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"Decadal Vegetation and Temperature Trends in Raipur District, India (2015–2025) Using Remote Sensing and GIS"

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Abstract: This research investigates decadal trends in the Normalized Difference Vegetation Index (NDVI) and Land Surface Temperature (LST) across Raipur District, India, from 2015 to 2025, utilizing Landsat-08 and Landsat-09 satellite imagery analyzed through remote sensing and GIS methods. The study identifies notable spatiotemporal variations in vegetation health and surface temperature over the ten-year period. NDVI values indicate a rise in average vegetation indices from 0.163 in 2015 to 0.410 in 2020, followed by a slight decrease to 0.396 by 2025, reflecting dynamic shifts in vegetation cover. Meanwhile, average LST shows a modest decline from 38.42°C in 2015 to 38.37°C in 2020, and a more significant drop to 32.76°C by 2025, with maximum temperatures also decreasing substantially by 2025. An inverse correlation between NDVI and LST highlights that regions with denser vegetation typically exhibit cooler surface temperatures, underscoring vegetation's role in temperature regulation. The study highlights how urbanization and land cover changes affect Raipur's climate and vegetation, offering insights for sustainable land management. Continuous monitoring via remote sensing and GIS is vital for climate adaptation in rapidly developing areas.

1. Introduction

Vegetation is one of the most vital components of the Earth's biosphere, as it regulates energy balance, hydrological cycles, and atmospheric composition. Healthy vegetation improves microclimates, provides ecosystem services, and functions as a major carbon sink, absorbing atmospheric carbon dioxide and mitigating the impacts of global climate change

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(Bonan, 2008). Conversely, vegetation degradation can accelerate soil erosion, reduce biodiversity, and intensify the effects of heat stress in urban and agricultural landscapes (Zhang et al., 2014). Land Surface Temperature (LST), an essential climatic variable, represents the radiative skin temperature of the land surface and plays a significant role in energy exchange between the land and atmosphere (Weng, 2009). It is strongly influenced by vegetation cover, land use patterns, and urban growth, making it an important parameter for environmental monitoring and climate change assessments (Voogt & Oke, 2003).

The relationship between vegetation dynamics and LST is well established in the scientific literature. Areas with dense vegetation typically exhibit lower LST due to evapotranspiration and shading, while barren lands and urban built-up areas exhibit elevated LST, commonly associated with the urban heat island (UHI) effect (Yuan and Bauer, 2007). Therefore, integrating vegetation indices such as the Normalized Difference Vegetation Index (NDVI) with LST provides a robust framework for assessing land surface processes, environmental stress, and human-induced landscape transformation (Tucker, 1979; Li et al., 2013).

In India, rapid population growth, urban expansion, and agricultural intensification over the past few decades have significantly altered natural landscapes (Roy et al., 2016). Chhattisgarh, located in central India, is undergoing both industrial and agricultural development, which directly affects its vegetation cover and local climatic conditions. Raipur District, the administrative and commercial hub of the state, has experienced rapid urban sprawl, infrastructural expansion, and agricultural land conversion, all of which have implications for vegetation dynamics and temperature regulation (Shukla and Pandey, 2020). Monitoring these changes is critical for understanding their environmental consequences and for formulating sustainable management strategies (Ghosh et al., 2019).

Remote Sensing (RS) and Geographic Information Systems (GIS) have emerged as indispensable tools in spatiotemporal environmental monitoring. Satellite-based vegetation indices such as NDVI are widely used to evaluate vegetation health, biomass, and productivity, as they provide reliable indicators of photosynthetic activity (Tucker, 1979; Xiao et al., 2006). Similarly, LST derived from thermal remote sensing enables detailed mapping of temperature variations at regional scales, facilitating the analysis of heat stress, urban heat islands, and climate variability (Voogt and Oke, 2003). The integration of RS and GIS makes it possible to assess both vegetation and temperature dynamics over long time periods with consistent and comparable datasets (Weng, 2009).

This study aims to analyze decadal vegetation and temperature trends in Raipur District, India, from 2015 to 2025, by integrating multi-temporal satellite datasets. Specifically, it seeks to:

(i) Assess vegetation cover dynamics using NDVI

(ii) Evaluate spatiotemporal variations in land surface temperature; and

(iii) Examine the relationship between vegetation changes and surface temperature patterns.

2. Study Area and Data

Raipur District, the capital and administrative center of Chhattisgarh state, is located in central India. Geographically, it lies between latitudes 20°942 N to 21°622 N and longitudes 81°53E to 82°192 E, covering an area of approximately 2,904.52 sq. km. The district is bounded by Baloda Bazar to the north, Dhamtari to the south, Mahasamund to the east, and Durg to the west.

Topographically, Raipur is characterized by a mix of fertile plains, low undulating terrain, and patches of forested areas. The district is part of the Mahanadi River basin, with major tributaries such as Kharun, Pairi, and Seonath supporting agricultural and domestic water needs (CGWB, 2020). The climate is tropical wet and dry, with hot summers (temperatures often exceeding 42°C), a monsoon season contributing about 1,200–1,400 mm of annual rainfall, and mild winters with average temperatures ranging from 10°C to 20°C (IMD, 2022).

Raipur is among the fastest-growing urban centers in central India, experiencing rapid urbanization, industrialization, and population growth. While agriculture remains a dominant activity in the rural hinterlands, the city of Raipur has expanded considerably, resulting in significant land use changes such as conversion of agricultural land and open areas into built-up spaces (Shukla & Pandey, 2020). The district's mixed land cover of urban, agricultural, water bodies, and forest patches makes it an ideal site for examining vegetation dynamics and temperature variations over time.

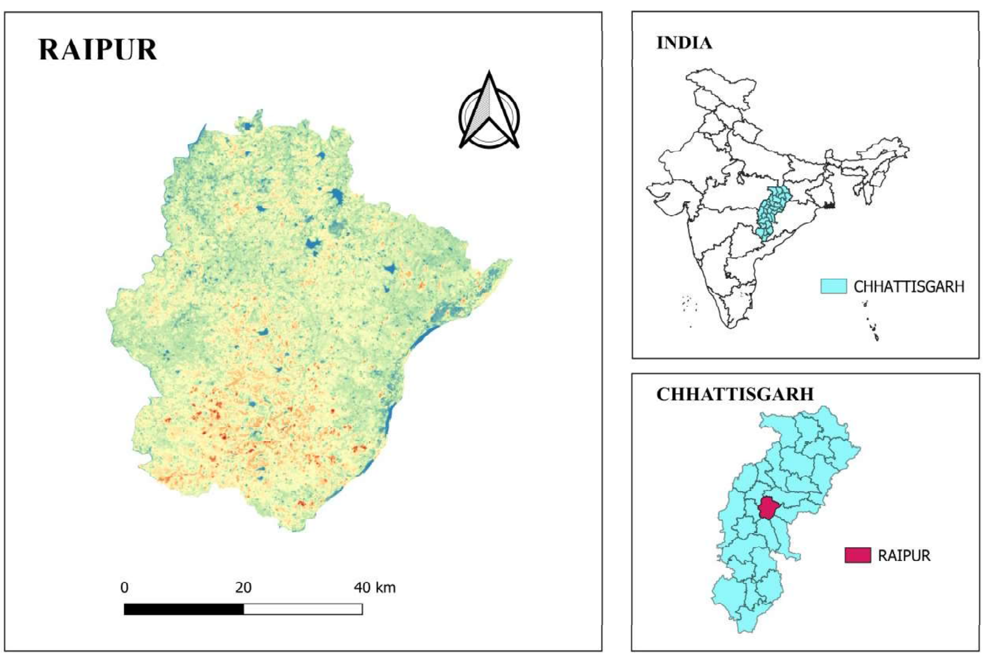

Fig. 1: Location Map of Raipur, Chhattisgarh, India

Data

The study's vector data came from DIVA-GIS (www.diva-gis.org), which offers free shapefiles with administrative boundaries and other geographic features that are necessary for spatial analysis and GIS-based mapping. The USGS Earth Explorer website, which provides free access to Landsat datasets and other remote sensing photos, is the source of the raster data, which is mainly satellite imagery. These merged raster and vector datasets served as the basis for the research's land cover classification and spatial analysis.

Time period (yyyy/mm/dd)	*Path & Row*	*Satellite*	*Sensors*	*Resolution*
2015-04-05	142-045	Landsat-8	OLI and TIRS	30 m
2020-05-04	142-045	Landsat-8	OLI and TIRS	30 m
2025-04-24	142-045	Landsat-9	OLI -2 and TIRS-2	30 m

3. Methodology

3.1. Preprocessing

Image pre-processing was carried out using QGIS (v3.34) to ensure the reliability of time-series analysis. First, geometric correction was applied to align all satellite images accurately, thereby maintaining spatial consistency across different years. This was followed by atmospheric correction using the Dark Object Subtraction (DOS1) method, which minimized atmospheric scattering effects and improved the spectral quality of the data. Finally, the images were clipped to the Raipur District boundary, enabling a focused analysis of vegetation and temperature trends within the study area.

3.2. NDVI Analysis

The Normalized Difference Vegetation Index (NDVI) is a widely used spectral index for assessing vegetation health, density, and vigor by exploiting the differential reflection of near-infrared (NIR) and red light by vegetation. Vegetation typically reflects a high amount of NIR radiation due to the internal leaf structure and absorbs visible red light for photosynthesis. NDVI quantifies this difference, providing an effective indicator of the presence and condition of vegetation.

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

- **Landsat-8/9 OLI**: NIR = Band 5, RED = Band 4
- **Landsat-5 TM (if used for earlier years)**: NIR = Band 4, RED = Band 3

NDVI values were categorized as:

<0.0	Water/ Non-vegetated
0-0.2	Barren/ Builtup
0.2-0.5	Sparse vegetation/Agriculture
0.5-0.8	Moderate vegetation
>0.8	Dense vegetation

3.3. Land Surface Temperature

Land Surface Temperature (LST) Estimation

LST was derived from the **thermal band (Band 10) of Landsat-8/9 TIRS** through the following steps:

1. **Conversion of DN to Top of Atmosphere (TOA) Radiance**

   $$L_{\lambda} = M_L * Q_{Cal} + A_L$$

   Where M_L is the radiance multiplicative scaling factor, A_L is the additive scaling factor, and Q_{cal} is the quantized calibrated pixel value.

2. **Conversion of TOA Radiance to Brightness Temperature (BT)**

   $$BT = \frac{K_2}{\ln\left(\frac{K_1}{L_\lambda} + 1\right)}$$

   where K_1 and K_2 are thermal conversion constants provided in the metadata.

   Band 10:

   - K1 = 774.89 W/(m²·sr·ìm)
   - K2 = 1321.08 K

3. **Proportion of Vegetation (PV)**

   The PV was estimated from NDVI values as:

   $$PV = \left(\frac{NDVI - NDVI_{\min}}{NDVI_{\max} - NDVI_{\min}}\right)^2$$

   where $NDVI_{min}$ and $NDVI_{max}$ are the minimum and maximum NDVI values of the scene.

4. **Land Surface Emissivity (LSE)**

   Emissivity (ε) was estimated using PV as:

   $\varepsilon = 0.004 * PV + 0.986$

5. **Land Surface Temperature (Kelvin)**

   The corrected LST in Kelvin was derived using:

$$LST_K = \frac{BT}{1 + \left(\frac{\lambda * BT}{\rho}\right)\ln(\varepsilon)}$$

   where λ = effective wavelength (10.895 μm for Band 10),

   ρ = h·c/σ = 1.438 \times 10^(-2) mK,

   ε = emissivity.

6. **Conversion to Celsius**

   Finally, LST was converted into Celsius as:

   $LST_K(°C) = LST_K - 273.15$

4. Results and Discussion

4.1. Vegetation Maps of Raipur

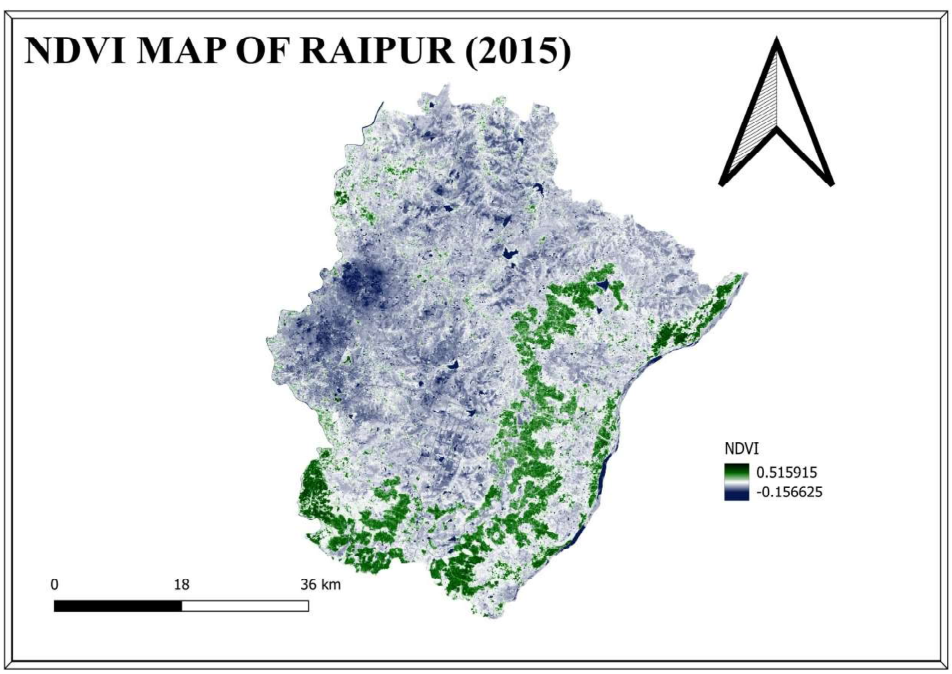

Fig. 2: NDVI Map of Raipur, India (2015)

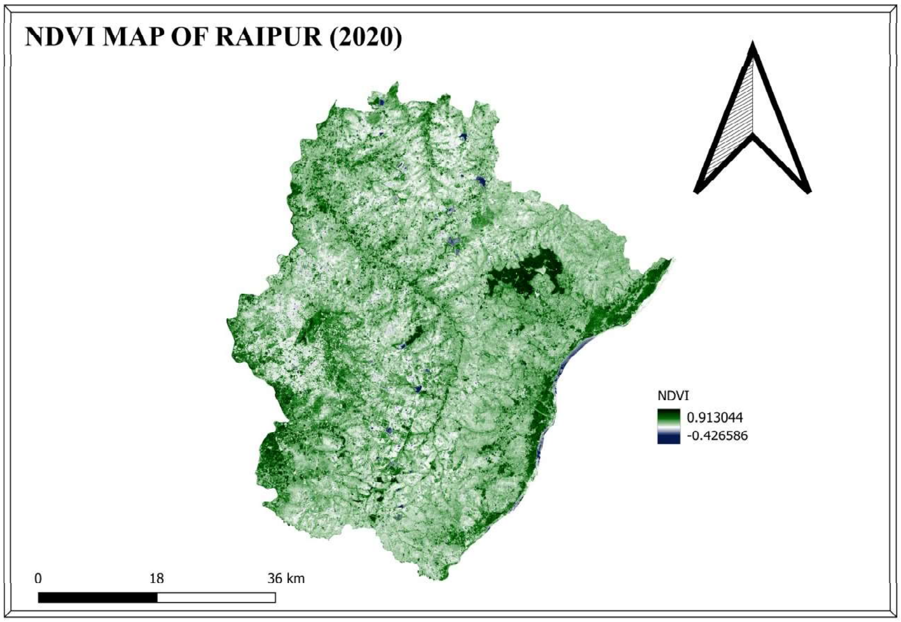

Fig. 3: NDVI Map of Raipur, India (2020)

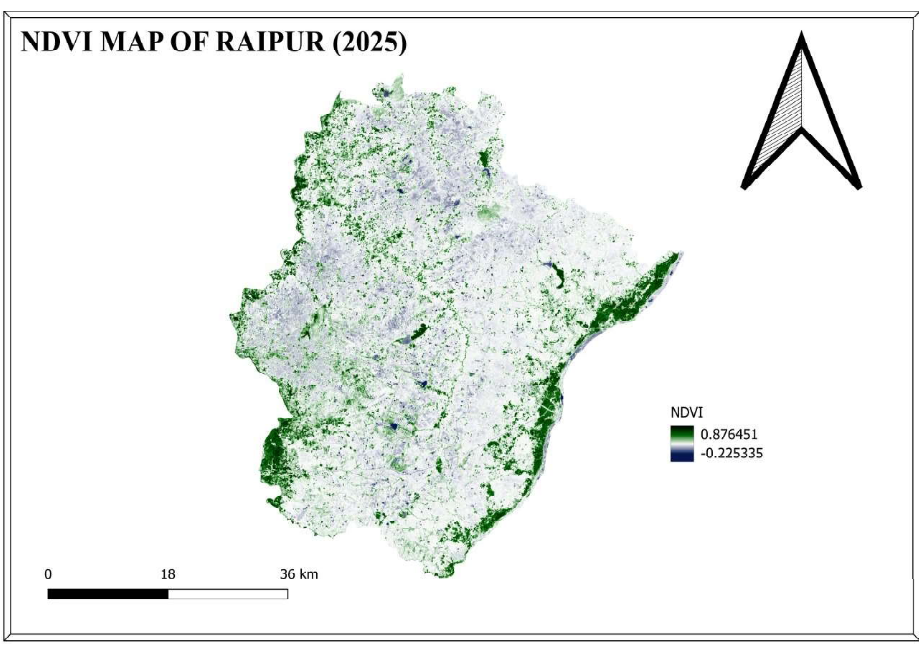

Fig. 4: NDVI Map of Raipur, India (2025)

The NDVI analysis for Raipur District between 2015 and 2025 highlights notable shifts in vegetation cover and condition over the decade. In 2015, the district recorded a mean NDVI of 0.16 with a maximum of 0.52, reflecting sparse to moderate vegetation presence. By 2020, the mean NDVI rose sharply to 0.41, while the maximum reached 0.91, signaling marked improvement in vegetation health and density—likely due to regeneration processes or agricultural growth. In 2025, the mean NDVI showed a slight decline to 0.40, with the maximum remaining high at 0.88, suggesting largely stable but marginally reduced vegetation compared to 2020. Across all years, negative minimum NDVI values were observed, corresponding to water bodies or barren surfaces. Meanwhile, the standard deviation increased from 0.09 in 2015 to 0.14 in 2025, pointing to rising variability in vegetation distribution, possibly linked to urbanization and land use changes. Overall, these NDVI trends offer key insights into the spatiotemporal dynamics of vegetation in Raipur, supporting ecological monitoring, land use planning, and sustainable development strategies.

The observed increase in mean NDVI from 2015 to 2020 in Raipur District, followed by slight stabilization in 2025, aligns with vegetation recovery trends reported by Sharma et al. (2021) from tropical regions in southern India, where afforestation and agricultural expansion contributed to improved vegetation cover.

4.2. Land Surface Temperature

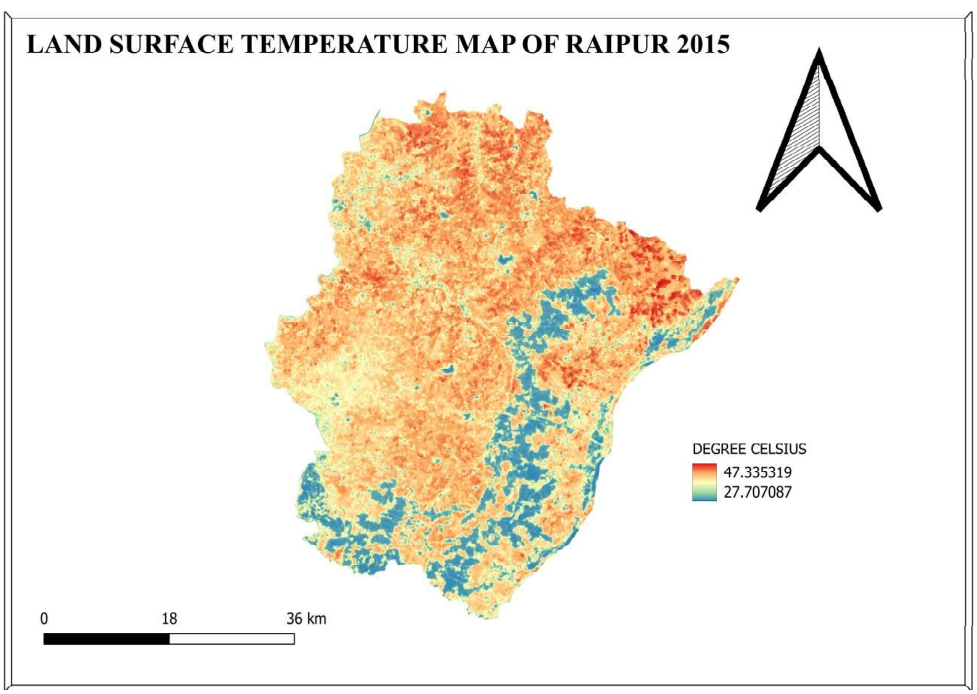

Fig. 5: Land Surface Temperature Map of Raipur, India (2015)

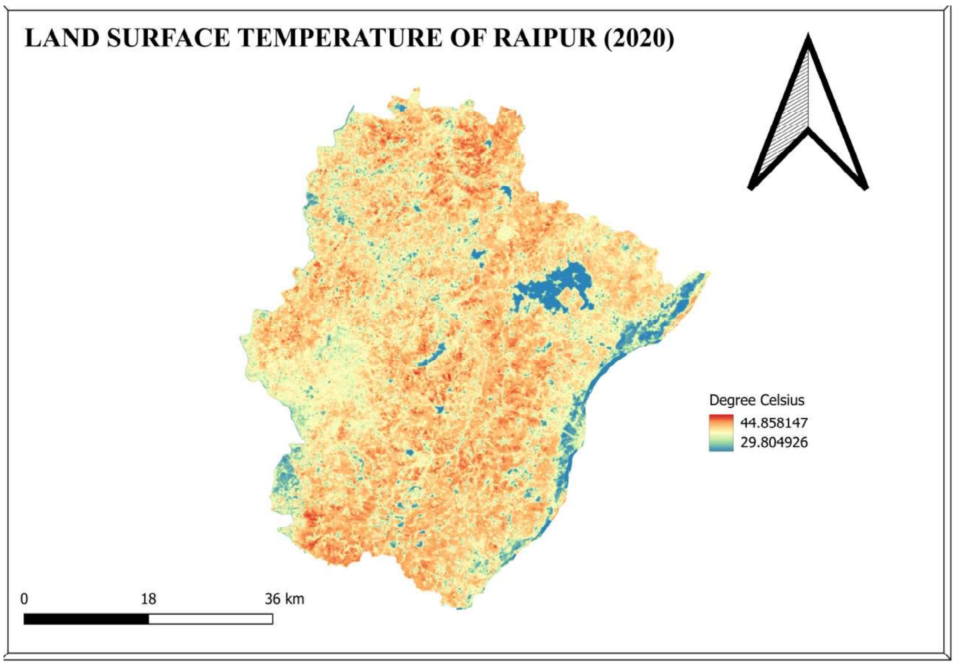

Fig. 6: Land Surface Temperature Map of Raipur, India (2020)

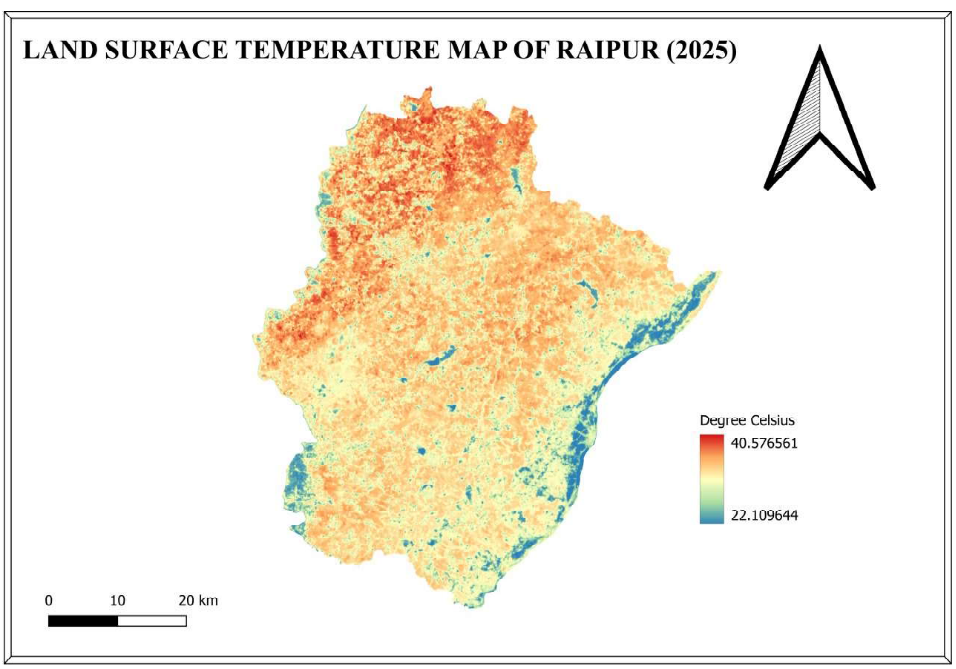

Fig. 7: Land Surface Temperature Map of Raipur, India (2025)

The Land Surface Temperature (LST) analysis of Raipur District over the decade from 2015 to 2025 shows a decreasing trend in both maximum and mean surface temperatures. In 2015, the maximum LST recorded was 47.34°C with a mean of 38.42°C, indicating relatively high surface temperatures consistent with urban heat and land cover patterns. By 2020, the maximum temperature declined slightly to 45.91°C, and the mean temperature was relatively stable at 38.37°C. Notably, the year 2025 shows a more pronounced decrease with a maximum LST of 40.58°C and a mean temperature reduced to 32.76°C, reflecting potential changes in land cover, increased vegetation, or climatic influences that may have mitigated surface heating. The minimum LST values also dropped from 27.71°C in 2015 to 22.11°C in 2025, indicating cooler zones within the district. The corresponding standard deviations reveal spatial variability in LST, with a reduction in variability between 2015 and 2020 followed by a slight increase by 2025. These LST trends highlight the dynamic surface thermal environment in Raipur, influenced by urbanization, vegetation cover changes, and climate factors, which are crucial for understanding local microclimatic conditions and guiding urban environmental management.

The declining trend in Land Surface Temperature (LST) corresponds to findings by Zhang et al. (2020) in Guangzhou, China, which documented an inverse relationship between NDVI and LST in a rapidly urbanizing tropical city, demonstrating vegetation's mitigating effect on urban heat.

4.3. Relationship Between NDVI and LST

Year	*Parameter*	*Maximum Value*	*Mean Value*	*Minimum Value*	*Standard Deviation*
2015	LST (°C)	47.34	38.42	27.71	4.01
2015	NDVI	0.52	0.16	-0.16	0.09
2020	LST (°C)	45.91	38.37	28.23	2.71
2020	NDVI	0.91	0.41	-0.54	0.13
2025	LST (°C)	40.58	32.76	22.11	3.33
2025	NDVI	0.88	0.4	-0.23	0.14

Vegetation health and surface temperature are clearly inversely correlated, according to an examination of Raipur District's NDVI and LST data from 2015 to 2025. The mean LST declined from 38.42°C to 38.37°C as NDVI values rose from 0.16 in 2015 to roughly 0.41 in 2020. This fall was more noticeable in 2025 when NDVI increased significantly to 0.40. Increased vegetation coverage improves evapotranspiration and shade, which lowers surface temperatures. This negative association is consistent with well-established biological concepts. Variable LST patterns correlate with the geographical heterogeneity shown by rising NDVI standard deviation, which reflects the district's varied land cover and human effects. These findings confirm that areas with denser, healthier vegetation exhibit lower surface temperatures, highlighting the critical role of vegetation in mitigating urban heat effects and supporting microclimate regulation. This relationship is consistent with previous studies in tropical and urban environments, reinforcing the utility of NDVI and LST metrics for integrated environmental assessment and urban greening policy development.

Urban growth pressures limit vegetation expansion and complicate surface temperature dynamics in rapidly emerging tropical cities, as evidenced by the minor decline in NDVI and stabilized LST after 2020, which is consistent with observations made by Rao et al. (2021) in Hyderabad, India.

5. Conclusion

This work uses GIS and remote sensing tools to give a thorough decadal analysis of land surface temperature and vegetation dynamics in Raipur District. The mean NDVI increased between 2015 and 2020 before slightly stabilizing in 2025, reflecting trends in vegetation growth that were moderated by the pressures of urbanization. Concurrently, the observed decrease in LST emphasizes how more vegetation cover cools the environment and may help reduce the effects of urban heat islands. The crucial role that vegetation plays in controlling surface temperature and preserving ecological balance in tropical areas that are quickly urbanizing is highlighted by the negative relationship between NDVI and LST. These results offer important information to guide urban planning and sustainable land management strategies targeted at increasing green space and fostering climate resilience in Raipur. Continuous monitoring using advanced geospatial tools is recommended to support adaptive strategies addressing future environmental challenges.

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