RESEARCH ARTICLE

Land Use, Vegetation, and Thermal Dynamics: A Geospatial Assessment of Mettupalayam, Tamil Nadu (2017–2024)

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ABSTRACT

This study uses multi-temporal remote sensing and GIS techniques to examine spatiotemporal changes in land use/land cover (LULC), vegetation cover, and land surface temperature (LST) in Mettupalayam, Tamil Nadu, between 2017 and 2024. To evaluate temporal and spatial changes in vegetation health, thermal regimes, and land use transitions, multitemporal geospatial datasets were examined. The findings show that while croplands and rangelands have declined, there has been a notable increase in tree cover and water bodies, reflecting both ecological regeneration and urbanization. While LST maps show localized thermal intensification linked to built-up growth, NDVI analysis shows an overall improvement in vegetation density. Terrain attributes further modulate these processes: elevation influences temperature gradients, slope affects land stability and vegetation distribution, and aspect controls exposure to solar radiation, thereby shaping microclimatic conditions. The study underscores the utility of integrated remote sensing approaches for supporting sustainable land management and climate-resilient planning in rapidly transforming agricultural landscapes.

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INTRODUCTION

Land use and land cover (LULC) changes have emerged as significant drivers influencing local climate, vegetation dynamics, and agricultural sustainability in rapidly transforming regions, particularly within the Indian subcontinent. Numerous studies have demonstrated the effects of LULC transitions on land surface temperature (LST) and vegetation indices, revealing clear associations between decreased vegetation cover and increased thermal variability (e.g., Sajan *et al*., 2025; Gogoi *et al*., 2019). Remote sensing indices such as the Normalized Difference Vegetation Index (NDVI) have been effectively used to monitor vegetation health and its inverse relationship with surface temperature across varied Indian landscapes (Lower Son River Basin Singh *et al*., 2024; Ambedkar Nagar, 2025). These integrated approaches have provided insights into how urban expansion and land cover modifications alter environmental conditions at regional scales (Vijayawada case, 2024).

Despite this growing body of research, there remains limited focus on foothill regions with mixed agricultural, forest, and peri-urban characteristics, such as Mettupalayam in Tamil Nadu, that experience spatially heterogeneous rainfall and land-use pressures due to both climatic variability and infrastructural growth. Tamil Nadu–specific analyses highlight diverse

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environmental settings in which LST and NDVI patterns vary across agricultural fields, vegetated areas, and built-up zones, underscoring the need for location-specific assessments (e.g., the Lalgudi Block study in Tamil Nadu). In such transitional landscapes, coupled analysis of LULC, vegetation cover, and surface temperature is pivotal for understanding localized land–climate interactions.

In this context, the present study aims to assess the spatio-temporal dynamics of land use/land cover, vegetation cover, and land surface temperature in Mettupalayam for 2017 and 2024 using remote sensing and geographic information systems techniques. The specific objectives are to (i) analyze changes in LULC patterns, (ii) examine variations in vegetation cover using NDVI, and (iii) evaluate associated changes in LST in relation to spatial rainfall distribution.

MATERIALS AND METHODS

Study Area

The study was carried out in Mettupalayam taluk, Coimbatore district, Tamil Nadu, India, which is situated between latitudes 11.28° N and 11.36° N and longitudes 76.88° E and 76.98° E. Situated at the base of the Western Ghats, the area serves as a transitional zone between agricultural plains, growing peri-urban settlements, and forested uplands. Due to the region's proximity to the Nilgiris hills, orographic effects influence the distribution of rainfall. The area's agricultural practices include both rainfed and irrigated systems. The area is appropriate for evaluating spatiotemporal changes in land use, vegetation cover, and surface thermal characteristics due to rapid land transformation driven by urban growth and infrastructure development, which has altered land-use patterns.

Data Sources

Multi-temporal satellite and gridded datasets were used to analyse land-use dynamics, vegetation cover, and land-surface temperature for 2017 and 2024. Land-use/land-cover data were obtained from the ESRI Living Atlas global land cover dataset. Vegetation cover was assessed using the Normalized Difference Vegetation Index from the Copernicus Sentinel-2 Harmonized dataset. Land surface temperature data were extracted from the Landsat 8 Collection 2 Level 2 surface temperature product, which integrates satellite observations with ground-based measurements.

Data Processing and Analysis

Google Earth Engine was used to process all datasets, and QGIS software was used for spatial analysis and map preparation. Maps of land use and land cover were reclassified into major categories, such as vegetation, built-up areas, water bodies, and agricultural land. To measure changes in land use between 2017 and 2024, area statistics were calculated. While annual mean land surface temperature maps were produced from cloud-free Landsat observations, annual composite NDVI maps were created to evaluate spatial variations in

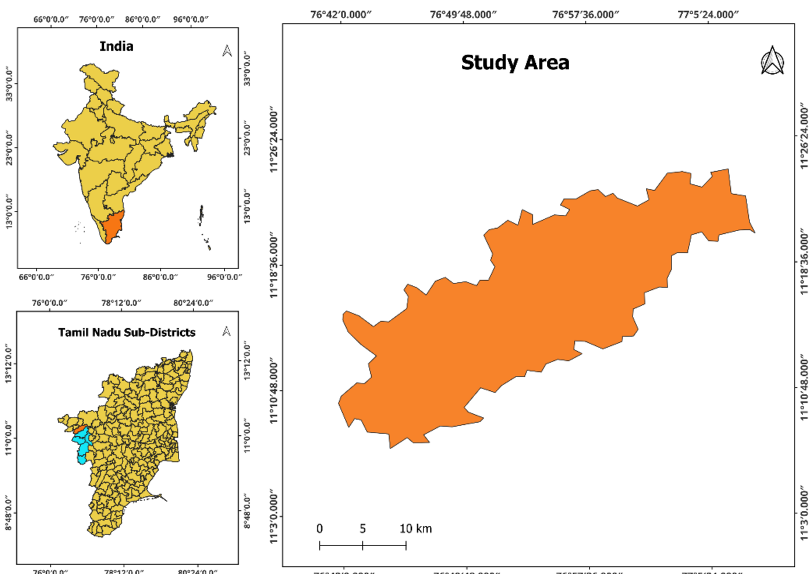

Fig. 1. Study area of Mettupalayam, Tamil Nadu, India

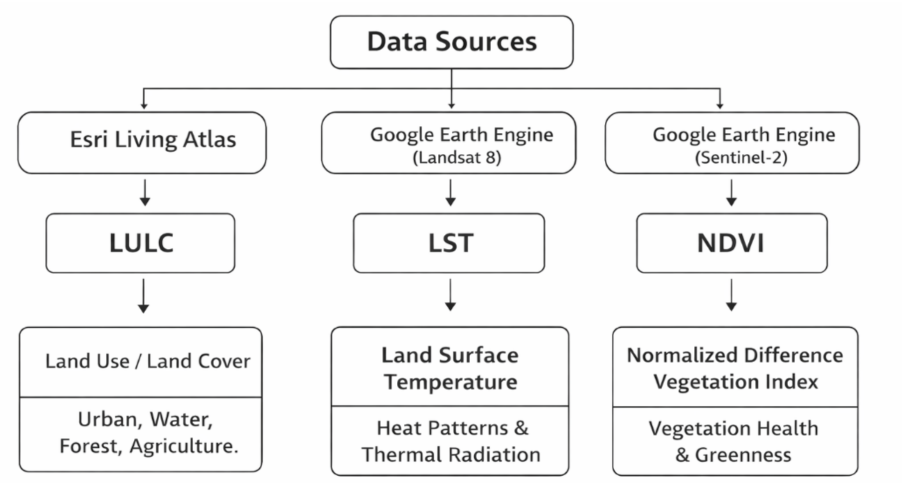

Fig.2. Data Sources

vegetation cover. To investigate spatial variability and provide climatic context for observed changes in land and vegetation, rainfall data were aggregated into annual totals.

Comparative analysis between the two study years was carried out to identify areas experiencing significant land transformation and associated changes in vegetation and surface thermal conditions.

METHODOLOGY

A spatio-temporal analytical framework was adopted to evaluate changes in land use dynamics, vegetation cover, and surface thermal variability in Mettupalayam between 2017 and 2024. Multi-source satellite datasets were processed and analysed using remote sensing and Geographic Information System (GIS) techniques.

Land use/land cover (LULC) information for the selected years was extracted from the ESRI Living Atlas dataset and reclassified into major land cover categories relevant to the study area. Changes in land-use patterns were quantified using area-based comparisons between the two time periods. Vegetation cover was assessed using the Normalized Difference Vegetation Index (NDVI) derived from Sentinel-2 Harmonized imagery, calculated using red and near-infrared spectral bands. Annual composite NDVI maps were generated to minimize the effects of seasonal variability and cloud contamination.

Land surface temperature (LST) was analysed using Landsat 8 Collection 2 Level-2 surface temperature products. Cloud-free observations were aggregated to generate annual mean LST maps for both years across the study area. All datasets were processed using Google Earth Engine and integrated within a GIS environment for spatial analysis. A comparative assessment of LULC, NDVI, and LST was conducted to identify spatial associations among land transformation, vegetation response, and surface thermal variability.

RESULTS AND DISCUSSION

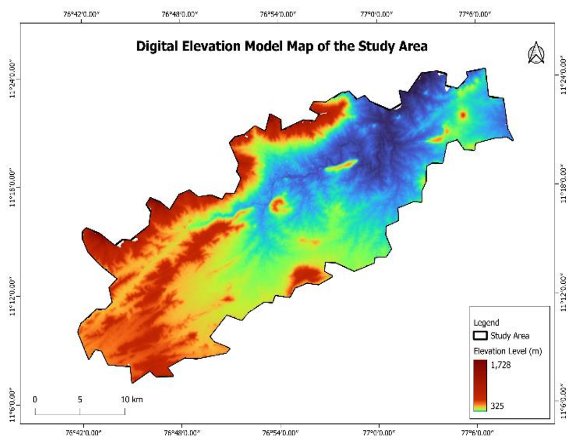

Fig.3. Digital Elevation Model of Mettupalayam

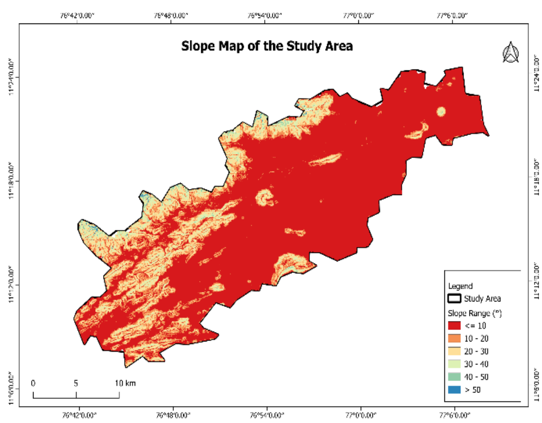

Fig.4. Slope of Mettupalayam

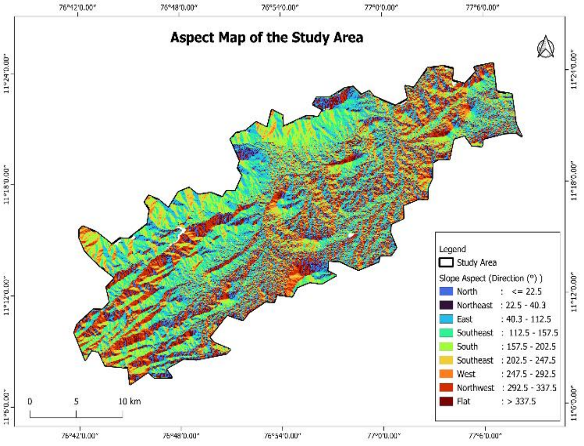

Fig.5. Aspect map of Mettupalayam

Digital Elevation Model (DEM)

The Digital Elevation Model (DEM) (Fig. 3) provides the fundamental terrain framework for environmental analysis. Elevation significantly influences climatic conditions, land surface temperature (LST), and vegetation distribution. Higher elevations near The Nilgiris generally experience cooler temperatures and exhibit distinct land-use/land-cover (LULC) patterns compared to low-lying areas. DEM data are also instrumental in identifying geomorphological features such as valleys, ridges, and plateaus, which are essential for interpreting variations in the Normalized Difference Vegetation Index (NDVI) and understanding ecological processes across the study area.

Slope

Slope (Fig. 4) plays a decisive role in shaping land use patterns and vegetation health. Gentle slopes are more suitable for agriculture, human settlements, and infrastructure development, whereas steep slopes limit anthropogenic activities and are often covered by forest. Steeper gradients are associated with higher erosion risk, leading to reduced soil fertility and vegetation density, which is reflected in lower NDVI values. In LST analysis, slope influences heat retention and surface runoff, making it a crucial factor in microclimate regulation and land cover distribution.

Aspect

Aspect (Fig. 5) determines the directional orientation of slopes, which governs solar radiation exposure and microclimatic conditions. South- and east-facing slopes receive greater solar insolation, often resulting in higher LST and enhanced vegetation growth, whereas north- and west-facing slopes remain relatively cooler and support moisture-dependent vegetation. This orientation effect directly influences NDVI by affecting photosynthetic activity and indirectly shapes LULC by guiding agricultural practices and vegetation types. Therefore, aspect is a critical parameter in linking terrain characteristics with thermal and ecological dynamics.

Land Use Land Cover Map

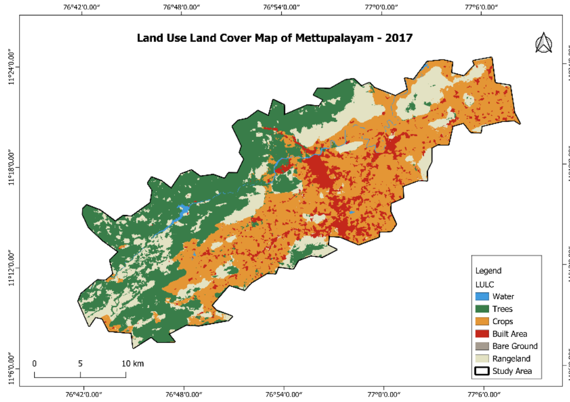

Fig.6. Land Use Land Cover Map of Mettupalayam -2017

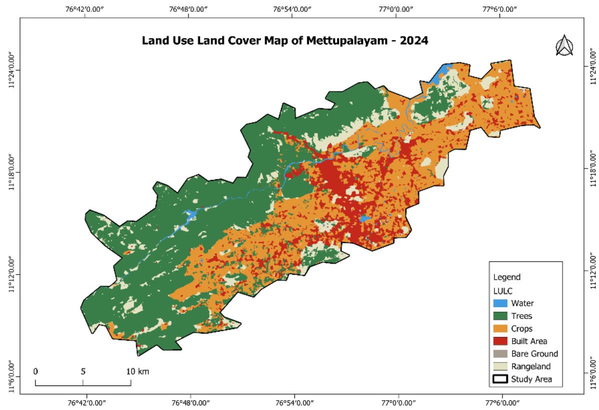

Fig.7. Land Use Land Cover Map of Mettupalayam -2024

Normalized Difference Vegetation Index (NDVI) Analysis

The Normalized Difference Vegetation Index (NDVI) was employed to assess vegetation presence, density, and health across the study area using the red and near-infrared bands of satellite imagery. NDVI values range from −1 to +1, where higher values indicate denser, healthier vegetation, while lower values indicate sparse vegetation, built-up areas, or exposed bare surfaces near the city.

The NDVI maps for 2017 and 2024 reveal distinct spatial variations in vegetation distribution within the study area. In 2017, high NDVI values (> 0.5) were predominantly concentrated in the western regions, corresponding to plantation-dominated landscapes and forested zones along the Nilgiri foothills. Low NDVI values (≤ 0.3) were primarily observed around urban settlements and exposed land surfaces, reflecting areas with minimal vegetation cover. Moderate NDVI values (0.4–0.5) were largely associated with agricultural lands in the central plains, indicating seasonal or managed vegetation.

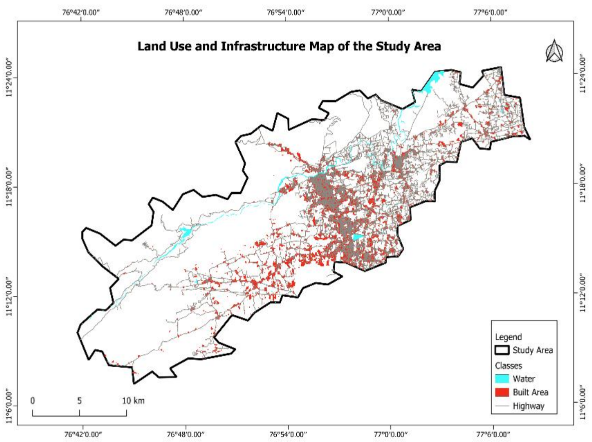

Fig.8. Land Use and Infrastructure Map of Mettupalayam

Table 1. Comparative Land Use and Land Cover (2017–2024)

Land Cover Value	Area (Ha) 2017	Area (Ha) 2024
Water Bodies	461.75	743.17
Trees	20,774.32	28,078.49
Crops	24,203.44	20,508.47
Built-up Area	5,655.30	7,668.19
Bare Ground	2.07	8.94
Range land	12,171.87	6,261.49

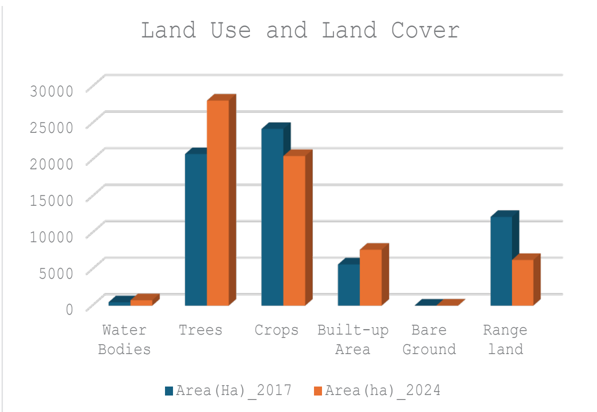

Fig.9. Land Use and Land Cover Change (2017–2024)

By 2024, a noticeable spatial expansion of low NDVI zones was observed across the eastern and central parts of the study area, suggesting a decline in vegetation cover in peri-urban and low-lying regions. Furthermore, increased spatial heterogeneity was evident in agricultural areas, with several zones shifting from moderate to lower NDVI classes. This transition may be attributed to changes in cropping patterns, land-use intensity, or vegetation stress.

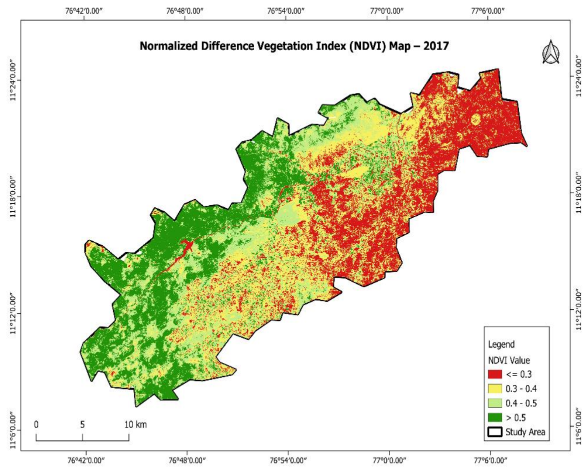

Fig.10. Normalized Difference Vegetation Index Map of Mettupalayam -2017

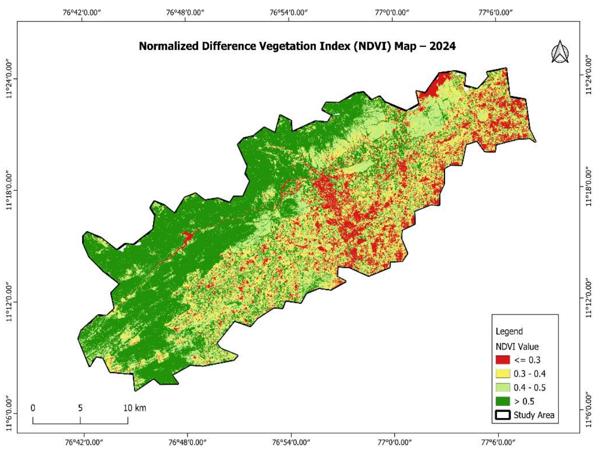

Fig.11. Normalized Difference Vegetation Index Map of Mettupalayam - 2024

NDVI Dynamics Over Time

The temporal analysis of NDVI highlights significant changes in vegetation health throughout the study period. The trend analysis indicates a general increase in NDVI values from 2017 to 2024, peaking in 2021 at approximately 0.45. This upward trend suggests

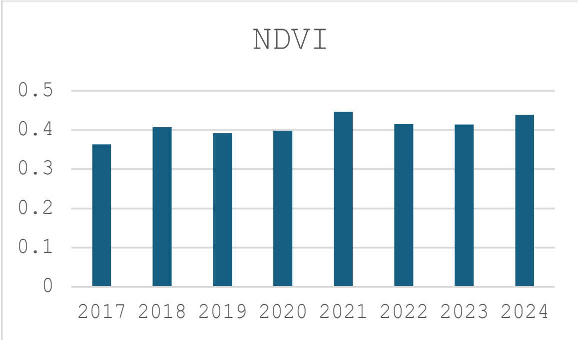

Fig.10. Normalized Difference Vegetation Index Changes(2017-2024)

an overall improvement in vegetation density and vigor, likely resulting from ecological regeneration, afforestation efforts, and improved land management practices. Despite minor inter-annual fluctuations after 2021, NDVI values remained consistently higher than in 2017, indicating sustained vegetation growth.

A spatial comparison between the 2017 and 2024 NDVI maps further supports these observations. In 2017, large portions of the study area exhibited moderate NDVI values (0.3–0.4), with only limited zones of dense vegetation (>0.5). By 2024, the spatial distribution had shifted toward higher NDVI classes (0.4–0.5 and >0.5), as indicated by yellow-green and green zones. This expansion of healthier vegetation corresponds with increased tree cover identified in the Land Use/Land Cover (LULC) analysis, while reductions in cropland and rangeland align with the observed improvements in NDVI.

Overall, the NDVI results demonstrate a positive trend in vegetation health over the study period, driven by a combination of natural regeneration and land use transitions. The integration of NDVI with Digital Elevation Model (DEM), slope, and aspect analysis enhances the interpretation of vegetation patterns, as terrain elevation and orientation influence solar radiation exposure, moisture availability, and photosynthetic activity. These findings highlight the effectiveness of NDVI as a key indicator for monitoring ecological sustainability and evaluating the impact of land management strategies.

Land Surface Temperature (LST) Analysis

The Land Surface Temperature (LST) analysis for Mettupalayam reveals a marked increase in surface temperatures between 2017 and 2024, highlighting significant thermal changes across the landscape. In 2017, moderate to high temperatures were primarily

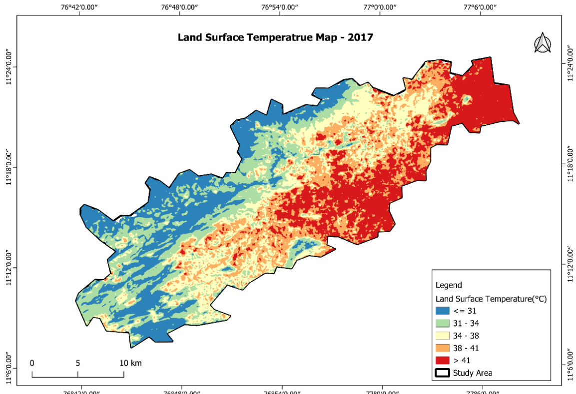

Fig.12. Land Surface Temperature Map of Mettupalayam - 2017

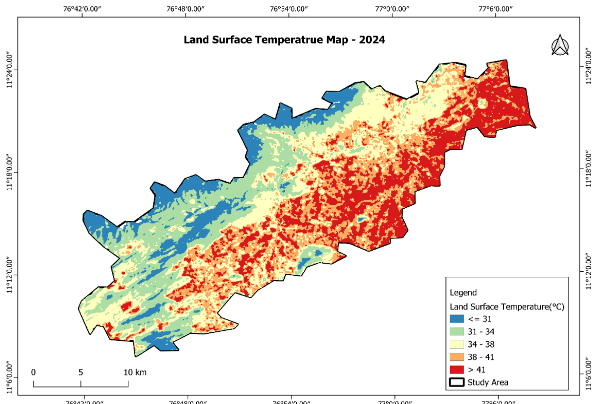

Fig.13. Land Surface Temperature Map of Mettupalayam - 2024

concentrated in the central and eastern regions, while comparatively lower LST values prevailed in the western elevated and forested areas. By 2024, a noticeable contraction of cooler zones was observed alongside a substantial expansion of high-temperature areas exceeding 38°C, particularly in the central and eastern sectors. This pattern indicates intensifying thermal stress in the region, likely driven by urban expansion, declining vegetation cover, and land-use changes.

A detailed spatial comparison of LST distribution between 2017 and 2024 further underscores these thermal shifts. In 2017, cooler zones (≤ 31°C) were largely confined to the western parts of the study area, whereas higher temperatures (> 41°C) dominated the eastern regions. By 2024, warmer zones had expanded significantly, with a greater proportion of the landscape falling within the 34-41°C range. This spatial progression reflects the combined influence of urban growth and vegetation loss in certain areas, emphasizing the sensitivity of LST to land-use transitions, particularly the conversion of croplands and rangelands into built-up surfaces.

Terrain characteristics, including elevation, slope, and aspect, play a crucial role in modulating LST patterns. Higher elevations generally experience lower surface temperatures due to cooler ambient conditions, while low-lying areas tend to accumulate more heat. Slope affects surface runoff and soil moisture retention, which, in turn, influence surface heating dynamics. Aspect significantly governs solar radiation exposure: south- and east-facing slopes receive greater insolation, leading to elevated LST values, whereas north- and west-facing slopes remain relatively cooler. These terrain-induced microclimatic variations align closely with vegetation patterns identified through NDVI analysis, reinforcing the interconnected relationship between topography, vegetation health, and thermal behavior.

The integration of LST, Land Use/Land Cover (LULC), and NDVI results provides a holistic understanding of environmental change in Mettupalayam. The expansion of built-up areas from 2017 to 2024 corresponds with localized thermal intensification, consistent with the urban heat island effect. Conversely, the increase in tree cover and water bodies has contributed to localized cooling, helping to alleviate some thermal stress. Overall, the findings demonstrate that LST is not merely a reflection of climatic conditions but also a direct indicator of land use dynamics and ecological resilience. These insights are critical for informed urban planning, climate adaptation strategies, and sustainable environmental management in rapidly evolving landscapes.

CONCLUSION

This study demonstrates the critical role of terrain parameters, Digital Elevation Model (DEM), slope, and aspect in shaping land use and land cover (LULC) dynamics, vegetation health (NDVI), and land surface temperature (LST) patterns in the Mettupalayam region. The comparative analysis between 2017 and 2024 highlights substantial changes, including increases in tree cover and water bodies, expansion of built-up areas, and declines in croplands and rangelands. These shifts reflect both ecological regeneration and anthropogenic pressures, particularly urban growth and land conversion.

The NDVI results confirm an overall improvement in vegetation density and vigor, supported by the expansion of tree cover, while the LST maps reveal localized thermal intensification associated with urban expansion. Terrain attributes further modulate these processes: elevation influences temperature gradients, slope affects land stability and vegetation distribution, and aspect controls exposure to solar radiation, thereby shaping microclimatic conditions. Integrating these parameters provides a more comprehensive understanding of environmental change, strengthening the reliability of spatial analysis.

Overall, the findings emphasize that DEM, slope, and aspect are not merely supporting datasets but fundamental determinants of ecological and thermal dynamics. Their integration with LULC, NDVI, and LST analysis offers valuable insights for sustainable land management, climate adaptation, and urban planning. This holistic approach underscores the need for terrain-informed strategies to balance development with ecological resilience in rapidly transforming landscapes.

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Ethics Statement:

This study does not involve human participants or animals. The research is based entirely on satellite data and geospatial analysis; and so, ethical approval was not required.

Originality and Plagiarism:

The authors declare that this manuscript is an original work and has not been published elsewhere. All sources of information have been properly cited. The manuscript has been checked for plagiarism, and it falls within acceptable limits.

Consent for Publication:

All authors have read and approved the final version of the manuscript and consent to its publication in the journal.

Competing Interests:

The authors declare that they have no competing financial or non-financial interests.

Data Availability:

The datasets used in this study are publicly available from:

Google Earth Engine, Copernicus Sentinel-2, Landsat 8 Collection 2, ESRI Living Atlas.

All processed data supporting the findings of this study are included within the manuscript. Additional information can be obtained from the corresponding author upon reasonable request.

Author Contributions:

Harini Mani – Conceptualization, methodology, data analysis, manuscript drafting

Maheshkumar P – Data processing, GIS analysis, writing and editing

Sakthivel R – Supervision, review

Balaji Kannan – Validation, visualization, review

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