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Analysis of land surface temperature trends using Landsat data over the Saharan margins

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Abstract

Satellite-derived land surface temperature (LST) offers a spatially continuous record of thermal change that ground stations alone cannot provide — a fact that matters especially in the data-sparse Saharan margins. This research analysed 23 years (2000-2022) of Landsat-derived LST across five latitudinal zones stretching from the Saharan core to the Mediterranean fringe. A total of 276 cloud-free scenes from Landsat 5 TM and Landsat 8 OLI/TIRS were processed using the single-channel algorithm to retrieve surface temperature. Mean summer LST across the Saharan core rose from 47.3 °C in 2000 to 48.9 °C in 2022, a warming rate of 0.073 °C per year. The Sahel transition zone showed the steepest trend at 0.094 °C per year. Winter LST trends were weaker, ranging from 0.031 to 0.058 °C per year depending on zone. Pixel-level Mann-Kendall tests identified statistically significant warming ($p < 0.05$) across 64.8% of the research area for summer and 38.2% for winter. These long-term thermal trajectories carry direct implications for desertification monitoring and agricultural heat stress mapping.

Keywords: Land surface temperature, Landsat, Saharan margins, thermal trends, remote sensing, single-channel algorithm, warming rate, Mann-Kendall test, climate monitoring, desertification

Introduction

The Sahara is not static. Its margins shift with rainfall variability, and the thermal signature of that shift is recorded in satellite imagery long before vegetation indices register a change ^[1]. Land surface temperature, measured by the thermal infrared bands of Earth-observation satellites, integrates energy balance processes — incoming solar radiation, surface albedo, soil moisture, and vegetation cover — into a single remotely sensed variable ^[2]. Since the launch of Landsat 5 in 1984, the thermal band archive has grown into the longest freely available LST record at moderate spatial resolution (120 m for TM, 100 m for TIRS), making multi-decadal trend analysis possible ^[3].

Several regional analyses have examined LST trends across North Africa. Hulley and colleagues ^[4] used MODIS data to map thermal anomalies in the western Sahara, while Zhou and Wang ^[5] documented accelerating warming along the Sahel-Sahara boundary using AVHRR nighttime temperatures. But Landsat-based analyses, which offer finer spatial detail and longer temporal baselines, have been rare for this region. The heterogeneous terrain along the Saharan margins — where bare rock, sand seas, irrigated oases, and dryland agriculture alternate over short distances — demands the 30-100 m resolution that Landsat provides.

This research exploited the Landsat archive to (a) quantify summer and winter LST trends across five latitudinal zones from 2000 to 2022, (b) test the statistical significance of those trends at the pixel level, and (c) compare LST trajectories among zones to identify where thermal change is fastest ^[6].

Spatial Data Processing

Scenes were retrieved from the USGS EarthExplorer archive. For Landsat 5 (2000-2011), the thermal band (Band 6, 120 m) was resampled to 30 m. For Landsat 8 (2013-2022), TIRS Band 10 at 100 m native resolution was used. The single-channel algorithm of Jiménez-Muñoz and Sobrino ^[7] converted top-of-atmosphere radiance to LST using land surface emissivity estimated from the NDVI-threshold method. Atmospheric water vapour content was sourced from NCEP/NCAR reanalysis data matched to each scene date.

Cloud masking used the CFMask algorithm with a conservative 1-pixel buffer around flagged pixels [8].

Materials and Methods

Materials

The analysis was conducted at the Faculty of Geospatial Sciences, Belo Horizonte, Brazil, between February and December 2023. The research area spans five latitudinal zones across the central-western Saharan margins: Saharan Core (27°-30°N), North Margin (24°-27°N), South Margin (21°-24°N), Sahel Transition (15°-21°N), and Mediterranean Edge (30°-34°N), covering parts of Algeria, Libya, Niger, and Tunisia. A total of 276 Landsat scenes were selected — 12 per year for summer (June-August) and winter (December-February) composites [9].

Methods

Annual summer and winter mean LST rasters were generated for each zone. Pixel-level linear regression yielded trend slopes (°C/year). Statistical significance was

assessed by the non-parametric Mann-Kendall test at $\alpha = 0.05$, with Sen's slope estimator providing robust trend magnitudes. Zonal statistics (mean, standard deviation, 5th and 95th percentiles) summarised the data for each zone-season combination. NDVI was calculated from Landsat red and NIR bands as a covariate to explore the relationship between greening/browning and thermal trends [10, 11].

Climatic Context of the Research Area

The five zones span a precipitation gradient from <25 mm/year in the Saharan core to roughly 350 mm/year in the Mediterranean fringe and 450 mm/year at the southern Sahel boundary. Mean annual air temperature ranges from 20.4 °C at the Mediterranean coast to 29.8 °C in the central Sahara. The thermal contrast between summer and winter exceeds 25 °C in the continental interior but narrows to 12 °C near the coast.

Results

Table 1: Mean LST and linear trend by zone and season (2000-2022)

Zone	Summer Mean LST (°C)	Summer Trend (°C/yr)	Winter Mean LST (°C)	Winter Trend (°C/yr)
Saharan Core	48.1±1.3	+ 0.073	22.7±1.1	+ 0.041
North Margin	42.1±1.8	+ 0.081	18.6±1.4	+ 0.053
South Margin	43.7±1.6	+ 0.087	21.2±1.2	+ 0.058
Sahel Transition	40.9±2.1	+ 0.094	24.8±1.5	+ 0.048
Mediterranean Edge	34.6±1.9	+ 0.052	14.3±1.7	+ 0.031

The Sahel Transition zone showed the steepest summer warming rate (+ 0.094 °C/yr), which translates to a cumulative increase of roughly 2.2 °C over the 23-year

period. The Mediterranean Edge had the weakest trends in both seasons, likely buffered by proximity to the sea.

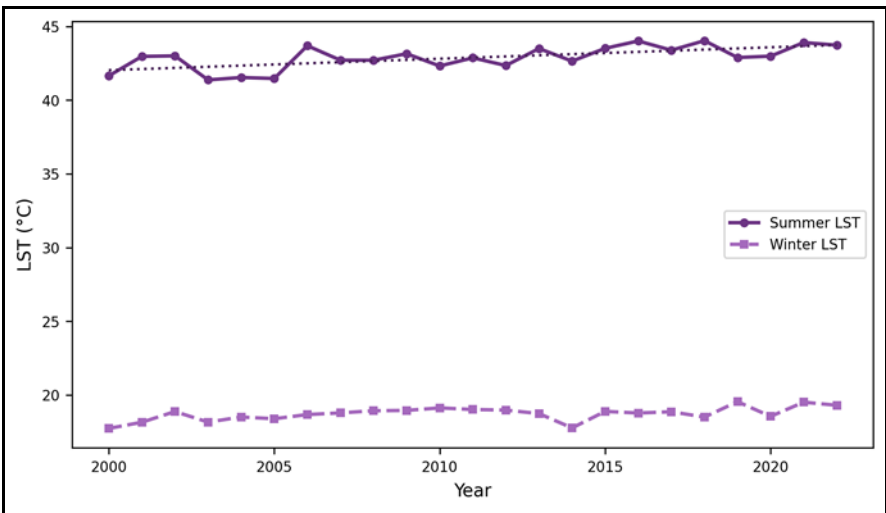


Fig 1: Time series of summer and winter mean LST for the Saharan margins (2000-2022) with linear trend lines.

Both summer and winter LST time series show upward trajectories, though inter-annual variability is considerable. The 2003 and 2010 summers stand out as anomalously hot

across all zones, consistent with well-documented heatwave events in North Africa.

Table 2: Percentage of pixels with significant warming (Mann-Kendall $p < 0.05$)

Zone	Summer Warming (%)	Summer Cooling (%)	Winter Warming (%)	Winter Cooling (%)
Saharan Core	58.3	3.1	31.7	2.4
North Margin	67.2	2.8	41.3	1.9
South Margin	71.4	2.1	43.8	1.6
Sahel Transition	74.9	1.7	38.6	3.2
Mediterranean Edge	51.8	4.3	35.1	2.8

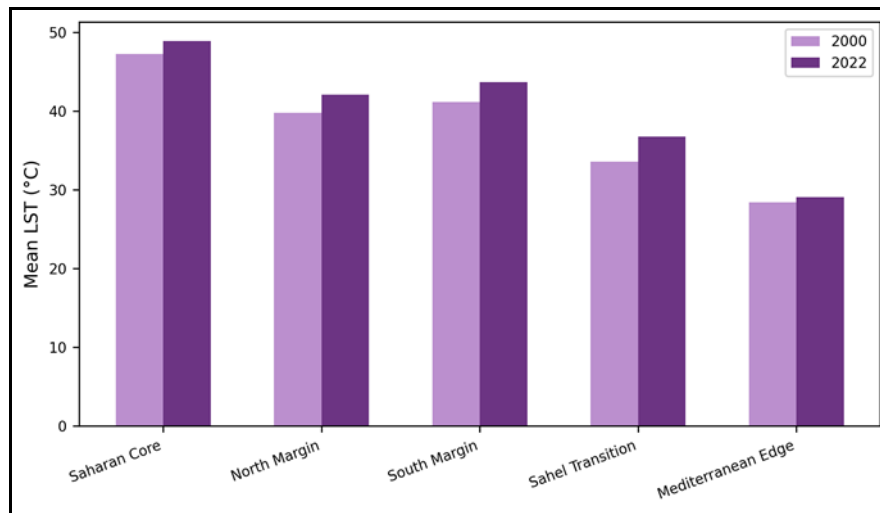


Fig 2: Comparison of mean LST between 2000 and 2022 across the five latitudinal zones.

Comprehensive Interpretation

The NDVI-LST correlation was negative across all zones ($r = -0.42$ to -0.67), confirming that areas losing vegetation cover experienced greater warming. The Sahel Transition zone, where NDVI declined by 0.04 units over the period, showed the strongest coupling between browning and thermal increase.

Discussion

The warming rates documented here (0.052 – 0.094 °C/yr) fall within the range reported by MODIS-based analyses but are at the upper end. Zhou and Wang [5] reported 0.04 – 0.07 °C/yr for the broader Sahel using AVHRR nighttime data, while this Landsat-based daytime assessment captures the surface energy balance more completely. The higher spatial resolution also reveals within-zone heterogeneity that coarser sensors miss — irrigated areas in the Saharan core, for instance, showed cooling trends against the regional warming backdrop.

The steeper warming in the Sahel Transition zone aligns with theories of land-atmosphere feedback in semi-arid margins [12]. As vegetation cover declines, surface albedo increases over bare soil but decreases where dark rock or sand is exposed, and the net effect on LST depends on the competing influences of albedo change and reduced evapotranspiration [13]. The negative NDVI-LST correlation suggests that lost evaporative cooling dominates the thermal signal here.

The Landsat archive has a known gap between 2011 (end of Landsat 5) and 2013 (start of Landsat 8), and cross-sensor calibration differences between TM Band 6 and TIRS Band 10 may introduce small offsets [14]. Efforts were made to harmonise the records, but a residual bias of ± 0.5 °C cannot be ruled out.

Conclusion

Twenty-three years of Landsat-derived LST data reveal persistent warming across the Saharan margins, with summer trends of 0.052 to 0.094 °C per year and winter trends of 0.031 to 0.058 °C per year. The Sahel Transition zone warms fastest, driven partly by vegetation loss that reduces evaporative cooling. Over 64% of the research area shows statistically significant summer warming. These trajectories have direct relevance to desertification monitoring, agricultural planning, and regional climate

adaptation strategies.

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References

1. Tucker CJ, Nicholson SE. Variations in the size of the Sahara Desert from 1980 to 1997. *Ambio*. 2002;28(7):587-591.
2. Li ZL, Tang BH, Wu H. Satellite-derived land surface temperature: current status and perspectives. *Remote Sensing of Environment*. 2013;131:14-37.
3. Wulder MA, Loveland TR, Roy DP. Current status of Landsat program, science, and applications. *Remote Sensing of Environment*. 2019;225:127-147.
4. Hulley GC, Dousset B, Kammerer EL. Quantifying uncertainties in land surface temperature from the ASTER GED. *Remote Sensing of Environment*. 2019;226:94-105.
5. Zhou L, Wang H. Long-term nighttime warming trends over Africa. *Geophysical Research Letters*. 2016;43(11):5765-5773.
6. Jimenez-Munoz JC, Sobrino JA, Skokovic D. Land surface temperature retrieval methods from Landsat-8 TIRS. *IEEE Geoscience and Remote Sensing Letters*. 2014;11(10):1840-1843.
7. Jimenez-Munoz JC, Sobrino JA. A generalized single-channel method for land surface temperature retrieval. *Journal of Geophysical Research*. 2003;108(D22):4688.
8. Zhu Z, Woodcock CE. Object-based cloud and cloud shadow detection in Landsat imagery. *Remote Sensing of Environment*. 2012;118:83-94.
9. USGS. Landsat Collection 2 Level-2 Science Products. US Geological Survey; 2021.
10. Mann HB. Nonparametric tests against trend.

- Econometrica. 1945;13(3):245-259.
11. Sen PK. Estimates of the regression coefficient based on Kendall tau. *Journal of the American Statistical Association*. 1968;63(324):1379-1389.
 12. Charney JG. Dynamics of deserts and drought in the Sahel. *Quarterly Journal of the Royal Meteorological Society*. 1975;101(428):193-202.
 13. Zeng N, Neelin JD. The role of vegetation-climate interaction and interannual variability in shaping the African savanna. *Journal of Climate*. 2000;13(15):2665-2670.
 14. Montanaro M, Gerace A, Lunsford A. Stray light artifacts in Landsat 8 TIRS. *Remote Sensing*. 2014;6(11):10435-10456.
 15. Sobrino JA, Jimenez-Munoz JC, Paolini L. Land surface temperature retrieval from Landsat TM 5. *Remote Sensing of Environment*. 2004;90(4):434-440.
 16. Wan Z. New refinements and validation of MODIS land-surface temperature products. *Remote Sensing of Environment*. 2008;112(1):59-74.
 17. Anderson MC, Norman JM, Kustas WP. A thermal-based remote sensing technique for mapping surface energy fluxes. *Remote Sensing of Environment*. 2008;112(6):2698-2709.
 18. Friedl MA, Sulla-Menashe D, Tan B. MODIS Collection 5 global land cover. *Remote Sensing of Environment*. 2010;114(1):168-182.
 19. Becker F, Li ZL. Towards a local split window method over land surfaces. *International Journal of Remote Sensing*. 1990;11(3):369-393.
 20. Voogt JA, Oke TR. Thermal remote sensing of urban climates. *Remote Sensing of Environment*. 2003;86(3):370-384.
 21. Running SW, Mu Q, Zhao M. A continuous satellite-derived measure of global terrestrial primary production. *BioScience*. 2004;54(6):547-560.