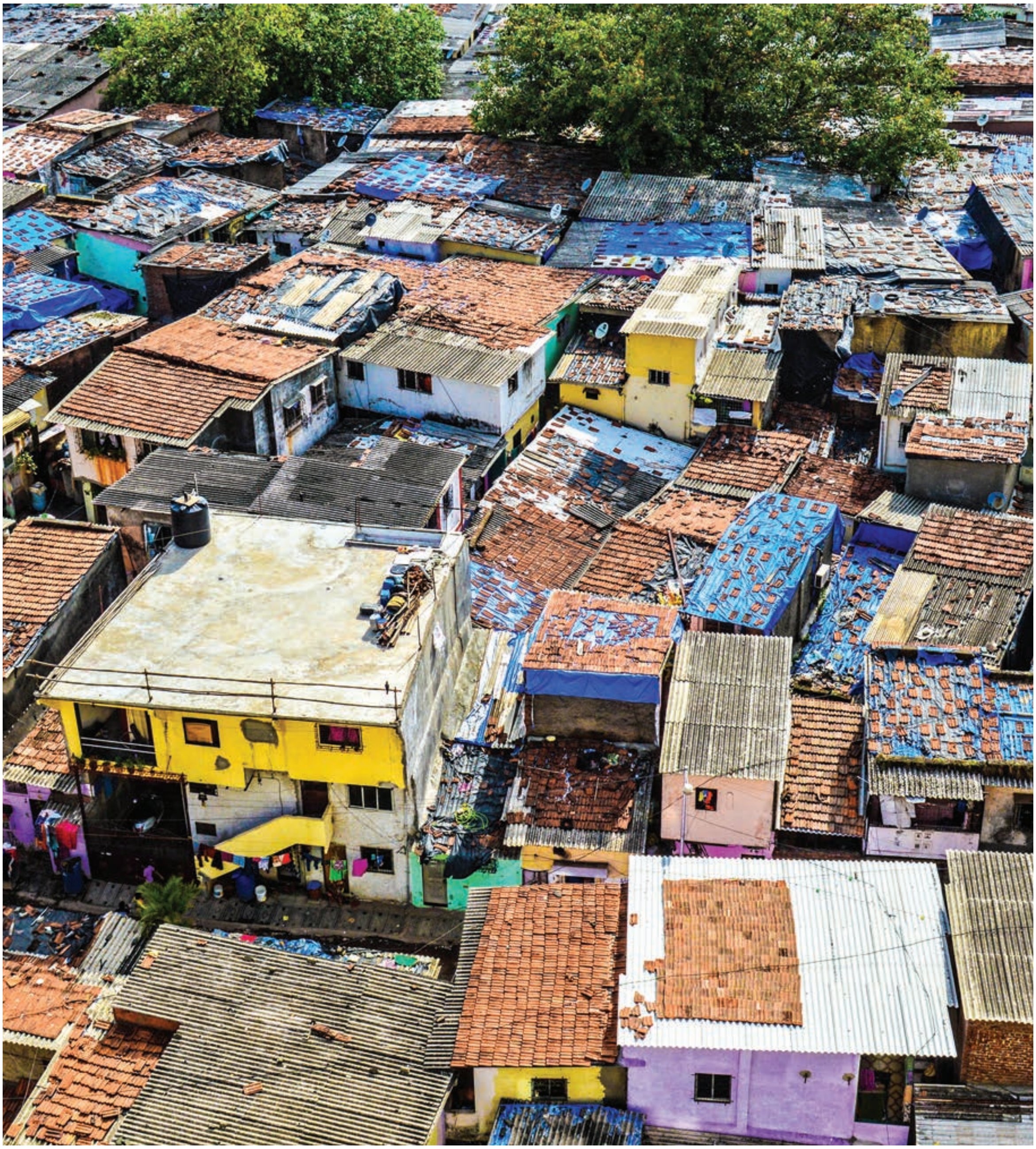
Vulnerability refers to the likelihood of being adversely affected by heat, encompassing social and physical conditions that heighten susceptibility and limit resilience. It includes sensitivity and adaptive capacity.

Sensitivity: It refers to the inherent demographic and housing conditions that make them more prone to heat-related harm, encompassing demographic, socio-economic, and housing-related factors. The ward-wise sensitivity shows the following:

Figure 4.4: Ward-level sensitivity assessment



Source: iFOREST Analysis

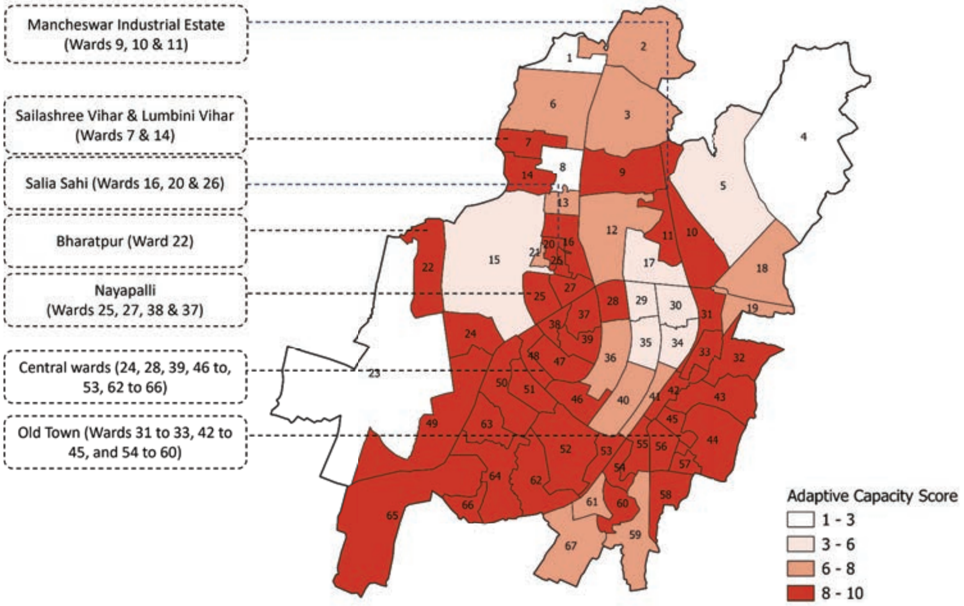


- **Per capita housing space:** Wards 20, 21, and 26 (Salia Sahi) record the lowest per capita housing space, clearly reflecting dense residential conditions that can exacerbate indoor heat accumulation and reduce thermal comfort. However, low per capita housing space in Ward 10 (Mancheswar Industrial Estate) and Ward 17 (Vani Vihar) is due to the limited share of residential land use as they are predominantly industrial and institutional areas, respectively.
- **Homeless and Slum Population:** Wards 20, 21, and 26 (Salia Sahi), Ward 22 (Bharatpur) and Ward 16 (Maitri Vihar), register the highest proportions of slum and homeless populations, indicating heightened sensitivity.
- **Women and Children Population:** Ward 66 (Raghunath Nagar), Ward 1 (Patia), Ward 22 (Bharatpur), Ward 4 (Pahala), and Ward 62 (Pokhariput) have a relatively higher share of women and children, demographic groups which are more physiologically and socially vulnerable to prolonged heat exposure.

Overall, wards with the highest sensitivity scores (8–10) in Bhubaneswar include ward 22 (Bharatpur), ward 65 (Raghunath Nagar), and ward 67 (Sundarpada). The second tier of wards, with sensitivity scores ranging from 6 to 8, consists of ward 1 (Patia), ward 9 (Railway Workshop Colony), ward 14 (Defence Colony), Wards 20, 21, and 26 (Salia Sahi informal settlement), ward 46 (PWD Staff Colony), ward 49 (Kalinga Vihar, Khandagiri & Baramunda), ward 53 (New Bapuji Nagar, Palaspalli), and ward 62 (Pokhariput). These areas are characterised by a high concentration of vulnerable populations and limited housing space, comprising a mix of high-density, low-income housing and informal settlements.

Adaptive capacity: It refers to the ability of individuals and communities to respond to and recover from heat stress, encompassing access to critical resources, emergency infrastructure, and systems that support resilience. The ward-wise assessment evaluates adaptive capacity through key indicators, such as per capita urban green space, the proportion of area covered by water bodies, access to water, and proximity to primary healthcare facilities. Together, these elements indicate a ward's ability to withstand extreme heat and support its population during periods of stress.

Figure 4.5: Ward-level adaptive capacity assessment



Source: iFOREST Analysis

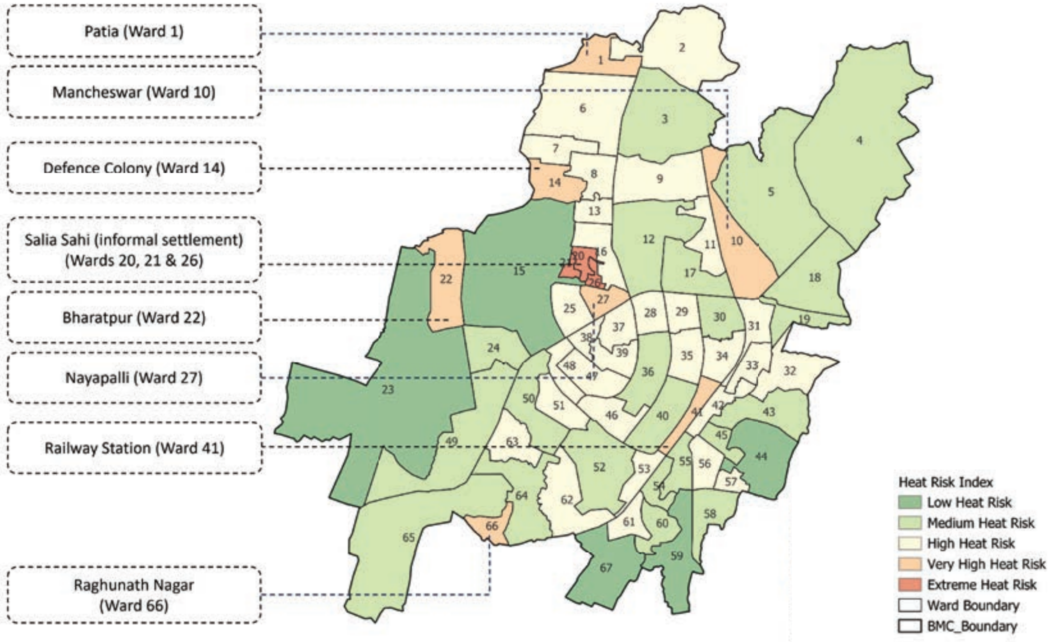
- **Urban Green Space:** Wards 26, 21, and 20 (Salia Sahi) have limited Urban Green Space due to dense informal settlements, increasing heat exposure.
- **Area under Water Bodies:** Wards 26, 21, and 20 (Salia Sahi) do not have waterbodies. At Ward 41 (Railway Station), due to paved transit zones there is limited opportunity for waterbodies to thrive.
- **Access to Water:** Peri-urban Ward 4 (Pahala) faces sparse water infrastructure due to low population density and high extension costs.
- **Access to healthcare:** Old Town wards 54, 58, and 60 lack formal healthcare facilities.

The assessment reveals that 43 out of 67 wards in Bhubaneswar fall into the highest risk category for adaptive capacity, indicating inadequate infrastructure or limited access to essential services in over half of the city. This highlights the significant efforts required towards equitable resilience-enhancing measures, with existing adaptive infrastructure and services concentrated in a few wards. Consequently, large portions of the city remain underserved and highly vulnerable to the impacts of extreme heat.

4.5 Ward-wise Heat Risk Index

The heat risk map highlights significant disparities between wards, revealing that heat risk is unevenly distributed across the city. While many southern and peripheral wards show lower risk levels (indicated in light green), a concentrated cluster of high-risk areas (shaded orange to red) is evident in the central and northern parts of the city.

Figure 4.6: Ward-level heat risk map for Bhubaneswar



Source: iFOREST Analysis

- Wards 20, 21, and 26 (Salia Sahi) form the city's most prominent heat risk hotspot. This can be attributed to a combination of dense population, limited per capita housing space, large slum populations, and inadequate access to adaptive infrastructure like healthcare and green spaces.
- Ward 27 (Nayapalli) and Ward 41 (Railway Station) also score high, with these zones having heavy built-up areas, traffic corridors, and relatively low vegetative cover, factors that intensify the Urban Heat Island effect.
- Ward 22 (Bharatpur) and Ward 66 (Raghunath Nagar) demonstrate high sensitivity due to social vulnerabilities, including lower housing adequacy and a high concentration of women and children, but also fall short in adaptive infrastructure provision.

In contrast, a closer look at the low risk wards and understanding their attributes can help inform strategies for building resilience in vulnerable parts of the city.

- Ward 15 (Bharatpur Reserve Forest) shows the lowest heat risk due to its dense forest cover and negligible population. While it highlights the value of green cover, its non-urban character makes it an unrealistic model for replication.
- As the city's largest ward spanning 17.6 km², Ward 23 (Kalinga Nagar) has low population density and built-up area, contributing to reduced heat stress. It also fares well on per capita housing space, indicating better socio-economic conditions. Despite this, it is seeing rapid growth, with one of the highest numbers of new construction projects between 2022-24, pointing to the need for climate-conscious planning.

- Ward 59 and 67 (Saraswati Mandap & Kalpila Prasad), located in the Old Town area of Bhubaneswar, both wards benefit from large tracts of land still under agricultural use, which helps reduce built-up intensity and moderate local temperatures. Additionally, Ward 67 contains a significant water body, further contributing to lower surface temperatures and enhancing its overall thermal performance.
- Ward 44 (north of Badagada Village), a peripheral part of the city, contains a large wetland and has minimal urbanised development within its boundary. Its limited building footprint and low population density contribute to reduced heat risk, with the wetland significantly aiding in local temperature regulation.

The findings underscore the pressing need for targeted, evidence-driven adaptation and mitigation strategies to address economic and health impacts, increasing energy demand and localised heat vulnerabilities across the city of Bhubaneswar.


Contact

05

Measuring the Impact of Heat Stress

SUMMARY

Mortality Patterns

All-cause mortality data, in contrast to the general perception show lower mortality in summer (Mar–Jul) and higher-than-average mortality in hot-humid months (Aug–Oct). Months with high humidity and elevated night-time temperatures.

Productivity losses

Seasonal variations show productivity drops of around 10% in hot-humid months (Jul-Sep) and 13% in peak summer (Apr–Jun), versus less than 5% in cooler months (Dec–Feb).

Workforce vulnerability and Wage Loss

- About 30% of Bhubaneswar's workforce faces notable productivity losses due to extreme heat. Medium intensity outdoor jobs like mechanics and clerks see a 10–15% decline, while physically intensive roles such as construction and transport labour experience losses of 20–25%. This has a significant impact on their wages, 10-20% loss for medium-intensity jobs; 20–30% for high-intensity outdoor work.
- In Bhubaneswar, the workforce groups most affected—considering their population share and job-related productivity declines—are mining and construction workers, protective services workers, refuse collectors, street vendors, and transport, storage and gig workers.
- The citizens of Bhubaneswar cumulatively suffered an earnings loss of 8.59% attributed to extreme heat.

Electricity demand growth

Between 2021–2023, city electricity use grew 12% annually, with commercial/institutional consumers growing fastest (+19%), followed by residential (+8%), industrial (+7%), and agriculture (+5%).

Seasonal Variation in Electricity Demand

In Bhubaneswar, electricity use peaks between April and October due to high heat and humidity, then drops during the cooler months. In 2023, residential consumption was 159% higher in the peak month than the lowest, while the commercial and institutional sector saw a 64% difference, underscoring the strong link between climate and energy demand.

Increasing AC Ownership

Between 2021 and 2023, residential AC ownership rose from 6% to 15% (73% annual growth), while C&I sector AC penetration increased from 71% to 89% (41% annual growth).

Space Cooling Share in Electricity Use

From 2021–2023, cooling accounted for 22–25% of residential and 54–55% of C&I electricity consumption. Overall, cooling represented 34-37% of total city electricity use, peaking at 45–55% of residential consumption and ~85% of C&I consumption during summer.

Heat stress significantly affects various aspects of life, including health, livelihoods, food security, work productivity, and energy consumption. Understanding these impacts is crucial for developing effective strategies to address the challenges posed by rising temperatures.

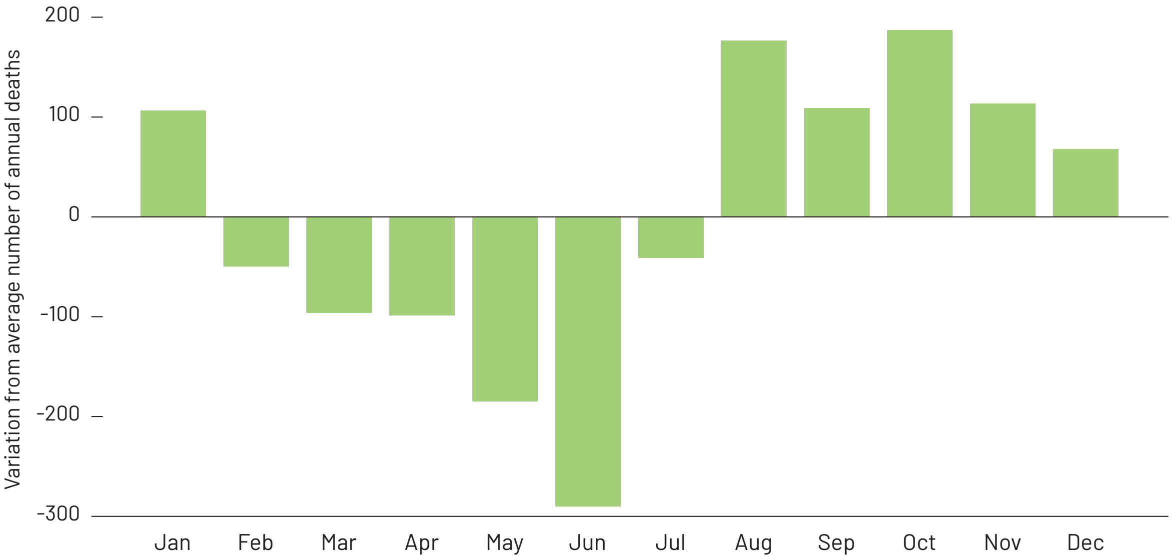
This chapter examines these impacts for the city of Bhubaneswar. It highlights the urgency of implementing adaptive strategies to safeguard public health, bolster economic resilience, and enhance urban infrastructure in the face of escalating heat stress. The insights presented serve as a foundation for developing targeted interventions aimed at mitigating immediate risks and addressing long-term vulnerabilities associated with extreme heat events.

5.1 Health and Mortality

Extreme heat exposure poses significant health risks, particularly for vulnerable populations. Conditions such as heat exhaustion and heatstroke can occur, especially among individuals with pre-existing health conditions. Additionally, warmer temperatures can exacerbate chronic diseases and contribute to the spread of vector-borne diseases, leading to increased mortality rates.

To assess the impact of heat on mortality in Bhubaneswar, all-cause mortality data from local hospitals were used, to compensate for the known under-reporting of heat-related deaths in India. A monthly trend analysis was conducted to examine the effects of rising humidity and heat on the city's population and to better understand seasonal variations in heat-related health risks.

Figure 5.1: Monthly all-cause mortality recorded in Bhubaneswar in 2024



Source: iFOREST Analysis

In contrast to the general perception, the death registration data indicates that mortality rates are much lower during the summer season (March to July). However, during the hot-humid months (August to October) the death rates are significantly higher than the annual average. Given the increasing humidity and night-time temperatures observed in the city, and the fact that the heat stress experienced during the hot-humid season results from the elevated night-time temperatures, this finding strongly advocates for considering the heat index and night-time temperature as heat warning thresholds for Bhubaneswar and for extending heat precautions during the hot-humid season as well.

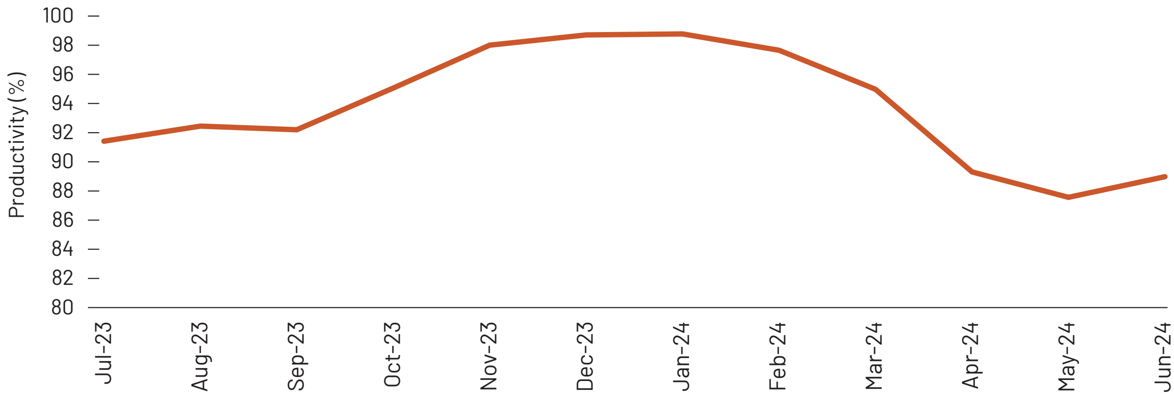
5.2 Work Productivity

Extreme heat significantly affects workforce productivity, especially for outdoor workers, leading to health risks and economic losses for the city. Understanding which sectors and job roles are most impacted is essential for designing targeted and effective policy responses.

The methodology for calculating work productivity loss involved using data on employment, wages, and working hours from the Periodic Labour Force Survey (PLFS), conducted by the Ministry of Statistics and Programme Implementation (MoSPI, GoI), and calculating the daily Wet-bulb Global Temperature (WBGT) for the study period. Subsequently, job roles were classified based on metabolic intensity, and a work-stress function was applied to estimate productivity and earnings loss due to heat stress.[20]

This analysis helped identify vulnerable occupational groups in Bhubaneswar and quantify the associated productivity and wage losses due to extreme temperatures.

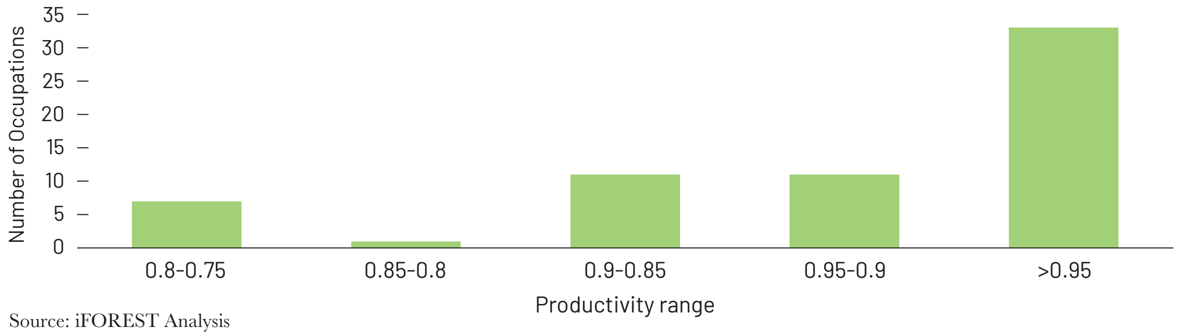
Figure 5.2: Month-wise average work productivity



Source: iFOREST Analysis

- Seasonal variations significantly influence productivity due to heat exposure. In Bhubaneshwar, during the cooler months (December to February), productivity remains relatively stable, typically declining by less than 5%. However, during the hot-humid months (July to September), productivity decreases by approximately 10%, and during peak summer (April to June), the decline is around 13%.

Figure 5.3: Distribution of occupations by work productivity due to heat stress in Bhubaneswar

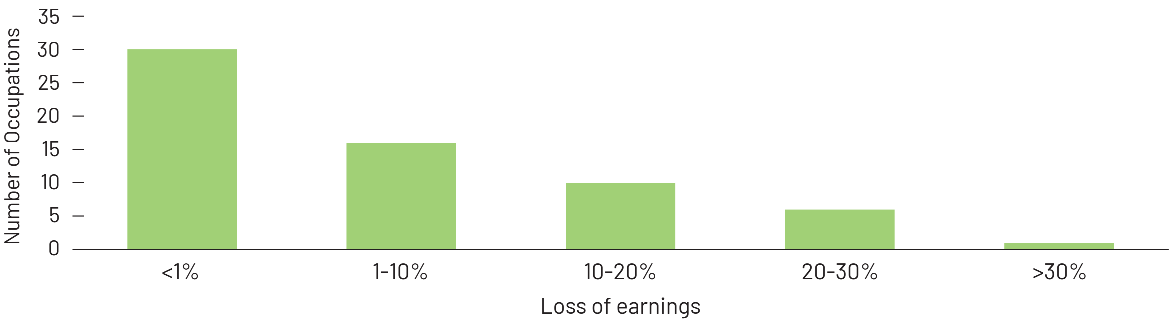


Source: iFOREST Analysis

- Approximately 70% of Bhubaneswar's workforce experiences minimal impact from extreme weather, with productivity losses below 10%. These roles - such as managers, designers, engineers, teachers, child care workers, waiters, technicians and others - typically involve low physical intensity or indoor settings with access to cooling.
- Around 30% of the workforce suffers significant productivity decline due to extreme heat. This workforce can be divided into two categories: the first includes low to medium intensity outdoor jobs such as mechanics,

clerks, and construction supervisors, which experience a productivity decrease of 10-15%. The second category comprises physically demanding outdoor work, like mining, construction, and labour in transport and storage, which is the most affected group, facing productivity losses of about 20-25%.

Figure 5.4: Distribution of occupations by earnings loss due to heat stress in Bhubaneswar



Source: iFOREST Analysis

- Wage losses are closely correlated with declines in productivity. Approximately 70% of the workforce in Bhubaneswar experiences minimal earnings loss. These are engaged in indoor work, falling into two main categories: about 48% are employed in low-intensity roles such as managers, engineers, and teachers, with earnings losses of less than 1%; the remaining group comprises medium-intensity occupations like childcare workers, waiters, and vehicle technicians, who encounter earnings losses of up to 10%.
- However, the remaining 30% of Bhubaneswar's workforce experiences significant income losses due to outdoor working conditions. Low- to medium-intensity outdoor jobs, such as mechanics, clerks, and construction supervisors face income losses ranging from 10% to 20%, whereas physically demanding outdoor workers, including mining, construction, and transport and storage labor lose between 20% and 30% of their income. Livestock farmers are particularly vulnerable, with losses reaching as high as 33%.
- Overall, for the studied year, citizens in Bhubaneswar suffered a cumulative earnings loss of 8.6% attributed to extreme heat.

This pressing issue demands that the city government prioritise and enact strategies such as worker heat safety guidelines, adjusting working hours, and providing subsidies for heat-resilient technologies. These measures aim not only to protect the population but also to mitigate economic losses.

5.3 Cooling Demand and Electricity Consumption

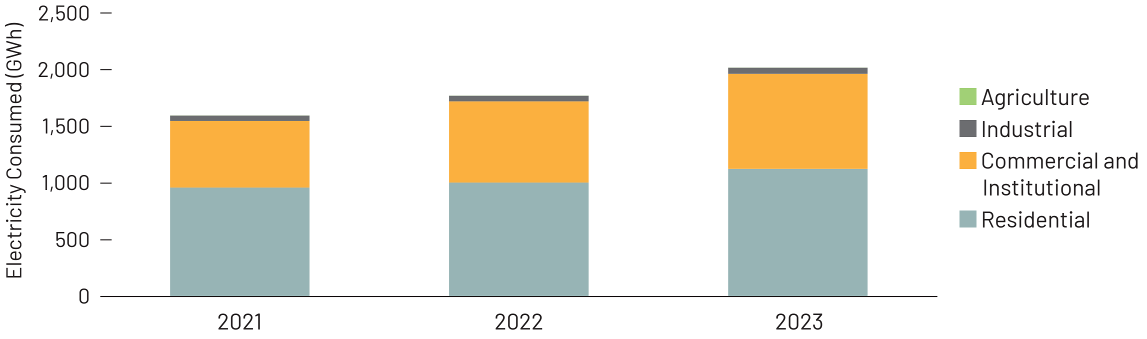
A key impact of rising temperatures is increased electricity consumption. As temperatures rise, the demand for air conditioning and fans increases as households and businesses seek to maintain thermal comfort. Electricity consumption also tends to spike during the hottest hours, increasing peak load and leading to frequent outages.

To assess the impact of heat stress on cooling loads and electricity consumption in Bhubaneswar, consumer-level electricity data from 2021 to 2023 from the Discom (Tata Power Central Odisha Distribution Limited), along with insights from a household-level primary survey conducted in the city on ownership and use of air conditioners (ACs) was analysed.

Electricity Consumption Trends

Bhubaneswar's yearly electricity usage shows a steady increase with an annual growth rate of 12% from 2021 to 2023. This rise varies among different consumer categories, with the commercial and institutional category experiencing the highest growth rate of around 19%, followed by residential and industrial sectors with annual growth at about 8% and 7%, respectively. The agricultural sector witnesses the least growth at 5% year-on-year.

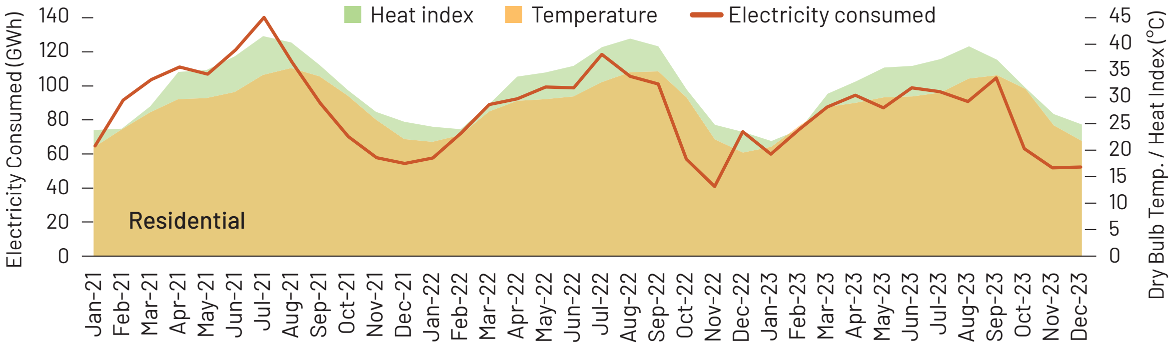
Figure 5.5: Sector-wise electricity consumption trend for Bhubaneswar

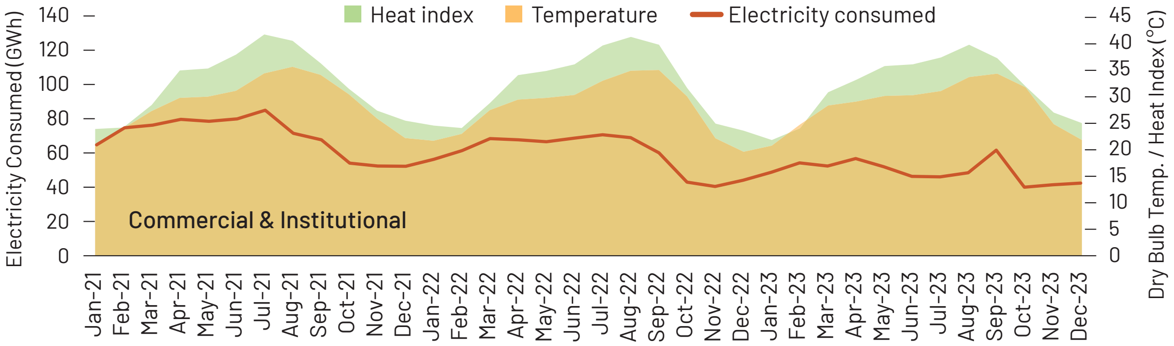


Source: iFOREST Analysis

The electricity consumption in Bhubaneswar displays a clear cyclical trend, with usage peaking between April and October in response to rising temperature and humidity levels and declining noticeably from November to February. Electricity consumption consistently reaches its highest levels during months of intense heat stress.

Figure 5.6: Monthly electricity consumption vs. temperature and heat index





Source: iFOREST Analysis

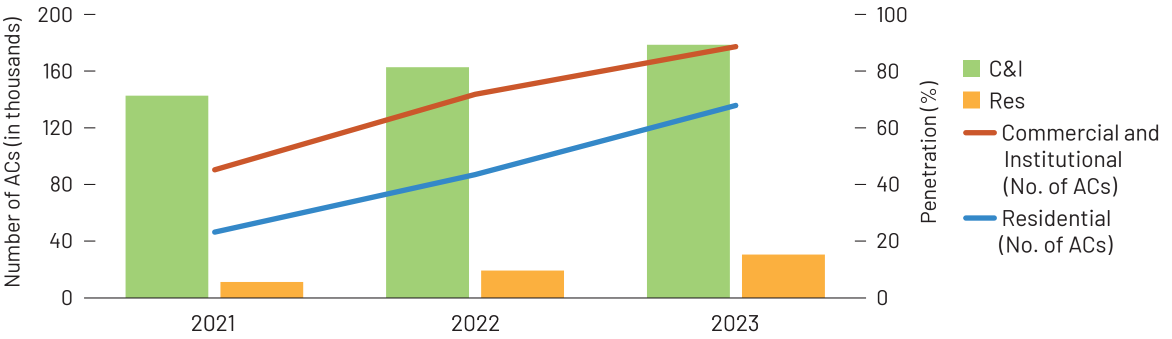
The seasonal trend is more pronounced in residential than in the commercial & institutional sector, which maintains a more consistent usage throughout the year. This implies that residential energy use is more sensitive to temperature variations. February records the lowest consumption across the years in both sectors.

In the residential sector, the consumption during the peak month of 2023 is approximately 159% higher than in the lowest month of 2023. This variation is 64% in the commercial & institutional sector, underscoring the strong correlation between climatic conditions and electricity consumption.

Electricity consumption from space cooling

A major factor driving the electricity consumption in Bhubaneswar is the demand for cooling. To estimate electricity uses for space cooling, a survey was conducted across 977 premises in 33 wards. Based on this survey, the number of equivalent Room Air Conditioners (RACs) was estimated across residential, commercial, and institutional sectors. The findings provide insights into RAC penetration trends, highlighting the scale and growth of space cooling infrastructure in the city.

Figure 5.7: Trends in RAC ownership

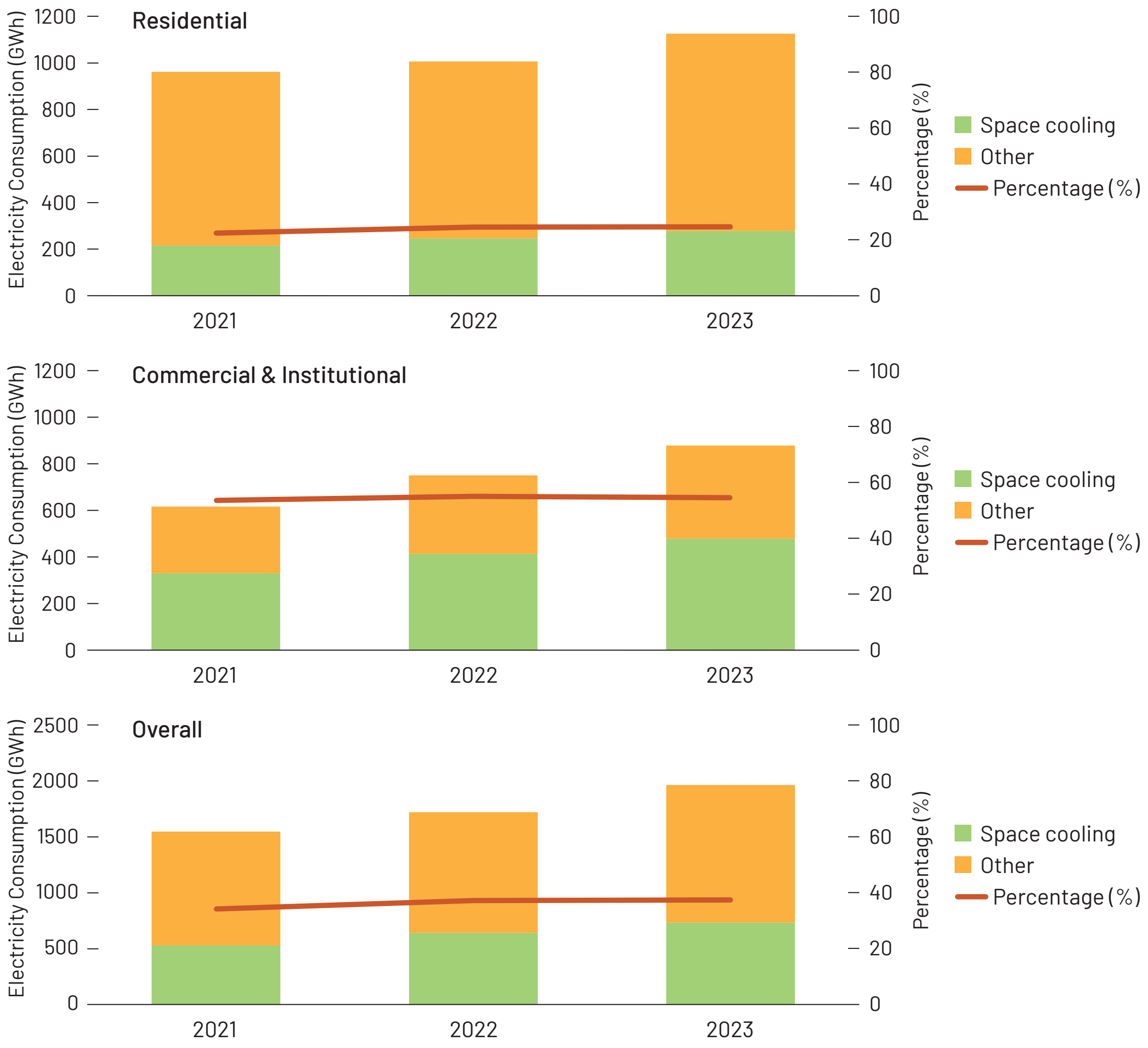


Source: iFOREST Analysis

Residential air conditioner ownership in Bhubaneswar grew at an annual rate of 73% between 2021 and 2023, significantly outpacing the commercial and institutional sector, which recorded a growth rate of 41% over the same period.

Despite a notable disparity in AC penetration between the two sectors, both have shown substantial growth in recent years. The commercial and institutional sector saw a steady increase in AC penetration, rising from 71% in 2021 to 89% in 2023. Meanwhile, residential penetration increased from 6% to 15%, reflecting a rapid uptake of cooling appliances.

Figure 5.8: Trends in space cooling electricity consumption



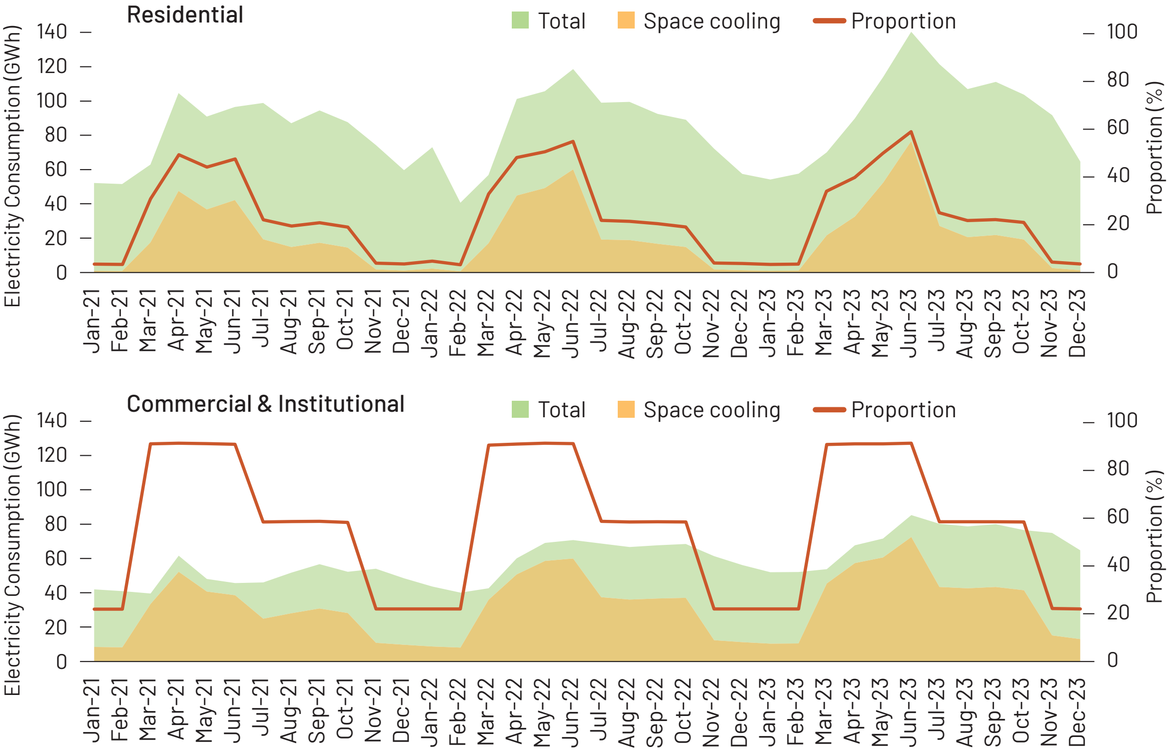
Source: iFOREST Analysis

This rising penetration is also reflected in the increasing electricity consumption attributed to space cooling. The share of space cooling in total residential electricity consumption increased from 22% in 2021 to 25% in 2023. In the commercial and institutional sectors, the share of space cooling remained in the range of 54–55% from 2021 to 2023, highlighting the centrality of air conditioning in commercial & institutional electricity use.

Overall, space cooling accounted for 34% to 37% of total electricity consumption between 2021 and 2023. This shows the growing role of cooling load in overall electricity demand across end-use sectors.

An analysis of monthly trends offers deeper insights into seasonal variations, revealing how electricity demand for cooling peaks during specific periods of the year, particularly in response to rising temperatures and humidity levels.

Figure 5.10: Monthly trend in space cooling electricity consumption



Source: iFOREST Analysis

Despite the relatively lower penetration of RACs in residential sector, space cooling accounts for a substantial 45–55% of electricity consumption during the summer months and contributes around 20% during the hot and humid monsoon period. In the commercial and institutional sectors, where AC penetration is significantly higher, space cooling represents an even larger share, approximately 85% during summer, decreasing to 54% in the monsoon and further to 20% in the winter season.

Bhubaneswar is witnessing a sharp rise in air conditioning adoption, which is expected to significantly increase electricity consumption for space cooling in the coming years. This trend is particularly pronounced in the residential sector, where AC penetration remains low but is poised for rapid growth. The resulting surge in cooling demand not only places additional stress on the energy system but also exacerbates the UHI effect by releasing substantial waste heat into the environment. These developments highlight the urgent need for integrated strategies that promote energy-efficient cooling technologies, sustainable urban planning, and the expansion of blue-green infrastructure to mitigate rising temperatures and manage future cooling demands effectively.

06

Modelling Heat Mitigation Strategies

SUMMARY

Study Scope

The study modelled heat mitigation strategies in two Bhubaneswar clusters, Salia Sahi (slum and low-rise-dominated) and Janpath (commercial corridor with taller buildings). To understand the impact of different measures on reducing temperatures and energy use intensity.

Present and Future Heat Conditions

Both Salia Sahi and Janpath experience similar levels of heat stress, with average summer PET values of around 34-35°C. By 2050, PET is expected to rise by around 3–3.5°C on typical days and 7.6–7.8°C during heatwaves, reaching midday peaks of up to 60°C.

Urban Level Interventions

Nature-based solutions in Janpath delivered significant local cooling, with urban parks cutting average surface temperatures by 6.56°C, green medians lowering them by 2.38°C, and water bodies reducing PET by 3.28°C. Strategic densification along Janpath Road improved shading and airflow, reducing daytime PET by up to 2.16°C.

Roof Interventions

Roof modifications proved highly effective, with green roofs delivering the greatest cooling, reducing daytime temperatures by 5–22°C depending on the time of day, followed by white-painted roofs, which lowered temperatures by up to 8.7°C in low-rise areas and 4.9°C in slums. PV roofs offered daytime cooling of about 3.5°C but retained heat at night, increasing temperatures by around 2°C, resulting in mixed thermal benefits despite their energy-generation potential.

Improved Construction Benefits

Upgrading construction to ECSBC/ENS 2024 standards reduces annual energy intensity by 10.1%, via better insulation, reflective coatings, and improved materials.

Appliance-Scale Efficiency

Upgrading cooling systems can deliver substantial energy savings. In the residential sector, replacing 3-star split ACs with 5-star models cuts consumption by 8.5–11.6%, while in commercial and institutional buildings, switching from 3-star split ACs to water-based chiller systems achieves even greater savings of 13.5–17.3% and reduces refrigerant-related greenhouse gas emissions.

City-Level Projections

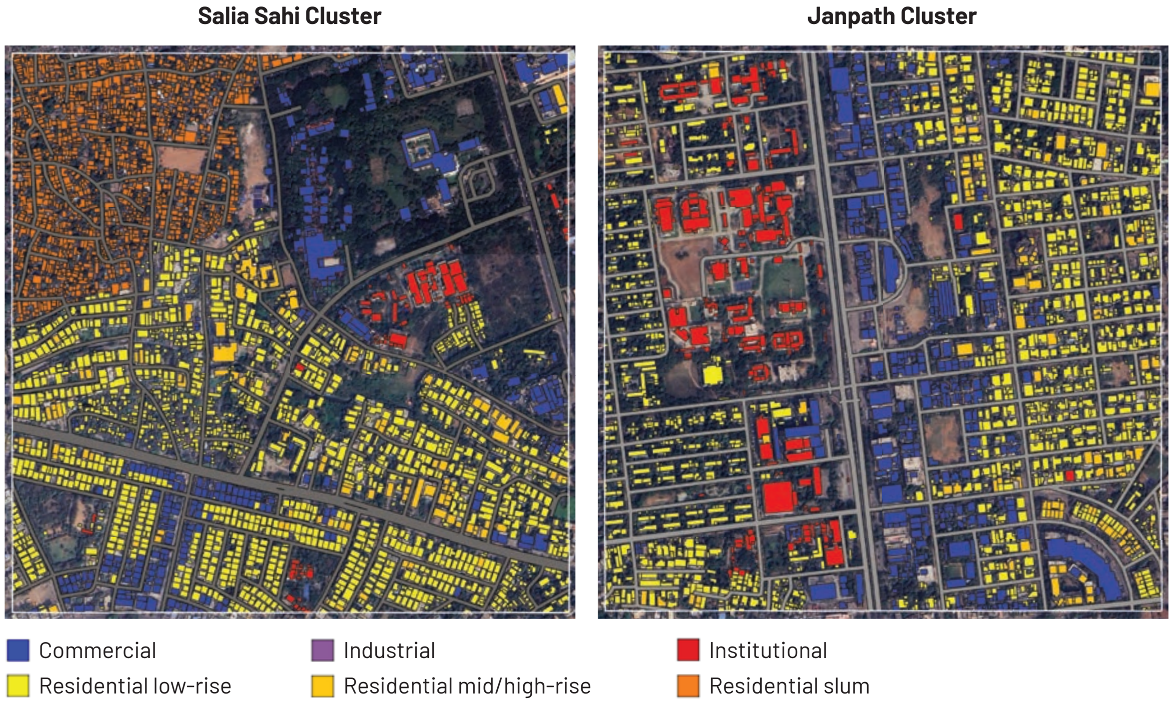
By 2050, cooling demand could increase 7.6 times under Business-as-Usual, but stronger building codes and efficient appliances could cut electricity use and GHG emissions between 44–67% based on regulation and enforcement. For a typical 2BHK home, the payback period for such upgrades is 6.5–8.5 years, likely to shorten as technology costs decline.

Understanding the effectiveness of heat mitigation and sustainable cooling strategies has become increasingly urgent to address heat risks in cities. For this, robust modelling across multiple scales—city, building, and appliance—is essential to identify interventions that not only improve thermal comfort but also reduce energy demand, Urban Heat Island (UHI) effects and GHG emissions.

To better understand the impacts of climate change and assess the effectiveness of heat mitigation strategies, two distinct areas in Bhubaneswar was selected for modelling – Salia Sahi and Janpath. These locations were carefully selected to represent the city's diverse urban forms and typologies. Modelling was done to assess the impacts of city-level interventions such as increased vegetation, water-sensitive design and high albedo and reflective materials; building-level interventions such as energy efficient building design and appliance-level solutions such as energy-efficient technologies and system-wide cooling solutions. Together, these modelling provide a comprehensive foundation for informed, scalable heat mitigation strategies for the city.

6.1 Present Conditions of the Clusters

Figure 6.1: Existing land use and land cover of areas modelled for mitigation strategies

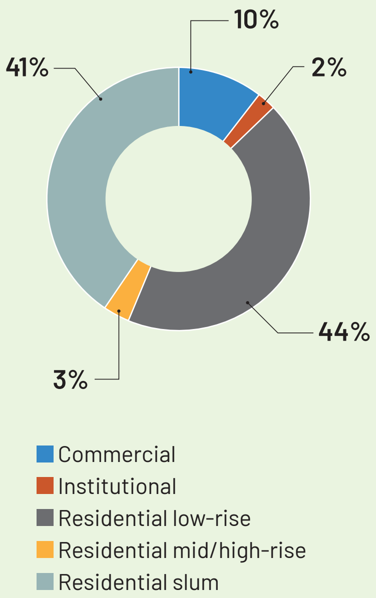
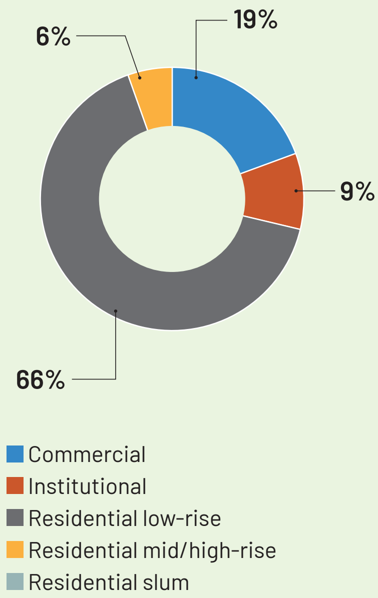


Source: iFOREST Analysis

The Saila Sahi cluster is predominantly composed of slum (41%) and low-rise residential buildings (44%), followed by commercial (10%), mid- and high-rise residential (3%), and institutional (2%) typologies. The overall building density in this cluster is 39 buildings per hectare.

The Janpath cluster, forming the city's primary commercial corridor, represents newer urban development with relatively taller construction. Despite this, low-rise residential buildings still dominate at 66%, followed by commercial (19%), institutional (9%), and mid- and high-rise residential (6%). The building density here is also 26 buildings per hectare.

Table 6.1: Building characteristics across Salia Sahi and Janpath Cluster

Parameters / AoIs	Salia Sahi	Janpath
Category-wise number of buildings		
Building Density	39 buildings / ha	26 buildings / ha
Area under roads	1,50,591 m^2 (15% of AoI area)	1,55,853 m^2 (16% of AoI area)
Area under tree cover	3,06,200 m^2 (31% of AoI area)	2,43,100 m^2 (24% of AoI area)

Source: iFOREST Analysis

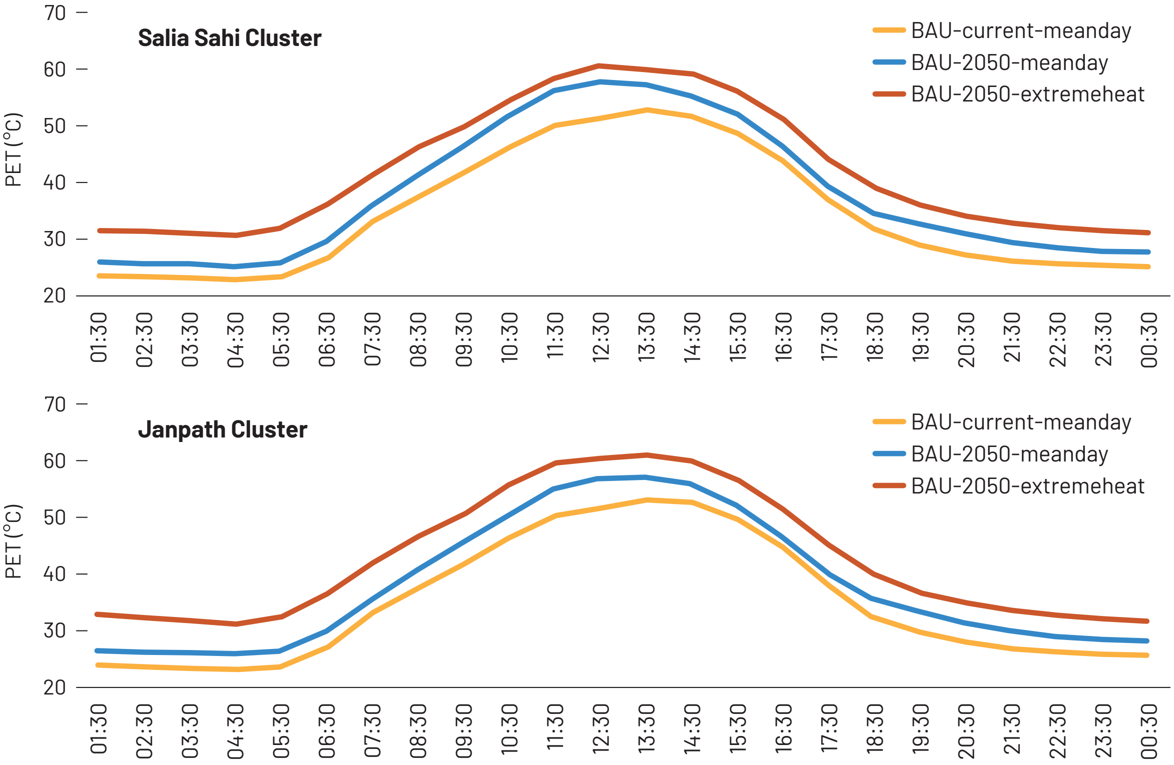
Both clusters have a similar proportion of area under roads, occupying approximately 15–16% of the total area. However, there is a noticeable difference in tree cover and open spaces. The Salia Sahi cluster has a higher share of such areas at 31%, compared to 24% in the Janpath cluster. However, in Salia Sahi, these open spaces are largely concentrated in the northeast area near the commercial buildings, whereas in the Janpath cluster, they are more evenly distributed throughout the area.

6.2 Present and Future Heat Stress

Despite their distinct urban forms, both the Salia Sahi and Janpath clusters exhibit comparable Physiological Equivalent Temperature (PET) levels across all three climate scenarios. On a typical present-day summer, hourly average PET ranges from 22°C to 52°C, with a daily average of 34.3°C in Salia Sahi and 34.7°C in Janpath, which falls under the 'strong heat stress' category.

By 2050, the daily average PET in Salia Sahi is projected to rise by approximately 3.5°C on a typical summer day and 7.6°C during an extreme heatwave day. Similarly, Janpath is expected to see increases of around 3.1°C and 7.8°C, respectively. Under extreme heatwave conditions in 2050, the maximum hourly average PET could reach up to 60°C during midday in both clusters.

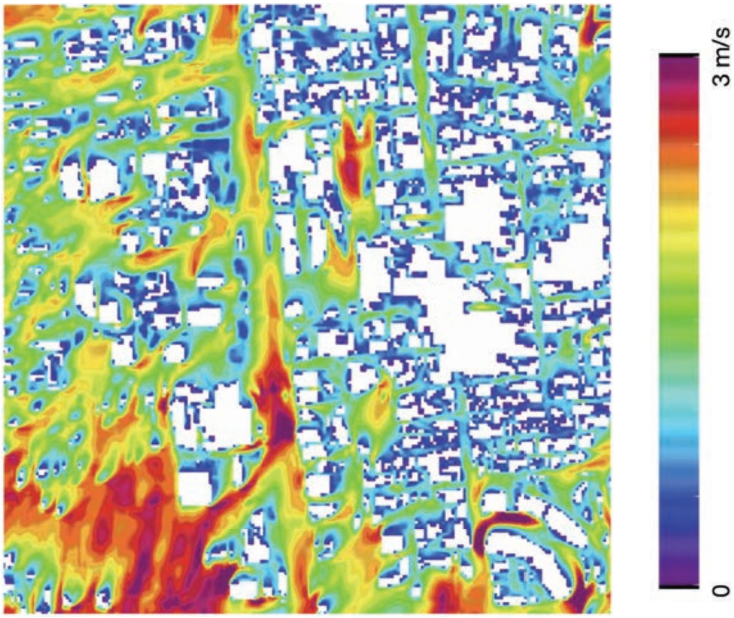
Figure 6.2: Hourly PET at Salia Sahi and Janpath cluster - Present vs. 2050



Source: iFOREST and SEC Analysis

Interestingly, despite Janpath having less green and open space than Salia Sahi, PET levels remain similar. This is largely due to the presence of a wind corridor created by the north-south orientation of Janpath Road and the wider gaps between buildings, which enhance natural ventilation and reduce heat build-up.

Figure 6.3: Wind speed contour map at noon time for Janpath cluster

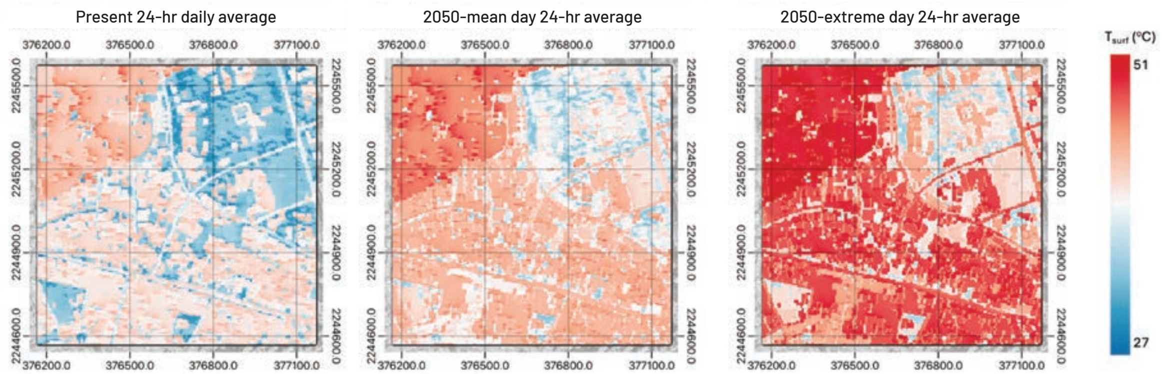


Source: iFOREST and SEC Analysis

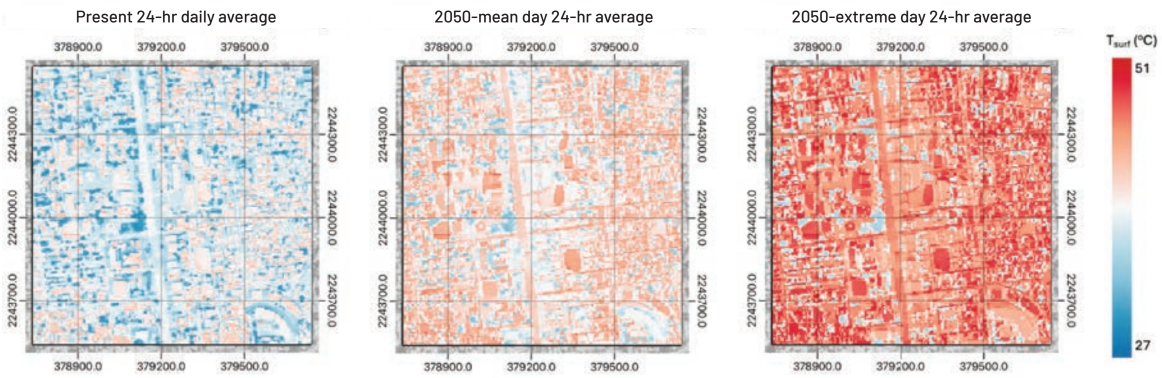
Another contributing factor to the similar PET levels in both clusters is the presence of slums in the Salia Sahi cluster, which record the highest surface temperatures, which is likely to reach up to 70°C during extreme heatwave conditions by 2050. In contrast, the Janpath cluster records a lower maximum hourly surface temperature of around 64°C at midday, approximately 7°C cooler than Salia Sahi. This significant heat build-up in slum areas offsets the benefits of higher green cover, leading to comparable PET values across both clusters.

Figure 6.4: Variation in surface temperature of the areas of interest – Present vs. 2050

Salia Sahi Cluster



Janpath Cluster



Source: iFOREST and SEC Analysis

However, Janpath exhibits a more uniform distribution of heat stress across the area, whereas Salia Sahi shows greater spatial variability.

6.3 Heat Mitigation Strategies

Given the differences in urban form and land use observed across the two clusters, tailored heat mitigation strategies were modelled for each location:

- In Salia Sahi cluster, the focus was primarily on cool roof interventions, including green roofs, white reflective roofs, and rooftop solar photovoltaic (PV) systems. Due to already high tree cover and limited available space, nature-based solutions could not be effectively implemented.
- In Janpath cluster, the emphasis was on nature-based interventions such as converting vacant open areas into urban parks and water bodies, introducing green medians along roads, and adopting urban densification strategies to optimise land use and improve microclimatic conditions.

Figure 6.5: Various heat mitigation interventions modelled in Salia Sahi and Janpath cluster

Source: iFOREST and SEC Analysis

6.3.1 Impact of interventions in Salia Sahi

Modifying roof surfaces is one of the most effective strategies for reducing heat stress at the building scale. Roofs play a critical role in influencing both indoor thermal comfort and the surrounding microclimate by minimising heat absorption, lowering surface and near-surface air temperatures, and reducing cooling energy demand.

This analysis evaluates three roof-based interventions applied across different building typologies in the Salia Sahi cluster: white-painted roofs for slum and low-rise structures, green roofs for mid- and high-rise residential and institutional buildings, and photovoltaic (PV) roofs for commercial properties. The impact of these targeted interventions at the specific sites is presented below. The observations on their cumulative impact at the cluster level will be provided in a subsequent section.

Table 6.2: Impact of roof interventions

Intervention	Building Typology	Change in Surface Temperature (°C)		
		24-hour Average	Daytime Average	Night-time Average
White Paint	Slum	-3.94	-4.90	-2.92
	Low-rise Residential	-3.90	-8.72	-1.52
Green Roof	High and Mid-rise Residential	-9.43	-22.28	-5.76
	Institutional	-8.15	-17.84	-5.71
PV Roof	Commercial	-0.56	-3.53	2.05

Source: iFOREST and SEC Analysis

- White paint: Applying white cool paint to building roofs significantly reduces surface temperatures by increasing solar reflectivity. During peak daytime hours, residential low-rise buildings see a roof surface temperature drop of up to 8.7°C, while slum areas experience a reduction of up to 4.9°C. In both cases, the 24-hour average surface temperature shows an improvement of around 3.9°C.
- Green roof: Green roofs demonstrated the most substantial overall cooling effect among the three roof strategies. Roof surface temperatures decreased by 5°C to 22°C, depending on the time of day. The 24-hour average surface temperature reduction was around 9.5°C for residential mid and high-rise buildings and 8.15°C for institutional buildings.
- Photovoltaic roof : Photovoltaic (PV) roofs showed a mixed impact on surface temperatures and the surrounding microclimate. During the daytime, there is a reduction in surface temperatures by an average of 3.5°C. However, at night, PV roofs retain more heat than conventional roofs, leading to an increase by an average of around 2°C. This indicates that while PV roofs are beneficial for daytime cooling and energy generation, their thermal behaviour at night is likely to add to heat stress.

Overall, these findings demonstrate that roof surface modifications can effectively decrease both surface and near-surface air temperatures, limiting heat gain.

6.3.2 Impact of interventions in Janpath

This analysis examines how some of the key urban design strategies can influence local microclimatic conditions. These include increasing tree cover, preserving and integrating water bodies, introducing green medians along roads, and optimising building density, strategies that serve to significantly reduce the UHI effect. The impact of these targeted interventions at the specific sites is presented below. The observations on their cumulative impact at the cluster level will be provided in a subsequent section.

Table 6.3: Impact of different urban interventions

Intervention	Change in Surface Temperature (°C)			Change in PET (°C)		
	24-hour Average	Daytime Average	Night-time Average	24-hour Average	Daytime Average	Night-time Average
Urban Parks	-6.56	-16.11	-3.23	-3.42	-8.72	-0.51
Road Medians	-2.38	-2.77	-3.46	-0.95	-3.62	0.05
Water Body	N/A	N/A	N/A	-3.28	-7.77	-1.28
Building densification	-1.05	-2.44	-0.47	-0.95	-2.16	0.002

Source: iFOREST and SEC Analysis

Impact of Urban Parks

To evaluate the effects of enhanced green cover, specific vacant land parcels were transformed into urban parks featuring tree plantations in the Janpath cluster. The modelling results indicate a marked improvement in thermal conditions, with surface temperatures at these sites dropping by an average of 6.56°C relative to existing conditions, with the maximum impact seen during the daytime by around 16.11°C.

As surface temperatures decrease, PET values at the intervention sites show a notable improvement, with an average reduction of 3.42°C. By transforming vacant land into green spaces, these parks act as cooling islands.

Green Median on Roads

A tree-lined central median covering 4,210 m² (0.4% of the precinct area) was added along Janpath road to assess the cooling benefits of green street design. This intervention led to a measurable reduction in heat stress, with average surface temperatures dropping by 2.38°C and PET values improving by 0.95°C across the 24-hours. However, at night, while the surface temperatures fell by 3.46°C, the PET increased slightly by 0.5°C.

While trees offer significant shading and help reduce surface temperatures, they can also hinder wind flow, potentially limiting natural ventilation and overall cooling performance. As a result, it is crucial to carefully assess this trade-off during the design process. The effectiveness of green medians depends on factors such as the road's right of way (ROW), aspect ratio, and alignment with prevailing winds. On Janpath Road, the wide ROW and its orientation along the dominant wind direction enhanced the intervention's performance, enabling both efficient shading and unobstructed airflow. This underscores the importance of context-sensitive design when incorporating greenery into urban streetscapes.

Impact of Water Body

A water body spanning 6,736 m² (accounting for 0.7% of the precinct area) was introduced in the Janpath AoI. Due to a limitation in the PALM-4U model, the water surface temperature is fixed at 27.5 °C. Given the constraint, the intervention led to a noticeable cooling effect in the surrounding areas, with PET decreasing by an average of 3.28 °C.

Figure 6.6: Impact of Water bodies on temperatures in Bhubaneswar

Source: iFOREST Analysis

To overcome the modelling limitation and better understand the influence of water bodies on surrounding areas, Bhubaneswar was divided into a grid. Surface temperatures in 15 grid cells containing water bodies were compared to adjacent areas without water bodies. The analysis revealed that neighbourhoods with water bodies experienced an average surface temperature reduction of 0.7 °C, highlighting their localised cooling effect.

Building Density

To assess how increased building density influences urban heat conditions, the model simulated 504 buildings along Janpath Road following the Odisha Development Authority (Planning and Building Standards) Rules, 2020. These regulations permitted an increase in Floor Area Ratio (FAR) from 2.75 to 7 for buildings along roads measuring 60 meters wide or more. In the simulation, the heights of commercial and institutional buildings facing Janpath Road were increased by 2.5 times, while the rest of the building footprints in the surrounding area were left unchanged.

The intervention led to a measurable improvement in thermal conditions, with surface temperatures dropping by 1.05°C, while the PET improved by 0.95°C. The maximum improvement is observed during the daytime, with surface temperatures dropping by 2.44°C and PET by 2.16°C. The increased building heights enhanced shading over streets and neighbouring structures, reducing direct solar exposure and consequently lowering both surface and ambient air temperatures. Additionally, because densification was limited to a select number of buildings, the resulting variation in building heights helped improve urban airflow, aiding in the dispersion of heat from street-level areas.

However, such densification strategies must be implemented carefully. Uniformly increasing building heights without accounting for urban morphology and street orientation can create a street canyon effect, where limited ventilation and greater heat retention degrade microclimatic conditions and outdoor comfort. Thus, while strategic densification can enhance cooling through improved shading and airflow, its success depends on context-sensitive planning to prevent negative side effects.

6.4 Cumulative Impact of heat mitigation strategies

Table 6.4: Cumulative impact of different heat mitigation interventions

Cluster	Change in Surface Temperature (°C)			Change in PET (°C)		
	24-hour Average	Daytime Average	Night-time Average	24-hour Average	Daytime Average	Night-time Average
Salia Sahi	-2.41	-5.15	-1.12	-	-	-
Janpath	-0.28	-0.68	-0.13	-0.20	-0.53	-0.02

Source: iFOREST and SEC Analysis

Janpath Cluster: The integration of blue-green infrastructure in the Janpath cluster, through tree-lined medians (4,210 m²), urban parks (1,25,350 m²), and water bodies (6,736 m²), significantly improved outdoor thermal comfort and helped mitigate urban heat. These interventions resulted in an overall reduction in surface temperature of 0.28°C and PET of 0.2°C. The cooling effect was most pronounced during daytime hours, with surface temperatures dropping by up to 0.68°C and PET by 0.53°C, primarily due to shading and evapotranspiration. Collectively, these measures reduce pedestrian heat exposure and support a more livable, climate-resilient urban environment.

Salia Sahi Cluster: The combined implementation of roof-based interventions – white reflective coatings on slum and low-rise residential buildings (0.24 km², 72% of AoI roof area), green roofs on mid/high-rise residential and institutional structures (0.04 km², 10%), and rooftop solar PV on commercial buildings (0.06 km², 18%), led to a substantial improvement in thermal conditions. These measures collectively reduced average 24-hour surface temperatures by 2.41°C compared to baseline scenario, with peak daytime reductions of up to 5.15°C and night-time reductions of around 1.12°C. This highlights the strong potential of integrated roof strategies in mitigating urban heat and enhancing thermal comfort across varied urban contexts.

6.5 Modelling Building-Scale Strategies

The building-level modelling explored the impact of using thermally efficient wall and slab materials on heat gain and the demand for active cooling. In addition, the adoption of energy-efficient cooling appliances was also modelled to assess the impact on electricity consumption and carbon emissions.

6.5.1 Reducing cooling energy demand through improved construction

To assess the reduction in cooling demand from improved roof and wall construction, the Residential Envelope Transmittance Value (RETV) and Roof Thermal Transmittance (U_{roof}) were modeled for both existing residential buildings and those designed to comply with the Energy Conservation & Sustainable Building Code (ECSBC) and Eco Niwas Samhita (ENS) 2024. This analysis estimated the potential decrease in heat gain and energy consumption resulting from the implementation of these building standards.

RETV and U_{roof} was specifically modelled because they can be broadly applied across the city through advancements in construction materials and practices, such as insulation, reflective coatings, and high-performance glazing. In contrast, other parameters from the ECSBC and ENS codes, like solar heat gain, are highly site-specific and depend on factors such as building orientation and surrounding context.

Table 6.5: Annual energy consumption intensity with improved RETV and U_{roof}

Scenario	Annual Energy Consumption Intensity (kWh/m^2/yr)
Current Building	126.9
Improved Building Construction as per ECSBC code	114.1
Improvement	10.1%

Source: iFOREST and SEC Analysis

The modelling results show that:

- With current construction materials and techniques, the annual energy consumption intensity of a representative building in Bhubaneshwar is approximately 1,269 kWh/m^2/year.
- By adopting improved materials in line with the ECSBC code, this consumption can be reduced to 1,141 kWh/m^2/year. This translates to a 10.1% reduction in electricity usage per household, highlighting the positive impact of thermally efficient construction on reducing energy demand and enhancing indoor comfort.

6.5.2 Modelling energy-efficient appliances

The analysis assessed the potential energy savings from adopting high-efficiency cooling technologies. In the residential sector, it compared conventional split air-conditioning units with the most energy-efficient models currently available. For commercial and office buildings, the study evaluated both advanced split AC systems and water-based chiller solutions. The energy efficiency values used in the assessement are based on the Minimum Energy Performance Standards (MEPS) set by the Bureau of Energy Efficiency (BEE) under its appliance labelling programme.

- Advanced Split AC Systems: India's Star Labelling Program assigns energy efficiency ratings to air conditioning systems based on their electricity consumption. Higher star-rated models, such as 4-star and 5-star units, are significantly more energy-efficient while maintaining optimal cooling performance. Additionally, split air conditioners are generally more efficient and consume less electricity compared to window AC models, making them a preferable choice for reducing energy use and managing heat more sustainably.
- Water-based chiller systems: Centralised cooling technologies, such as water-based chiller systems, offer a more energy-efficient and sustainable solution for large buildings and campuses compared to multiple standalone air conditioning units. These systems use water as a cooling medium, which has a higher heat

capacity and enables more effective heat transfer, reducing overall electricity consumption. Moreover, replacing conventional refrigerants with water helps drastically cut down greenhouse gas emissions, making these systems not only more environmentally friendly but also a critical tool in mitigating urban heat.

In the context of rising heat stress, widespread adoption of higher star-rated and centralised cooling appliances can help reduce the peak electricity demand, ease pressure on the grid, and lower greenhouse gas emissions. This not only supports urban heat mitigation efforts by decreasing waste heat emissions but also reduces household energy bills, making it a cost-effective and sustainable solution for both cities and consumers.

Table 6.6: Annual energy consumption for the current and improved air conditioning appliances

Building Typology	Water-based Chiller		
	Current Cooling Appliance	Energy-Efficient Split AC	Energy-Efficient Water-based Chiller
Residential	115.2	105.3 (8.6 %)	-
Commercial	482.2	426.1 (11.6 %)	398.8 (17.3 %)
Institutional	231.1	206.3 (10.7 %)	199.9 (13.5 %)

Source: iFOREST and SEC Analysis

The modelling done on a typical residential, commercial/institutional building in Bhubaneshwar shows significant reduction in energy consumption due to the use of efficient appliances:

- Currently, 3-star rated split ACs are the most commonly used cooling systems across the residential, commercial, and institutional sectors in Bhubaneshwar. Upgrading these systems to 5-star rated split ACs results in a notable reduction in annual energy consumption ranging from 8.5% to 11.6% across different building types at a consumer level.
- In the commercial and institutional sectors, replacing 3-star split ACs with energy-efficient water-based chiller systems offers significantly greater energy savings, reducing consumption by 13.5% to 17.3% across different building typologies.

6.6 City-Level Impact of Building and Appliance Efficiency

As Bhubaneswar continues to grow in both population and built-area, space cooling demand, especially for the residential sector, is escalating rapidly. To assess the impact of improved bulding material and appliance efficiency on city's energy consumption and GHG emissions, a comprehensive modelling was done using three specific scenarios. The residential sector is the primary focus of this analysis, as it currently accounts for about 60% of Bhubaneswar's electricity consumption, a share that is projected to rise sharply due to the rapid growth in cooling demand. Additionally, residential buildings represent the dominant typology across the city, making this sector central to any building-level cooling strategy.

The three scenarios used for modelling are:

- **Business-as-Usual Scenario (BAU):** The BAU scenario assumes that the current building material and construction techniques remains dominant till 2050. The energy conservation code for the residential sector is implemented slowly and inconsistently, as is the case presently. By 2050, it is assumed that only 30% of the existing buildings will undergo retrofitting, while 45% of new buildings will be constructed in compliance with energy efficiency codes. The efficiency of residential cooling appliances is projected to improve slowly, reaching an Indian Seasonal Energy Efficiency Ratio (ISEER) of 5.0 by 2050, reflecting an annual improvement rate of approximately 2%.
- **Intervention Scenario:** This is a middle-of-the-road scenario. It assumes that the city adopts the energy conservation code with stronger enforcement and higher compliance. By 2050, 45% of existing buildings are retrofitted with improved materials and techniques, and 70% of new buildings meet the energy efficiency code. Cooling appliance efficiency is projected to reach an ISEER value of 7.5 by 2050, representing the most efficient residential air conditioner currently available in the Indian market.

- **Deep-cut Scenario:** This scenario envisions a highly ambitious and forward-looking approach to energy conservation. The city enacts stringent and regularly updated energy efficiency code with high compliance level. By 2050, 80% of existing buildings are retrofitted, and 100% of new constructions fully adhere to the latest energy codes. The efficiency of cooling appliances reaches an ISEER of 10, representing a significant technological leap and aligning with best-in-class performance benchmarks.

Tables 6.7 to 6.9 provide the inputs used for the modelling study.

Table 6.7: Improvement in RETV, U_{roof}, and ISEER values in the BAU scenario

BAU Scenario							
Category	**Parameter**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Existing Buildings	RETV (W/m^2)	16.1	15.3	14.5	13.7	12.8	12
	U_{roof} ($m^2/W{\bullet}K$)	2.9	2.7	2.5	2.2	2	1.8
	Penetration Level (%)	100	10	15	20	25	30
New Buildings	RETV (W/m^2)	12.4	11.9	11.4	11	10.5	10
	U_{roof} ($m^2/W{\bullet}K$)	2.9	2.6	2.2	1.9	1.5	1.2
	Penetration Level (%)	100	10	15	25	35	45
Cooling Appliances	ISEER	3.13	3.5	3.88	4.25	4.63	5
	Penetration Level (%)	15	25	35	45	55	70

Source: iFOREST Analysis

Table 6.8: Improvement in RETV, U_{roof}, and ISEER values in the intervention scenario

Intervention Scenario							
Category	**Parameter**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Existing Buildings	RETV (W/m^2)	16.1	14.1	12	11	10	9
	U_{roof} ($m^2/W{\bullet}K$)	2.9	2.4	1.8	1.5	1.3	1
	Penetration Level (%)	100	15	20	25	35	45
New Buildings	RETV (W/m^2)	12.4	11.2	10	9.3	8.7	8
	U_{roof} ($m^2/W{\bullet}K$)	2.9	2.1	1.2	1	0.7	0.5
	Penetration Level (%)	100	30	40	50	60	70
Cooling Appliances	ISEER	3.13	4.01	4.89	5.76	6.64	7.52
	Penetration Level (%)	15	25	35	45	55	70

Source: iFOREST Analysis

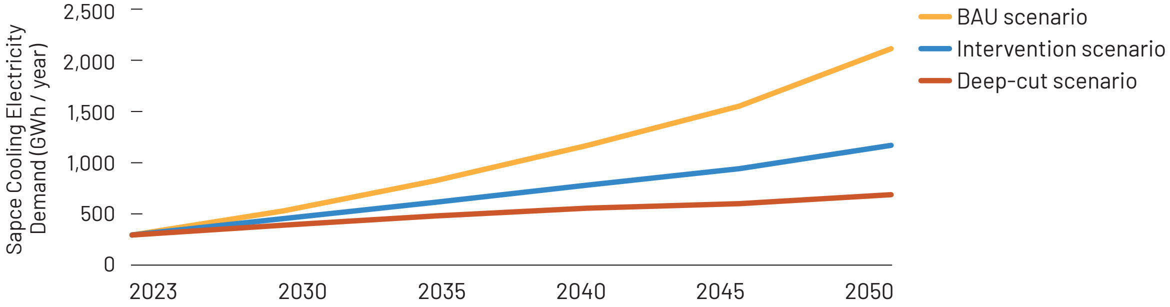
Table 6.9: Improvement in RETV, U_{roof}, and ISEER values in the deep-cut scenario

Deep-cut Scenario							
Category	**Parameter**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Existing Buildings	RETV (W/m^2)	16.1	12	11	10	9	8
	U_{roof} ($m^2/W{\bullet}K$)	2.9	1.8	1.3	1	0.8	0.5
	Penetration Level (%)	100	20	35	50	65	80
New Buildings	RETV (W/m^2)	12.4	10	8.6	7.2	7.2	7.2
	U_{roof} ($m^2/W{\bullet}K$)	2.9	1.2	1	0.8	0.5	0.33
	Penetration Level (%)	100	30	45	60	85	100
Cooling Appliances	ISEER	3.13	4.5	5.88	7.25	8.62	10
	Penetration Level (%)	15	25	35	45	55	70

Source: iFOREST Analysis

6.6.1 Electricity Demand for Residential Cooling

Figure 6.7: Residential cooling electricity demand in different scenarios



Source: iFOREST Analysis

In the BAU scenario, cooling electricity demand is projected to surge to 2,130 GWh by 2050, increasing by 7.6 times over the current electricity consumption levels, with an annual growth rate of 8.5%. While modest gains in construction quality and cooling efficiency are anticipated, these are outweighed by the substantial rise in building stock—expected to grow by 200% over the next 25 years—and a dramatic increase in air conditioner ownership, from the current 15% to 70%. This sharp escalation highlights the urgent need for proactive energy efficiency and cooling demand management strategies.

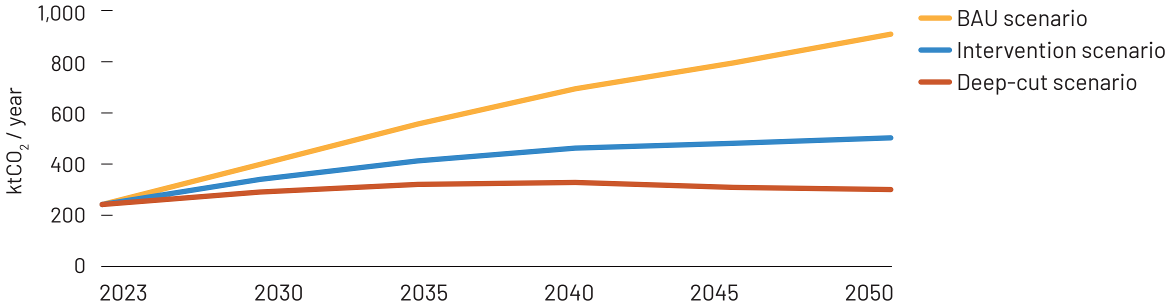
In the Intervention scenario, through the implementation of a comprehensive policy framework that supports sustainable building practices and encourages the uptake of energy-efficient cooling technologies, Bhubaneswar has the potential to significantly lower electricity consumption and CO_2 emissions from the residential cooling. Electricity demand in 2050 could be reduced by around 44% compared to the Business-as-Usual (BAU) scenario, but it will still be more than four-time the current levels.

With more ambitious actions in a Deep-cut scenario, such as implementing best-in-class regulations, regularly updating policies to reflect technological advancements, and ensuring rigorous enforcement, the residential cooling electricity demand can be reduced to one-third of the BAU scenario by 2050. While, this will still be close to three-times more than the current electricity consumption for residential cooling, it will significantly alleviate pressure not only on the power grid but also contribute to the city's climate resilience and sustainability goals.

6.6.2 CO_2 emissions from Residential Cooling

To estimate future CO_2 emissions from residential space cooling, the model applies state-specific emission factors to projected electricity demand figures. For 2025, a weighted average emission factor was calculated based on the Baseline Carbon Dioxide Emission Database (Version 20.0).[18] Recognising the ongoing transition in India's power sector, a 2.7% annual reduction in emission factor was assumed.[19] This national trend was applied to Odisha's 2025 baseline emission factor to reflect expected improvements from renewable energy (RE) integration and captive power generation.

Figure 6.8: CO_2 emissions from Residential cooling demand in different scenarios



Source: iFOREST Analysis

The results indicate that despite a significant increase in space cooling electricity demand, the decarbonisation of the electricity mix significantly alters the emissions trajectory. Under the BAU scenario, due to an increase in cooling demand, the CO_2 emissions increase by around 4 times by 2050. In the intervention scenario, the emissions can be reduced by 44%, and up to 67% in the deep cut scenario by 2050. In the deep-cut scenario, the CO_2 emissions in 2050 are only 12% higher than the current CO_2 emissions from residential cooling. Thus, by improving construction practices, adopting energy-efficient appliances, and decarbonising the grid, the CO_2 emissions can be significantly reduced.

6.6.3 Cost of transition

While improving envelope efficiency helps to reduce cooling demand and CO_2 emissions, it is equally important to consider the associated upgradation costs. To calculate the increased initial cost and the rate of returns from the reduced electricity consumption, a typical 2BHK house of 120 m^2 in Bhubaneshwar, with 1-2 air conditioners, was used for modelling. To calculate the savings from the reduced electricity consumption, the present tariff rate slabs for Bhubaneswar city were used.[20] The cost implications of improved construction practices and energy-efficient appliances were estimated based on the CPWD Schedule of Rates[21], supplemented by market data, literature review, and indexation[22]. It is important to note that these costs may be overestimated, as they are based on current prices for future construction, which are likely to decrease as technology advances and becomes more widely adopted.

Table 6.10: Cost for achieving envelope and appliance efficiency targets in different scenarios

Scenario	Cost of Construction (₹/m^2)	Cost of Cooling Technology Upgrade (₹/unit)
Business As Usual	13,765	35,000
Intervention	14,085	45,000
Deep Cut	14,181	65,000

Source: iFOREST Analysis

Table 6.11: Tariff rates for residential sector in Bhubaneswar

Consumption Slab	Tariff Rate (₹/kWh)
0–50 kWh	2.90
51–200 kWh	4.70
201–400 kWh	5.70
Above 400 kWh	6.10

Source: TPCODL

Table 6.12: Cost and benefits of building and appliance efficiency in Bhubaneswar

Scenario	Cost of Construction (₹)	Cost of Cooling Appliance (₹)	Total Compliance Differential (₹)	Annual Electricity Consumed (kWh/yr)	Annual Electricity Cost (₹)	Electricity Savings Differential (₹)	Payback Period (years)
Business As Usual	16,51,800	52,500		13,692	78,121		
Intervention	16,90,200	67,500	53,400	12,336	69,850	8,271	6.5
Deep Cut	17,01,720	97,500	94,920	11,856	66,922	11,199	8.5

Source: iFOREST Analysis

The results show that for a typical household, the payback period for recovering the additional cost of complying with building codes through energy savings is approximately 6.5 years in the intervention scenario and 8.5 years in the deep cut scenario. However, the payback period is likely to be lower as the cost of efficient cooling appliances and construction materials will reduce significantly in future. Considering that the average residential building in India is designed for a lifespan of 50 years, implementing these codes offers substantial long-term benefits through sustained electricity savings.

Overall, improving construction materials and techniques and enhancing appliance energy efficiency present some of the most cost-effective and scalable strategies for mitigating heat stress and reducing electricity demand in rapidly urbanising cities.

07

Strengthening Heat Adaptation Measures

SUMMARY

Expanding Heat Threshold Definitions for Early Warning

Bhubaneswar's current HAP uses only maximum dry bulb temperature for heat thresholds, triggering 76 alert days in 2024. Applying IMD's Heat Index threshold and nighttime Heat Index raises this to 232 days, extending heat stress to 8 months. The study recommends using all three, DBT, Heat Index, and Nighttime Heat Index, for more accurate warnings.

Improving Primary Healthcare Infrastructure

While Bhubaneswar has adequate heat-related healthcare infrastructure, its effectiveness can be improved by digitising the appointment and patient record system to enhance public service delivery.

Strengthening Heat-resilient Infrastructure

- Homeless shelter capacity in Bhubaneswar meets only 40% of demand, leaving most high-risk wards uncovered. To close this gap and strengthen heat resilience, the city should integrate shelters into its heat strategy by updating homelessness data to target priority areas and ensuring new shelters include cooling features such as drinking water, ventilation, passive cooling, and equipment like fans and coolers.
- Cooling shelters should be established by repurposing existing public infrastructure and deploying new mobile units in wards with high activity of vulnerable working groups such as construction workers, gig workers, etc.
- Many peripheral wards lack coverage, requiring equitable placement of water kiosks, while many existing kiosks are defunct and need improved O&M systems.
- Bus stops should be upgraded with shading, misting, and heat-resistant design elements.

Addressing Governance and Implementation Gaps

While departmental roles are assigned, they lack a clear operational roadmap. For instance, power utilities must ensure an uninterrupted supply during heat waves, yet have no contingency plans or infrastructure assessments. Key departments, such as electricity, water, sanitation, police, fire, and veterinary, should build capacity, assess vulnerabilities, and secure dedicated funds for heat-season readiness.

Integrating Sector-Specific Measures

Develop and implement targeted actions for key sectors, such as waste management strategies (including bans on open waste burning) and a summer-specific electricity use action plan.

This chapter addresses the critical need to strengthen heat adaptation measures in Bhubaneswar to build a more heat-resilient city. It builds on the previous Bhubaneswar Heat Action Plans (HAP), which were released in 2020 and 2025. It identifies key gaps in these existing HAPs and proposes actionable strategies based on the local requirements and successful interventions from other Indian cities. The focus of the heat adaptation measures is to build heat-resilient infrastructure, provide access to cooling, particularly for vulnerable populations, and strengthen implementation of the HAP.

7.1 Revising Heat Thresholds for Early Warning

Bhubaneswar's HAP relies on maximum dry bulb temperatures to define heat thresholds, following India Meteorological Department (IMD) guidelines. However, with increasing humidity and elevated night-time temperatures significantly worsening thermal discomfort and driving heat-related illnesses and fatalities, there is a growing need to reconsider this approach. Expanding heat threshold definitions to incorporate humidity and nighttime temperature would allow for a more accurate and responsive early warning system.

To evaluate the implications of incorporating humidity and night-time temperature on heat threshold, the study analysed 2024 weather data from the Patia and Lingaraj monitoring stations – the two monitoring stations of the Central Pollution Control Board (CPCB) installed in the city.

Definition 1: Heat thresholds based on maximum dry-bulb temperature

Using the IMD guideline, the National Disaster Management Authority (NDMA) has set the heat threshold for Bhubaneshwar based on dry bulb temperature (DBT) as 36.2 °C for a hot day (Yellow alert), 39.1 °C for a heat day (Orange alert) and 41.4 °C for an extreme heat day (Red alert). Based on this criterion, in 2024, the heat threshold in Bhubaneshwar was exceeded only between March and June, corresponding with the summer months. Extreme heat day alert was for 12 days, heat day alert for 19 days and hot day alert for 45 days. In total, Bhubaneshwar crossed the heat threshold on 76 days.

Table 7.1: Heat thresholds using maximum DBT

Temp Range (°C)		Alerts	Days crossing the threshold in each month												
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
36.2	39	Yellow	0	0	7	6	21	11	0	0	0	0	0	0	**45**
39.1	41.3	Orange	0	0	0	9	2	8	0	0	0	0	0	0	**19**
41.4		Red	0	0	0	11	1	0	0	0	0	0	0	0	**12**

Source: iFOREST Analysis

Definition 2: Heat threshold based on Heat Index

In 2023, IMD launched an experimental Heat index, which measures the combined impact of humidity and temperature and thus provides a measure of "feels like temperature". A Heat Index of 36 °C will lead to a Yellow alert, 46 °C to an Orange alert, and 55 °C to a Red alert.

The Heat Index for Bhubaneshwar was calculated for each day in 2024, and the threshold values were applied.

Table 7.2: Heat thresholds based on the Experimental Heat Index of IMD

Heat Index (°C)		Alerts	Days crossing the threshold in each month												
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
36	45	Yellow	0	4	23	17	14	10	27	30	25	26	1	0	**177**
45	55	Orange	0	0	0	10	17	20	3	1	3	1	0	0	**55**
> 55		Red	0	0	0	0	0	0	0	0	0	0	0	0	**0**

Source: iFOREST Analysis

When the Heat Index is used, in 2024, heat alert days extended from March to October. This reveals a significantly extended heat stress period in Bhubaneswar, well beyond the currently designated summer months. While there were no Red alert days, the number of Yellow and Orange alert days went up to 232, which is 8 months of heat alert days.

Definition 3: Heat Threshold based on night-time Heat Index

Heat Index was calculated for 7:00 pm to 6:00 am (nighttime) for each day in 2024. As IMD has not issued any guidelines on heat alert based on nighttime temperatures using heat index, the heat thresholds were defined under this study based on percentiles: the 90th percentile as Red alert, the 80th percentile as Orange alert, and the 60th percentile as Yellow alert. Based on these percentiles, a Heat Index of 36°C will lead to a Yellow alert, 39.8°C an Orange alert, and 41.5°C a Red alert in Bhubaneshwar.

Table 7.3: Heat thresholds based on night-time Heat Index

Heat Index (°C)		Alerts	Nights crossing the threshold in each month												
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
36	39.8	Yellow	0	0	4	7	3	8	17	12	15	10	0	0	**76**
39.8	41.5	Orange	0	0	0	5	9	8	6	5	1	3	0	0	**37**
> 41.5		Red	0	0	0	7	13	13	0	0	2	1	0	0	**36**

Source: iFOREST Analysis

When nighttime Heat Index is considered, several dates between March and October exceed the heat thresholds. Additionally, 15 unique days that were not declared as heat alert days using DBT were identified as exceeding the heat thresholds during the nighttime. These findings underscore the critical need to expand the definition of heat thresholds in Bhubaneswar beyond maximum DBT. It is evident that both high humidity and elevated night-time temperatures significantly extend the duration and intensity of heat stress, particularly during the hot-humid months of July to October. Relying solely on daytime temperatures underestimates the true extent of thermal discomfort and public health risks.

Bhubaneswar should adopt a comprehensive approach by using all three indices – maximum DBT, maximum Heat Index, and nighttime Heat Index- to establish more locally relevant heat thresholds. Incorporating both heat index and nighttime temperature data is crucial for strengthening early warning systems, enhancing preparedness and response strategies, and building greater climate resilience for the city's residents.

7.2 Heat-related Infrastructure

The Bhubaneswar HAP 2020, while a crucial step toward climate resilience, lacks a detailed ward-level action plan for effectively addressing the city's growing heat risks. Particularly when compared to a few of the latest HAPs developed by cities such as Delhi, Thane, Jodhpur, and Ahmedabad, Bhubaneswar's HAP has scope for improvements. One area where major improvements in required is in heat-related infrastructure.

Developing targeted infrastructure in high-risk wards is crucial to reducing the impacts of extreme heat, especially for low-income communities, informal workers, and other at-risk groups. These infrastructures serve as a core component of urban resilience, addressing the immediate health, safety, and comfort needs during periods of intense heat and humidity. By prioritising localised solutions, the city can move toward a more inclusive and heat-resilient future.

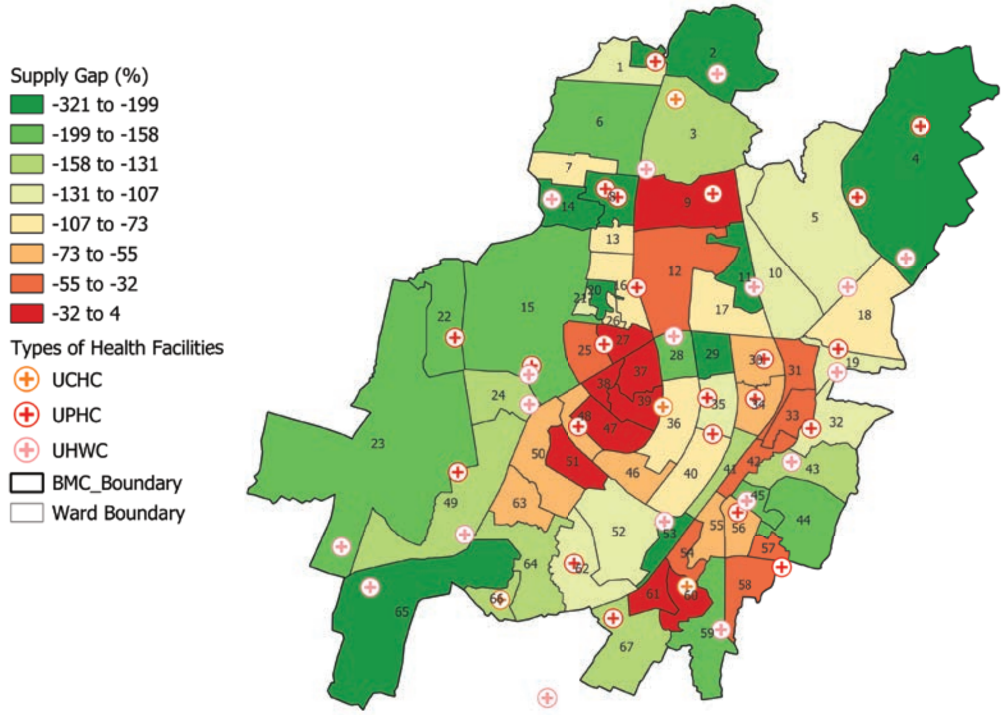
7.2.1 Healthcare Centres

Primary Health Centres (PHCs) play a critical frontline role in protecting communities during heat waves. As the first point of contact for medical care—particularly for low-income and vulnerable populations—PHCs are essential for the early diagnosis, treatment, and management of heat-related illnesses..

As per the Ministry of Health and Family Welfare guidelines[23], each Urban Health and Welfare Centres should cater to 20,000 people, each Urban Primary Health Centre (UPHC) should serve around 50,000 people, and each Urban Community Health Centre (UCHC) should cover approximately 2,50,000.

Based on these norms, and as per the list of PHCs included in the 2025 Bhubaneswar Heat Action Plan (HAP), the city has adequate primary healthcare infrastructure in place.

Figure 7.1: Ward-wise supply gap in health care centres in Bhubaneswar



Source: iFOREST Analysis

Further in line with the National Action Plan on Heat Related Illnesses (NAPHRI) issued by the Ministry of Health and Family Welfare in 2021, Bhubaneswar has also deployed mobile vans and ambulances, and equipped dispensaries and hospitals with ice packs for first aid. These measures have strengthened the city's capacity to provide immediate medical response during extreme heat events.

However, iFOREST's field survey highlighted persistent challenges in service delivery. Long queues outside PHCs continue to expose patients to extreme weather conditions, often worsening their health vulnerabilities. To make primary healthcare delivery more effective, and to reduce the burden on public health infrastructure, it is essential for the Government of Odisha and the Bhubaneswar Municipal Corporation to digitise the appointment and patient record system across the city's healthcare facilities.

Digitise appointment system: By enabling patients to book time slots in advance, waiting times can be significantly reduced, thereby minimising direct exposure to heat or rain. At the same time, PHCs should retain an in-person appointment window to ensure that citizens without access to digital tools are not excluded.

Digital patient records and real-time reporting: Further, creating a centralised digital health database would support timely reporting of cases, improve data accuracy, and address the issue of underreporting, which currently hampers policy and resource planning. Over time, this dataset could also enable predictive modelling of health risks, allowing for proactive interventions during extreme heat events.

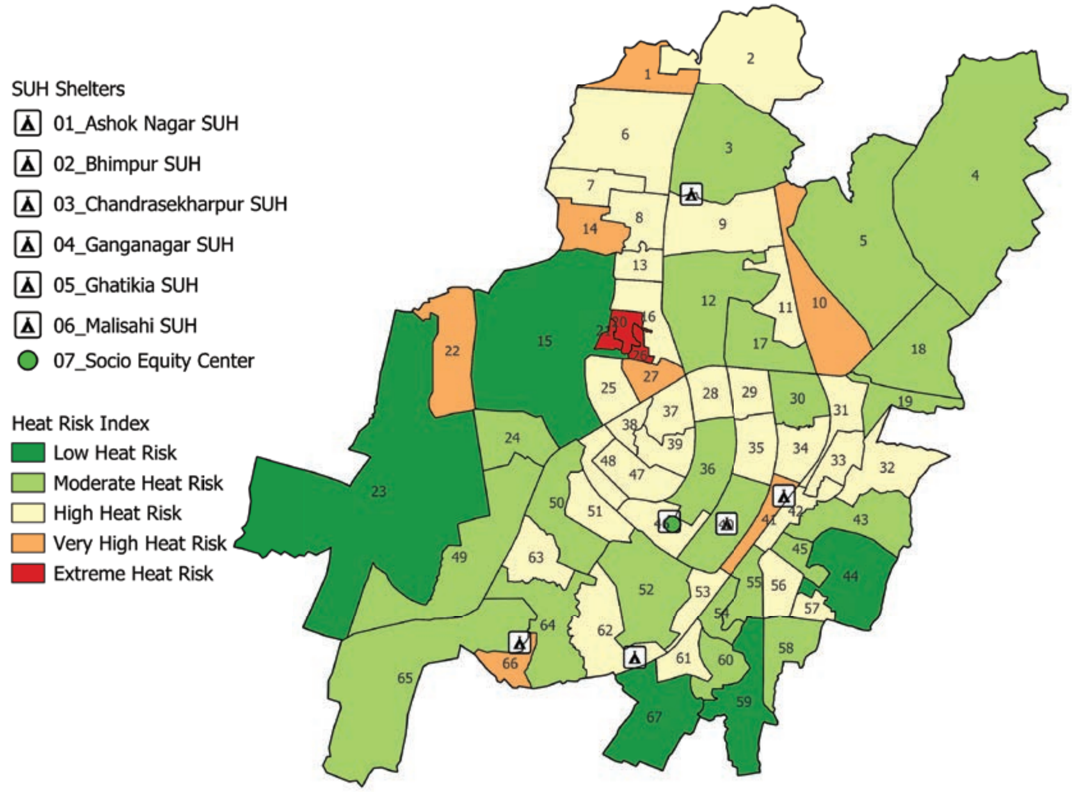
By adopting these measures, Bhubaneswar can make its healthcare system more resilient, responsive, and inclusive in addressing the growing health impacts of climate change.

7.2.2 Homeless Shelters

Homeless care centres play a vital role in safeguarding the health and well-being of unhoused populations during extreme heat events. Constant exposure to harsh outdoor conditions, limited access to shelter, and greater health vulnerabilities place this group at elevated risk.

According to the Deendayal Antyodaya Yojana – National Urban Livelihoods Mission (DAY-NULM) guidelines, cities are required to provide permanent shelters for at least 100 individuals per 1,00,000 urban residents. Based on Bhubaneswar's projected 2025 population of 11.56 lakh, the city should have shelter capacity for at least 1,155 individuals. Currently, only seven such facilities exist, with a capacity of accommodating only 468 people. This indicates a shortfall of about 60% in homeless shelters.

Figure 7.2: Heat risk map along with the existing homeless shelters



Source: iFOREST Analysis

In addition, overlaying the HRI map with the existing shelter infrastructure in the city reveals the lack of strategic placement of shelters. Of all the high heat risk wards, only wards 41 and 66 have homeless shelters.

To address this infrastructure gap and to strengthen its response to extreme heat, Bhubaneswar should integrate homeless shelters into its broader heat resilience strategy. This can include:

- Conduct a comprehensive homelessness survey to update existing data and identify high-priority areas for establishing new shelters, particularly in wards with high heat risk.
- Incorporate cooling functions such as access to drinking water, proper ventilation, passive cooling techniques, and cooling equipment like fans and coolers in future shelters.

7.2.3 Cooling Shelters

Cooling shelters are vital infrastructure during heatwaves, offering immediate respite from extreme temperatures, especially for vulnerable groups like the slum dwellers, outdoor workers, and the unhoused. These shelters provide a safe, shaded, and air-cooled space where people can rest, rehydrate, and recover from heat exposure. In dense urban environments, where limited greenery and heat-retaining surfaces worsen thermal stress, accessible cooling shelters play a crucial role in preventing heat-related illnesses and deaths. Integrating cooling shelters into the city's HAP can strengthen public health preparedness and enhance resilience to rising temperatures.

Figure 7.3: Cooling shelters developed in various Indian cities

Image Source: Mahila Housing Trust and Chennai Municipal Corporation

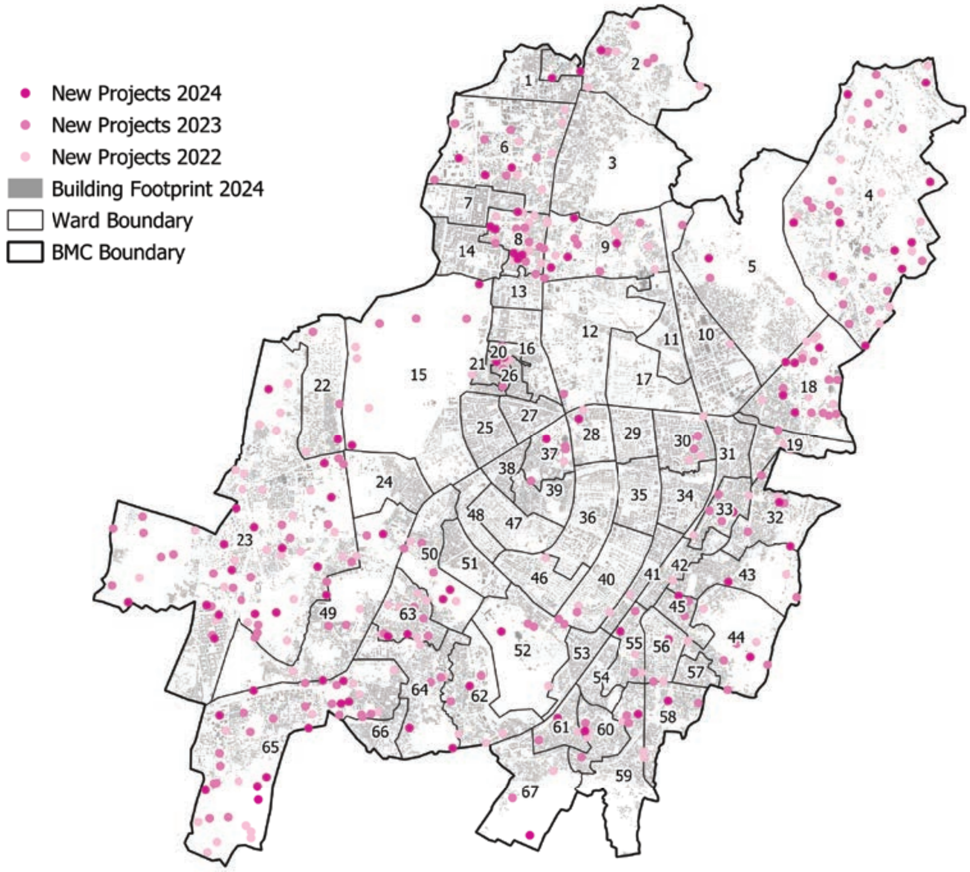
a. Repurpose existing infrastructure to develop flexible cooling shelters

The best approach towards developing cooling shelters in Bhubaneswar is to repurpose existing public infrastructure, such as homeless shelters, community halls, anganwadi centres, and government school buildings, as dual-purpose cooling centres during peak heat periods. These facilities are often distributed across the city and already have basic amenities like electricity, water supply, and seating, making them cost-effective and quickly deployable options. By equipping these spaces with fans, air coolers, drinking water stations, and first-aid kits, they can provide safe and accessible refuge for heat-vulnerable populations, particularly during heat and humidity peaks. This strategy not only reduces the need for new construction but also optimises the use of underutilised public assets, ensuring rapid scalability and better integration with the city's existing emergency response systems.

b. Mobile Cooling Shelters for vulnerable working population

To protect highly exposed groups such as construction and gig workers during extreme heat events, there is a need to develop mobile cooling shelters that can be deployed in high-activity zones. Instead of relying solely on fixed infrastructure, mobile cooling units offer a flexible and targeted solution that can be stationed at or near active construction sites and other high-traffic zones where gig workers operate.

Figure 7.4: Construction sites from 2022 to 2024 in Bhubaneswar



Source: iFOREST Analysis

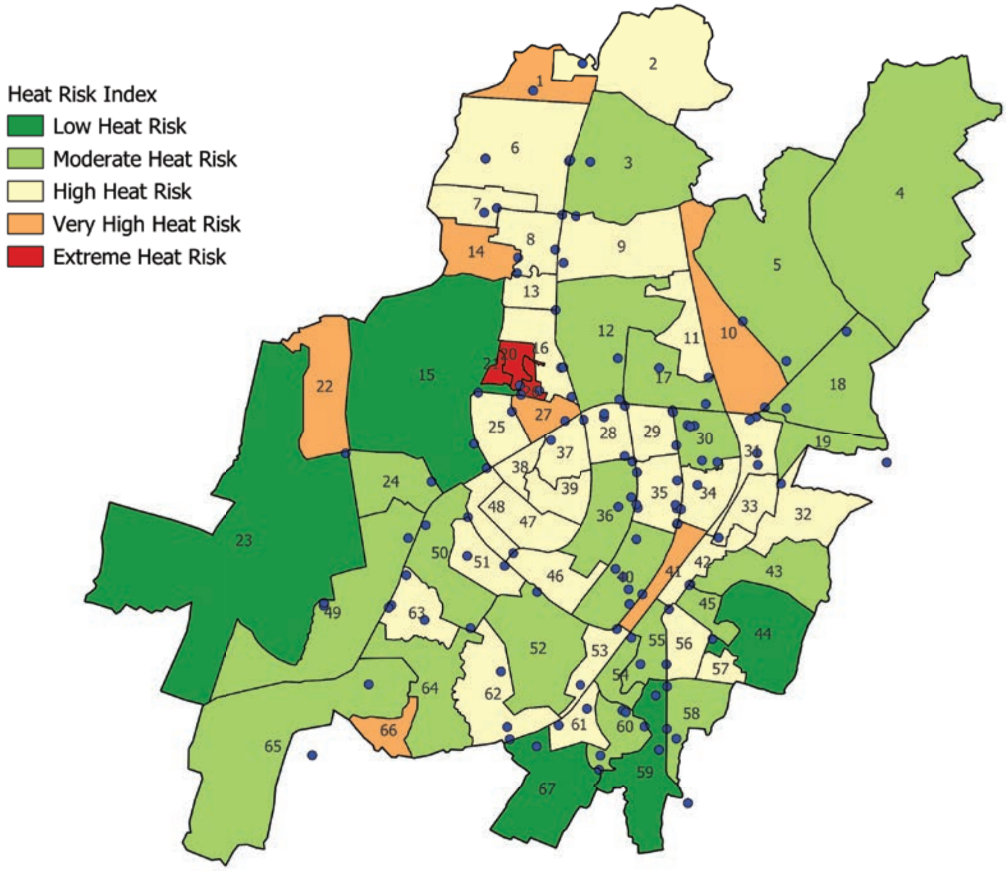
Mapping of new construction sites from 2022 to 2024 reveals that Wards 23, 65, and 4 have the highest concentration of construction activity, pointing to areas with a high density of vulnerable outdoor workers.

City government, in collaboration with NGOs, can play a key role in the deployment and maintenance of these shelters. Large construction projects can be mandated to provide such cooling shelters during peak heat stress days. These mobile cooling shelters should be equipped with air coolers, drinking water, basic first-aid, and rest areas to offer immediate relief. Integrating such mobile infrastructure into Bhubaneswar's heat response will ensure greater accessibility and responsiveness for vulnerable populations, especially in rapidly developing and expanding areas.

7.2.4 Water Kiosks

Water kiosks are an essential public health measure during heat waves, providing continuous access to safe drinking water in public areas. As extreme heat heightens the risk of dehydration and heat-related illnesses—particularly for outdoor workers, street vendors, the elderly, and the homeless—these kiosks offer a simple, cost-effective solution to reduce heat stress. Placing them strategically in high-risk, high-footfall locations such as markets, transit hubs, construction sites, and informal settlements can greatly improve the city's heat resilience. However, while central Bhubaneswar has a reasonable concentration of kiosks and has also started developing Solar water ATMs, many peripheral wards remain underserved, highlighting the need for more equitable and consistent distribution.

Figure 7.5: Heat risk map along with the existing water kiosks



Source: iFOREST Analysis

The existing model for water kiosks operates through a collaboration between the city government and NGOs, where BMC provides the infrastructure and NGOs are responsible for regular refilling and maintenance. This model has seen mixed results, successful in some locations, while several kiosks remain non-functional due to a lack of water supply and poor upkeep, leaving them unused. To enhance this, Bhubaneswar can take below steps:

- Strengthen the current collaboration model between the city government and NGOs, ensuring clear roles and responsibilities for infrastructure provision, refilling, and maintenance.
- Address inconsistencies by exploring alternative operational and maintenance frameworks to guarantee reliable and continuous service across all kiosks.
- Prioritize regular monitoring and prompt repair of non-functional kiosks to prevent abandonment and ensure consistent water availability.
- Focus on equitable distribution by expanding water kiosks in heat-vulnerable wards and underserved peripheral areas.
- Make the availability of safe drinking water a central element of the city's heat adaptation and resilience plans.

Figure 7.6: Water kiosks set up across Bhubaneswar

Image Source: Sambad English

7.2.5 Cool Bus Stops

Improving transport infrastructure is essential for strengthening a city's heat resilience. One impactful measure is the installation of cool bus stops, which benefit thousands of daily commuters—particularly informal workers, older adults, and students—who are frequently exposed to high temperatures while waiting in open, unshaded areas during the hottest parts of the day.

Figure 7. 7: Cool bus stop at Ahmedabad

Image Source: Mahila Housing Trust

Based on best practices and steps being taken in other cities, Bhubaneswar can do the following:

- Upgrade bus stops with passive and active cooling features, such as high-pressure misting systems and khus curtains (vetiver grass), to lower ambient temperatures and improve commuter comfort.
- Incorporate climate-responsive design elements, including:
  - » Reflective or heat-resistant materials
  - » Shaded and insulated roofing
  - » Natural ventilation
  - » Nearby trees or green buffers
- Identify and prioritise high-use bus stops in vulnerable areas for intervention, particularly where informal workers, students, and the elderly are most affected.
- Integrate transit infrastructure upgrades into the city's broader heat action plan as a key component of an inclusive, long-term heat risk measure.

7.3 Capacity and Finance

Building a heat-resilient city necessitates strengthening municipal governance. Different departments will need to be assigned clear responsibilities, along with capacity-building measures and financial provisions. While the current HAP (Heat Action Plan) of Bhubaneswar outlines the responsibilities of key departments, it does not provide a detailed roadmap for how these responsibilities will be executed.

For example, while power utilities have been tasked with supplying uninterrupted electricity during the peak heat season—particularly to healthcare establishments—no concrete plan has been developed to ensure this. To maintain uninterrupted power supply, DISCOM must assess the impact of heat on power infrastructure, identify failure points, strengthen critical infrastructure, and develop a plan to ensure quality power during the heat season. This will require both capacity enhancement and financial resources. Similarly, departments responsible for water supply, sanitation, firefighting, police, and labour will also require capacity building and adequate financial support to prepare and implement plans for the peak heat season.

Bhubaneswar must develop a comprehensive capacity-building program and earmark financial resources to strengthen the capabilities of departments such as electricity, water and sanitation, police, fire services, and veterinary care. It is essential to institutionalise mechanisms that support sustained adaptation efforts and enable the implementation of long-term measures.

Bhubaneswar should also adopt best practices followed by other cities, such as:

- **Waste Management Measures:** Integration of waste management and emissions control into city HAPs is increasingly becoming a focus area. Given that solid waste burning and fossil fuel use worsen localized heat and air pollution, such measures are essential. For example, Ahmedabad's HAP includes a ban on open waste burning and introduces targeted air quality improvement measures during peak summer.
- **Energy-Related Measures:** Several cities and districts across India have incorporated energy-related measures in their HAPs to address rising electricity demand in the summer, driven by increased AC usage and prolonged heat stress. For instance, Delhi has diversified its power supply sources and deployed AI-based demand forecasting tools to ensure grid stability during peak periods.

08

Integrated Action Plan

8.1 Action Plan for Bhuwaneshwar

Strategy	Description	Implementing Agency	Implementation Timeline
Cool the City			
Urban Greening	• Enhanced green cover across wards	BMC	3-5 years
Water Body Restoration	• Develop a water body conservation and restoration policy • Targeted water body restoration across the city	BMC	1 year 3-5 years
Cool Roof	• Cool Roof Programme	BMC	1-5 years
Street Design and Traffic Management	• Revise Street Design Guidelines for Bhubaneswar to integrate heat mitigation strategies • Priority Roads for better traffic management and design • Planning for Sustainable Mobility	BDA BMC BMC + HUDD	1 Year 1 Year 3-5 years
Sustainable Cooling for All			
Promote energy-efficient cooling systems	• Incentivise the shift from 3-star to 5-star cooling appliances • Pilot and incentivise emerging sustainable cooling technologies • Identify sites and develop district cooling in the city	BMC + Energy Dept + HUDD (District Cooling)	Continuous 1-3 years 3-5 years
Enhance Heat Resilience			
Health Infrastructure	• Adopt digitalisation for appointments and patient records	BMC	1-3 years
Homeless Shelters	• Conduct a homelessness survey to identify high-priority areas • Develop new homeless shelters	BMC	1 year 1-3 years
Cooling Centers	• Repurpose existing government infrastructure as public cooling shelters during designated hours (Mention according to new guidelines) • Establish new public cooling shelters	BMC	1-3 years 1-5 years
Water Kiosks	• Improve O&M system	BMC	1 year
Cool Bus Stops	• Upgrade the current bus infrastructure to cool bus stops	BMC	1-2 years
Heat Adaptation Measures			
Revise Heat Thresholds	• Add Heat Index and night-time indices to the current heat threshold	BMC + IMD	1 year
Parametric Insurance	• Introduce parametric insurance for vulnerable groups based on relevant thresholds for protection against extreme heat	BMC + Labour	1-3 year
Strengthening Different Sectors	• Incorporate Waste Management Measures	BMC	1 year
Finance and Capacity Development	• Develop a comprehensive capacity-building program • Earmark financial resources to strengthen the capabilities of departments	BMC + relevant state	Long-term
Policy Recommendation			
IHCAP Framework	• Adopt IHCAP Framework • Focus on capacity building and improving data collection processes to institutionalise these new processes • Revise every 5 years	BMC	1 year

8.1.1. Cool the City

a. Urban Greening

1 Enhance green cover across wards

The city government should enhance green spaces in wards 26, 21, 38, 57, 20, 41, and 61 that currently have significantly lower green cover compared to other areas of the city. This uneven distribution contributes to localised UHI effects. The selection of sites for future projects should strategically focus on under-served wards which would also help meet the target set by World Health Organisation of 9 m^2 of open space per inhabitant.

Table 8.1: Wards with least per capita urban green spaces

S No	Ward No.	Urban Green Spaces per capita (m^2/person)	Additional Tree Cover Required (m^2)	Additional Tree Cover Required (km^2)
1	26	2.0	1,49,586	0.15
2	21	3.6	1,39,173	0.14
3	38	4.7	1,46,500	0.15
4	57	5.3	1,39,234	0.14
5	20	5.4	1,43,562	0.14
6	41	6.8	1,66,282	0.17
7	61	6.9	1,66,245	0.17
8	27	8.3	1,48,013	0.15

Source: iFOREST Analysis based on NDVI

b. Water Body Restoration

1 Develop a water body conservation and restoration policy

The city of Bhubaneswar has seen a sharp decline in area under water bodies which highlights the urgent need to protect and restore the city's remaining water assets. While BMC has initiated rejuvenation efforts under various state and national schemes, these tend to be project specific.

To strengthen and sustain these efforts, BMC should adopt a dedicated Water Body Conservation Policy. Such a policy would provide a long-term, institutional framework for identifying, mapping, protecting, and restoring all natural and man-made water bodies in the city, including ponds, lakes, wetlands, and seasonal streams.

Key elements of the policy should include:

- Legal protection for identified water bodies and their buffer zones to prevent encroachment.
- Integrated planning to link water body restoration with storm water management, groundwater recharge, and climate resilience goals.
- Community stewardship models to involve local residents, RWAs, and institutions in the upkeep and monitoring of water bodies.
- Incentives and funding mechanisms to encourage private and institutional participation in restoration projects.
- Data and monitoring systems for real-time tracking of water body health and area.

Such a policy would help BMC transition from reactive, project-based interventions to a strategic, citywide approach, ensuring that urban development coexists with ecological restoration and climate resilience.

2 Targeted water body restoration

BMC should prioritise the restoration and rejuvenation of water bodies across the city. Research indicates that 32 wards have experienced a decline of over 50% in surface water levels between 2018 and 2024, with

Wards 45, 51, 44, 32, and 10 being the most affected. To address this critical issue, the city government must proactively align restoration efforts with existing state and national policies, ensuring a coordinated and sustained approach to urban water resilience.

c. Cool Roof

1 Cool Roof Program

While compliance with cool roofs is a provision under energy-efficiency building codes, it excludes informal settlements and low-income housing. These are highly vulnerable to extreme heat and are unlikely to invest in coof roofs on their own. As a result, these populations risk being left out of the direct benefits of passive cooling interventions.

To bridge this gap and ensure inclusivity, Bhubaneswar should implement a dedicated cool roof programme which would facilitate large-scale roof upgrades across all housing typologies, with a priority focus on vulnerable communities, older housing stock, and heat-prone zones.

The programme should include:

- Targeted financial subsidies and incentives to promote adoption among households with limited resources.
- Awareness campaigns and technical assistance to build capacity and ensure proper implementation.

In informal settlements, a community-led implementation model can be adopted to maximise local participation and reduce costs. This model can include:

- Free, first-time application of solar-reflective paint for eligible households.
- Microfinance support for maintenance and future expansion of cool roof coverage.
- Training and mobilisation of local residents for application and upkeep, lowering labour costs while creating community ownership.

Based on research estimates, applying solar-reflective white paint across all slum roofs in the city would cost the municipal government approximately ₹33 crore.

Table 8.2: Cost of applying solar reflecting white paint across all slum roofs

Total Slum Roof Area (ft^2)	Rate of solar reflecting paint (₹/ft^2)	Quantity of paint required (litres) [0.08 ltrs/ft^2]	Total Cost of SR Paint (₹)
1,33,35,014	25	10,66,801	33,33,75,340 (33.3 crores)

Source: iFOREST Analysis

d. Street Design and Traffic Management

1 Revision of the Street Design Guidelines

Bhubaneswar's current Street Design Guidelines, developed by the BDA, majorly focus on the effective use of the right-of-way (ROW), which marks a significant step towards creating more walkable and efficient public streets. However, there is an urgent need to revise these guidelines to incorporate climate-responsive street design principles.

Key additions could include:

- Green medians and verge plantations to reduce surface temperatures, improve shading, and enhance the urban microclimate.
- Use of semi-permeable pavers for sidewalks and parking bays to support natural percolation and reduce surface heat accumulation.
- High-albedo and reflective materials for footpaths and pavements to lower ambient surface temperatures and reduce heat retention.
- Shaded walkways through tree canopies or pergola structures, especially in high-pedestrian areas such as near transit hubs, schools, and markets.

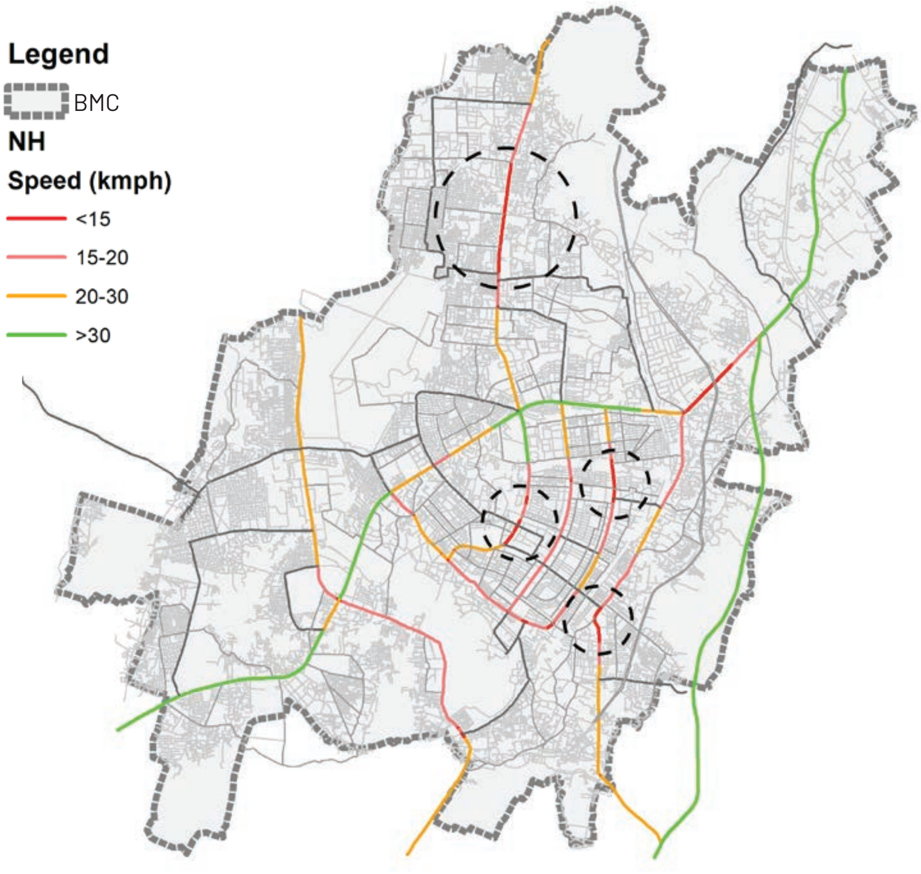
Incorporating these features will enable Bhubaneswar to align its urban mobility infrastructure with broader goals of heat resilience, environmental sustainability, and citizen well-being, especially as street corridors represent some of the most publicly accessible and modifiable urban spaces.

2 Priority Roads for Better Traffic Management and Design

Given the significant contribution of traffic congestion and vehicular emissions to urban heat stress, it is essential for the city government to improve traffic management. To address this, the city should undertake a detailed road congestion audit and identify priority roads for decongestion. Some of the areas where immediate decongestion is required are:

- Nandankanan Road towards the north of the city
- Intersection of Bidyut Marg and Raj Path
- Janpath Road stretch between Maharishi College and Ramadevi Women's University
- Cuttack Road junction near Odisha State Museum

Figure 8.1: Most congested roads in Bhubaneswar city



Source: iFOREST Analysis

These measures will help reduce congestion and localised heat build-up caused by idling vehicles, thereby lowering ambient temperatures and mitigating heat stress. They will also deliver co-benefits such as reduced greenhouse gas emissions, improved air quality, and shorter commute times—enhancing both environmental quality and productivity.

8.1.2 Sustainable and Energy-Efficient Buildings and Cooling Technologies

a. Promote energy-efficient cooling systems

Increasing cooling demand is a reality that cities will need to brace and prepare for. Meeting rising cooling-related electricity demand sustainably calls for rapid green energy integration and promotion of energy-efficient technologies. Bhuwaneshwar, therefore, should:

- **Incentivise energy efficient cooling appliances:** BMC along with the energy department and DISCOM should introduce targeted incentives to encourage residents to adopt the highest star rated cooling appliances.
- **Pilot and incentivise emerging sustainable cooling technologies:** The city government should support the adoption of emerging not-in-kind cooling technologies by piloting them in government buildings and offering incentives to encourage uptake in the private sector.
- **Promote District Cooling:** The city government should identify zones with high potential for district cooling systems. An analysis of new construction between 2022 and 2024 shows that Wards 23, 65, and 4 have the highest concentration of development activity, making them potential sites for such infrastructure. Additionally, district cooling solutions can be explored for the several upcoming planned IT zones in the city.

To support these efforts, the city government should commission research and feasibility studies to map out potential sites for district cooling systems and pilot projects for emerging cooling technologies.

8.1.3 Enhance Heat Resilience

a. Health Infrastructure

To strengthen primary healthcare delivery and ease the burden on public health infrastructure, the Government of Odisha and BMC should:

- Enable advance booking to reduce waiting times and exposure to extreme weather, while retaining in-person options for inclusivity.
- Establish a centralised database for real-time case reporting, improved data accuracy, and predictive modelling to guide proactive health interventions..

b. Homeless Shelters

Homeless shelters are critical for protecting unhoused populations during extreme heat, given their constant exposure and health vulnerabilities. As per DAY-NULM guidelines, Bhubaneswar should have shelter capacity for at least 1,155 individuals based on its projected 2025 population but currently accommodates only 468—highlighting a 60% shortfall.

To close this gap and enhance heat resilience, the city should:

- Conduct a detailed homelessness survey to identify high-risk areas for new shelters.
- Develop new homeless shelters and ensure future shelters are equipped with cooling features such as drinking water, ventilation, passive cooling, and fans or coolers.

c. Cooling Centers

Cooling centers are essential during heatwaves, providing immediate relief to vulnerable groups such as slum dwellers, outdoor workers, and the unhoused. In line with the National Disaster Management Authority's recently released guidelines, which set minimum standards for infrastructure, accessibility, and service delivery, Bhubaneswar should establish cooling centers that comply with these standards to enhance heat resilience and protect public health.

- The most effective strategy is to repurpose existing public infrastructure—such as homeless shelters, community halls, anganwadi centres, and government schools—as dual-purpose cooling shelters during peak heat periods.

- In addition, mobile cooling shelters should be introduced to support high-risk outdoor workers, including construction and gig workers. Mapping from 2022–2024 shows Wards 23, 65, and 4 as construction hotspots, ideal for deploying such shelters. These mobile units—equipped with coolers, water, seating, and first-aid—can be stationed at high-activity zones and should be mandated for large-scale construction sites during heat alerts. Collaboration between the city government, NGOs, and private developers will be crucial for deployment and maintenance.

d. Water Kiosks

Water kiosks are a crucial public health measure during heatwaves, offering safe drinking water to vulnerable groups like outdoor workers, street vendors, the elderly, and the homeless. While central Bhubaneswar has a fair number of kiosks and has begun installing solar water ATMs, many peripheral wards remain underserved, highlighting the need for more equitable distribution.

The current city-NGO collaboration model—where BMC provides infrastructure and NGOs handle refilling and maintenance—has seen mixed success. To improve this system, Bhubaneswar should:

- Strengthen coordination with clear roles and accountability.
- Explore alternative operation models to ensure reliable service.
- Monitor and repair non-functional kiosks promptly.
- Prioritise kiosk expansion in heat-prone, underserved areas.

e. Cool Bus Stops

Improving transport infrastructure is key to building Bhubaneswar's heat resilience. Installing cool bus stops can protect thousands of daily commuters—especially informal workers, students, and the elderly—from extreme heat. The city can upgrade high-use bus stops in vulnerable areas with passive and active cooling features like misting systems, khus curtains, shaded roofing, reflective materials, natural ventilation, and nearby green buffers. These climate-responsive upgrades should be integrated into the city's broader Heat Action Plan as a vital, inclusive measure.

8.1.4 Heat Adaptation Measures

a. Revise Heat Thresholds

Bhubaneswar should adopt a comprehensive approach by using all three indices – maximum DBT, maximum Heat Index, and night-time Heat Index, to establish more locally relevant heat thresholds. Incorporating both heat index and night-time temperature data is crucial for strengthening early warning systems, enhancing preparedness and response strategies, and building greater climate resilience for the city's residents.

Table 8.3: Additional heat thresholds suggested for Bhubaneswar

Heat Index Parameter	Heat Threshold Value		
	Yellow	Orange	Red
Daytime using Heat Index	36-45	45-55	≥55
Nighttime using Heat Index	36-39.8	41.5	≥41.5

Source: iFOREST Analysis

b. Parametric Insurance

Bhubaneswar faces significant challenges in protecting the livelihoods and health of its vulnerable populations. The city's informal workers, daily wage earners, and small-scale traders are particularly exposed to heat stress, which often leads to reduced productivity, health emergencies, and consequent income losses.

To address this, a proactive risk management approach through parametric insurance offers a critical opportunity. Parametric insurance relies on pre-agreed thresholds to trigger rapid, automatic payouts when extreme events occur. This mechanism bypasses lengthy claims assessments, ensuring timely financial support to those impacted. For Bhubaneswar, this could translate into swift compensation for livelihood disruptions caused by heat waves, thereby stabilising incomes and reducing vulnerability.

Drawing on insights from various models incorporated around India, the design of a parametric insurance scheme can incorporate the following elements:

Table 8.4: Different elements for a parametric insurance

Element	Details
Target Population	Vulnerable workers groups, such as construction, vendors, delivery workers, labourers, and so on
Funding Model	Hybrid: subsidised premiums (by state/NGOs/CSR), with beneficiary contribution
Insurance Design and Trigger Metrics	Use locally calibrated temperature percentiles incorporating humidity, and night-time temperatures. Scaled payout system for different threshold levels – yellow, orange, and red.
Delivery Mechanism	Direct bank/mobile transfers; couple with financial inclusion drives
Institutional Framework	Pass through Odisha Disaster Funds, coordinate between OSDMA, Health Dept., Labour Dept., NGOs
Pilot Program	Launch in high-heat wards (e.g., 1–9, 20s, 26, 38) with 5,000–10,000 beneficiaries

Source: iFOREST Analysis

By ensuring that vulnerable workers receive rapid compensation for heat-induced livelihood losses, the city can safeguard economic stability, promote climate justice, and foster a more resilient urban community in the face of growing climate challenges.

c. Strengthening Different Sectors

1 Health Sector Improvements

To improve the management of heat-related illnesses and reduce the burden on public health infrastructure, the Government of Odisha should digitise the appointment and patient record system for managing cases across the state's healthcare system.

- Currently, long queues outside the PHCs force people to wait in extreme weather conditions, such as heat or rain, often exacerbating their health conditions. A digitised appointment system would allow patients to book time slots in advance, significantly reducing waiting times and exposure to extreme weather. Recognising that not all citizens have access to digital tools, PHCs should retain an in-person appointment window to ensure inclusivity and accessibility for all.
- Furthermore, digitising patient records and allowing online case reporting can help build a real-time health inventory, improving data collection and addressing the issue of underreporting that currently limits policy and resource planning. Over time, this digital health dataset can inform predictive models for health emergencies and better guide interventions.

2. Finance and Capacity Development

Building a heat-resilient Bhubaneswar requires stronger municipal governance with clear departmental roles, capacity-building, and financial support. While the current HAP outlines responsibilities, it lacks an execution roadmap. The city must develop a comprehensive capacity-building program and allocate funds for key departments like electricity, water, sanitation, police, fire services, and veterinary care. Institutional mechanisms are needed to ensure sustained, long-term adaptation.

8.1.5 Policy Recommendation

a. IHCAP Framework

While Bhubaneswar's current HAP marks a step in addressing the growing threat of urban heat, it primarily focuses on relief and adaptation. As climate risks intensifies, the city must adopt a more anticipatory, integrated approach that addresses both heat mitigation and sustainable cooling.

The findings of this report underscore the urgent need to break the vicious cycle where conventional cooling solutions contribute to increased urban heat, elevated energy demand, reduced work productivity, and health-related wage losses. To enhance resilience and enable sustainable urban development, Bhubaneswar should expand its current HAP into an IHCAP that aligns heat management with long-term cooling strategies.

In addition to adopting the IHCAP framework, the following actions are recommended to make it more effective:

- **Institutionalise Climate Modelling and Simulation**
  - » Embed modelling and simulation into the action planning and revision processes. Use digital tools to forecast heat, energy demand, and climate impacts to design and test effective interventions before implementation.
  - » Develop a continuous monitoring and evaluation process. Track key climate and energy indicators to assess the effectiveness of interventions, update models with new data, and iteratively refine policies based on evolving risks.
- **Develop Local Capacity and Collaborations**

  Build in-house technical capacity and forge partnerships with academic and research institutions to develop and maintain context-specific models and ensure informed decision-making.
- **Enhance Data Collection and Model Validation**

  Invest in local weather infrastructure—such as weather stations and energy sensors—to gather real-time data for accurate model calibration and to improve the reliability of planning tools.

8.2 State Policy to support IHCAP

Strategy	Description	Implementing Agency	Implementation Timeline
Urban Cooling Policy	• A dedicated policy focusing on nature-based solutions, cool roofs, and cooling centers	HUDD	• Short
EE Building Codes	• Revise Existing OECBC 2022 • Adopt Residential Building Codes • Strengthen implementation of building codes	Energy BMC + Energy Dept	• Short • Short • Short to Medium
Electricity Policy	• Develop a specific heat season electricity policy	BMC/Energy	• Short with regular revisions

8.2.1 Urban Cooling Policy

Urban greening and water conservation efforts in Odisha are currently project-based and driven by specific schemes such as AMRUT and state-level initiatives, with no initiatives yet focused on cool roofs. While these efforts have made important contributions, the absence of an overarching Urban Cooling Policy limits the city's ability to scale, coordinate, and sustain green infrastructure in a systematic and long-term manner.

A dedicated Urban Cooling Policy, that promotes green and blue infrastructure and cool roof programme, would provide a long-term, strategic framework that moves beyond ad-hoc initiatives and embeds cooling solutions into the city's core planning and development processes.

Key benefits of such a policy would include:

- Institutionalisation of Long-Term Greening Goals
- Integrated Planning and Coordination across Departments
- Clear Mandates for Implementation and Maintenance
- Sustainable Budgeting and Maintenance Mechanisms – Leveraging Partnerships and Funding
- Data-driven Monitoring, Evaluation, and Accountability Framework

8.2.2 Energy Efficiency Building Codes

a. Revise Existing OECBC 2022 Codes

The Odisha government should revise the existing OECBC 2022 to align with the updated Energy Conservation and Sustainable Building Code (ECSBC) 2024 for commercial and office buildings. To ensure enforceability and integration into urban planning processes, these codes must be formally notified under the Odisha Development Authorities (Planning and Building Standards) Rules. However, to maximise the benefits of these codes, they must be tailored to local climatic conditions, material availability, and construction practices.

- **Lower the code compliance threshold**

  As per OECBC 2022, every building which is used or intended to be used for commercial purposes, having a connected load of 100 kilowatt (kW) or above or a contract demand of 120 kilo-volt-ampere (kVA) or above or total built-up area of 1000 m^2, falls under the purview of the codes.

  Analysis of building permit applications for the city reveals that only 25% of new buildings in Bhubaneswar meet the current built-up area threshold of 1,000 m^2. In contrast, under the earlier OECBC 2011 guidelines, which applied to buildings over 500 m^2, around 70% of the city's construction activity would have been subject to code compliance. Thus, the current threshold excludes a large portion of urban development from energy efficiency mandates.

To address this gap and strengthen the city's energy regulation framework, it is recommended that Bhubaneswar revise the code applicability threshold back to 500m². This adjustment would considerably broaden the code's reach, enabling better enforcement of energy efficiency standards across a larger share of the building stock.

- **Raise the minimum standard for Unitary, Split, Packaged Air-Conditioners Compliance target for the Code**

  The ESCBC 2024 prescribes that unitary, split, or packaged air conditioning systems must have a minimum rating of 3-star. However, survey data indicates that 60% of consumers in the commercial and institutional sectors in Bhubaneswar already utilise 3-star split ACs. Therefore, to drive further efficiency gains and encourage the adoption of higher-performing technologies, the OECBC should consider raising the minimum standard to a BEE 4 or 5-star rating. This upward revision would serve both as a regulatory push and a market signal, promoting the transition towards more energy-efficient cooling solutions across the state.

b. Develop Residential Building Codes

The energy department should also develop a state-level guideline for the residential sector based on the recently released Eco-Niwas Samhita (ENS) 2024, which provides standards for residential buildings. To ensure enforceability and integration into urban planning processes, these codes must be formally notified under the Odisha Development Authorities (Planning and Building Standards) Rules. However, ENS 2024 should be modified to suit Odisha's conditions.

- **Lower the code compliance threshold**

  As per the national guidelines, the residential energy conservation code applies to buildings or complexes with a minimum connected load of 100 kilowatt (kW), a contract demand of 120 kilovolt ampere (kVA), or a plot area of ≥ 3000 m², whichever is more stringent. However, based on construction application data of from Bhubaneswar, only 1.5% of residential constructions currently meet this threshold, making the applicability of the code extremely limited in the state.

  To ensure broader adoption and meaningful impact, it is recommended that Odisha revises the threshold for plot area to ≥ 225 m², which would bring approximately 50% of new residential constructions under the code's purview. In subsequent revisions, the threshold should be further lowered to 150 m², thereby covering up to 75% of new constructions, and gradually expanded to include all new residential developments, aligning with the state's long-term sustainability and energy efficiency goals.

- **Adopt stricter compliance standards for thermal resistance of building envelope**

  The ENS 2024 residential building codes specify that the compliant range for Residential Envelope Transmittance Value (RETV) for walls should lie between 6 and 15 W/m². In Odisha, and particularly in Bhubaneswar, construction practices commonly use fly ash bricks and AAC blocks, which naturally offer better thermal performance. Analysis shows that current building envelopes in the region typically achieve an RETV of approximately 12.4 W/m², indicating that local construction is already performing near the mid-range of the national standard.

  Given this context, it is both feasible and beneficial for Odisha to adopt stricter RETV norms in its upcoming residential building codes. It is recommended that the state set a RETV compliance range of 6 to 12 W/m², which aligns with local construction practices while also promoting more thermally efficient buildings.

- **Proactively mandate Cool Roofs for residential codes**

  The national guidelines for the residential sector do not require the provision of a solar PV roof or a cool/green roof, as is mandated in the non-residential sector codes. To effectively encourage the adoption of cool and green roofs across Odisha's residential buildings, the Odisha government could consider mandating cool roofs in the residential building code. This approach would ensure that new construction includes such climate-resilient roofing technologies.

c. Strengthen implementation of building codes

Odisha has had Energy Conservation Building Codes (ECBC) for the non-residential sector since 2011, with revisions in 2018 and most recently in 2022. Despite this progress, actual adoption and enforcement have remained limited. To ensure effective implementation and scale-up of energy-efficient buildings across the state and in Bhubaneswar, several systemic changes are necessary.

1. Mandate Adoption in Public Sector Projects

The state should lead by example by:

- Mandating the revised OECBC for all upcoming government buildings, ensuring they meet current energy efficiency standards.
- Making compliance with Odisha Residential Building Codes compulsory for all Odisha State Housing Board projects, thereby setting a precedent for sustainable housing development.

2. Streamline Process

One of the major challenges stems from a fragmented implementation structure. To overcome this, the following measures are recommended:

- Institutional Integration
  - » Embed ECBC compliance into BMC's building approval and occupancy certification processes, making energy code verification a mandatory step.
  - » Integrate energy efficiency checks alongside other planning and structural reviews to streamline procedures and minimise delays.
  - » Leverage digital tracking platforms (e.g., SUJOG) to monitor compliance, enhance transparency, and reduce procedural friction.
  - » Appoint or designate Energy Officers within BMC to serve as nodal points for guidance, review, and coordination of code compliance.
- Capacity Building
  - » Organise regular training programs and workshops for local planning authorities, architects, builders, and engineers on the revised codes, compliance tools, and technical solutions.
  - » Encourage academic and technical institutions in Odisha to include ECBC and energy-efficient design as part of their curriculum.
- Incentivise Compliance

  The State and City government should consider introducing incentives, such as fast-tracked approvals, tax rebates, or additional FAR, to encourage voluntary compliance with energy efficiency standards.

  These reforms will ensure that energy codes are not just a policy mandate but a practical and effective tool for sustainable urban development in Odisha. By improving coordination, simplifying processes, and building stakeholder capacity, the state can significantly expand the reach and impact of its energy efficiency initiatives.

8.2.3 Electricity Policy

To ensure electricity supply during extreme heat events, the Energy Department and BMC should develop a dedicated Heat Season Electricity Policy as a part of Bhubaneswar IHCAP. While power utilities are expected to provide uninterrupted electricity—particularly to critical services like healthcare facilities—there is currently no concrete plan to achieve this. A robust policy must include measures for assessing the impact of heat on power infrastructure, identifying potential failure points, and strengthening critical systems to maintain quality and uninterrupted supply during peak heat periods.

DISCOM should take the lead in developing a heat-season preparedness plan with an implementable roadmap focusing on grid resilience, infrastructure upgrades, and service continuity. Drawing from national best practices, Bhubaneswar can adopt strategies used in cities like Delhi, which has diversified power sources and implemented AI-based demand forecasting tools to manage peak loads and ensure grid stability.

8.3 National Policies to support IHCAP

Policy Document	Implementing Agency	Description
Guidelines for Preparation of Heat Action Plan – Prevention and Management of Heat Wave, 2019	National Disaster Management Authority	Convert HAP guidelines to IHCAP. Some of the key changes required includes: • Revision of Heat Wave Definition and Guidance on Incorporating Humidity and Nighttime Temperatures for Heat Thresholds • Strengthening the Spatial Risk Assessment and Response to UHI • Integrate Cross-Sectoral Impacts of Heat • Integrate Future Heat Stress Projections • Expand the scope of HAPs to include heat mitigation and sustainable cooling measures
Urban and Regional Development Plans Formulation and Implementation, 2015	Ministry of Housing and Urban Affairs	Include Heat Assessment into the Urban Planning processes to tackle the UHI Effect

8.3.1. Guidelines for Preparation of Heat Action Plan

a. Revision of Heat Wave Definition

The IMD currently defines a heat wave primarily based on maximum dry bulb temperature thresholds, without incorporating other critical factors such as humidity and night-time temperatures, which are key contributors to actual human heat stress. Consequently, most HAPs across Indian cities continue to use only the maximum daytime temperature as the defining criterion for declaring and managing heat waves.

Research findings from Bhubaneswar IHCAP clearly indicate that rising humidity levels and increasing night-time temperatures are the primary drivers of heat stress in the city. As a result, relying solely on maximum daytime temperature to define heat thresholds overlooks a significant number of days where heat stress is driven by high humidity and elevated night-time temperatures, thereby underestimating the actual risk to public health.

While the NDMA's 2019 guidelines for the preparation of HAP acknowledge the role of humidity in worsening heat stress, it relies on the National Oceanic and Atmospheric Administration (NOAA) heat index chart designed for the USA. Further, while IMD has defined experimental heat index thresholds for the Indian context, these are limited to the maximum daytime heat index values, and do not account for night-time temperatures.

Recommendation: The NDMA should revise its national guidelines to establish a more comprehensive and climate-responsive framework for defining heat waves and supporting the development of local HAPs. In collaboration with the IMD and relevant climate and health institutions, a standardised yet adaptable methodology should be developed for calculating composite local heat thresholds. These thresholds must integrate both Heat Index (reflecting humidity) and night-time temperatures.

b. Strengthening the Spatial Risk Assessment and Response to UHI

While the current NDMA 2019 Guidelines include a brief Section 2.4 on the built environment and the impact of Urban Heat Island (UHI) effect, the guidance provided is limited and lacks operational clarity.

As a result, although many HAPs conduct a UHI analysis, they often do not translate these findings into actionable interventions. Also, some progressive HAPs go a step further and conduct ward-level risk assessments that combine heat exposure with socioeconomic vulnerabilities, but, even in such cases, the insights gained from these assessments are rarely integrated into the solution design or implementation planning.

Recommendation: The NDMA should strengthen its guidelines by:

- **Mandating Spatial Heat Risk Assessments:** Incorporate a standardised framework, based on the IPCC risk assessment model, to guide all cities in conducting spatial heat risk assessments as part of their HAPs. This should be a required step in the planning process.
- **Specifying Key Indicators:** Provide a recommended list of ward-level indicators to be included in the risk assessment. Some key indicators may include:

Table 8.5: Indicators for heat risk assessment

Hazard	Spatial heat index and surface temperatures (UHI)
Exposure	Population and building density Housing typology and shortages (per capita housing space) Impervious surface fraction
Sensitivity	Demographic and socioeconomic factors (homeless and slum population, old age, children, women, etc.)
Adaptive Capacity	Green cover and areas, Water supply and shortages, Electricity supply and outages, Access to health infrastructure, Cooking fuel usage

Source: iFOREST Analysis

Including these indicators in national guidelines will encourage cities to systematically collect and maintain this data, thereby addressing current data availability gaps, particularly at the ward level.

- **Linking Risk to Spatially Targeted Solutions:** The revised guidelines should also introduce a new framework that connects spatial risk findings to solution planning. This framework should complement the existing implementation structure, which currently links actions only to responsible agencies but not to specific geographic areas.

c. Integrate Cross-Sectoral Impacts of Heat

The current NDMA guidelines primarily focus on early warning systems to minimise public health impacts, but they overlook the wider, cross-sectoral effects of extreme heat, particularly on work productivity, electricity use, and cooling demand. These effects have considerable consequences for urban economies, energy infrastructure, and planning.

The current NDMA guidelines primarily focus on early warning systems to minimise public health impacts. However, there is no established methodology to assess the impact of heat on health, making it difficult to evaluate whether early warning systems and other interventions are truly effective in reducing heat-related risks. Further, the guidelines overlook the broader cross-sectoral effects of extreme heat, such as reduced work productivity, increased electricity consumption, and higher cooling demand—factors that significantly affect urban economies, energy infrastructure, and planning.

Recommendation: The NDMA should expand its guidelines to formally incorporate the multi-sectoral impacts of heat. This should include:

- **Sectoral Assessment Methodologies:** Develop and recommend formal methodologies for assessing heat impacts across sectors, including:
  - » **Labour Productivity:** Adapt and institutionalise an assessment methodology for productivity loss specific for Indian climatic conditions and occupational structures. This methodology could leverage nationally representative datasets such as the Periodic Labour Force Survey (PLFS) to estimate heat-induced productivity losses across various employment categories.

- » **Electricity Consumption and Cooling Demand:** Develop an approach to help cities assess the impact of heat on electricity consumption patterns and cooling needs by utilising data from local electricity distribution companies to identify peak load patterns and temperature-linked spikes in consumption, and giving a framework for conducting household and institutional surveys to gather information on air conditioner ownership, usage patterns, and cooling practices, especially in different income and vulnerability segments.
- » **Morbidity and Mortality:** Develop a methodology to assess the impact of heat on health, to understand the effectiveness of various interventions.

- **Cross-Sector Coordination Framework:** Require that HAP planning and implementation include representation from key departments such as labour, energy, urban development, and industry, to ensure coordinated action and policy alignment across sectors affected by heat.

d. Integrate Future Heat Stress Projections

While some HAPs in India include future heat stress analysis, most do not, mainly because NDMA guidelines lack frameworks for incorporating climate projections. Each HAP employs its own methodology, often with differing levels of scientific rigor and data quality, which reduces the credibility and policy relevance of these future risk estimates. As a result, most HAPs tend to be reactive, focusing on current heat risks without accounting for how heat intensity, duration, and frequency might change in the coming decades.

Recommendation: To strengthen long-term preparedness and ensure methodological consistency, the NDMA should develop a standard methodology for conducting future heat stress analysis, to ensure consistency and quality across HAPs. These methodologies must be scientifically robust, tailored to India's diverse climate zones and urban contexts, and based on credible national and international sources such as IMD, IITs, INCCA, and IPCC climate scenarios. To support effective adoption, these tools should be accompanied by clear, step-by-step guidance on data sourcing, climate modelling, and interpretation, enabling cities with varying technical capacities to carry out reliable and comparable assessments.

e. Expand the scope of HAPs to include heat mitigation and sustainable cooling measures

The current NDMA guidelines restrict HAPs largely to adaptation measures such as early warning systems and basic relief interventions like water distribution, shading, and so on. While these are important for immediate risk reduction, they do not address the root causes of rising urban heat. With climate change driving more intense and prolonged heat events, HAPs must evolve into Integrated Heat and Cooling Action Plans that combine adaptation with heat mitigation and sustainable cooling measures.

Leading cities like Singapore (as a part of their Cooling Singapore Initiative) are already using advanced climate modelling to evaluate the benefits of nature-based solutions, urban design interventions, centralised cooling systems, and energy-efficient appliances in reducing both ambient temperatures and energy demand. To enable such an integrated approach in India, NDMA should develop standard methodologies, support research, and build capacity in cities to adopt these tools. This will allow for evidence-based planning, long-term cooling strategies, and a shift from short-term relief to sustained heat resilience.

8.3.2 Urban and Regional Development Plans Formulation and Implementation, 2015

a. Include Heat Assessment into the Urban Planning processes

While the URDPFI guidelines recognise the Urban Heat Island effect and recommend a Green City Planning approach, including allocating 25–35% of the city area to recreational and open spaces, protecting environmentally sensitive zones, and incorporating green and compact city design elements, there are critical gaps in their applicability for heat mitigation.

- First, the guidelines lack a clear distinction between green, open, and recreational spaces. Evidence from Bhubaneswar shows that while green areas can alleviate heat stress, barren or paved open grounds can exacerbate it, even if classified as "recreational."
- Second, there is no ward-level standard for green area distribution, despite UHI mitigation requiring targeted interventions at a smaller scale to manage heat stress across all parts of the city.
- Third, while the guidelines outline potential measures, they do not specify tools or methodologies to evaluate their heat-reduction impact. Cities like Singapore, Melbourne, and Shanghai demonstrate the use of the Weather Research and Forecasting model to highlight the importance of modelling land use, land cover, and urban morphology changes for planning purposes. The URDPFI should incorporate such heat assessment tools into urban planning to enable Indian cities to shift from a reactive approach—relying on Heat Action Plans—to proactive, long-term spatial strategies that improve sustainability, public health, and liveability amidst climate change.

Annexures

Annexure 1: Models used in research

1. Weather Research Forecasting Model

To evaluate the performance of the WRF model, simulated climatic variables were validated against observational data from two weather stations in Bhubaneswar over a 24-hour period on 25th April 2024. The variables selected for validation were 2-meter air temperature, 2-meter relative humidity, and 10-meter wind speed, as these are most relevant for assessing thermal comfort in urban environments. Observational data were obtained from two representative locations: Lingaraj Temple (20.24°N, 85.83°E) and Patia Station (20.34°N, 85.81°E). Hourly instantaneous readings from these stations were directly compared with the corresponding hourly outputs from the WRF model.

Model performance was assessed using two standard statistical metrics: Root Mean Square Error (RMSE) and Mean Bias Error (MBE). These metrics were calculated at the model grid points closest to each observation site to enable point-wise comparison, and then averaged across both stations to determine overall model accuracy. Indicative values for acceptable model performance have been provided based on criteria used in previous studies conducted in different climatic regions of India.[24]

Table A.1: Performance metrics of WRF model for validation

Parameter	Weather Station	RMSE value for the model	Acceptable Value
2m Air Temperature (°C)	Lingaraj Temple	1.17	≤ 2.0 °C
	Patia	1.11	
	Average	1.14	
2m Relative Humidity (%)	Lingaraj Temple	17.90	≤ 20%
	Patia	15.49	
	Average	16.695	
10m Wind Speed (m/s)	Lingaraj Temple	0.72	≤ 2.0 m/s
	Patia	0.62	
	Average	0.67	

Source: iFOREST and SEC Analysis

2. Parallelized Large-Eddy Simulation Model for Urban Applications

To ensure consistency with the WRF model validation, the PALM-4U simulation was also conducted for the 24-hour period on 25th April 2024. Validation was carried out at one of the two previously selected locations. Patia Station was chosen due to the strong advection patterns identified in the WRF simulation, which led to the accumulation of warm air in the northern part of the city near the station. This location represents a mix of urban typologies, characterised by a concentration of institutional buildings in the northern section of the domain and a diverse blend of commercial and low-rise residential areas throughout the rest of the site.

Model outputs from PALM-4U, including ambient temperature, wind speed, and relative humidity, were extracted from the grid cell closest to the Patia weather station (20.34°N, 85.81°E). These outputs were compared directly with observed hourly data to assess the model's performance. Quantitative evaluation was conducted using RMSE and MBE, following the same methodology used for the WRF model validation. The results for which are summarised in table A.2.

Table A.2: Performance metrics of PALM-4U model for validation

Parameter	RMSE value for the model	Acceptable Value
2m Air Temperature (°C)	0.91	≤ 2.0 °C
2m Relative Humidity (%)	9.32	≤ 20%
10m Wind Speed (m/s)	0.41	≤ 2.0 m/s

Source: iFOREST and SEC Analysis

3. City Energy Analyst

The validation process for the CEA model involved calibrating the simulated energy demand outputs against real-world electricity consumption data. Key input parameters used in the model included building envelope properties (such as U-values for walls, roofs, and windows, window-to-wall ratio, and solar transmittance), internal loads (HVAC system efficiency and cooling set points), and usage patterns (including the proportion of electrified and conditioned space, net usable floor area, and weekday/weekend occupancy schedules).

The modelling sample consisted of 77 residential, 59 commercial, and 11 office buildings representing typical typologies in Bhubaneswar. To validate the model, the simulated energy demand per building was adjusted using a city-specific connection factor to derive the energy demand per connection. These results were then compared to the average electricity consumption data from Tata Power Central Odisha Distribution Limited (TPCODL), Bhubaneswar's distribution company, for 2023. A summary of the validation outcomes is presented in Table A.3.

Table A.3: Performance metrics of CEA model for validation

Building Typology	Model Value (kWh/Consumer)	TPCODL Mean Value (kWh/Consumer)
Commercial	2,46,908.7	2,11,784
Office	2,21,431.5	2,80,611.9
Residential	12,949.5	7,716

Source: iFOREST and SEC Analysis

Annexure 2: Climatological tables for Bhubaneswar

Table A.4: Mean Dry Bulb Temperature

Time Period	Mean Dry Bulb Temperature												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
1961-1990	22.65	25.3	28.4	30.45	31.7	30.45	28.35	28.25	28.4	27.6	25.25	22.5	**27.45**
1971-2000	22.55	25.3	28.55	30.5	31.5	30.35	28.5	28.3	28.5	27.7	25.2	22.35	**27.45**
1981-2010	22.45	25.45	28.6	30.6	31.55	30.35	28.65	28.4	28.5	27.6	25.1	22.2	**27.45**
1991-2020	22.25	25.55	28.9	30.8	31.75	30.6	28.85	28.5	28.6	27.55	24.95	22.05	**27.5**

Table A.5: Daily Maximum Temperature

Time Period	Mean Dry Bulb Temperature												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
1961-1990	28.3	31.4	34.9	36.9	37.4	35.3	32	31.6	32	31.8	30.2	28.2	**32.5**
1971-2000	28.8	31.5	35.2	37	37.2	35.1	32.2	31.7	32.2	32.1	30.5	28.6	**32.7**
1981-2010	29.1	32	35.5	37.2	37.2	35.1	32.5	31.9	32.3	32.1	30.7	28.9	**32.9**
1991-2020	29.2	32.5	35.9	37.7	37.7	35.3	32.4	32	32.4	31.9	30.8	28.9	**33**

Table A.6: Highest Monthly Temperature

Time Period	Mean Dry Bulb Temperature												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
1961-1990	31.7	35.7	38.9	41	42.2	41.2	35.7	34.2	34.6	34.2	32.7	30.8	**43.3**
1971-2000	32.2	35.7	39.3	40.9	42.1	40.6	36.1	34.4	34.8	34.4	32.8	31.5	**43**
1981-2010	32.7	36.1	39.6	41.2	41.8	40.5	36.3	34.7	35	34.4	33.1	31.9	**43.1**
1991-2020	32.8	37	39.8	41.2	42.4	40.9	36.3	35.1	35.3	34.4	33.2	32	**43.6**

Table A.7: Daily Minimum Temperature

Time Period	Mean Dry Bulb Temperature												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
1961-1990	15.5	18.5	22.2	24.9	26.2	26	25.1	25	24.7	22.8	19	15.3	**22.1**
1971-2000	15.5	18.7	22.4	25	26.3	26.1	25.3	25.1	24.8	23.1	19.3	15.2	**22.2**
1981-2010	15.7	18.8	22.6	25.2	26.4	26.3	25.5	25.3	25	23.1	19.1	15.4	**22.4**
1991-2020	15.5	18.5	22.8	25.3	26.7	26.4	25.6	25.4	25.2	23.4	19.3	15.4	**22.4**

Table A.8: Lowest Monthly Temperature

Time Period	Mean Dry Bulb Temperature												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
1961-1990	11.8	14.5	18.2	20.7	21.2	22.5	22.7	22.8	22.4	19.3	14.9	11.8	**11.2**
1971-2000	11.6	14.4	18.3	20.9	21.3	22.4	22.9	22.9	22.6	19.5	15.1	11.9	**11.1**
1981-2010	11.7	14.4	18.4	20.8	21.4	22.4	23.2	23.3	22.7	19.5	14.9	12	**11.1**
1991-2020	11.4	14.1	18.6	21.1	21.7	23	23.3	23.5	23.1	19.7	15.1	11.6	**10.7**

Table A.9: Relative Humidity

Time Period	Mean Dry Bulb Temperature												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
1961-1990	60	61	62	64.5	65.5	73	83.5	83.5	82.5	75.5	65	58.5	**69.5**
1971-2000	61.5	61.5	64	67	67	75	83.5	85	83	76.5	66.5	60.5	**71**
1981-2010	63.5	62.5	64.5	66	68.5	76.5	84.5	86	84	78	68.5	63	**72**
1991-2020	66	64	66.5	68	70	78	86.5	87.5	86	81.5	72.5	66.5	**74.5**

Table A.10: Mean Wet-Bulb Temperature

Time Period	Mean Dry Bulb Temperature												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
1961-1990	17.6	19.95	22.9	25.15	26.4	26.5	26.15	26.2	26.1	24.35	20.7	17.4	**23.3**
1971-2000	17.8	20.15	23.3	25.6	26.65	26.8	26.4	26.35	26.25	24.6	20.95	17.5	**23.55**
1981-2010	17.95	20.4	23.55	25.6	26.95	27	26.65	26.6	26.45	24.65	21.05	17.8	**23.75**
1991-2020	18.15	20.65	24.15	26.1	27.35	27.4	27	26.9	26.8	25.25	21.6	18.1	**24.1**

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