

## Spatio-Temporal Dynamics of Urbanization and Urban Heat Island Development in Rohtak City

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### *Abstract*

Rohtak has been emerging as a rapidly developing urban area in the state of Haryana owing to its closeness to the National Capital Region (NCR) of Delhi along with socio-economic development. This paper analyzes the transformation of LULC in Rohtak City over 24 years from 2000 to 2024 along with their effects on LST and UHI formation. Landsat satellite images and geo-spatial analysis have been used to determine the extent of urbanization and changes in various LULC types, as well as their impact on urban LST conditions. The findings indicate that there have been marked changes in LULC types such as an increase in the proportion of built-up zones coupled with a decrease in vegetation cover, which resulted in the creation of an altered urban thermal environment. It was found that regions that had dense built-up areas had higher LSTs than areas with less vegetation cover. NDBI was strongly correlated with LST. These results clearly highlight the increasing role played by anthropogenic changes on the urban microclimate as well as the necessity of using remote-sensing-derived spectral indices in assessing the dynamics of urban heat islands. This study is quite informative in devising sustainable urban planning practices to counteract the negative impacts of urbanization on Rohtak City.

**Keywords-** Land Surface Temperature (LST); Land Use/Land Cover (LULC) Change; Remote Sensing; Urban Heat Island (UHI); Urbanization.

### I. INTRODUCTION

Urbanization is one of the major factors causing environmental changes in the twenty-first century, especially in developing countries like India. Increased population, industrialization, and infrastructural development have led to land conversions from agricultural fields, open lands, and natural vegetation cover to developed land covers. Such processes bring about a change in the physical nature of the Earth's surface, thus influencing climatic conditions, thereby resulting in Urban Heat Island phenomenon in which temperatures in urban areas are relatively higher than in adjacent rural regions (Jain & Redhu, 2023). As an urban area that is expanding at a fast pace in the state of Haryana, Rohtak has experienced significant spatial expansion in recent years because of its position within the impact range of the NCR of Delhi. The development of infrastructure for residence, industry, and transportation purposes has resulted in the conversion of natural vegetative land cover and agricultural cover into impervious cover comprising concrete and asphalt material. Impervious surfaces have a greater ability to store solar energy and contribute to higher LST and the Urban Heat Island phenomenon (Kumar & Ripudaman, 2024). Previous research has shown that there is a significant correlation between LULC change and urban thermal properties, especially in expanding urban centers. The decrease in vegetation cover or loss of green space, expressed in reduced NDVI, as well as increased built-up density, expressed in increased NDBI, was associated with high LST and greater thermal stress (Khan et al., 2024; Sharma et al., 2025). Remote sensing and GIS technologies have made it possible for scientists to detect such changes with the help of satellite images from different times and their indices (Hàng & Alshayeb, 2025; Karagwal et al., 2025). Studies that involve long-term analysis of the geospatial dynamics are crucial in examining issues related to the urban expansion and its environmental impact. Long-term multi-temporal studies using Landsat imagery are extremely useful in analyzing land cover pattern change, distribution of vegetation, and heat signatures that occur due to increased anthropogenic activity. Such studies allow us to determine the spatial extent of urbanization, fragmentation of natural areas, and thermal anomalies (Duan et al., 2025; Sharma et al., 2026). Though there has been a considerable number of studies conducted on the urban heat island effect in metropolitan areas, medium-size cities such as Rohtak have received limited attention so far. This deficiency in the literature base has hindered the formulation of relevant urban planning policies as well as climate change adaptation plans for secondary, rapidly urbanizing cities (Nooji et al., 2025). Considering the fast-paced rate of urbanization taking place in Rohtak and its ecological importance in the NCR influence area, a study is overdue. In light of all these factors, the current research work is an attempt to understand the spatio-temporal dynamics of land use land cover change and development of Urban Heat Island phenomenon in Rohtak City

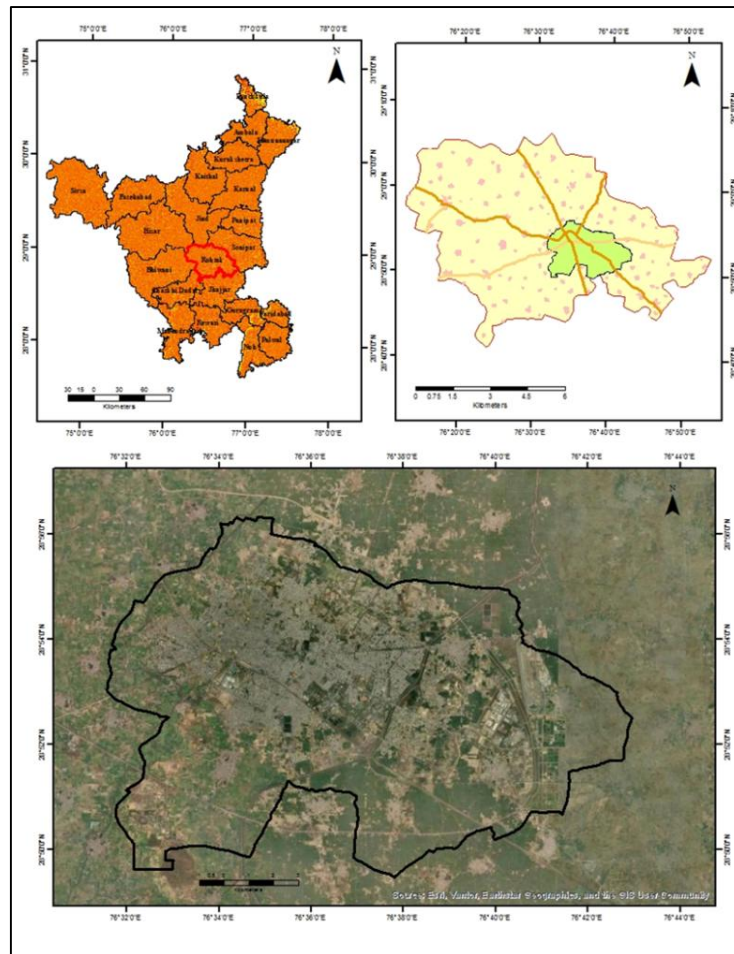
using multitemporal Landsat images and geographic information system techniques from 2000 to 2024. In addition, the objectives of the study include mapping of urbanization, estimating LULC changes among the various categories, analyzing the correlation between LULC and land surface temperature and finally assessing the contribution of built-up land cover change towards Urban Heat Island development. This research will be beneficial in understanding the environmental impacts due to urbanization and help plan future development accordingly.

## II. RESEARCH PROBLEM

The phenomenon of fast-paced urbanization has become one of the principal factors behind the transformation of environments in the Indian urban context, bringing about considerable changes in terms of land use and land cover (LULC) along with the changes in local climate conditions. Due to the fact that farmland and green vegetation areas are being replaced with concrete structures, the area covered by impervious surfaces has been growing, absorbing a higher amount of energy. In particular, numerous urban centers across India have been experiencing higher temperatures, leading to UHI effect (Kushwaha & Nithiyandam, 2019; Tiwari & Kanchan, 2024). Studies carried out in several prominent Indian cities like Delhi, Mumbai, and Faridabad indicate an evident connection between urbanization, lack of vegetation, and increased thermal load (Ashraf et al., 2024; Wijesinghe et al., 2025). The quick substitution of vegetative or agricultural land surfaces by concrete structures causes less evaporation-transpiration, hinders natural cooling mechanisms, and leads to the accumulation of sensible heat in the city regions (Dhankar et al., 2024; Naserikia et al., 2022). Additionally, the depletion of the area covered with vegetation and water sources diminishes the ability of the urban environment to regulate temperatures, whereas the density of buildings, along with impervious surfaces, promotes thermal accumulation (Verma et al., 2021; Imran et al., 2021; Joshi et al., 2024). These factors altogether result in the formation of characteristic Surface Urban Heat Islands, making the cities noticeably warmer than the adjacent rural territory (Roy & Roy, 2024; Liyaqat et al., 2025). One of the fastest growing cities in the state of Haryana is Rohtak, which has experienced significant spatial development over the last two decades owing to the increase in population, construction of infrastructures, and its advantageous position in the proximity of the National Capital Region (NCR) of the Indian capital, Delhi. The fast pace of urbanization in the area has led to a significant change in the use of land, as farmlands and vegetations have been converted to accommodate new housing, industries, and infrastructures. Such changes are expected to modify the thermal environment in the city (Rana et al., 2023; Akram et al., 2024). Although the rate of urbanization in Rohtak is accelerating, very few studies have attempted to understand the link between LULC change and the formation of the Urban Heat Island effect in Rohtak. Studies conducted so far have mostly concentrated on metropolitan cities, and thus, little attention has been paid by the scientific community to smaller cities (Bhatt et al., 2023; Jain, 2023). Therefore, it is important to note that the effects of urban sprawl and the loss of vegetation cover on LST variability are yet to be properly studied. It is necessary to bridge this research gap for any sustainable city planning and development with resilience against climatic variability. A complete understanding of the association between urbanization and changes in thermal environments can be used as a foundation for developing appropriate mitigation measures such as conservation of urban green areas and environmentally sustainable land use. For these reasons, this paper analyzes the spatiotemporal pattern of urbanization and UHI in Rohtak City from 2000 through 2024 by employing remote sensing and GIS methods. Through investigating the effect of LULC changes on Land Surface Temperature, an attempt will be made to offer a scientific basis for urban planning and environmental management.

## III. STUDY AREA

The area under consideration is about 149 km<sup>2</sup> of Rohtak City, which is situated in the central part of Haryana in India at around 70 km northwest from the city of Delhi, in the National Capital Region (NCR) influence zone (Figure 1). As for the geographical situation, the considered territory is found in the rich Indo-Gangetic Plain, with mostly plain terrain, low relief, and wide-spread alluvial soils. Rohtak belongs to the semi-arid climate zone, characterized by very hot summers, cold winters, and monsoon rains being the major source of annual precipitation. In the recent 20 years, there have been some important social, economic, and spatial transformations in Rohtak because of population growth, expansion of the urban infrastructure, and increased economic activity in this area. The advantageous geographical position of Rohtak and enhanced connections between the city and Delhi as well as other urban centers of Haryana led to the further development of the city. As a result, there were some considerable alterations in land use/land cover in the territory of Rohtak City. These changes have made significant impacts on the physical properties of the land's surface and the micro-climatic condition of the area. Due to the increasing share of impervious surfaces of construction, along with declining plant cover, LSTs and SUHI hot spots have emerged as results. In other words, Rohtak offers a perfect case study for studying the temporal and spatial effects of urbanization, LU/LC changes, and the formation of urban heat islands. It is important from the perspective of assessing the effects of urban expansion on the natural environment and developing effective policies for sustainable urban development.



**Figure 1. Location Map of the Study Area: Rohtak City, Haryana, India.**

#### IV. RESEARCH OBJECTIVES

The principal focus of this study is to investigate the spatio-temporal dynamics of urbanization and their influence on Urban Heat Island (UHI) development in Rohtak City. Rapid urban expansion and associated land use/land cover (LULC) transformations have significantly altered the city's thermal environment, posing challenges to environmental sustainability and urban ecological health. To address these concerns, the study seeks to achieve the following objectives:

- i. To map and quantify the spatio-temporal patterns of land use/land cover (LULC) change and urban expansion in Rohtak City during the period 2001–2024.
- ii. To map and assess the spatial extent, intensity, and temporal evolution of the Urban Heat Island (UHI) in Rohtak City from 2001 to 2024.

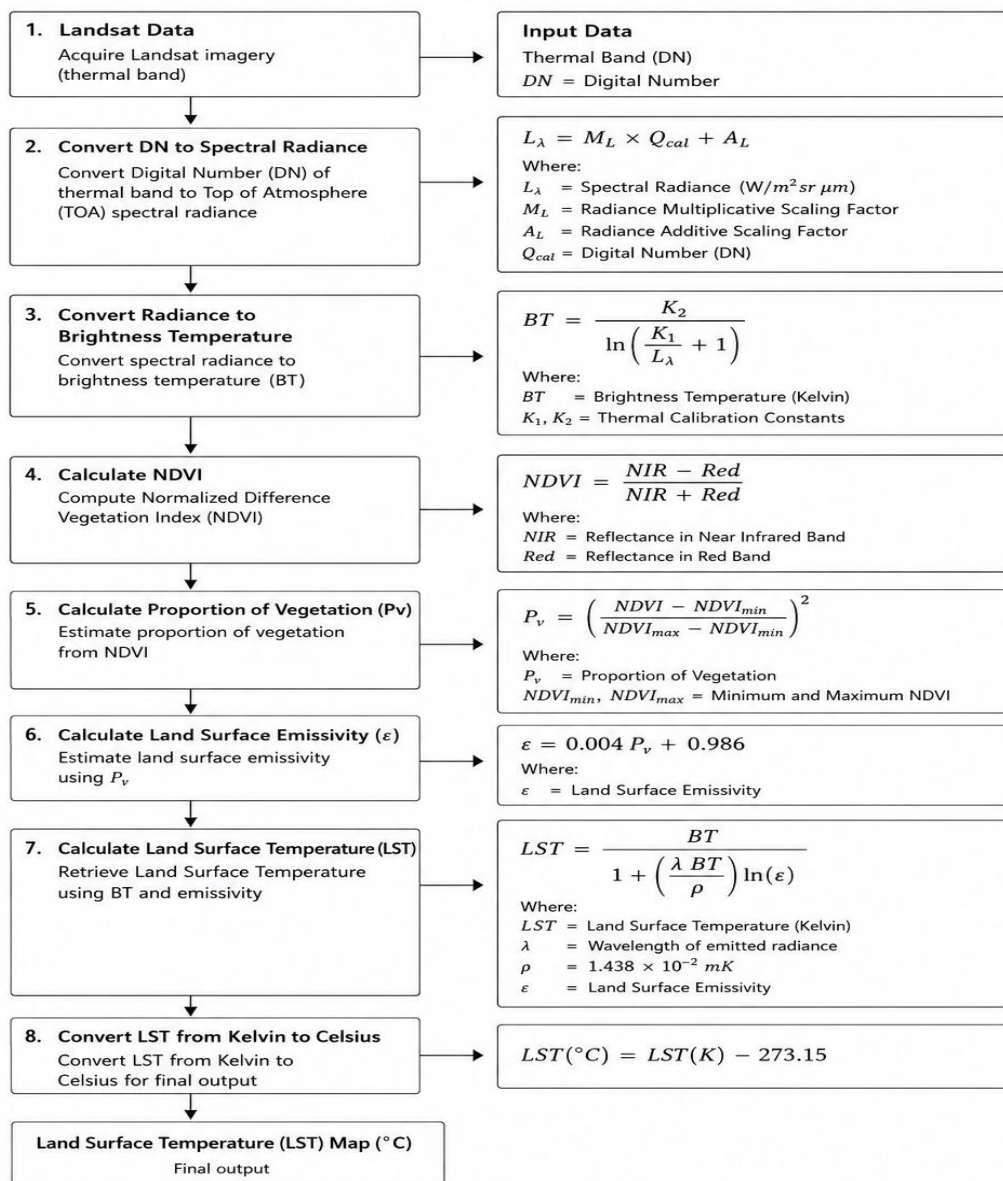
#### V. DATA SOURCES AND METHODOLOGY

The current research made use of a mix of satellite imagery, census data, and weather data in analyzing the influence of urbanization on LULC changes and UHI formation in Rohtak City from 2001 to 2024. Multi-temporal Landsat satellite images for the years 2001, 2013, and 2024 were obtained through the USGS Earth Explorer website. Supporting data such as population data from the Census of India and weather data from the IMD were also gathered in interpreting the findings. A summary of the datasets used in the research is shown in Table 1.

**Table 1. Details of the Data Sources and Characteristics of Datasets Used in the Study**

Satellite/Platform	Sensor	Year	Scale/ Resolution	Source
Landsat 7	ETM	2001	30m	USGS( <a href="https://earthexplorer.usgs.gov/">https://earthexplorer.usgs.gov/</a> )
Landsat 8	OLI	2013	30m	
Landsat 9	OLI	2024	30m	

Firstly, the satellite images were processed through pre-processing, which included radiometric correction, atmospheric correction, geometrical correction, and clipping of the study area from the image. Then, supervised classification was carried out using the Maximum Likelihood Classification (MLC) approach to create the LULC map of the selected time period. Five major classes of land use/land cover have been observed, namely, built-up areas, agriculture lands, vegetation, bare lands, and water bodies. In order to measure the vegetation state as well as its relationship with the urban heat status, the Normalized Difference Vegetation Index (NDVI) was calculated based on the processed imagery data. In turn, the Land Surface Temperature (LST) was estimated through Landsat imagery based on thermal bands using an algorithm including several stages such as conversion from digital numbers to spectral radiance, estimation of brightness temperature, emissivity, and finally calculation of surface temperature (Figure 2). The intensity of the UHI effect was determined through the thermal comparison of urban built-up land cover with its surroundings. Maps of the spatial distribution of LST were created to determine the thermal hotspots and estimate the level of urban heat in the study area. Lastly, an integrated analysis of the three datasets of LULC, NDVI, and LST was performed to investigate the connection between urbanization and changes in temperature in association with vegetated areas. Additionally, the findings were analyzed in relation to the growth of the population and urbanization trends in Rohtak City.

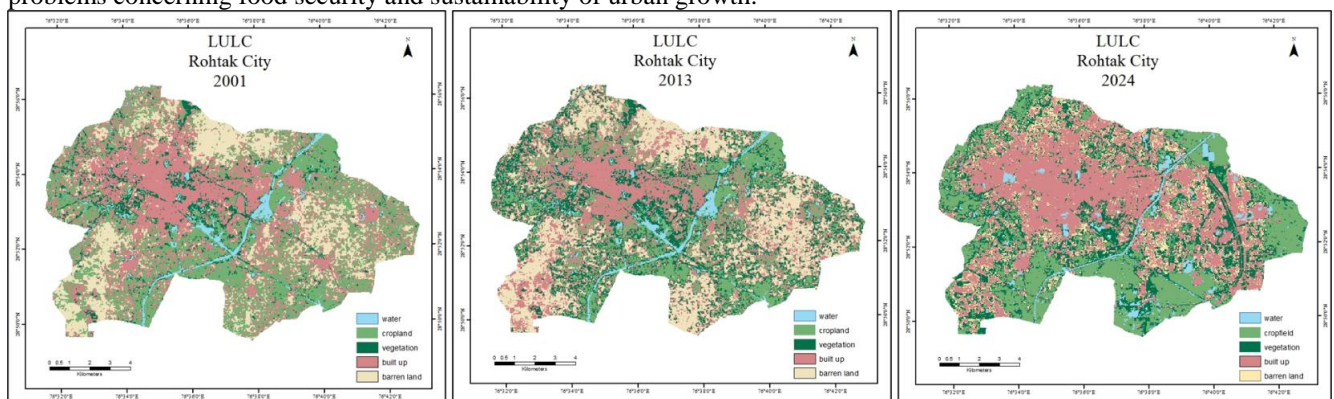


**Figure 2. Methodological Framework for Land Surface Temperature (LST) Retrieval from Landsat Satellite Data.**

## VI. RESULTS AND DISCUSSION

**Land Use/Land Cover (LULC) Change Analysis**

The analysis of LULC change of Rohtak city between 2001 and 2024 has shown significant change in its landscape caused mainly by urbanization processes and changes in land use. Within the analyzed period, there were several important changes in the proportion of built-up lands, fields of crops, vegetation, barren lands, and water resources in the studied territory due to the growing urban impact. Thus, according to the data for 2001, it is possible to observe an almost equal distribution of built-up lands and agricultural cropfields, which covered 53 km<sup>2</sup> and 52 km<sup>2</sup>, respectively. In 2013, however, it was observed that the area of built-up lands decreased slightly and was equal to 45 km<sup>2</sup>, what can be explained by the classification changes and transitional land uses that occurred within the process of urban restructuring. At the same time, vegetation increased significantly from 11 km<sup>2</sup> to 28 km<sup>2</sup>, and the area of barren land increased from 28 km<sup>2</sup> to 37 km<sup>2</sup>. The most dramatic changes occurred in 2024; the built-up land increased to 59 km<sup>2</sup> and emerged as the largest type of land use in the city. This increase can be associated with urbanization, infrastructure construction, and the growth of the city's population in the past decade. Agricultural lands reduced to 35 km<sup>2</sup>; the conversion of agricultural lands to other types of lands was observed. Barren lands declined dramatically to 17 km<sup>2</sup>. The reason for the reduction could be the conversion of barren lands to built-up lands and vegetation. Moreover, the vegetation area increased to 32 km<sup>2</sup> as a result of an increase in the number of green zones, agricultural plantations, and landscaped territories. Finally, water bodies slightly increased from 5 km<sup>2</sup> to 6 km<sup>2</sup> in the analyzed period. According to the results of percentage changes, the built-up land increased by 11.3%, which confirms the continuous urban expansion processes. Agricultural lands declined by 32.7%; that is why urbanization has an adverse impact on farmland. Vegetation demonstrated the greatest increase, namely 190.9%. As for barren lands, their amount declined by 39.3%. Water bodies increased insignificantly by 20.0% in the analyzed period (Table 2). In summary, the results of the analysis of Land Use Land Cover indicate that there have been major changes in the urban development of Rohtak over the last few years (Figure 3). The conversion of agriculture and barren lands into urbanized areas, which are a reflection of the increasing economy and infrastructure development in the region. Although the increase in vegetation cover can be regarded positively from the environmental point of view, the reduction in agricultural lands can pose several problems concerning food security and sustainability of urban growth.



**Figure 3. Land Use/Land Cover Changes in Rohtak City from 2001 to 2024**

**Table 2. Temporal Changes in Land Use/Land Cover Classes in Rohtak City (2001–2024).**

Classes	2001 Area (km <sup>2</sup> )	2013 Area (km <sup>2</sup> )	2024 Area (km <sup>2</sup> )	Net Change (%)
<b>Built-up Area</b>	53	45	59	+11.3%
<b>Agriculture Land/ Crop field</b>	52	34	35	-32.7%
<b>Vegetation</b>	11	28	32	+190.9%
<b>Barren Land</b>	28	37	17	-39.3%
<b>Water Bodies</b>	5	5	6	+20.0%

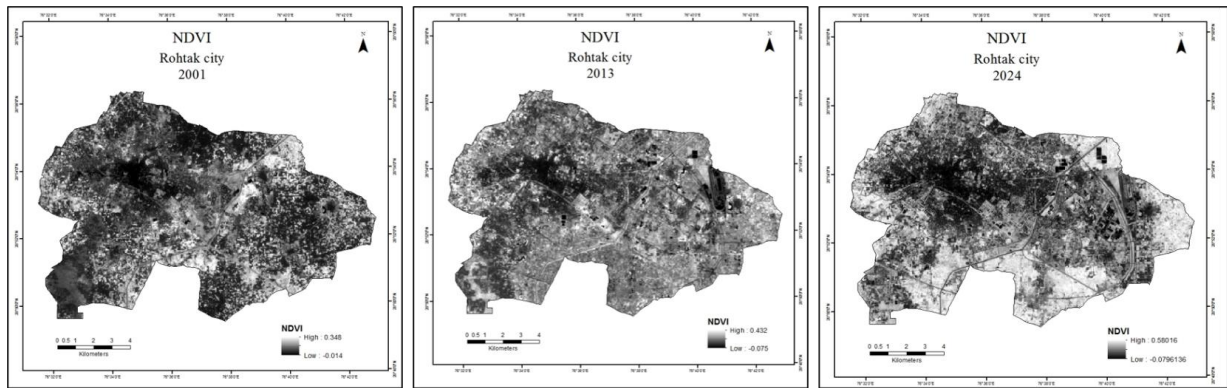
**NDVI Analysis and Vegetation Dynamics**

Analysis of the NDVI reveals that there is an improvement in the condition of vegetation cover in Rohtak City from the year 2001 to 2024. In particular, the highest value for NDVI in 2001 was 0.348, which increased to 0.432 by 2013 and up to 0.580 in 2024 (Table 3 and Figure 4). This shows that there is an improvement in vegetation cover in various parts of the area under study. Improvements in vegetation cover have been recorded in peri-urban agricultural lands and green cover areas. Nevertheless, there is an unequal distribution of vegetation because low values of NDVI are found in the densely built up urban area because of continued urbanization (Figure 4). There is a clear indication that even though urbanization has led to degradation of

vegetated land in some areas, efforts at environmental management and agriculture have improved vegetation cover in other areas.

**Table 3. Temporal Variation in NDVI Values and Vegetation Characteristics in Rohtak City (2001–2024)**

Year	Minimum NDVI	Maximum NDVI	Interpretation
2001	-0.014	0.348	Low to moderate vegetation cover
2013	-0.075	0.432	Moderate increase in vegetation density
2024	-0.079	0.580	Higher vegetation intensity with urban fragmentation

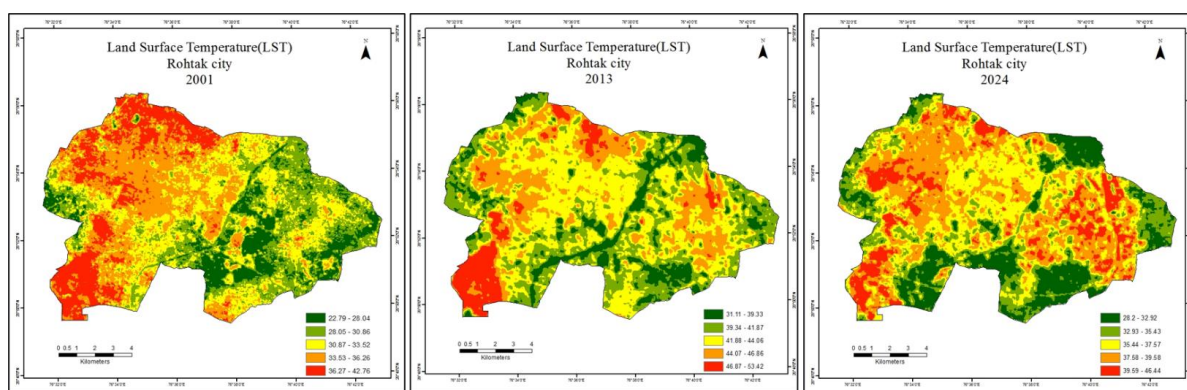


**Figure 4. Spatio-Temporal Distribution of NDVI in Rohtak City, 2001–2024**

### *Land Surface Temperature (LST) Dynamics*

From the analysis conducted, there is evidence of thermal intensification in Rohtak City, indicating an increase in the impact of urbanization on the climatic state of the city. This is evidenced by the variations shown in the LST through time and space over the period under study. In 2001, the highest LST value observed was 42.76°C, mainly occurring at the western and northern regions of the city. The high thermal values observed in 2001 were attributed to bare surface soils, lack of vegetation, and development sites within the city. In the year 2013, the highest LST registered was 53.42°C, signifying an increase in the urban heat effect. Increased LST values were noted in the central and eastern sections of the city due to high density development and impermeable surfaces within the city (Figure 5). While the highest LST value in 2024 was recorded to be 46.44°C, there was a marked increase in fragmentation and a spatial spread in high-temperature areas from the previous year. The occurrence of hot spots was no longer restricted to a few urban centers but instead occurred in a multitude of clusters. Therefore, one can observe that the SUHI phenomenon is not only continuing but also spreading and fragmenting. The increase in surface temperatures cannot be said to be too much since the rise was just slight despite the overall extension. An increase in surface temperature can be attributed to the changes in land use described above. It has been noted that the presence of built-up lands resulted in higher LST values while the increased coverage by vegetation corresponded to the lower values. As such, vegetation plays an essential part in the management of urban warming via shading and cooling effects. On the other hand, impervious surfaces absorb much more energy which results in localized heat islands.

Moreover, from the integrated results of LST and NDVI data analysis, it is observed that the relationship between the surface temperature and vegetation cover can be described as highly inversely proportional to each other. It means that low NDVI levels are correlated to high-temperature hotspots within the region, whereas places having more vegetation will usually exhibit lower surface temperatures. Therefore, vegetation emerges as an essential component in reducing thermal heat from urban areas and building up their environmental resilience. Conclusively, after analyzing Rohtak City using the LST method, it becomes evident that Rohtak City experiences thermal heat stress due to the expansion of the built-up areas since the last two decades. This development has resulted in a greater Surface Urban Heat Island effect in Rohtak City.



**Figure 5. Spatio-Temporal Distribution of Land Surface Temperature (LST) in Rohtak City, 2001–2024**

## VII. DISCUSSION

The results from this investigation clearly indicate that the rapid growth of the city over the years has led to changes in the LULC patterns of Rohtak City along with changes in the thermal environment of the city within the timeframe of 2001-2024. Expansion in the built-up land alongside reduction in agricultural and barren lands can be attributed to the growing developmental needs of the city due to its increasing population, infrastructure, and economic activity. It is common knowledge that such changes have taken place in numerous other rapidly developing cities of India and other developing nations due to which the climatic environment of the city has undergone considerable changes (Ahmad et al., 2024; İŞLER, 2025).

From the LULC analysis of the area, it can be deduced that there has been an increasing trend in terms of built-up land. Such changes in LULC patterns have contributed to urban warming because the presence of impervious land cover absorbs and retains a high amount of heat energy. As per previous literature, an increase in the land surface temperature indicates the contribution of urban development in altering the surface energy balance of the city, thereby leading to an enhanced SUHI effect (Veeravalli, 2023). According to the results of the NDVI, the vegetation greenness had improved overall, especially in peri-urban settings. Nevertheless, the distribution of vegetation greenness still shows considerable spatial unevenness since the low NDVI values are evident in highly urbanized areas. The negative correlation found between NDVI and LST means that vegetation-free areas usually have higher surface temperatures. Vegetation helps to reduce surface temperatures owing to the shading effect and evapotranspiration processes (Salam et al., 2023). This result correlates with those obtained earlier, which prove the importance of vegetation for minimizing the effects of urban heat island and ecological imbalance (Dong, 2025; Palanisamy et al., 2023).

Based on the distribution of LST, one can conclude about the development of thermal hot spots in the urban environment. In particular, highly built-up, transportation-intensive, and commercial areas have higher temperatures compared to their vegetated neighbors. It shows that the morphology of the city plays a crucial role in thermal conditions and indicates the increase in vulnerability of the population to urban heat stress (Agrawal et al., 2023; Veeravalli, 2023). The findings suggest that even though there was an increase in vegetation cover in some areas, this was not enough to counterbalance the heat effects associated with the urban growth. This has been observed in several North Indian cities where urbanization and removal of vegetation have led to the intensification of UHI effects (Akram et al., 2024; Aqdas et al., 2025; Gupta, 2025). Therefore, urban planning must focus on conserving green spaces, creation of urban forests, roadside plantation, and construction of green networks to combat urban heat (Dong, 2025; Palanisamy et al., 2023). Moreover, management of impervious surfaces via scientifically sound land use planning is critical in addressing the vicious cycle of urban density and heat (Aboelnour & Engel, 2018; YILMAZ & Öztürk, 2024). This highlights the importance of the application of green infrastructures in addressing future heat issues in Rohtak City.

## VIII. CONCLUSION

Rohtak city has undergone significant changes in land use from 2001 to 2024, with the notable features being an increase in the developed area while there has been a reduction in agricultural land use. It is evident from the results of the study that urban development has greatly affected the thermal regime of the city, leading to an increase in land surface temperatures and the formation of SUHI.

Despite improvements in the percentage of vegetated area in some parts of the city outskirts, there were still high-temperature patches in areas with dense development and low NDVI. This study demonstrates the importance of the presence of urban green space for moderating the land surface temperature.

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