Spatiotemporal Analysis of Land Surface Temperature and Land Use-Land Cover Dynamics in Mangaluru, India

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Abstract

Urban expansion and unplanned land use changes have significantly altered the thermal landscape of Indian cities. This study investigates the spatial and temporal variations in Land Surface Temperature (LST) and their relationship with Land Use and Land Cover (LULC) transformations in Mangaluru, a rapidly growing coastal city in Karnataka. Using remote sensing data and geospatial analysis techniques, LULC patterns and corresponding LST distributions over selected timeframes to assess the Urban Heat Island (UHI) effect were mapped. Landsat 8 satellite imagery from the years 2015, 2020, and 2024 was analyzed using Google Earth Engine (GEE) and QGIS platforms. LST was derived using the single-channel (mono-window) algorithm, based on Planck's law and the radiative transfer equation, enabling accurate surface temperature estimation. Supervised classification techniques were applied to categorize the region into four primary LULC classes: built-up areas, vegetation, water bodies, and barren land. The summer maximum LST exhibited a modest increase, rising

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from 61.47°C in 2015 to 61.52°C in 2020, followed by a more noticeable uptick to 63.99°C in 2024. In contrast, winter maximum LST values remained relatively stable, with 57.93°C in 2015 and 57.92°C in 2020, indicating minimal thermal variation during the cooler season. Notably, the summer minimum LST showed a gradual decline over time, decreasing from 31.42°C in 2015 to 31.13°C in 2020, and further to 29.97°C in 2024, suggesting a widening diurnal temperature range and potential shifts in night-time cooling patterns. The findings reveal a strong correlation between increasing built-up areas and elevated LST values, particularly in densely urbanized zones. Conversely, regions with sustained vegetation and water bodies exhibit relatively lower surface temperatures. The study underscores the critical role of green cover in regulating urban microclimates and highlights the need for integrating green infrastructure and sustainable land use planning to mitigate rising urban heat. The results indicate a clear trend of increasing heat intensity across Mangalore, with summer temperatures exhibiting a more pronounced rise compared to winter. The Mangaluru city demonstrated relatively stable thermal conditions, attributed to its moderate urban expansion and the preservation of water bodies, which collectively contributed to mitigating the UHI effect. These findings highlight the role of balanced urban development and natural resource conservation in regulating urban microclimates. These insights provide valuable input for policymakers and urban planners seeking climate-resilient strategies for Mangaluru's future development.

1 Introduction:

Urbanization and climate change have become pressing global concerns in recent years, with average global surface temperatures steadily climbing since the late 1800s. As urban populations now comprise over half the world's inhabitants, cities have become central to addressing climate-related issues. The transformation of natural landscapes into built environments with concrete, asphalt, and other impervious materials significantly disrupts local energy and water cycles, thereby altering microclimates. This shift contributes to

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the Urban Heat Island (UHI) phenomenon (Bharath. H Aithal et al., 2019), where urban areas experience notably higher temperatures than nearby rural zones. The swift conversion of green spaces into developed land interferes with natural cooling mechanisms in cities. Vegetation is vital for temperature regulation through evapotranspiration, and its replacement by materials with high heat retention amplifies heat absorption. These landscape modifications not only affect the thermal energy balance in urban regions but also influence air circulation and moisture availability, thereby exacerbating city warming[1].

Understanding changes in land use and land cover (LULC) is crucial for assessing these thermal dynamics. Urban expansion introduces vast impervious surfaces, decreasing surface moisture and reducing cooling through evapotranspiration. Diminished vegetation coupled with more developed areas alters the natural energy flow, increasing surface temperatures. These land cover changes also modify physical surface properties like reflectivity (Tapas Das et al., 2021), heat storage capacity, and thermal conductivity intensifying urban heat build-up.

This study examines the geographical and temporal variations in Land Surface Temperature (LST) in Mangaluru, a fast-expanding coastal metropolis in Karnataka, as well as its connection to changes in land use and land cover (LULC). The Urban Heat Island (UHI) effect was evaluated by mapping LULC patterns and related LST distributions across chosen time periods using remote sensing data and geospatial analysis methods.

Mangalore, a coastal city located in the southern part of Karnataka, India, has been considered a suitable study area for Urban Heat Island (UHI) research due to its rapid urbanization, diverse land use patterns, and unique geographical setting. Positioned between the Arabian Sea and the Western Ghats, Mangalore experiences significant variations in microclimatic conditions, making it ideal for analyzing temperature differences between urban and rural areas. The city has witnessed accelerated infrastructural growth, population increase, and changes in vegetation cover over the past few decades, all of which contribute to UHI effects. These factors, combined with the availability of meteorological data and satellite

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imagery, make Mangalore an important case for understanding the localized impacts of UHI, guiding sustainable urban planning and climate adaptation strategies.

Data:

Landsat:

The longest-running series of Earth Observation Satellites (EOS) is Landsat, which has been continuously monitoring the Earth for more than 40 years. The sensors, initially known as the Earth Resources Technology Satellite when it was launched in 1972 before being given the name Landsat 1, have evolved over the years, and there have been a total of eight Landsat satellites created. Most notably, Landsat 6 failed in 1993, but the other satellites have had successful careers, providing a wealth of data covering electromagnetic radiation in the visible and thermal infrared bands, as well as all intermediate wavelengths. Because of their temporal consistency and high-quality images, Landsat data, which is freely available from the United States Geological Survey (USGS), have been utilized extensively in a variety of research.

The primary data source for this research was Landsat 8 imagery (LANDSAT/LC08/C02/T1). The mapping and analysis of land surface temperature and land use/land cover dynamics in Karnataka's major cities relies heavily on images from Landsat 8. The high-resolution multispectral imagery from Landsat 8 is used here to accurately measure the growth of the city, deforestation, and other changes in the landscape that are necessary for understanding the dynamics of the Urban Heat Island in our study area.

Land Surface Temperature:

A key factor in understanding the energy balance at the Earth's surface is the temperature of the land surface (LST). Using a single-channel (mono-window) method, it is derived from the thermal data of Landsat 8 images. This method first converts the digital numbers into at-sensor radiance and then uses an inverted form of Planck's law to determine brightness temperature. The correction for land surface emissivity (LSE), which quantifies the efficiency of different materials in emitting thermal energy and varies with material

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composition, viewing angle, and surface roughness, is a crucial step in this process.

Common NDVI-based methods for calculating emissivity take into account the effects of flora and other surface features. This modification is necessary to guarantee that the calculated LST properly represents the actual thermal circumstances of different land cover types. The resulting LST values offer a solid foundation for evaluating urban heat islands, comprehending surface energy budgets, and tracking environmental changes over time by combining thermal and optical data from Landsat 8 with effective emissivity correction.

Land Use/Land Cover Mapping:

Up-to-date and reliable data on land usage and land cover is crucial for a wide variety of planning and management operations. Additionally, it is essential for simulating and comprehending the planet as an interdependent ecosystem. Despite the fact that the words "land use" and "land cover" are frequently used synonymously, they denote distinct meanings. The physical characteristics of the Earth's surface, such as trees, lakes, roads, and buildings, are referred to as land cover. In contrast, land use refers to how people use the land, such as building single-family houses on a site outside a town. Depending on the amount of detail in the mapping, the land use in this instance may be categorized as urban, residential, or exclusively single-family residential, while the land cover would consist of roads, roofs, trees, and grass.

Remote sensing data have been widely utilized to map land use and land cover at scales ranging from global to local. Methods range from the visual analysis of images to sophisticated spectral and object-based categorization algorithms. The classification system selected is determined by the scale, image quality, and analytical instruments being used. The commonly used categorization system created by the U.S. Geological Survey (USGS) includes both land cover and land usage components. Although it's best to map them separately, it's frequently more useful to combine them when remote sensing is the main data source. The USGS system acknowledges that certain kinds of land usage data may need more data sources beyond aerial or satellite imagery, concentrating on categories that

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can be reliably interpreted from these images.

2 Methodology:

Landsat 8 data from 2015, 2020, and 2024 were used to analyze changes in land use/land cover and surface temperature over time. Radiometric, atmospheric, and geometric corrections were applied to the images as part of the preprocessing procedure in GEE and QGIS. The mono-window method, which is based on Planck's law and the radiative transfer equation, was employed to estimate the surface temperature from thermal bands. The research region was classified into urban, vegetation, water bodies, and barren land using a supervised Random Forest classifier, which was then assessed and validated with ground truth data. The impact of changing land cover on the dynamics of urban growth was highlighted by comparing LULC and LST trends, which showed a significant correlation between urban expansion and surface temperature rises. (Figure 2).

3 Results and discussions:

This section looks at how the landscapes of Mangaluru, have changed over time by analyzing satellite images from 2015, 2020, and projected data for 2024. It focuses on shifts in urban areas, vegetation, water bodies, and barren land. These changes help us understand how expanding cities and declining green cover impact surface temperatures.

As shown in Figure 3 and Table 1, the summer maximum LST in Mangaluru increases slightly from 61.47°C in 2015 to 61.52°C in 2020, before rising significantly to 63.99°C in 2024. The winter maximum LST values, on the other hand, stay at a steady 57.93°C (2015) and 57.92°C (2020), indicating little change throughout the cooler months. In contrast, the minimum LST for summer falls somewhat over time, dropping from 31.42°C in 2015 to 31.13°C in 2020, and eventually to 29.97°C in 2024. According to this trend, summer daytime highs are rising, but night-time or early morning cooling may still be possible. Overall, the

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data indicates that winter conditions are rather steady, perhaps as a result of Mangaluru's coastal location, while summer heat is expected to increase noticeably by 2024, which may be attributable to ongoing urbanization or changes in land cover.

Table 1:

Table 1: Land surface temperature analysis (°C)

Place	**Year-Season**	**Maximum**	**Minimum**
Mangaluru	2015-Summer	61.47	31.42
	2015-Winter	57.93	31.22
	2020-Summer	61.52	31.13
	2020-Winter	57.92	31.06
	2024-Summer	63.99	29.97
	2024-Winter	59.31	31.18

4 Conclusion:

Due to urban expansion in Mangaluru, ground surface temperatures have risen, demonstrating a significant Urban Heat Island impact. The surface temperatures in communities with thick flora and open water were consistently lower, proving that green and blue spaces have a cooling effect. Summer highs have increased dramatically, from 61.47°C in 2015 to 63.99°C in 2024, while winter highs have been milder. Night-time cooling has decreased, widening the gap between daytime and night-time temperatures, as evidenced by the minimum summer LST falling from 31.42°C to 29.97°C. The computed sensitivity (0.29 °C for +1% urban cover) is consistent with Oke's (1982) 0.5–1.0 °C per +10% envelope and very similar to that of Imhoff [2]. The thermal environment has been stabilized by the combination of moderate urban expansion in Mangaluru and the maintenance of bodies of water. The study's findings can aid lawmakers and municipal officials in implementing urban planning legislation in order to increase public knowledge and foster sustainable planning and management in the years ahead.

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