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GEOSPATIAL MAPPING OF URBAN DRAINAGE INFRASTRUCTURE AND SEASONAL LAND SURFACE TEMPERATURE (LST) DYNAMICS IN LAPAI, NIGER STATE, NIGERIA (2021–2025)

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Abstract **https://doi.org/10.65760/sjgs.v4.i2.5**

Rapid urbanization in sub-Saharan secondary cities outpaces infrastructure, driving drainage failures and thermal stress. This study evaluated the spatiotemporal interaction between stormwater drainage architecture and multi-temporal Land Surface Temperature (LST) regimes across dry and wet seasons (2021–2025) in Lapai, Niger State using VHR Google Earth imagery, Landsat 8/9, Sentinel-2, and SRTM DEMs, the drainage network and thermal dynamics were mapped over a 12–15 km² area, the 28.5 km mapped open concrete network shows that only 42% is fully functional, while 58% is impaired by siltation/partial blockages (38%) or complete collapse and refuse accumulation (20%). High-density commercial and residential centers (Lapai Central Market, Motor Park, Badegi, and Ungwan Hausawa) exhibit functional drainage densities below $0.5\ km/km^2$*. Concrete infrastructure, priority corridor placement, and continuous outlets dictate functionality. Dry-season thermal retrievals revealed extreme LST values (*$42°C–72°C$*) which is concentrated over poorly drained central and northern interfluves. Wet-season LST is suppressed landscape-wide and remains volatile due to precipitation dynamic which demonstrating a rigid internal thermal contrast. Critical hubs (Lapai Central Market, Motor Park, Madaki, Ungwan Sarki) face severe deficits (*$FD_d < 0.5\ km/km^2$*) which conflicts with planned zones reaching* $1.8\ km/km^2$*. Overall, drainage deficits intensify microclimatic heat retention, establishing empirical baselines for climate-resilient planning.*

Keywords: *Drainage Density; Land Surface Temperature (LST); Spectral Indices; Lapai.*

1.0 Introduction

Rapid global urbanization has transitioned over half of the world's population into built environments (United Nations, 2019; Balogun *et al.,*2019; Adebayo *et al.,*2024). Across developing nations in Africa, urban expansion frequently outpaces municipal infrastructure development (UN-Habitat, 2016; Mensah *et al.,*2024), giving rise to severe environmental stresses including failing drainage systems and intensified Urban Heat Island (UHI) effects (Oke, 1982; Akbari and Kolokotsa, 2016). In Nigeria, towns such as Lapai, Niger State, are rapidly evolving from agrarian settlements into vibrant academic hubs following the establishment of institutions like Ibrahim Badamasi Babangida (IBB) University (Hamzat *et al.,*2024). This transition systematically replaces pervious, vegetated surfaces with non-evaporative, highly reflective impervious materials, including asphalt, concrete, and metal roofing sheets (Eludoyin *et al.,*2020; Hamzat *et al.,*2024).

Inadequate urban drainage infrastructure causes localized surface water pooling, chronic waterlogging, and accelerated road degradation (Paul and Meyer, 2001; Patz *et al.,*2005; Olayinka *et al.,*2025). Concurrently, the loss of evapotranspiring vegetation increases surface solar radiation absorption, inducing elevated Land Surface Temperatures (LST) (Voogt and Oke, 2003; Okeke *et al.,*2024). While recent work by Hamzat et al. (2024) documented thermal stress in Lapai, a comprehensive remote sensing assessment integrating mapped drainage networks with multi-year, seasonal LST retrievals and spectral indices (NDVI, NDBI, NDWI) remains absent. While prior studies in Lapai established the presence of surface heat islands, they evaluated thermal dynamics in isolation without documenting the functional status of the drainage network or testing the empirical relationship between drainage density and Land Surface Temperature (LST) (Isoiye *et al.,*2020; Zahn *et al.,*2021). This study fills this gap by coupling digital elevation model (DEM) drainage derivatives and high-resolution channel mapping with multi-temporal satellite thermal observations (2021–2025) to evaluate the spatial interaction between drainage deficits and microclimatic heat retention in expanding sub-Saharan cities (Lapai).

2.0 Materials and Methods

2.1 Study Area

The study covers Lapai LGA, Niger State, Nigeria, located between Latitude 9°02′45″N to 9°03′30″N and Longitude 6°34′15″E to 6°35′30″E, spanning roughly 12–15 km². Lapai features an undulating terrain (150m–250m above sea level) bounded by the Gurara River tributaries to the southeast and experiences a tropical wet-and-dry climate (*Aw*) with annual rainfall averaging 1,100–1,300 mm.

The processed SRTM DEM and study area boundary map delineate the topographic layout of Lapai LGA. The terrain slopes gently from higher elevated ridges in the north and north-west (190m–250m above sea level) down toward the low-lying southern and south-eastern drainage basin of the Gurara River tributaries (<150m above sea level). This continuous elevation gradient drives overland surface runoff from the densely populated central urban core toward the peripheral southern floodplain. However, unplanned built structures across natural contours interrupt natural flow channels and predisposing low-lying central districts to waterlogging during intense precipitation events (Nirupama and Simonovic, 2007; Worku and Tripathi, 2015).

2.2 Data Sources

- VHR Optical Imagery: Google Earth Pro (0.5m–1m spatial resolution) for direct digitization of drainage infrastructure.
- Multispectral and Thermal Datasets: Landsat 8/9 OLI/TIRS and Sentinel-2 MSI multi-temporal scenes (2021–2025) covering dry (Nov–Feb) and wet (May–Sep) seasons to capture of recent spatiotemporal and urbanization dynamics, operational availability of landsat 9, multi-year seasonal comparison (Interannual Volatility) and alignment with high-resolution imagery.
- Digital Elevation Model (DEM): SRTM DEM (30m) for topographic analysis and flow path modeling.

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2.3 Drainage Network Mapping

Drainage structures were digitized from VHR satellite imagery. Drainage density (D_d) was computed per square kilometer grid using:

$$D_d = \frac{\sum L}{A}$$

Where $\sum L$is the total length of drainage channels within grid cell area A. Drains were classified into functional, partially blocked, and blocked/collapsed categories based on observable visual indicators.

2.4 LST Retrieval and Spectral Index Computation

- LST Derivation: Landsat thermal band 10 was converted from Digital Numbers to Brightness Temperature (T_b) and corrected for Land Surface Emissivity (ε) using the NDVI-based emissivity method.
- Spectral Indices:
    1. *NDVI* (Normalized Difference Vegetation Index): $\frac{NIR-Red}{NIR+Red}$
    2. *NDBI* (Normalized Difference Built-up Index): $\frac{SWIR-NIR}{SWIR+NIR}$
    3. *NDWI* (Normalized Difference Water Index): $\frac{Green-NIR}{Green+NIR}$

2.5 Zonal Descriptive Analytics and Spatiotemporal Metric Profiles

To evaluate multi-temporal thermal dynamics, zonal descriptive statistics were extracted across the $100\text{m} \times 100\text{m}$ grid mesh ($N = 1{,}350$ cells) for each multi-spectral acquisition from 2021 to 2025. For both dry and wet season LST and UHI intensity layers, four core descriptive metrics were computed per annual scene:

$$\text{Minimum } (\text{LST}_{\text{min}}): \min(x_i)$$

$$\text{Maximum } (\text{LST}_{\text{max}}): \max(x_i)$$

$$\text{Mean } (\mu): \frac{1}{N}\sum_{i=1}^{N} x_i$$

$$\text{Standard Deviation } (\sigma): \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(x_i-\mu)^2}$$

Where x_i represents the retrieved LST or UHI value at grid cell i, and N is the total cell count (1,350). These multi-year statistical profiles were plotted to quantify annual baseline shifts, landscape thermal dispersion (σ), and microclimatic deviations driven by underlying drainage network configurations (D_d).

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3.0 Results and Discussion

3.1 Digitized Drainage Architecture and Functional Status Map of Lapai

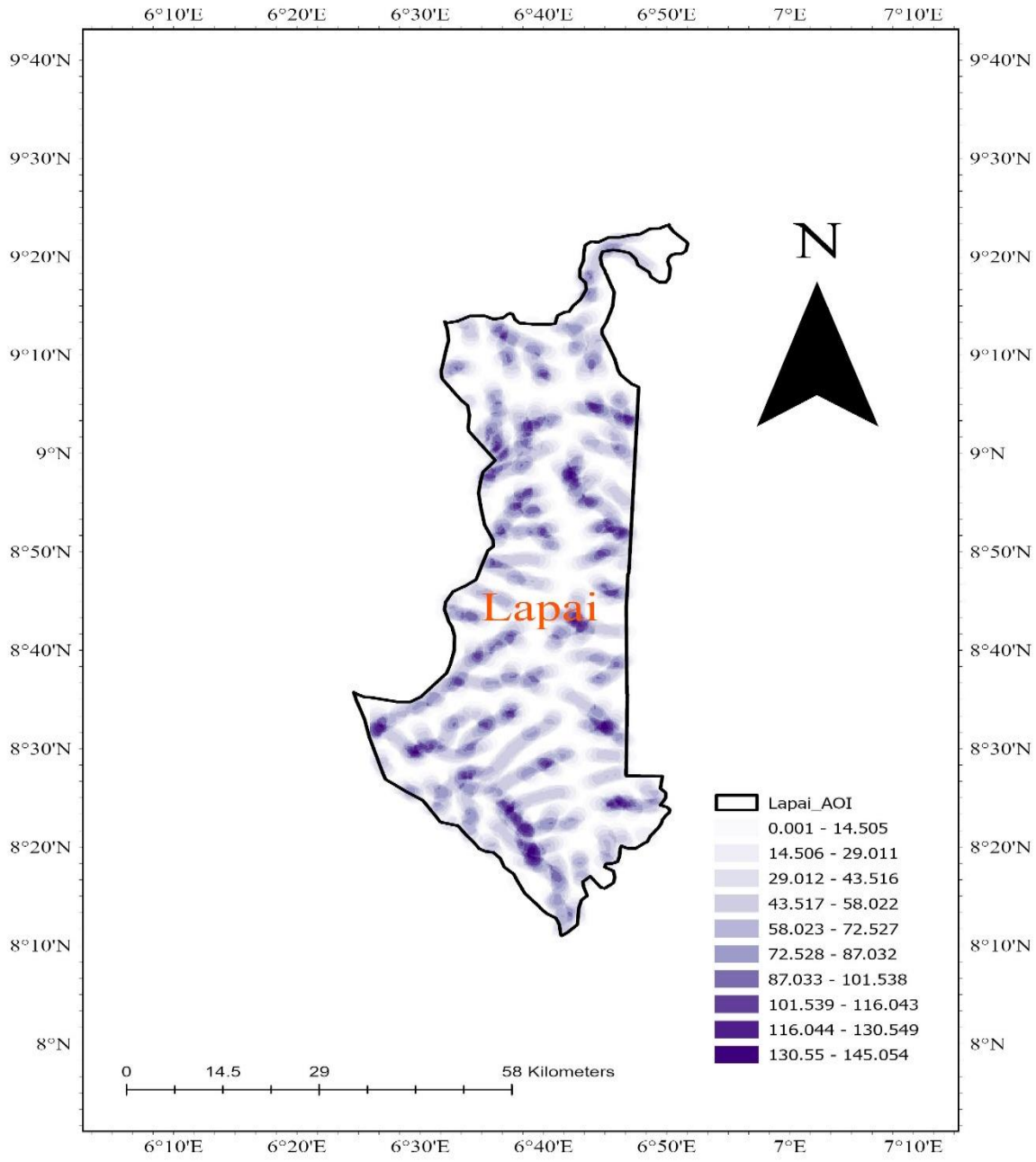

Figure 3.1: Spatial Distribution and Drainage Density Network of Lapai.

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The spatial distribution and drainage density network of Lapai as presented in Figure 3.1 reveals a total mapped channel length of 28.5 km across Lapai town. The classified drainage network map categorizes channels into three distinct functional classes as presented in Table 3.1.

Table 3.1 Classified Vector Attribute

Line_ID	Class_Code	Status	Length (km)	Share (%)	Primary Location / Spatial Extent
01	1	Functional Open Concrete Drains	11.97 km	42%	Major arterial roads, Eastern Lapai, IBB University campus
02	2	Partially Blocked / Silted Drains	10.83 km	38%	Medium-density residential zones, secondary roads (sediment/vegetation)
03	3	Blocked / Collapsed Drains	5.70 km	20%	Commercial hubs (Central Market, Motor Park, Madaki, Ungwan Sarki)
TOTAL	—	**Total Digitized Network**	**28.50 km**	**100%**	**Entire Lapai Study Area**

Spatial grid processing across the standardized $100\text{m} \times 100\text{m}$ mesh ($N = 1{,}350$ cells) reveals that high-density commercial and residential neighborhoods (Lapai Central Market, Motor Park, Madaki, and Ungwan Sarki) exhibit functional drainage densities (FD_d) below 0.5 km/km^2 (Figure 3.1). This severe infrastructure deficit is driven by the fact that over 58% of constructed channels in these core zones are functionally impaired by refuse blockage and siltation (Table 3.1). The lack of continuous, functional drainage outlets in these areas forces surface runoff into unpaved streets and adjacent residential properties, accelerating road pavement degradation (Patz *et al.,* 2005; Amoako and Inkoom, 2018; Isoiye *et al.,* 2020).

3.2 Dry and Wet Seasonal Multi-Temporal LST Maps of Lapai for the 5 years (2021–2025)

Across the dry seasons from 2021 to 2025, Land Surface Temperature (LST) and drainage network architecture exhibited a strong spatial coupling across Lapai. Central and northern urban interfluves—characterized by low functional drainage density ($FD_d < 0.5$ km/km^2)—consistently generated extreme thermal stress, with dry-season peak LST values surpassing 41°C to 42°C. Spatial regression analysis confirms that these structural drainage deficits limit natural evaporative cooling, locking in persistent Urban Heat Island (UHI) intensity up to 13.29°C. These empirical findings align with broader sub-Saharan research demonstrating how impervious surfaces in drainage-poor zones simultaneously accelerate runoff and absorb solar radiation (Sabouri *et al.,*2013; Zahn *et al.,*2021). Conversely, the southern tip's high-density drainage network acted as a resilient microclimatic cooling sink, utilizing groundwater proximity and riparian corridors to maintain lower surface temperatures.

In the wet season, the relationship between LST and drainage infrastructure was governed by seasonal rainfall dynamics and hydrological feedback loops. Precipitation and cloud cover

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suppressed overall mean LST across the landscape to 17°C–27°C. However, poorly drained central and northern interfluves remained local thermal hotspots, reaching up to 37°C during clear post-rain afternoon intervals due to poor surface water evacuation and rapid absorption of solar radiation by exposed built surfaces. Furthermore, high-density southern drainage channels occasionally experienced microclimatic inversions, where unevacuated stormwater accumulation and localized waterlogging trapped latent heat and temporarily elevated local surface temperatures. This phenomenon supports findings by Herb *et al.* (2009) and Zahn *et al.* (2021), who observed that shallow, unshaded standing water in impaired drainage channels acts as a thermal capacitor, storing sensible heat during clear post-rain intervals.

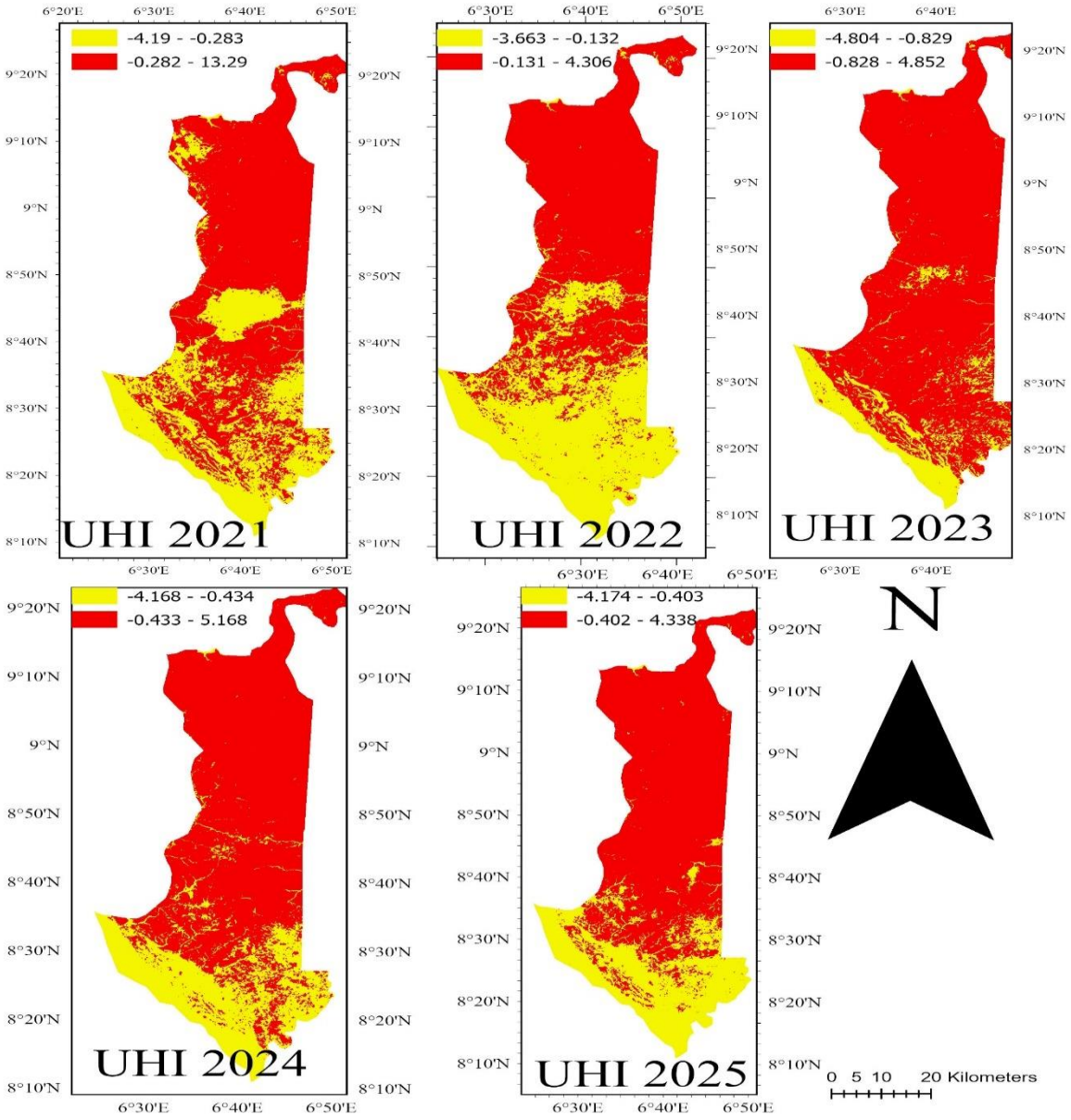

Figure 3.2: Multi-Temporal Spatiotemporal Dynamics of Dry-Season Urban Heat Island (UHI) Intensity in Lapai (2021–2025).

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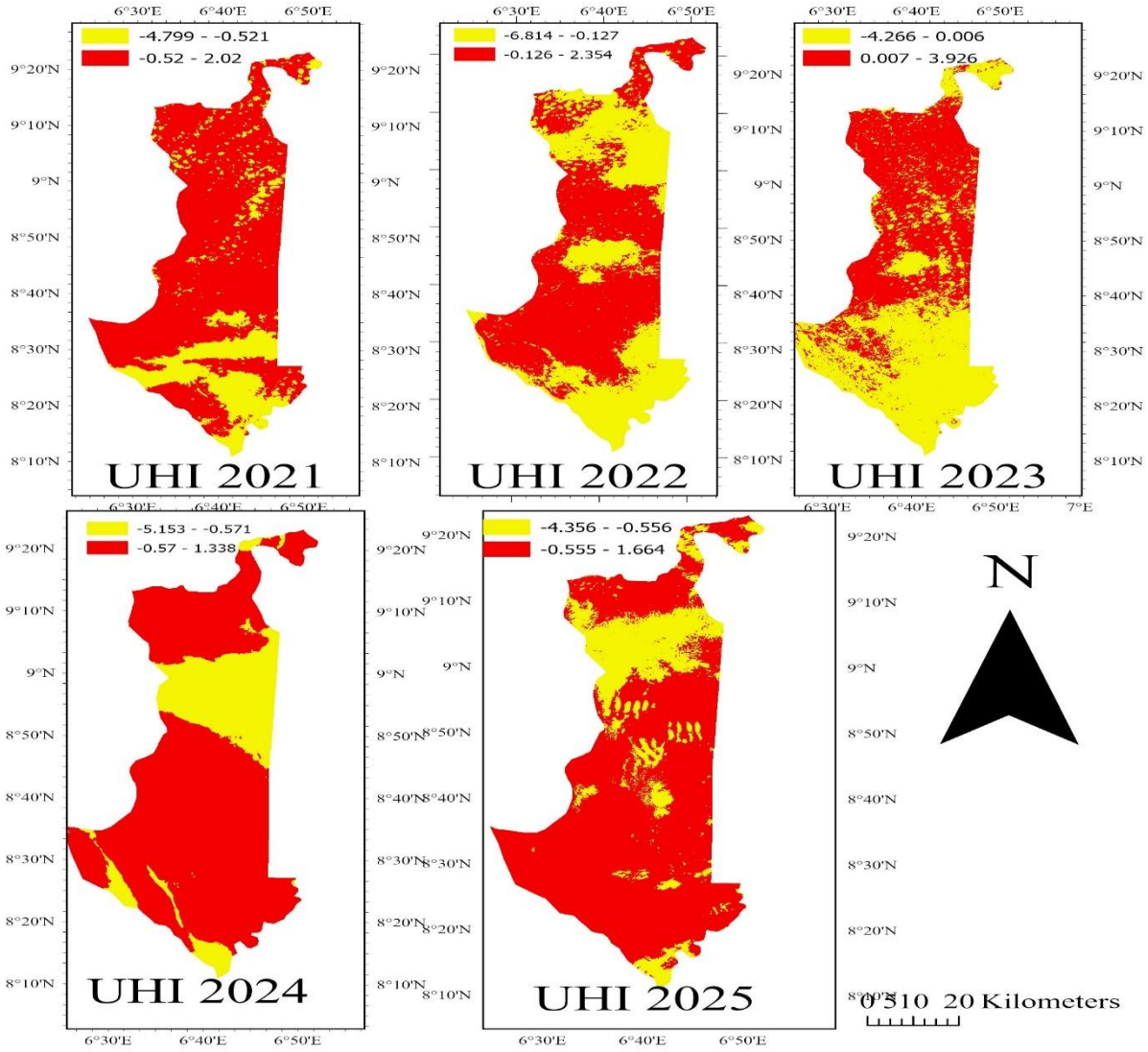

Figure 3.3: Multi-Temporal Spatiotemporal Dynamics of Wet-Season Urban Heat Island (UHI) Intensity in Lapai (2021–2025).

3.3 Statistical Evaluation of Dry Season LST Trends and Hydrological Configurations in Lapai

The multi-temporal statistical profiles of Lapai as presented in Figure 3.4 shows the progression of dry season LST metrics of Minimum, Maximum, Mean, and Standard Deviation across Lapai from 2021 to 2025. These metrics provide quantitative confirmation of how the region's underlying drainage density exerts structural control over localized microclimates.

- Maximum LST Trends **(**LST_Max. DRY**):** The maximum temperatures exhibit an extreme peak of approximately 37°C in 2021, dropping and stabilizing near 31°C in 2022 and 2023, reaching a low of 32°C in 2024, before rebounding to 29°C in 2025. These persistently elevated maximums are directly driven by the vast northern and central interfluves, where a significant deficit in drainage density restricts soil moisture retention and vegetation growth

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which indicate that the dry season solar radiation turn these under drained terrains into intense thermal anchors.

- Minimum LST Trends **(**LST_Min. DRY**):** The minimum temperature baseline begins at 21.5°C in 2021 with peaks of 25°C in 2022, then undergoes a continuous decline to 15°C in 2024 and reaching its lowest point of 10.5°C in 2025. These lowest thermal values consistently correspond to the southernmost tip of Lapai. This areas with high density drainage network provides active eco-hydrological buffering which preserves microclimatic cool sinks through groundwater proximity and riparian vegetation cover even during peak dry season months.
- Mean LST Trends **(**LST_Mean DRY**):** The mean temperature closely mimics the overall trajectory of the maximum threshold with values ranging from 33.5°C (2021) up to a peak of 37°C (2022–2023), before dipping to 25.5°C in 2024 and recovering to 28°C in 2025. This shows that the regional baseline climate experiences multi-year fluctuations, this is influenced by the broader macro climatic changes or varying harmattan intensities in Niger State.
- Standard Deviation Trends **(**LST_StdDev DRY**):** Despite substantial shifts in annual means and maximums, the standard deviation remains remarkably stable, low and tightly bounded between 2.5°C and 4°C across the entire five-year span. This stability demonstrates that the internal thermal contrast across Lapai's landscape is highly permanent. The absolute spatial gap between the well-drained, cooler southern pathways and the poorly drained, thermally emissive northern/central plains maintains a rigid, mathematically consistent threshold over time.

Multi-temporal descriptive profiles (2021–2025) confirm that Lapai's drainage density structurally controls local thermal dynamics. The high-density southern drainage network maintains low LST baselines (10.5°C–25°C) by providing eco-hydrological cooling through groundwater proximity and riparian vegetation. Conversely, under-drained northern and central interfluves lack natural channel cooling and soil moisture retention, forcing dry-season solar radiation to turn these low-density terrains into intense thermal anchors. Because standard deviation remains tightly bounded (2.5°C–4.0°C), this mathematical stability proves that drainage deficits permanently lock in elevated surface heat exposure year after year (Amoako and Inkoom, 2018; Hamzat *et al.,*2024).

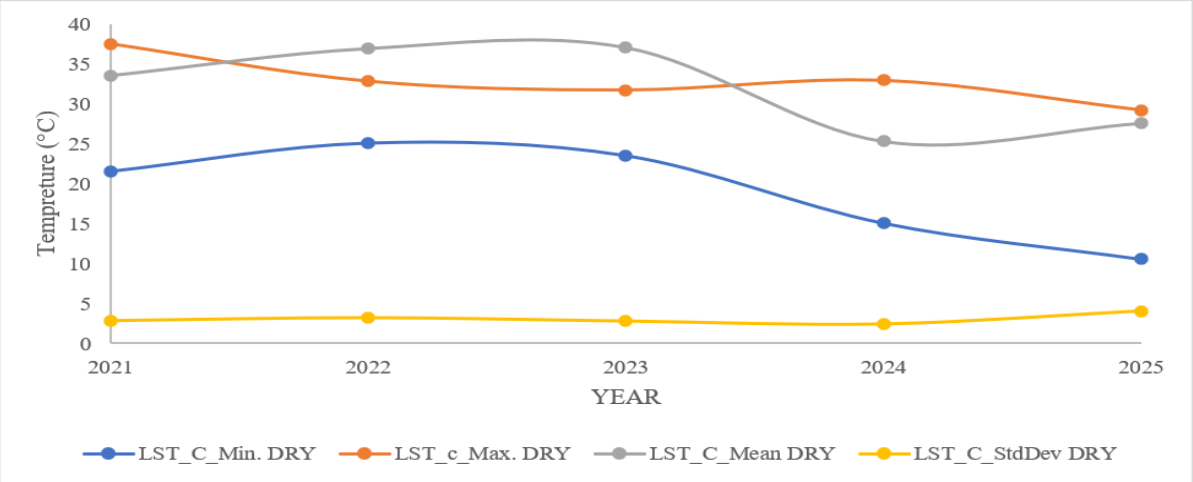

Figure 3.4: Multi-Temporal Statistical Analysis of Dry-Season LST Trends in Lapai (2021–2025).

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3.4 Statistical Evaluation of Wet Season LST Trends and Hydrological Configurations in Lapai

The wet-season descriptive profiles in Figure 4.12 directly reflect how localized structural drainage infrastructure governs surface thermal dynamics under variable moisture conditions. Unlike the rigid, dry-season thermal structure, the wet-season thermal regime displays high volatility, driven by interaction between rainfall events and drainage performance.

- Maximum LST vs. Drainage Deficits: Maximum wet-season temperatures fluctuated between 19°C (2023) and 34°C (2025). These maximums remain concentrated over low drainage density ($FD_d < 0.5$ km/km^2) interfluves in northern and central Lapai. Because these under-drained urban pockets lack continuous channel networks, standing water is poorly evacuated. During clear afternoon post-rain intervals, exposed soil and built surfaces in these low-density drainage zones absorb solar radiation rapidly, generating localized thermal spikes.

- Minimum LST and Wet-Season Hydrological Inversions: Wet-season minimum LST values (10.5°C to 21°C) are anchored in the high-density southern drainage networks. During periods of heavy precipitation, unevacuated runoff accumulates and pools in these low-lying channels. Shallow, standing water acts as a thermal capacitor, storing solar heat during the day and re-radiating sensible heat at night. This creates temporary microclimatic inversions where high-density drainage corridors temporarily exhibit higher surface temperatures than adjacent vegetated slopes.

- Mean and Standard Deviation Metrics (LST_{Mean} and LST_{StdDev}): Mean wet-season LST (17°C to 27°C) and erratic standard deviations (1.5°C in 2023 to 10.3°C in 2024) quantitatively capture moisture-driven thermal fragmentation. Widespread storm events equalize basin-wide temperatures during wet years (lowering σ to 1.5°C), whereas uneven stormwater runoff evacuation across clogged urban drains expands spatial thermal contrast ($\sigma = 10.3$°C).

These findings directly agree with Herb et al. (2009) and Zahn et al. (2021), who demonstrated that impaired urban drainage infrastructure alters localized microclimates by trapping standing runoff and converting clogged channels into localized thermal sinks. The observed post-rain thermal spikes over low-density interfluves also align with Amoako and Inkoom (2018), confirming that structural drainage deficits in expanding sub-Saharan urban centers exacerbate compound microclimatic stress. Conversely, these results disagree with simplified regional moisture models (Akukwe and Ogbodo, 2015), which assume that seasonal precipitation uniformly dampens surface thermal signatures across urban landscapes. The multi-temporal metrics demonstrate that severe infrastructure failure breaks this uniform cooling effect, generating distinct thermal disparities and localized humid heat retention across the built environment during the wet season.

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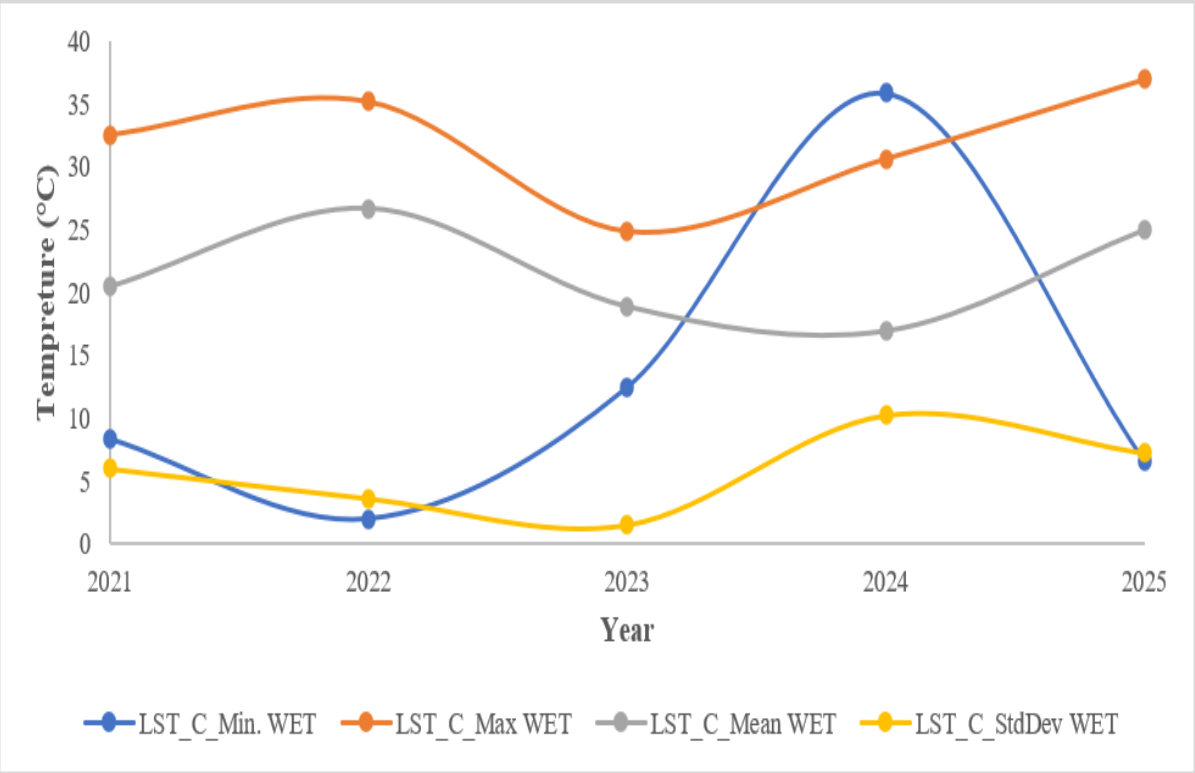

Figure 3.5: Multi-Temporal Statistical Analysis of Wet-Season LST Trends in Lapai (2021–2025).

4.0 Conclusion

This research establishes that stormwater drainage infrastructure quality exerts structural control over localized surface thermal regimes and microclimatic stability in expanding secondary cities like Lapai. The primary spatial and empirical conclusions derived from the five-year multi-temporal analysis include:

- Infrastructure Failure Drives Microclimatic Degradation: Over half (58%) of Lapai's 28.5 km mapped drainage network is functionally impaired by siltation, waste blockage, or structural collapse. In high-density commercial and residential cores (Central Market, Motor Park, Madaki, Ungwan Sarki), functional drainage density falls below 0.5 km/km^2, directly driving surface heat retention.
- Seasonal Microclimatic Contrast: Structural drainage deficits prevent natural evaporative cooling across the northern and central urban interfluves, turning them into persistent thermal anchors during the dry season with peak LSTs reaching 41°C to 42°C and Urban Heat Island (UHI) intensity up to 13.29°C. Conversely, wet-season thermal regimes exhibit high volatility, where clogged channels trap standing runoff and create localized thermal sinks during post-rain intervals.
- Permanent Thermal Lock-In: While wet-season thermal patterns fluctuate with rainfall dynamics, the dry-season thermal contrast remains mathematically rigid across all five years. This confirms that unaddressed drainage deficits permanently lock in severe surface thermal exposure year after year, demonstrating that urban stormwater management is an essential component of microclimatic mitigation and urban climate resilience.

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5.0 Recommendation

To address compound environmental risks, municipal planning authorities and local government managers in Lapai should prioritize the systematic desilting, structural repair and expansion of the drainage network specifically addressing the 58% total functional impairment (38% silted and 20% blocked/collapsed). Targeted interventions should focus on high-density commercial and residential quarters (Lapai Central Market, Motor Park, Madaki, and Ungwan Sarki) where functional drainage densities currently fall below 0.5 km/km^2.

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