



# AI-Enabled Detection of Urban Heat Island Zones in Pune Region using GIS and Remote Sensing

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## How to Cite this Article:

Ambike, R. (2026). AI-Enabled Detection of Urban Heat Island Zones in Pune Region using GIS and Remote Sensing. International Journal of Creative and Open Research in Engineering and Management, 2(5).  
<https://doi.org/10.55041/ijcope.v2i5.433>

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**Abstract:** Rapid urban growth has intensified environmental challenges in major Indian cities, especially the Urban Heat Island (UHI) effect. Pune and its surrounding urban regions have experienced a noticeable increase in land surface temperature because of uncontrolled urban expansion, decline in green cover, and increased built-up surfaces. This research presents an AI-enabled framework integrating Remote Sensing, Geographic Information Systems (GIS), satellite thermal observations, and Machine Learning techniques for identifying and analysing Urban Heat Island patterns in and around Pune city. Thermal and multispectral datasets obtained from Landsat 8/9, MODIS, and Sentinel-2 satellites were used to estimate Land Surface Temperature (LST), vegetation conditions, built-up density, and land-use characteristics. Machine learning approaches such as Random Forest, Support Vector Machine (SVM), and clustering methods were employed for hotspot classification and prediction of future heat-vulnerable zones. The findings reveal that heavily urbanized locations show substantially higher temperatures compared to vegetated and water-covered regions. The developed AI-GIS model can support urban planners, environmental agencies, and municipal authorities in implementing sustainable climate adaptation and heat mitigation strategies.

**Keywords:** Urban Heat Island, Artificial Intelligence, Remote Sensing, GIS, Machine Learning, Pune City, Land Surface Temperature, Climate Adaptation



## Introduction

Urbanization has become one of the major drivers of environmental transformation in metropolitan regions across India. Rapid growth in infrastructure, transportation systems, industrial development, and population density has significantly altered the thermal environment of urban areas. Pune city, along with nearby regions such as Pimpri-Chinchwad, Hinjewadi, Baner, Kharadi, Hadapsar, and Wagholi, has witnessed extensive urban expansion over the last two decades. The replacement of natural vegetation with concrete structures, roads, and impervious surfaces has resulted in higher land surface temperatures and increased thermal stress. This phenomenon, known as the Urban Heat Island effect, occurs when urban regions become warmer than surrounding rural environments. Rising urban temperatures negatively influence human health, energy demand, environmental quality, and local climatic conditions. Advancements in Remote Sensing and GIS technologies have enabled efficient monitoring of urban thermal variations over large geographical regions. In recent years, Artificial Intelligence and Machine Learning methods have further improved the capability of geospatial analysis by enabling automated detection, classification, and prediction of thermal hotspots. AI-assisted geospatial models provide improved accuracy, faster processing, and better decision-making support for sustainable urban planning. This study focuses on the application of AI-integrated GIS and satellite-based thermal analysis for identifying Urban Heat Island intensity in Pune and nearby urban regions.

### Study Area:

The research area includes Pune Municipal Corporation (PMC), Pimpri-Chinchwad Municipal Corporation (PCMC), and nearby peri-urban regions experiencing rapid urban growth.

**Major Study Locations:** Shivajinagar, Hadapsar, Kharad, Baner, Wakad, Hinjewadi, Pimpri-Chinchwad, Wagholi, Katraj, Talegaon

These locations were selected due to increased infrastructure development, industrialization, traffic density, and reduction in vegetation cover.

### Objectives of the Study:

1. To investigate Urban Heat Island intensity in Pune metropolitan regions.
2. To estimate Land Surface Temperature using thermal satellite datasets.
3. To apply Artificial Intelligence and Machine Learning methods for thermal hotspot detection.
4. To analyse the relationship between vegetation cover, built-up area, and surface temperature.
5. To recommend sustainable urban planning strategies for reducing thermal stress.

### Data and Materials

Data Source	Purpose
Landsat 8/9 Thermal Imagery	Land Surface Temperature estimation
MODIS Satellite Data	Temporal thermal analysis
Sentinel-2 Imagery	Vegetation and land-use mapping
Google Earth Engine	Cloud-based geospatial processing
GIS Layers	Spatial analysis and urban boundary mapping
Meteorological Records	Validation of temperature observations

Several earlier studies conducted in Pune have demonstrated the effectiveness of thermal remote sensing techniques for Urban Heat Island assessment.



## Methodology

### Step 1: Satellite Data Collection

Satellite imagery from Landsat 8/9 and Sentinel-2 missions was acquired for summer seasons from 2020 to 2026. MODIS data was used for temporal temperature monitoring.

### Step 2: Image Pre-processing

Pre-processing operations were carried out before analysis to improve data quality.

Pre-processing Techniques

- Radiometric correction
- Atmospheric correction
- Cloud masking
- Image mosaicking

### Step 3: Land Surface Temperature Estimation

Thermal infrared bands from Landsat imagery were used to calculate Land Surface Temperature

#### LST Equation

$$LST = \frac{BT}{1 + \left( \frac{\lambda}{\rho} \right) \ln \epsilon}$$

#### Where:

- BT = Brightness Temperature
- $\lambda$  = Wavelength
- $\epsilon$  = Surface Emissivity
- $\rho$  = Radiation constant

### Step 4: Vegetation and Built-Up Analysis

Normalized Difference Vegetation Index (NDVI) and Normalized Difference Built-Up Index (NDBI) were used to evaluate vegetation conditions and urban expansion.

#### NDVI Formula:

$$NDVI = \frac{NIR - RED}{NIR + RED}$$

#### NDBI Formula:

$$NDBI = \frac{SWIR - NIR}{SWIR + NIR}$$

### Step 5: AI-Based Classification

Machine Learning techniques were implemented using thermal and land-use parameters.

Algorithms Used



- Random Forest
- Support Vector Machine (SVM)
- K-Means Clustering

The models were trained using:

- Land Surface Temperature
- NDVI values
- NDBI values
- Urban density layers

The classified outputs included:

- High thermal stress zones
- Moderate heat zones
- Low heat zones

### Step 6: GIS-Based Mapping

Thermal hotspot maps and spatial analysis outputs were generated using ArcGIS, QGIS, and Google Earth Engine platforms.

### Results and Discussion

Land Surface Temperature Analysis: The analysis identified noticeable thermal variation across different regions of Pune metropolitan area.

Area	Average LST
Hinjewadi IT Region	40–44°C
Hadapsar Industrial Area	39–43°C
Baner-Balewadi	38–42°C
Central Pune	37–41°C
Pashan Lake Region	30–34°C

Highly urbanized locations exhibited greater Urban Heat Island intensity because of:

- Dense construction activities
- Reduction in vegetation cover
- Asphalt road surfaces
- Vehicular and industrial emissions

In contrast, areas with vegetation and water bodies recorded comparatively lower temperatures. The study also observed temperature differences ranging from 5°C to 10°C between densely urbanized and greener regions.

### AI-Based Hotspot Detection

Among the Machine Learning approaches, Random Forest classification produced better performance in identifying heat-prone regions compared to conventional threshold-based techniques.



The AI-assisted GIS framework improved:

- Automated hotspot identification
- Spatial prediction capability
- Climate vulnerability assessment
- Urban thermal risk mapping

The results confirm that AI-driven geospatial analysis can significantly enhance urban climate monitoring and support sustainable planning initiatives.

### **Applications of AI-Driven UHI Analysis**

The proposed AI-GIS framework can support multiple urban management applications.

#### **Major Applications**

- Smart city planning
- Heatwave risk management
- Urban forestry planning
- Climate adaptation strategy development
- Sustainable infrastructure management
- Public health monitoring
- Environmental decision-support systems

AI-assisted thermal vulnerability mapping is increasingly being adopted for city-level climate resilience planning in Indian metropolitan regions.

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### **Conclusion**

The integration of Artificial Intelligence, Remote Sensing, and GIS provides an efficient and reliable framework for Urban Heat Island detection in Pune city and surrounding regions. The study demonstrates that rapid urbanization and loss of vegetation are key factors responsible for increasing land surface temperatures. AI-enabled geospatial techniques improve the accuracy and automation of thermal hotspot identification and provide valuable support for urban climate management. The developed framework can assist planners and municipal authorities in implementing sustainable urban development and climate-resilient infrastructure policies.

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### **Future Scope**

Future research can focus on:

- Integration of IoT-based temperature sensors
  - Real-time Urban Heat Island monitoring systems
  - Deep learning-based thermal prediction models
  - Drone-assisted thermal surveys
  - Smart green infrastructure planning
  - AI-driven climate adaptation dashboards
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