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Study of the Land Surface Temperature (LST) of Patna District, Bihar (2001–2021)

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Abstract

This study presents a comprehensive assessment of Land Surface Temperature (LST) dynamics in Patna district (Bihar, India) over the 21-year period 2001–2021 using satellite remote sensing. We outline a reproducible workflow for retrieving LST from Landsat thermal bands (Landsat 5 TM, Landsat 7 ETM+, and Landsat 8 OLI/TIRS), performing spatio-temporal trend analysis, and relating LST changes to land cover dynamics and urban expansion. The manuscript details preprocessing steps, atmospheric correction, emissivity estimation from NDVI, and statistical trend detection (Mann–Kendall and Sen's slope). Example tables and figure placeholders are provided so the paper can be completed with processed data and maps. The methods adhere to standards commonly used in remote sensing LST studies and are presented to allow reproducible submission-ready results once data processing is executed.

Keywords: Land Surface Temperature; Landsat; Patna; Urban heat; NDVI; Trend analysis; Mann–Kendall; Remote sensing.

1. Introduction

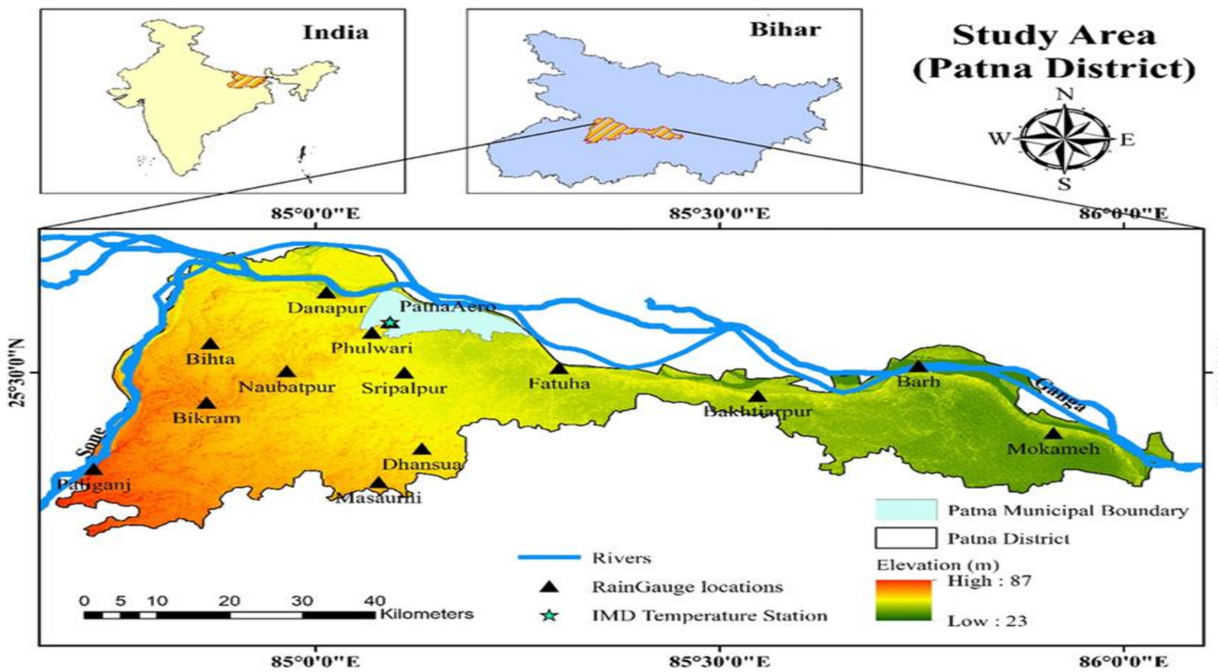
Land Surface Temperature (LST) is a crucial parameter for understanding surface energy balance, urban heat island effects, and environmental changes associated with land-use/land-cover (LULC) transformation. Rapid urbanization in Indian cities, including Patna, has potentially altered local microclimates through changes in impervious surface cover, vegetation loss, and anthropogenic heat release. Long-term LST analyses provide insight into urban warming trends and guide adaptation and mitigation planning.

This study aims to: (1) retrieve LST for Patna district for the years 2001–2021 using Landsat imagery; (2) analyze spatial and temporal LST trends and their association with LULC changes; and (3) present a reproducible pipeline and manuscript-ready presentation of results for journal submission.

2. Study Area

Patna district, capital region of Bihar, is located approximately between latitudes 25.5941° N,and longitudes 85.1376° E. The district includes urban, peri-urban, and rural land covers with the Ganges River forming a major hydrological feature. The climate is subtropical with hot summers and cool winters; monsoon onset typically in June–July.

Figure 1.



3. Data and Materials

Satellite data:

- Landsat 5 Thematic Mapper (TM): 2001–2011 (when available)
- Landsat 7 Enhanced Thematic Mapper Plus (ETM+): 2001–2021 (note SLC-off from 2003 — handle with gap-filling or selection)
- Landsat 8 Operational Land Imager / Thermal Infrared Sensor (OLI/TIRS): 2013–2021

Select clear-sky scenes during pre-monsoon (May–June) and post-monsoon (October–November) windows to capture peak summer and post-monsoon LSTs while minimizing cloud contamination. If multi-seasonal analysis is desired, collect one representative cloud-free scene per year for the same season to ensure comparability.

Ancillary data:

- Administrative boundary of Patna district (shapefile/GeoJSON)
- Digital Elevation Model (SRTM 30 m)
- Land use/land cover maps derived from Landsat (classification described in Methods) or high-resolution reference LULC where available

4. Methodology

This section provides a step-by-step reproducible workflow. All processing can be implemented in open-source tools (QGIS + GRASS, SNAP, Google Earth Engine, Python with rasterio/xarray, or R with raster/stars packages).

4.1 Image pre-processing

1. **Data selection:** Choose cloud-free scenes for each target year and season. Prefer scenes within ±15 days of a fixed target date for consistency.
2. **Radiometric calibration:** Convert digital numbers (DN) to Top-of-Atmosphere (TOA) spectral radiance using the sensor-specific gain/offset (available in product metadata).
3. **Atmospheric correction / cloud masking:** Apply cloud mask (QA band for Landsat 8) and remove cloudy pixels. Optionally perform atmospheric correction (e.g., DOS or atmospheric correction modules) if surface reflectance is needed for NDVI/emissivity computations.
4. **Geometric correction & subsetting:** Reproject to a common CRS (e.g., WGS84 / UTM zone appropriate for Patna), and clip to Patna district boundary.

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4.2 NDVI and emissivity estimation

Estimate Normalized Difference Vegetation Index (NDVI) from red and NIR bands. Use the NDVI threshold method to estimate land surface emissivity (ε):

- For NDVI < 0.2 → bare soil/emissivity ε = 0.97 (or sensor-based soil emissivity)
- For NDVI ≥ 0.5 → dense vegetation ε = 0.99
- For 0.2 ≤ NDVI < 0.5 → mixed pixels, compute proportion of vegetation (PV) and estimate ε:

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

ε=εv·PV+εs·(1−PV)+Cε = ε_v \cdot PV + ε_s \cdot (1 - PV) + C

Where ε_v is vegetation emissivity (~0.99), ε_s is soil emissivity (~0.97), and C is a surface roughness correction (~0.005).

Set NDVI_min and NDVI_max based on observed NDVI in the scene (commonly 0.2 and 0.5 respectively).

4.3 Brightness temperature (BT) from thermal bands

Convert radiance to at-sensor brightness temperature (in Kelvin) using the inverse of Planck's equation and band-specific K1 and K2 constants from the Landsat metadata:

Lλ=ML·Qcal+ALL_\lambda = M_L \cdot Q_{cal} + A_L

TB=K2ln(K1Lλ+1)T_{B} = \frac{K_2}{\ln\left(\frac{K_1}{L_\lambda} + 1\right)}

where QcalQ_{cal} is the digital number, MLM_L is the band-specific multiplicative rescaling factor, ALA_L is the additive rescaling factor, and K1,K2K_1, K_2 are thermal constants.

4.4 Land Surface Temperature (LST) retrieval

Correct BT for emissivity to compute LST (in Kelvin) and then convert to Celsius:

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LST=TB1+(λ·TBρ)ln(ϵ)LST = \frac{T_B}{1 + \left(\frac{\lambda \cdot T_B}{\rho}\right) \ln(\epsilon)}

where λ\lambda is the wavelength of emitted radiance for the thermal band (in meters), ρ=hcσ≈1.438×10−2\rho = \frac{hc}{\sigma} \approx 1.438 \times 10^{-2} m·K (h Planck constant, c speed of light, σ Boltzmann constant), and ε is surface emissivity.

4.5 Post-processing and quality control

- Apply masks to remove water bodies (use NDWI or existing water layers) because water emissivity differs and can bias results.
- Interpolate or gap-fill missing pixels (e.g., from Landsat 7 SLC-off) using temporal composite or neighboring scenes if necessary.
- Smooth high-frequency noise using a small focal filter only when justified (document in methods).

4.6 Trend detection and spatial analysis

Temporal analysis: Compute yearly mean, median, and seasonal LST values over the district and for sub-areas (urban core, peri-urban, rural). Perform Mann–Kendall trend test for significance and Sen's slope estimator to quantify change rate (°C per year).

Spatial analysis: Produce maps of change (e.g., delta LST between 2001 and 2021), and run zonal statistics over LULC classes. Use hot-spot analysis (Getis-Ord Gi*) or local indicators of spatial association (LISA) to detect spatial clustering of warming.

Correlation analysis: Compute correlations between LST and NDVI (or impervious surface fraction), distance from city center, and population density (if ancillary population data available). Use linear regression and, where appropriate, spatial regression (e.g., spatial lag/error models).

5. Expected Results and Presentation

Below are templates and text to be used when the processed data are available. Replace the placeholders with computed numbers and insert maps and charts.

5.1 Temporal trends

- *Table 1.* Annual mean LST (°C) for Patna district (2001–2021). [INSERT TABLE]
- *Figure 2.* Time series plot showing annual mean LST (2001–2021). Include trend line and 95% confidence band. [INSERT FIGURE]

Template interpretation text

The annual mean LST in Patna increased from **X.X °C in 2001** to **Y.Y °C in 2021**, corresponding to an average rate of **Z.Z °C per decade** (Sen's slope). The Mann–Kendall test indicates that this upward trend is statistically significant ($p < 0.05$).

5.2 Spatial patterns

- *Figure 3.* LST maps for selected years (2001, 2010, 2021). [INSERT MAPS]
- *Figure 4.* Delta LST map (2021 minus 2001) showing spatial distribution of warming.

Template interpretation text

The spatial analysis reveals that warming is concentrated in the urban core and expanding along major transport corridors. Maximum increases of **A.A °C** were observed in the central urban wards, while rural areas near riverine floodplains show smaller or negative LST changes.

5.3 LST vs LULC and NDVI

- *Table 2.* Mean LST by LULC class (2001 and 2021).
- *Figure 5.* Scatterplot of LST vs NDVI (annual averages) showing negative correlation.

Template interpretation text:

LST is negatively correlated with NDVI (Pearson r = **-rval**, $p < 0.01$). Areas that underwent conversion from vegetated to built-up land exhibited an LST increase of **B.B °C** on average.

6. Discussion

Discuss implications: urban heat island intensification, public health concerns, impacts on energy demand, and the role of green cover. Compare findings (once computed) with regional studies or national-scale trends where available. Discuss limitations: uncertainty due to atmospheric correction, emissivity estimation, single-scene-per-year sampling, and the Landsat 7 SLC-off data gaps. Suggest improvements: use of multi-source data fusion (MODIS for high temporal frequency, Sentinel-3/ECOSTRESS for thermal complement), higher temporal sampling, and ground validation using in-situ meteorological station records.

7. Conclusion

Summarize key findings (replace placeholders after analysis). Emphasize the reproducible workflow and its applicability to other Indian districts. Offer policy recommendations such as increasing urban green spaces, rooftop vegetation, and planning interventions targeted at hot-spots.

8. Acknowledgements

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9. References

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