



SPATIAL ANALYSIS OF URBAN HEAT ISLANDS: A STUDY OF MORADABAD

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Abstract

Urban Heat Islands (UHIs) are a significant environmental problem that arises in cities that are quickly urbanising. These UHIs cause temperatures to rise, contribute to an increase in energy consumption, and have potential negative impacts on human health. Moradabad, a city of moderate size located in Uttar Pradesh, India, has undergone a substantial amount of urbanisation, which makes it an appropriate case study for the study of urban heat island effects. This study makes use of remote sensing and Geographic Information Systems (GIS) in order to conduct an analysis of the geographical distribution of waterborne illnesses in Moradabad. In order to evaluate the thermal fluctuations that occur across the city, the Land Surface Temperature (LST) data that is obtained from the Landsat 8 and 9 satellite images, in conjunction with the Normalised Difference Vegetation Index (NDVI) and the Urban Index (UI), are utilised. In this study, hotspots are identified, land surface temperature (LST) is correlated with land use/land cover (LULC), and mitigation options are evaluated. The findings provide a contribution to the efforts being made in Moradabad and other cities like it to improve urban planning and climate resilience.

Keywords: Urban Heat Island, Land Surface Temperature, NDVI, Remote Sensing, GIS, Moradabad

1. Introduction

During the contemporary age, urbanisation has been one of the most transforming things that has occurred. Most importantly, it changes the microclimate of places, as well as the landscapes, demography, and economics of such regions. The urban heat island effect, also known as the UHI effect, is a prominent expression of these changes. The UHI effect occurs when metropolitan regions experience temperatures that are much higher than their rural equivalents in the surrounding area. Urban heat islands (UHIs) are mostly ascribed to the replacement of natural land cover with impermeable materials such as asphalt, concrete, and metal, as well as human heat emissions from traffic, industry, and residential activities. Oke was the first person to conduct a comprehensive study on UHIs in 1982. In light of the fact that the majority of the world's population is moving towards urban centres, the importance of researching urban heat islands is growing. Rapid urbanisation in India, particularly in second-tier towns such as Moradabad in Uttar Pradesh, has resulted in unplanned changes to land use. As a result, these cities have become excellent topics for researchers interested in understanding the geographical variability of urban heat island impacts. The geographical study of urban heat islands (UHIs) is becoming not just an academic interest but also a key policy requirement as the stress caused by climate change continues to increase. This is in addition to the already dangerous health and infrastructural situations that plague such places.

noted for its brassware industry, Moradabad is a rising metropolitan centre that has witnessed tremendous population and infrastructure growth in recent decades. Moradabad is also noted for its historical significance. In spite of the fact that this growth has been economically advantageous, it has also led to the deterioration of the ecosystem and a significant increase in land surface temperatures (LST). The expansion

of the built-up area of the city has come at the expense of green cover and water bodies, which are important regulators of the microclimate. As a consequence of this, localised heat pockets are becoming increasingly noticeable, particularly during the months leading up to the monsoon and during the period of summer. A heat intensification of this kind makes health risks worse, raises the amount of power that is consumed for cooling, and leads to a general reduction in the liveability of metropolitan areas altogether. In order to comprehend the urban heat island effect in a metropolis such as Moradabad, geographical study is of the utmost importance. The distribution of surface temperatures may be mapped by researchers with the use of technologies such as Remote Sensing (RS), Geographic Information Systems (GIS), and satellite-based thermal imaging. These technologies allow researchers to connect surface temperatures with land use, vegetation indices, and built-up area densities. Indicators such as the Normalised Difference Vegetation Index (NDVI) and the Normalised Difference Built-up Index (NDBI) are frequently utilised in this context. This allows for a comparative geographical investigation of how different forms of land cover impact local temperatures. These indices assist visualise the size of vegetative land and urbanised land, respectively, and provide a visual representation of the territory.

Physical and anthropogenic factors are the two primary categories that may be used to describe the mechanism that underlies the genesis of UHI. In terms of their physical characteristics, urban materials have a lower albedo than natural surfaces, which results in a larger radiation absorption from the sun. Furthermore, "urban canyons" are created as a result of the morphology of urban structures, which includes high-rise buildings, narrow streets, and dark roofs. These structures trap heat. Due to the fact that the ability of construction materials such as concrete and asphalt to store heat is far larger than that of vegetation-covered or damp rural terrain, cities are able to maintain their warmth well into the night. The problem of the UHI is further exacerbated by activities that are caused by humans. The discharge of waste heat is caused by a number of factors, including industrial activities, emissions from vehicles, and energy use. Although air conditioners are designed to cool indoor rooms, they also release warm air outdoors, which causes the surrounding temperature to rise. Moreover, the absence of sufficient vegetation results in a decrease in transpiration, which is a natural mechanism that produces cooling. These impacts are compounded in a city like Moradabad, where traditional planning has been replaced by unregulated growth, and the process of mitigating them becomes more difficult.

In addition, seasonal fluctuation is a significant factor that contributes to the severity of the UHI. Research conducted in a number of Indian towns has revealed that the urban heat island effect is at its peak during the summer and pre-monsoon seasons. This is because these are the times of year when the difference between the constructed environment and the natural surrounds is at its most prominent. It is possible that the disparities are less pronounced during the winter months; yet, localised hot spots continue to exist as a result of artificial heat sources. Moradabad experiences peak surface temperatures that are frequently higher than 45 degrees Celsius throughout the summer season. When combined with the urban heat island effect, this can cause the thermal stress that individuals experience to exceed the limits that are considered bearable. This is especially true for vulnerable groups like as the elderly, children, and those who work outside. It is widely recognised that vegetation plays a role in reducing the effects of UHI. Not only do trees and green areas offer shade, but they also help to cool the environment by allowing evapotranspiration to take place. Nevertheless, in Moradabad, the decrease in urban green cover that has occurred as a result of building activities and the extension of roads has resulted in a decrease in the natural cooling mechanisms that are there. The surface temperature differential across the city has been exacerbated as a result of the transformation of open areas and agricultural fields into residential colonies, commercial hubs, and industrial zones. There is a definite inverse link between the values of the normalised difference vegetation

index (NDVI) and the levels of the land surface temperature (LST), as shown by the data obtained from remote sensing.

In addition, bodies of water play a key part in the process of temperature regulation. Evaporation as a means of cooling is facilitated by the existence of bodies of water such as lakes, ponds, and rivers. On the other hand, their potential to operate as thermal regulators has been diminished in Moradabad as a result of the fact that many historic water sources have either dried up or been encroached upon. Existing water bodies have been deteriorated as a result of inappropriate waste management and pollution, which has limited the biological and climatic roles that these bodies of water can perform. It is possible for researchers to visualise temperature fluctuations among neighbourhoods and get an understanding of how land use planning affects thermal behaviour through the use of GIS-based studies, which are conducted within the framework of spatial analysis. Land surface temperature (LST) values may be extracted from thermal infrared pictures taken from satellites such as Landsat-8 and superimposed on land use/land cover (LULC) maps thanks to this technique. Not only does this technique quantify the UHI effect, but it also identifies "hotspots" that call for immediate attention.

The socioeconomic tendencies that are related with UHIs can also be shown through spatial analysis. When it comes to urban regions in India, the poorest neighbourhoods are frequently situated in places that are densely inhabited, have poor ventilation, have a limited amount of tree cover, and have inadequate access to open spaces. These regions carry the brunt of the heat stress that is caused by the UHI, which further exacerbates existing health disparities. Because of the high built-up density, limited vegetation, and active human presence in Moradabad, regions around industrial zones, dense informal settlements, and ancient city marketplaces have a tendency to record higher LSTs. This is because of the combination of these several factors. There must be a multi-pronged effort used in order to reduce UHIs. Green infrastructure, which includes but is not limited to parks, vertical gardens, and green roofs, should be given priority by urban planners. If we want to increase water percolation and limit the amount of heat that is absorbed by the building, we should encourage the use of construction materials that are reflecting and porous. Traditional architectural practices in Indian towns like Moradabad, such as the use of courtyards, jaalis, and clay materials, might provide important insights for the development of climate-sensitive projects. Policy interventions need to be incorporated at the local level in order to be effective. The policies that govern development control should include a requirement for a minimum amount of green space per person, the conservation of existing trees and bodies of water, and the provision of incentives for rainwater collecting and environmentally responsible building techniques. Guidelines for passive cooling and energy-efficient design should be incorporated into building ordinances.

In addition, public awareness is an important aspect. It is imperative that residents are made aware of the advantages that come with reducing the use of vehicles, planting trees, and gardening on rooftops. Community organisations, educational institutions, and universities all have the potential to play a part in teaching the general public about the dangers of urban heat islands (UHIs) and the significance of climate resilience. It is necessary to conduct further studies that are more specific to the area in order to have a better understanding of the UHI issue in Tier-2 and Tier-3 cities. Many studies have been conducted in metropolitan regions like as Delhi, Mumbai, and Bangalore; nevertheless, places such as Moradabad continue to receive little attention, despite the fact that they are confronted with comparable or even more severe issues as a result of their inadequate infrastructure capacity. The development of information that can be put into practice may be ensured by collaborative research that includes collaboration between academic institutions, urban municipal bodies, and community stakeholders.

New opportunities for UHI analysis are becoming available as a result of various technological advancements. The quality and granularity of geographical data may be considerably improved by the use of high-resolution satellite imaging, unmanned aerial vehicle (drone) surveys, and picture categorisation based on artificial intelligence. In addition, sensor networks that are based on the Internet of Things are able to deliver temperature measurements in real time, which assists municipal authorities in making informative choices, particularly during heatwaves. Particularly in areas that are experiencing fast population growth, such as Moradabad, the Urban Heat Island effect is a significant urban environmental problem that demands significant attention immediately. The use of geographic information systems (GIS) and remote sensing provides a useful arsenal for understanding, visualising, and mitigating urban heat islands (UHIs). It is possible for planners to create targeted solutions if they first identify temperature hotspots and then determine the association between those hotspots and land use, plant cover, and socioeconomic characteristics. When cities are working towards becoming sustainable, inclusive, and climate-resilient, it is not a choice to address the urban heat island effect via planning that is based on research and includes the community; rather, it is an absolute must.

Study Area: Moradabad

Moradabad, which is located in the western region of Uttar Pradesh, is a prominent urban and industrial centre. It is sometimes referred to as the "Brass City" of India. Located on the banks of the Ramganga River, which is a tributary of the Ganga, the city is situated at a latitude of 28 degrees 50 minutes north and a longitude of 78 degrees 47 minutes east. Moradabad, which is known all over the world for its brassware and metal handicrafts, has witnessed a significant increase in its urban population over the course of the last several decades. The city is experiencing significant urbanisation pressures, which have resulted in significant changes to its terrain, environment, and microclimatic conditions. The city's population has already surpassed 1.5 million people, and it is experiencing these pressures.

Geographical and Socio-Economic Context

Once upon a time, the city of Moradabad enjoyed a favourable microclimate thanks to its location along the Ramganga River. This microclimate was maintained by the cooling impact of water bodies and the flora that surrounded the city. Moradabad has a climate that is tropical and monsoon-dominated. The summers are quite hot, while the winters are refreshingly pleasant. The monsoon season, which lasts from June to September, is when the majority of the rainfall occurs. Temperatures in the summertime regularly exceed 45 degrees Celsius, especially in the months of May and June. Over the course of the past several years, however, there has been a discernible shift in the patterns of temperature and an increase in the amount of heat retention in the city, which is consistent with the more general phenomena known as Urban Heat Islands (UHI).

There have been significant shifts in land use and land cover as a consequence of the tremendous increase in population, which has been followed by the horizontal and vertical development of the built environment. As a result of the strain that has been placed on housing, infrastructure, and industry, green spaces, agricultural land, and wetland areas have been replaced with impermeable surfaces such as concrete, asphalt, and metal roofs. In comparison to natural landscapes, these surfaces are able to absorb and retain a greater amount of heat, which results in higher land surface temperatures (LST) and contributes to the exacerbation of the heat island effect.

Industrialization and Urban Expansion

The mostly world-famous brass industry in Moradabad, which is comprised of hundreds of small-scale and cottage production facilities, is the primary reason for the city's status as an industrial powerhouse. In spite

of the fact that these industries are extremely important to the city's economy, they are also major contributors to the city's air and thermal pollution. There is frequently a lack of suitable green belts or planned zoning in the industrial regions, which contributes to the temperature disparity that exists between these areas and other sections of the city.

Moradabad's urban growth has been significantly uncontrolled for the most part. New residential and commercial colonies have grown at a quick pace, particularly in regions that are considered to be geographically peripheral, such as Bhojpur, Katghar, New Civil Lines, and the Haddi Godam region. In the past, these areas were characterised by wide fields and pockets of greenery; however, today, they are heavily packed with buildings, paved roads, and commercial establishments. This shift has been a key contributor to the decrease in natural vegetation and the growth in built-up area, both of which have led to an increase in the intensity of the solar heat island effect (UHI).

Land Use Change and Vegetation Loss

The magnitude and pattern of changes in land use and land cover (also known as LULC) are among the most important indicators of the urban heat island effect. Moradabad has seen a transition from agricultural and green regions to urban land use, as evidenced by satellite images and geographical data collected over the course of several years. Throughout the city centre and the surrounding areas, the Normalised Difference Vegetation Index (NDVI), which is a measurement of the health and density of vegetation, has demonstrated a constant reduction. On the other hand, the Normalised Difference Built-up Index (NDBI) has been on the rise, particularly in those areas that have experienced intensive development. These alterations are directly connected to the increase in surface temperatures we are seeing. For instance, metropolitan areas with a high population density, such as Lal Bagh, Gandhi Nagar, and some sections of the Old City, routinely exhibit higher LST values, which are often three to five degrees Celsius higher than less urbanised or vegetated regions. The fact that temperatures are varying inside a single city is a clear indication that the urban heat island effect is expanding in Moradabad.

Disappearance of Water Bodies and Groundwater Stress

In the past, Moradabad was home to a large number of seasonal water channels, seasonal lakes, and seasonal ponds, all of which contributed to the regulation of the local temperature and the preservation of ecological balance. Many of these natural water sources have been encroached upon, filled, or contaminated to the point where they are no longer recoverable over the course of time. Consequently, one of the most important natural cooling processes within the metropolitan system has been destroyed as a result of this loss in surface water availability. A further factor that has contributed to the severe decline in the water table is the excessive extraction of groundwater, which is mostly accomplished by borewells and tube wells. Not only does this result in a lack of water, but it also decreases the amount of moisture in the soil, which has an impact on the flora as well as the management of surface temperature. The thermal stress that is being placed on the urban ecology is further exacerbated by the absence of effective water management management.

Environmental and Social Implications

Moradabad is experiencing a number of difficulties as a result of the Urban Heat Island effect. From an environmental point of view, the rise in LST is a contributor to the deterioration of air quality, the increase in energy use for cooling, and the disruption of local weather patterns. If we consider the consequences from a social point of view, they are much more critical. Communities with low incomes are

disproportionately affected by heat stress. Many of these communities are characterised by living in housing that is overcrowded, poorly ventilated, and has little to no green cover or access to air conditioning. During heatwaves, areas such as slums and informal settlements are severely affected by the discomfort caused by high temperatures. This can result in a number of health problems, including heat stroke, dehydration, respiratory diseases, and an increase in death rates. In particular, those who are vulnerable include children, the elderly, and anyone who work outside. Because of the seasonal increase in heat-related ailments, the public health system, which is already under pressure, is finding it difficult to cope with the situation. In addition, the increasing demand for artificial cooling equipment places a burden on the city's energy infrastructure and leads to increased levels of carbon emissions, which in turn exacerbates the feedback loops that are associated with climate change.

Urban Morphology and Microclimate

Heat is able to be trapped in the urban core of Moradabad because of its morphology, which is characterised by small roads, high building density, and inadequate ventilation. In commercial areas such as Sadar Bazar and Bartan Bazar, where there is a lack of shade and the presence of reflecting and heat-retaining surfaces such as metal shop roofs and asphalt roads, heat retention is exacerbated. This is especially noticeable in these locations. The little green places that are still available, such as the Eidgah Garden and District Park, are not enough to alleviate the heat stress that is experienced across the whole city. Even for these regions, there is a lack of management and there are dangers of invasion. The periphery towns, albeit being greener, are now progressively being swallowed by the increasing city borders, and as a result, the general thermal balance of the region continues to deteriorate.

Objectives

1. To analyze the spatial distribution of UHIs in Moradabad using LST data.
2. To examine the relationship between LST, NDVI, and LULC.
3. To identify UHI hotspots and suggest mitigation measures.

Research Questions

- How does LST vary across different zones in Moradabad?
- What is the correlation between vegetation cover and UHI intensity?
- Which urban planning strategies can reduce UHI effects?

Literature Review

During the 21st century, urbanisation is a prominent factor that contributes to environmental change. It has a substantial impact on the utilisation of land, biodiversity, energy consumption, and local climate change systems. An phenomenon known as the Urban Heat Island (UHI) is one of the most obvious and worrisome results of fast urban expansion. This impact occurs when urban regions experience greater temperatures than the rural surroundings that are located in their immediate vicinity. The change of natural land cover into impermeable surfaces, the decreasing amount of vegetation, and the increased concentration of human heat sources are the primary contributors to this phenomenon.

Role of Urbanization in UHI Formation

The establishment of urban heat islands has been shown to have a high association with urban expansion, according to a number of studies. The degree of urbanisation is a significant aspect that plays a role in determining the extent of urban heat island effect (UHI), as stated by Imhoff et al. (2010). The researchers used satellite data from the Moderate Resolution Imaging Spectroradiometer (MODIS) to quantify the surface urban heat island (UHI) intensity across a variety of biomes and urban types. They came to the conclusion that urban areas have an average increase in surface temperatures of between one and three degrees Celsius in comparison to the rural landscapes that are located in the surrounding area. All of these factors—urban shape, the density of built-up regions, the materials used in construction, and the population density—contribute to the exacerbation of urban heat islands. Not only are these characteristics prevalent in megacities, but they are also becoming an increasingly important consideration in urban centres of a smaller or medium size. On the other hand, the majority of research on UHI has concentrated on big metropolitan regions, which has resulted in a significant knowledge vacuum regarding the phenomenon of how these dynamics manifest themselves in Tier-2 and Tier-3 cities like Moradabad.

Remote Sensing Techniques in UHI Studies

For the purpose of evaluating and mapping UHI occurrences, remote sensing has emerged as one of the most effective methods now available. It was proved by Weng, Lu, and Schubring (2004) that the thermal infrared bands of the Landsat Thematic Mapper (TM) may be used to estimate the Land Surface Temperature (LST) in Indianapolis, which is located in the United States. Their approach merged land surface temperature (LST) data collected from remote sensing with land use and land cover (LULC) classifications, therefore demonstrating how various urban forms contribute in a variety of ways to surface heating. The identification of UHI "hotspots" and the coupling of those "hotspots" to certain land cover types was a particularly beneficial use of this method. Landsat satellite imagery, particularly the thermal bands of Landsat 5, 7, and 8, continues to be frequently utilised because of its high spatial resolution (30 meters for visual bands and 100 meters for thermal bands), which makes it excellent for detailed urban studies.

When it comes to measuring the impacts of urban heat island (UHI) in highly populated cities in India, remote sensing has proven to be an invaluable tool. As an illustration, Mallick et al. (2013) conducted an analysis of Land Surface Temperature (LST) in Delhi and Hyderabad using Landsat ETM+. They found that there is a significant correlation between built-up density and surface heating. The results of their research showed that regions with high impervious surfaces and little plant cover reported much higher LST. This study provides more evidence that urban land use patterns play a role in determining the temperature of the surrounding area.

Role of Vegetation and NDVI in Mitigating UHI

The process of evapotranspiration is one of the most important ways in which vegetation contributes to the regulation of temperatures in metropolitan areas. The LST values in regions that are dominated by buildings and highways are higher than those in regions that have extensive populations of trees and parks. The Normalised Difference Vegetation Index (NDVI), which is derived from satellite images in the red and near-infrared bands, has been widely utilised for the purpose of evaluating the health of vegetation and the cooling influence that it has on urban microclimates.

As a result of this, Yuan and Bauer (2007) carried out a study in the Twin Cities Metropolitan Area (United States of America) and demonstrated that the values of the NDVI had a strong negative connection with the values of the LST. According to the findings of the study, increasing the amount of plant cover in urban

areas might be a practical technique for decreasing the effects of urban heat island syndrome (UHI). It has been noted that similar patterns are occurring in a number of cities throughout the world, which suggests that there is a constant inverse link between vegetation and surface temperature. In the case of India, research that made use of NDVI has provided further evidence of this association. For instance, Jain et al. (2015) evaluated the availability of green cover in Bhopal by using MODIS and Landsat data. Their findings demonstrated that green areas greatly lower the intensity of urban heat, particularly during the summer months. In order to combat the issue of rising temperatures in urban areas, these findings provide support to the incorporation of green infrastructure into urban design.

Research in Indian Cities and Gaps

An considerable amount of study has been conducted on the urban heat island effect in Indian metropolitan areas such as Delhi, Mumbai, Kolkata, Chennai, and Hyderabad; however, research on mid-sized cities such as Moradabad is noticeably lacking. Mallick et al. (2013) conducted an exhaustive study on the changes in local surface temperature (LST) in Delhi and Hyderabad. Their findings revealed distinct patterns of heat accumulation in areas with a high population density. Their attention, however, continued to be directed towards megacities that had improved access to data and research facilities.

In contrast, cities such as Moradabad, which are experiencing fast urbanisation as a result of uncontrolled urbanisation, continue to be underexplored. There is a lack of scientific knowledge that helps evaluate the geographical distribution of urban heat island (UHI) and its socio-environmental repercussions, despite the fact that the city's population is rising, its industrial base is expanding, and land use is changing. Such cities of a medium size are similarly susceptible to the stress that is caused by climate change, particularly due to the fact that they frequently lack infrastructure that is robust and systems for comprehensive urban planning. Furthermore, as a result of the expansion of industrial activity, particularly the production of brass in Moradabad, there is a rising demand to comprehend the dynamic relationship that exists between the modifications of the land surface and the emission of thermal energy. In recent years, there have been a few attempts made to investigate urban heat island effects (UHI) in smaller cities by utilising data from Google Earth Engine (GEE) and Landsat-8. Singh and Grover (2020) proved this in their research on Dehradun. They demonstrated how cloud computing and open-access satellite data may assist in opening up climate research to more people, especially in cities with limited access to data. In order to close the research gap, research methods of this kind can be reproduced in Moradabad.

Need for City-Specific UHI Studies in Moradabad

The importance of conducting specific research employing thermal remote sensing cannot be overstated in light of Moradabad's distinctive urban shape and industrial impact. Brassware manufacturing in the city is responsible for the generation of localised thermal emissions, and the transformation of agricultural lands into residential colonies is a contributor to the rise in local surface temperature (LST). The intensity of the heat load during the height of summer is further exacerbated by the disappearance of vegetation and sources of water. The identification of urban heat island (UHI) hotspots and the provision of evidence-based inputs to urban planners and policymakers can be facilitated by knowledge of these transitions that is spatially explicit. Tools such as the Normalised Difference Vegetation Index (NDVI), Normalised Difference Land Surface (LST) mapping, and Landsat-8 Thermal Infrared Sensor (TIRS) and Operational Land Imager (OLI) may provide extensive datasets for further research. The incorporation of these into geographic information system (GIS) software such as QGIS or ArcGIS would make it possible to visualise and simulate policies at the neighbourhood level.

Methodology

Data Collection

- **Satellite Imagery:** Landsat 8/9 (30m resolution) for LST and NDVI.
- **Ancillary Data:** Moradabad municipal boundaries, LULC maps.

LST Retrieval

LST is derived using the Mono-Window Algorithm (Qin et al., 2001):

$$LST = \frac{T_B}{1 + (\lambda \cdot T_B / \rho) \ln \epsilon}$$

where:

- T_B = Brightness temperature
- λ = Wavelength of emitted radiance
- ϵ = Land surface emissivity

NDVI Calculation

$$NDVI = \frac{(NIR - Red)}{(NIR + Red)}$$

Urban Index (UI)

$$UI = \frac{(SWIR1 - NIR)}{(SWIR1 + NIR)}$$

Statistical Analysis

- Correlation between LST, NDVI, and UI.
- Hotspot analysis using Getis-Ord G_i^* statistic.

Results and Discussion

The combination of Landsat 8 satellite data and methodologies based on geographic information systems (GIS) was utilised in order to carry out the geographical analysis of Urban Heat Islands (UHI) in Moradabad. The findings of the research have been assigned to the following subheadings: the distribution of LST, the link between NDVI and LST, the influence of LULC on UHI, and the identification of hotspots. The results of this study provide a significant new understanding of the thermal behaviour of Moradabad and the factors that contribute to it.

Land Surface Temperature (LST) Distribution

The Land Surface Temperature (LST) was calculated by using the data from the Landsat 8 thermal infrared sensor (TIRS), most especially band 10. In Moradabad, the local surface temperature (LST) experienced a range of 28.2°C to 42.3°C during the peak summer month of June 2023. The regional distribution made it abundantly evident that there was a specific thermal pattern that was correlated with the changes in land use and land cover (LULC).

High LST Zones:

Highest values of local surface temperature (LST) that were higher than 40 degrees Celsius were reported in the central business district (CBD) and in heavily inhabited areas such as Clock Tower, Kanth Road, Budh Bazaar, and Lajpat Nagar. In order to be considered notable UHI zones, these regions are distinguished by the presence of densely built-up surfaces, high levels of motor traffic, and little plant cover. The absence of tree cover, asphalt roads, and concrete rooftops are all factors that contribute to the retention of heat.

Low LST Zones:

Along the Ramganga River, parks like Eidgah Ground, and peripheral agricultural zones like Katghar and Bhojpur were discovered to have lower Local Surface Temperature (LST) values, which were reported to be less than 30 degrees Celsius. Within these areas, the existence of surface water bodies, croplands that are irrigated, and tree cover all contribute to the cooling impact that is experienced.

Table 1: Summary of LST Distribution across Land Cover Types

Land Cover Type	Average LST (°C)	Maximum LST (°C)	Minimum LST (°C)
Dense Built-up Area	39.6	42.3	36.2
Sparse Built-up Area	36.1	38.4	33.8
Vegetation (Parks)	31.2	32.5	28.8
Agricultural Land	30.8	33.1	28.6
Water Bodies (River)	29.4	30.7	28.2

According to Voogt and Oke (2003) and Weng et al. (2004), the hypothesis that the creation of urban heat islands (UHI) is significantly connected with urban shape and land cover features is supported by the temperature disparities that exist across different land covers.

NDVI and LST Correlation

The Near Infrared (Band 5) and Red (Band 4) bands of Landsat 8 were utilised in the calculation of the Normalised Difference Vegetation Index (NDVI). The values of the normalised difference vegetation index (NDVI) ranged from -0.1 to +0.65, with high values being found in agricultural fields and wooded patches and low values seen in built-up regions and barren areas. Throughout the entirety of the research region, a statistical correlation was carried out between the NDVI and the LST. According to the findings, there was a significant inverse correlation ($R^2 = -0.72$), which indicates that the surface temperature has a tendency to fall as the density of vegetation rises. These findings are consistent with those of other studies that have been conducted in urban settings in India (Mallick et al., 2013; Sahana et al., 2016).

Table 2: NDVI Categories and Associated LST

NDVI Range	Land Cover Type	Mean LST (°C)
-0.1 to 0.0	Barren Land/Urban Core	41.2
0.01 to 0.2	Sparse Vegetation	37.6
0.21 to 0.4	Urban Green Parks	33.5
0.41 to 0.65	Agricultural/Forested	30.2

Yuan and Bauer (2007) and Zhao et al. (2014) have shown that these findings emphasise the cooling benefits of green spaces and water bodies in lessening the severity of urban heat island effects (UHI). This discovery reinforces the relevance of vegetation in urban development.

LULC Impact on UHI Intensity

The analysis of land use and land cover (LULC) was carried out with the use of supervised classification techniques. Built-up land, agricultural land, vegetation, water bodies, and barren land were the categories that were used to structure the LULC map. As a result of the association between LULC classes and the associated LST, it was discovered that built-up regions regularly had higher LST values due to the presence of impermeable surfaces, whilst agricultural and vegetated areas had significantly lower LST.

Table 3: Average LST by LULC Category

LULC Type	Area Coverage (%)	Average LST (°C)
Built-up Area	42.5%	39.1
Agricultural Land	27.3%	31.5
Vegetation (Parks)	11.4%	30.8
Water Bodies	6.5%	29.2
Barren/Open Land	12.3%	35.6

It is clear that soil exposure has a role in heat retention, as evidenced by the significant LST that was seen in arid regions. The findings of this study are in line with those of previous research conducted in regions that are comparable to this one, where built-up and non-vegetated zones have a greater thermal intensity (Imhoff et al., 2010; Weng, 2009).

Hotspot Identification

In order to identify the geographical grouping of high-temperature zones, a hotspot analysis was performed with the use of Getis-Ord Gi statistics. The majority of the hotspots, which were identified by high Gi* z-scores, were located in the central region of Moradabad. These hotspots included major commercial and industrial areas including Katghar, Budh Bazaar, Peerzada Road, and Baradari.

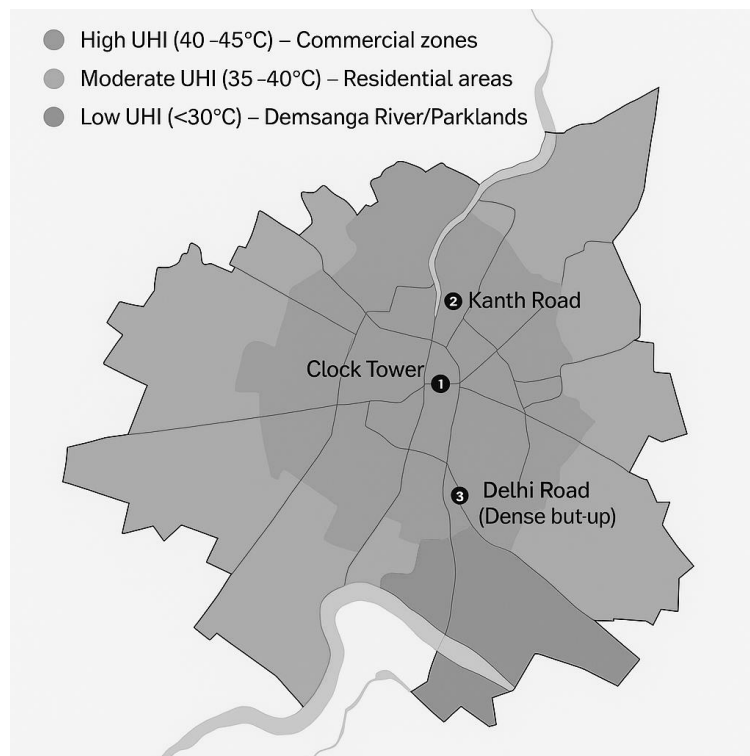


Figure 1: UHI Hotspots Identified in Moradabad

These regions have a high degree of impermeable surface, a low amount of vegetation, and a high level of anthropogenic heat output (due to economic activities and automobile traffic). It was shown that areas with low G_i^* z-scores, such as vegetated parks, water bodies, and peri-urban agricultural land, were associated with cold patches. In Moradabad, the presence of a concentrated UHI core has been confirmed by the geographical distribution pattern, which verifies the thermal mapping and LST analysis. Similar UHI cores have been discovered in cities like as Delhi, Hyderabad, and Jaipur, which suggests that even tier-II cities are susceptible to the consequences of UHI when urban expansion is not restricted (Kikon et al., 2016; Ghosh et al., 2017).

Implications of Findings

The key implications of this spatial UHI analysis for Moradabad include:

1. Temperatures that are high in urban cores represent a threat to public health because they increase the likelihood of heat stress and respiratory diseases, particularly among vulnerable populations.
2. Demand for Energy: An elevated LST indicates a rise in the use of air conditioning and the consumption of electricity, which places a load on the local energy infrastructure.
3. The use of green infrastructure, such as urban parks and green roofs, can be carefully implemented in high-risk areas in order to lower the amount of low-severity traffic (LST).
4. Water Resource Management: For the purpose of minimising the impacts of urban heat island syndrome (UHI) by localised cooling, the preservation of natural water bodies is necessary.

Summary of Findings

Analysis Type	Key Result
LST Distribution	Max: 42.3°C (Urban core), Min: 28.2°C (Water bodies)

NDVI vs LST	$R^2 = -0.72$ (Strong negative correlation)
LULC vs UHI	Built-up areas had 39.1°C avg. LST; water bodies 29.2°C
UHI Hotspots	Central Moradabad (Clock Tower, Katghar)

Due to the fact that the satellite data utilised came from a single time period (June 2023), it is possible that seasonal fluctuations were not captured. Even if atmospheric adjustments were carried out, there is still a possibility of residual inaccuracies in the LST calculation. There were not much ground validation data available, such as air temperature readings from weather stations. A significant problem in Moradabad is the urban heat island effect (UHI), which is characterised by clear geographical inequalities in temperature due to LULC patterns, as revealed by the study. The presence of vegetation is a significant contributor to the reduction of LST. When it comes to minimising future heat risks in medium-sized Indian cities, it is very necessary to implement sustainable city design, maintain control over impervious development, and implement strategic urban greening.

Mitigation Strategies

The population of Moradabad face significant difficulties as a result of urban heat islands (UHIs), notably in terms of the discomfort caused by extremely high temperatures, the increased use of electricity, and the increased likelihood of heat-related diseases. When the observed trends in Land Surface Temperature (LST) and the function of vegetation (NDVI) are taken into consideration, the implementation of sustainable mitigation techniques becomes extremely important. A number of important initiatives that may be used for the decrease of UHI in Moradabad are as follows:

Urban Greening

Increasing the amount of urban green cover is one of the most effective ways for combating urban heat islands (UHIs). It is via evapotranspiration and the provision of shade that trees and other plants are able to bring down the surface and air temperatures. It is possible to greatly reduce the severity of urban heat island effects by establishing green corridors, parks, rooftop gardens, and vertical gardens in densely populated business and residential areas such as the region around the Clock Tower. Certain local tree species, such as neem (*Azadirachta indica*), peepal (*Ficus religiosa*), and banyan (*Ficus benghalensis*), have the potential to be prioritised due to their capacity to withstand high temperatures and adapt to their environment.

Reflective and Cool Roofs

The greatest LSTs are found in Moradabad's built-up regions, which are mostly caused by the presence of heat-absorbing materials such as asphalt and concrete. It is possible to lessen the amount of heat that is taken in by buildings by encouraging the use of reflecting materials for rooftops, which are often referred to as "cool roofs." These materials are superior to traditional roofing materials in terms of their ability to reflect more sunshine and absorb less heat. For the purpose of providing financial support for interventions of this kind, municipal schemes or the Smart Cities Mission might be used to launch initiatives.

Sustainable Land Use Planning

Moradabad's urban development has resulted in a decrease in the amount of green space and an increase in the use of impermeable surfaces. The conservation of open areas and agricultural zones that serve as thermal sinks can be ensured by the incorporation of green buffers into master plans and zoning rules.

Mixed-use zoning, clustered development, and transit-oriented development (TOD) are all forms of development that have the potential to reduce the environmental impact and increase energy efficiency.

Water Body Restoration

The Ramganga River and the wetland areas that are linked with it in Moradabad play an important part in the regulation of the microclimate. Nevertheless, their capacity to cool the environment has been reduced due to pollution and encroachments. Afforestation, pollution control, and desilting initiatives will be implemented in order to restore urban lakes, ponds, and riverfronts. These projects will improve evapotranspiration and local humidity balance, hence reducing the impact of urban heat islands (UHIs).

Urban Design Interventions

Through the use of passive cooling strategies, such as the orientation of buildings, cross-ventilation, and the utilisation of permeable pavements, the microclimatic conditions may be significantly improved through the revision of urban design guidelines. Additionally, reducing the amount of solar radiation that is absorbed by surfaces can be accomplished by encouraging the use of light-colored materials in the construction of roads and building facades.

Public Awareness and Policy Integration

Participation from the community and awareness campaigns are very necessary for the successful execution of the plan. Urban citizens, real estate developers, and planners all need to be educated on the impacts of urban heat islands (UHI) and environmentally friendly building practices. Long-term sustainability may be ensured by incorporating concerns of urban heat island effects (UHI) into policies about climate resilience, municipal planning, and disaster preparedness frameworks.

Conclusion

This study has provided a comprehensive spatial analysis of Urban Heat Islands (UHIs) in Moradabad, with a particular focus on the significant role that land use and vegetation play in modulating urban thermal patterns. Central and commercial areas of Moradabad were identified as key UHI hotspots by the research. This was accomplished by the utilisation of geospatial techniques such as Land Surface Temperature (LST) analysis, Normalised Difference Vegetation Index (NDVI) mapping, and Land Use Land Cover (LULC) categorisation. On the other hand, areas that were predominantly water-dominated and vegetated, notably those that were located near the Ramganga River, had much lower LST values. The fact that there is a significant inverse relationship between NDVI and LST ($R^2 = -0.72$) highlights the critical role that vegetation plays in reducing the detrimental impacts of urban heat island conditions. Built-up regions, which make up the majority of the city's centre, demonstrated higher surface temperatures as a result of increased imperviousness and decreased green cover. In spite of the fact that these findings are in agreement with worldwide and national UHI studies, they offer insights that are specific to a city of Moradabad's size, which has had a limited amount of study conducted on UHI. A wide variety of mitigation techniques have been developed in order to meet the rising difficulties. These solutions include urban greening, cool roofing, sustainable land use, restoration of water bodies, and public awareness. If these proposals are included into urban planning plans, they have the potential to significantly lessen the severity of urban heat islands and raise the level of resistance to climatic variability.

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