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Seasonal And Diurnal Variations Of Urban Heat Island Intensity In Ludhiana: A Zone-Wise Comparative Study

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Abstract
In fast-growing Indian cities, the Urban Heat Island effect is becoming a significant concern for both microclimates and public health. The study examines the seasonal and diurnal temperature and relative humidity variations of Urban Heat Island in representative locations, including two locations from the inner zone, one location from the outer zone, one location from the peri-urban area, and one rural location developed as a reference location. To see the seasonal variations with respect to the different types of neighborhoods in composite climate of Ludhiana, data loggers are fixed at all locations, which collected the data on an hourly basis for three representative months: January, June, and December. To determine the diurnal temperature difference, observations were taken at 6 AM, 6 PM, and the afternoon peak hours temperature (3 PM-4 PM). The results show the strongest UHI effect is in the month of summer with a temperature difference of more than 5°C, and also, there is an intercity temperature difference between all the locations due to the different types of Geometries (Road orientation, spec Ratio, and Sky View Factor) across all locations. The conclusions from the study clearly shows that Urban Heat Island Effect Intensity in Ludhiana is influenced by both seasonal climate and urban geometry and also highlight the urgent need to incorporate policies in the Ludhiana smart city mission for existing and new residential developments, including mitigation techniques for retrofitting current locations and planning guidelines for upcoming neighborhoods.
Key Words: *Urban Heat Island, Urban Geometry, Sky View Factor, Aspect Ratio, Diurnal Temperature, Neighborhood.*

1. INTRODUCTION:

Urban heat islands are characterized by elevated urban temperatures compared to surrounding rural areas, primarily due to city geometry, surface materials, reduced vegetation and anthropogenic heat emission (Oke,1987:Santamouris) and energy consumption that lead to heat absorption, creating "heat islands" .These heat islands significantly alter the microclimate of urban areas. The UHI effect is most pronounced in the summer season due to the constant exposure of surfaces to solar radiation. Despite its growing global recognition, urban climate change research in India is still in its infancy. Most studies have been concentrated in southern urban areas, while research in the northern regions of the country remains limited. Furthermore, the majority of these studies primarily focus on urbanization and its effects on air temperature and humidity, while giving little attention to micro-level studies that examine the geometry and urban fabric of the city and their impact on the intensity of the UHI effect, as well as potential mitigation strategies for it.
On June 12, 2025, the India Meteorological Department issued a red alert for a severe heat wave in many parts of Punjab, warning that temperatures were 5–6°C above normal and could cross 45°C. Over the past five decades, Ludhiana has witnessed immense population growth, accompanied by pollution, environmental degradation, the proliferation of slums, and the strain or failure of physical and social infrastructure. The city's unplanned industrial growth and urban sprawl have intensified heat retention due to extensive built-up areas and the reduction of green cover. On May 22, 2025, the Ludhiana Health Department released a heat wave advisory asking people to avoid going out in the afternoon sun and to drink plenty of water, as the city was facing extreme heat. This underscores the urgent need for microclimate-focused studies in northern India. Ludhiana, Punjab—owing to its rapid urbanization and status as one of the state's largest and most densely populated and smart cities—presents an ideal case for examining the UHI effect.
Previous research in Indian cities has shown that the intensity of the Urban Heat Island (UHI) effect changes with the time of day and the season (Kikon et al., 2016; Kumar & Kaushik, 2022). The impact is usually

stronger at night, especially in dense city areas where the narrow streets and built-up structures reduce the sky view and trap heat, which gets released slowly after sunset (Gupta et al., 2021).
This study focuses on how the seasonal UHI effect behaves across different representative locations in Ludhiana city. Five locations were selected to represent the Inner Zone, Outer Zone, and Peri-Urban Zone, and a rural baseline location for comparison. Following are the Objectives of the study.

- To quantify the Seasonal comparison of UHI intensity in Intercity and rural locations for the months of January, June, and October.
- To observe the diurnal temperature difference across all locations.
- To relate UHI intensity to the location geometry, including Road orientation, Aspect ratio, and Sky View Factor.
- To provide location-specific mitigation techniques for reducing the intensity of the UHI Effect in Ludhiana.

2. Study Area

Ludhiana, located at 30°56' N and 75°52' E, is the first metropolitan city in Punjab. Due to its rapid urbanization and significance as an industrial centre in northern India, Ludhiana is frequently referred to as the "Manchester of India." The city has a unique identity shaped by its historical growth, physical, economic, and social structures, and its service to the people of the city, state, and country over time. Centrifugal forces cause cities to grow outward, resulting in three zoning layers that show the evolution of the city over time. Analysing these zones reveals important planning and management difficulties, as well as trends of urban expansion. These zones are the Inner Zone, Middle Zone, and Outer Zone (Peri-urban Zone). The composite climate of Ludhiana experiences seasonal variation throughout the year. The district has distinct seasons, including extreme summer (temperature exceeding 45 °C), chilly winter (Minimum below 5 °C), and the rainy season. Following Table 1.1 showing the morphological and typological features of each location.

Table 1.1: Morphological and Typological features of each location

Location Detail	**Zone& Land Use**	**W/ H**	**SVF**	**Road Orientati on**	**Vegetatio n**	**Urban Surfaces**
L-1, Choura bazaar	Inner Zone, high-density urban built-up with continuous Wall-to-Wall construction, mix of residential and commercial	1	0.54	E to W	no greenery	Brick, Cement, Plaster, Glass, Asphalt Road with cemented pathways
L-2, Dal Bazaar	Inner Zone high-density narrow streets without pathways, continuous Wall-to-Wall construction mix of residential and commercial	3		0.24	no greenery	Brick, Cement, Plaster, Glass, Asphalt Road
L-3, Jabaddi Road	Outer Zone, high-density urban built-up area, continuous Wall-to-Wall construction with front and rear set back, land use.	0.7	0.54	NE to SW	Fewer trees on both sides of the road.	Brick, Cement, Plaster, glass, marble cladding Glass, Asphalt Road
L-4, Agar Nagar, ,near house	Peri-Urban, high-density urban built-up area continuous Wall-to-Wall construction with front rear and some where side set	0.5	0.33	N to S	Very Less trees, shrubs	Brick, Cement, Plaster, Glass, Asphalt Road

number 100 a	back, dominating residential					
L-5, Jhande Pind	Rural. Agriculture land use with few residential developments	Op en	0.7	NE to SW	less trees	Green with few brick and cement material developments

Source: Author

3. METHODOLOGY

To gather real-time monitoring data across all the locations**, G, Tech** data loggers were installed at all the locations**.** The factory -calibrated accuracy of these loggers is ±0.5°C and each logger was set to record hourly readings, continuously collecting of ambient temperature humidity. The loggers were placed in the shield, with dimensions of 8” × 8” × 8”, was constructed from wood due to its insulating properties. To minimize the influence of surrounding built-up structures, each shield was positioned at least 1 m away from walls or other obstructions. The shields were mounted at heights ranging from 2.0 to 2.5 m above ground level, ensuring placement within the urban canopy while reducing risks from pedestrians, anthropogenic heat, vandalism, or theft. Season wise temperature data were collected for the month of January (winter), June (extreme summer), and October (post-monsoon) during 2023–24.These months are selected as extreme seasons representative and transition periods. Excel files prepared by displaying daily temperatures for every month were created by compiling hourly data from each station. Interpretation was carried out through graphical analysis showing the maximum and minimum temperature differences, diurnal temperature range (DTR), and location-wise temperature differences between rural and urban areas.Urban Heat Island (UHI) intensity was calculated as:

UHI=Turban−Trural UHI = T_{urban} - T_{rural}UHI=Turban−Trural

(Where Turban is the temperature at each urban/peri-urban site and Trural is the temperature at Jande Pind)

Data is analyzed bases on the Seasonal comparison (January, June and October), Diurnal Temperature Difference, Zone wise comparison, Linking UHI effect intensity to the geometry of the locations.

Figure 2 Summer Period Temperature pattern

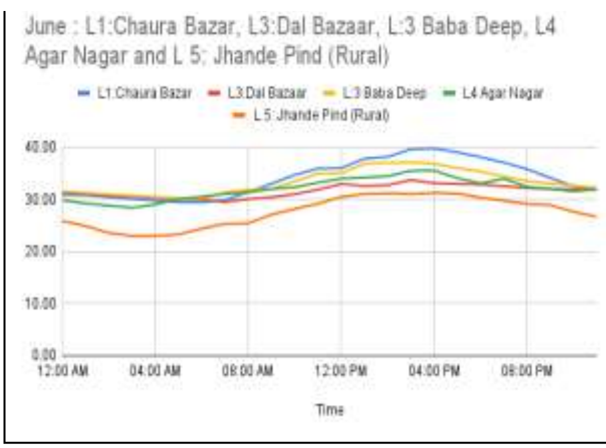
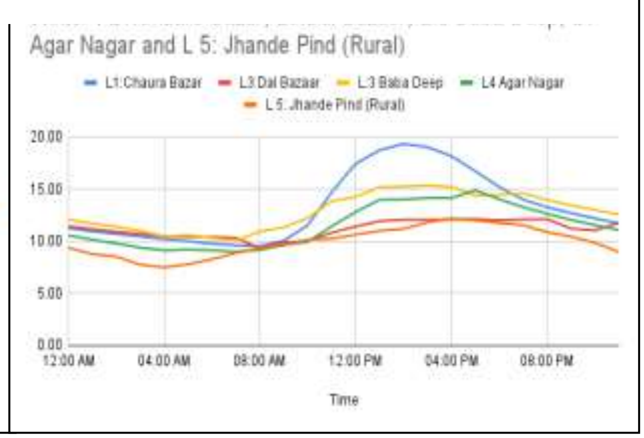


Figure 1 Winter Period Temperature pattern



4. RESULTS

4.1 Seasonal Patterns

- **Summer Period (June Month):**

The summer (June) temperature pattern across all locations shows a clear UHI effect in the city with different intensities due to the different urban geometry of each zone (Graph 1). The highest temperature across all the locations in the inner zone (L1) with a maximum average temperature of 39°C. The rural village has a temperature of 34°C, which is less than across all the locations and 5 degrees different from the hottest location, 1. Outer residential areas like Agar Nagar were not as hot as the inner city but still warmer than the rural location. This shows that the built form and lack of greenery in dense areas are the main reasons for the stronger UHI in Ludhiana.

Winter Period (January Month): The winter temperature pattern across all the location showed a modest UHI intensity as compare to the summer (Graph 2). The Location 1 choura bazaar again recorded the day time peak temperature higher than other locations. It is 19°C which is 4-5 °C warmer than the rural Location. In the intra city temperature pattern shows that the temperature difference is shown after noon hours. Although location 2 is also in the inner zone but its temperature is less than the location one due to its increased aspect ratio. Rural development shown remained cool than all the other locations. Outer zone location 3 shown moderate temperature difference.

Post Monsoon Period (October Month): The post-monsoon temperature pattern also showed a moderate UHI intensity (Graph 3). Location 1, Choura Bazaar, and Location 4, Agar Nagar, showed the maximum temperature around 27°C. The Rural Location remained cooler than all the other locations (24°C). The difference between peak and rural locations is 3-4°C during the day. It indicates UHI intensity is low in the post-monsoon period, but there is an effect of UHI in the urban locations.

Figure 4 Post Season temperature pattern

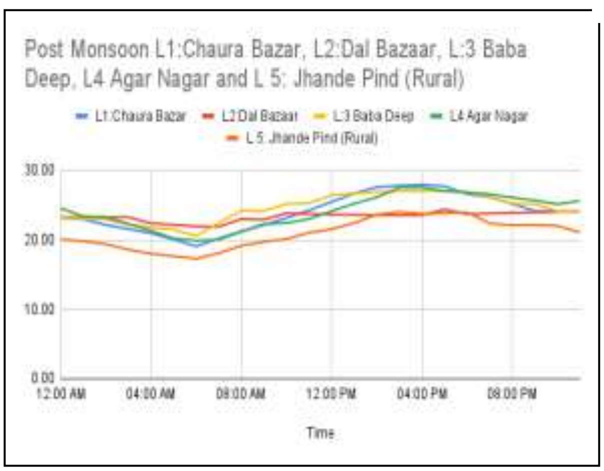
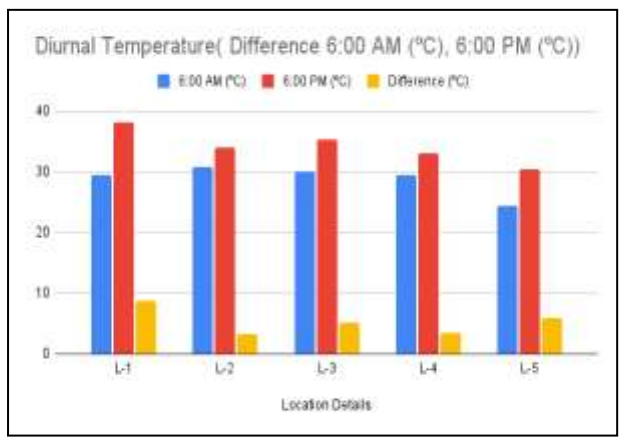


Figure 3 Diurnal Temperature Difference



4.2 Diurnal Temperature Difference:

Graph 4 shows that the locations of the inner, outer, and peri-urban zones are warmer than the rural zones both in the morning (6 AM) and in the evening (6 **PM).** At 6 AM, urban locations were 3°C –5 °C warmer than rural baseline locations. This data indicates the presence of the nocturnal Urban Heat Island (UHI) effect in the city. In the evening, location 1 has the maximum temperature, and its difference from the rural location is also greater. Further, the nighttime cooling is maximum in location 1; it is due to its aspect ratio and SVF, and location 2 has minimum nighttime cooling due to its high aspect ratio and lower sky view factor. The results confirm that dense urban locations experience strong UHI intensity during the daytime and slower nighttime cooling.

4.3 Zone –Wise Differences

Inner Zone: Compact land use, Highest Urban Heat Island intensity in the inner zone location 1 at the same time L2 has less temperature due to the deep canyon and less aspect ratio (shadow effect).The temperature

difference from all the other locations is ranges from 3°C -6°C.
Outer Zone: Having front and rear set back, Morderate Urban Heat Island Intensity from 1.5 °C to 3°C.
Peri-Urban Zone: Planned residential Neighborhood development having temperature difference of 1-2, with few hours showing neutral UHI during morning.
Rural: Base line location cooler than all the other locations both in day time and Night time temperature.

5. DISCUSSION: WRITE UP FOR DISCUSSIONS

According to the study, Ludhiana's Urban Heat Island intensity varies with the time of day and the season. The strongest UHI was recorded during the summer, when Chaura Bazar was almost 5°C hotter in the afternoon than the rural location. The effect persisted into the night, with open rural surroundings cooling more quickly than densely populated areas. The temperature raised in the different location is also depend on the orientation of the road .The locations on the EW road has maximum temperature during day as in Location 1. The difference was less pronounced in the winter, ranging from 2 to 3°C at night to as much as 4 to 5°C during the day. The post-monsoon and transitional months displayed moderate values. This study shows that climate also has a significant influence on the amount of UHI.
The diurnal temperature analysis highlights the temperature difference between the coolest and hottest periods of the day and night. Although city locations are warmer than rural ones at 6 AM, by the evening, the difference had increased more. Urban Heat Island Intensities were consistently highest in the inner city, moderate in the outer residential zones, and coolest in the rural areas. The day and nighttime temperature pattern shows distinct diurnal temperature variations across different zones. Observations showed that if the Aspect ratio is 1 or nearby 1, then the diurnal temperature difference is much better than the location having more than 1 aspect ratio.
The recordings from all the locations differ, indicating that, in addition to the rural and urban location, city geometry with respect to Aspect Ratio, Sky view factor, and orientation of the Road also influences the intensity of the UHI effect. So there is an immediate need for climate-responsive urban design. The increase in the intensity of the Urban Heat Island not only raises energy consumption and outdoor comfort but also affects the health of city residents.

6. CONCLUSION AND RECOMMENDATIONS:

This study shows the notable temporal and spatial variations in the intensity of Ludhiana's UHI Effect. June records the highest intensities in compact and dense inner zones, reaching temperatures of 3.5–4°C.In January, a significant nocturnal UHI (~2–3 °C).Transitional intensities were observed in October. Microclimates were largely shaped by morphological parameters, especially SVF, H/W ratio, and vegetation.
Recommendations
Green Infrastructure: In the inner zone, as the road size is fixed, we cannot widen the road or plant trees along the side of the roads, so we can provide wall creepers and avoid heat-absorbing materials and cool-color facades towards the vertical surfaces. Along the outer and peri-urban zones, plant trees along the side of the roads. Use reflective or high-albedo materials to promote cool roofs, permeable pavements, and light-colored roof surfaces. For the new development, enhance the street design modifications by enhancing the ventilation by controlling road orientation, aspect ratio, and sky view factors. The Ludhiana Smart City Initiative also incorporates Urban Heat Island mitigation policies into its building bylaws.

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