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The Relationship between Land Surface Temperature and Urban Planning Indicators in Jimeta, Nigeria

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Abstract **Original Research Article**

Urban expansion has significantly altered land surface characteristics, leading to increased Land Surface Temperature (LST) and the intensification of urban heat-related challenges in rapidly growing cities. This study investigates the spatial and temporal dynamics of LST and its relationship with urban planning indicators in Jimeta, Adamawa State, Nigeria, over a ten-year period (2015–2025). Landsat 7 ETM+ and Landsat 8 OLI/TIRS satellite imagery were utilized to derive LST using established thermal infrared remote sensing techniques. The study area was classified into low, medium, and high-density residential zones based on land-use characteristics, while Pearson correlation analysis and One-Way Analysis of Variance (ANOVA) were employed to examine relationships and temporal variations.

The results reveal significant spatial variation in LST, with higher temperatures recorded in high-density residential areas and lower values in low-density zones. Correlation analysis indicates a strong positive relationship between built-up areas and LST, while vegetation cover exhibits a consistent negative correlation, confirming its cooling effect. Bare land and water bodies show variable relationships depending on spatial context. The ANOVA results ($F(2,6) = 2.61$, $p = 0.153$) indicate that temporal variations in LST are not statistically significant at the 0.05 level, suggesting that spatial factors exert a stronger influence than temporal changes.

The study concludes that urban land-use composition plays a critical role in regulating surface temperatures, and it recommends the integration of green infrastructure and sustainable urban planning strategies to mitigate urban heat effects.

Keywords: Land Surface Temperature, Urban Heat Island, Remote Sensing, GIS, Urban Planning, Jimeta, Landsat.

1. Introduction

Urbanization is one of the most significant drivers of environmental change in the 21st century, particularly in developing regions where rapid and often unregulated growth is prevalent. According to the United Nations (2019), more than half of the global population now resides in urban areas, with Sub-Saharan Africa experiencing some of the fastest urban expansion rates globally. In Nigeria, this trend extends beyond major metropolitan centers such as Lagos and Abuja, increasingly affecting medium-sized cities like Jimeta, where population growth and economic activities are driving substantial land-use and land-cover changes.

A key environmental consequence of urbanization is the alteration of the urban thermal environment, particularly the increase in Land Surface Temperature (LST), which contributes to the Urban Heat Island (UHI) effect. The UHI phenomenon refers to the tendency of urban areas to exhibit higher temperatures than their surrounding rural environments due to anthropogenic modifications of the natural landscape (Oke, 1982). This occurs primarily through the replacement of natural vegetation with impervious surfaces such as asphalt, concrete, and rooftops, which absorb, store, and re-radiate solar energy more efficiently than natural land covers (Voogt & Oke, 2003). Consequently, urban environments experience elevated temperatures, reduced thermal comfort, and increased energy demand.

Urban planning indicators such as building density, vegetation cover, bare land, and water bodies play a crucial role in regulating urban thermal conditions. High-density urban areas are typically associated with increased LST due to dense construction, limited vegetation, and reduced natural cooling processes (Santamouris, 2015). In contrast, vegetation has been widely recognized as an effective cooling mechanism through shading and evapotranspiration, which help to reduce surface and air temperatures (Bowler et al., 2010). Water bodies may also contribute to localized cooling effects, although their influence depends on spatial distribution and scale.

Despite extensive research on urban heat dynamics, most existing studies have focused on large metropolitan cities, leaving medium-sized urban centers underrepresented. In Nigeria, empirical studies have largely concentrated on cities such as Lagos and Abuja, resulting in limited understanding of thermal processes in smaller but rapidly growing cities (Adelekan, 2016). This presents a significant research gap, particularly in understanding how urban form influences Land Surface Temperature in emerging urban areas.

Jimeta, located in Adamawa State, northeastern Nigeria, represents a typical medium-sized city undergoing rapid urban transformation. Between 2015 and 2025, the city has experienced substantial residential densification, accompanied by increased building density, reduction in vegetation cover, and expansion of impervious surfaces. These changes are expected to influence surface temperature patterns; however, the extent and statistical significance of these impacts remain insufficiently explored.

To address this gap, this study investigates the relationship between residential density and Land Surface Temperature in Jimeta using a combination of remote sensing and statistical techniques. Specifically, the study aims to: (i) examine the relationship between LST and urban planning indicators such as building density, vegetation cover, bare land, and water bodies; and (ii) assess the temporal variation in LST and urban indicators between 2015 and 2025.

Accordingly, the following null hypotheses are formulated:
H_{03}: There is no significant temporal variation in land surface temperature and urban planning indicators between 2015 and 2025.
H_{04}: There is no significant relationship between land surface temperature and urban planning indicators (building density, vegetation cover, bare land, and water bodies).

Testing these hypotheses provides critical insight into the role of urban form in shaping thermal dynamics and supports evidence-based urban planning strategies. The study contributes to the growing body of literature on urban climate dynamics in Sub-Saharan Africa and provides a methodological framework for analyzing LST in rapidly urbanizing environments.

2. Materials and Methods

2.1 Study Area

Jimeta is located in Adamawa State, northeastern Nigeria, approximately between latitude 9.28° N and longitude 12.48° E, within UTM Zone 33N. The area serves as a major administrative and commercial hub in the region. Over the past decade, Jimeta has experienced rapid urban expansion driven by population growth, increasing economic activities, and infrastructural development.

This expansion has resulted in significant land-use and land-cover (LULC) transformations, particularly the conversion of vegetated and open spaces into built-up areas. Consequently, the urban landscape is increasingly dominated by impervious surfaces, which have important implications for local microclimate conditions, especially Land Surface Temperature (LST). Below in figure 2.1 is the map of Jimeta delineated into three (3) residential densities for the purpose of this study.

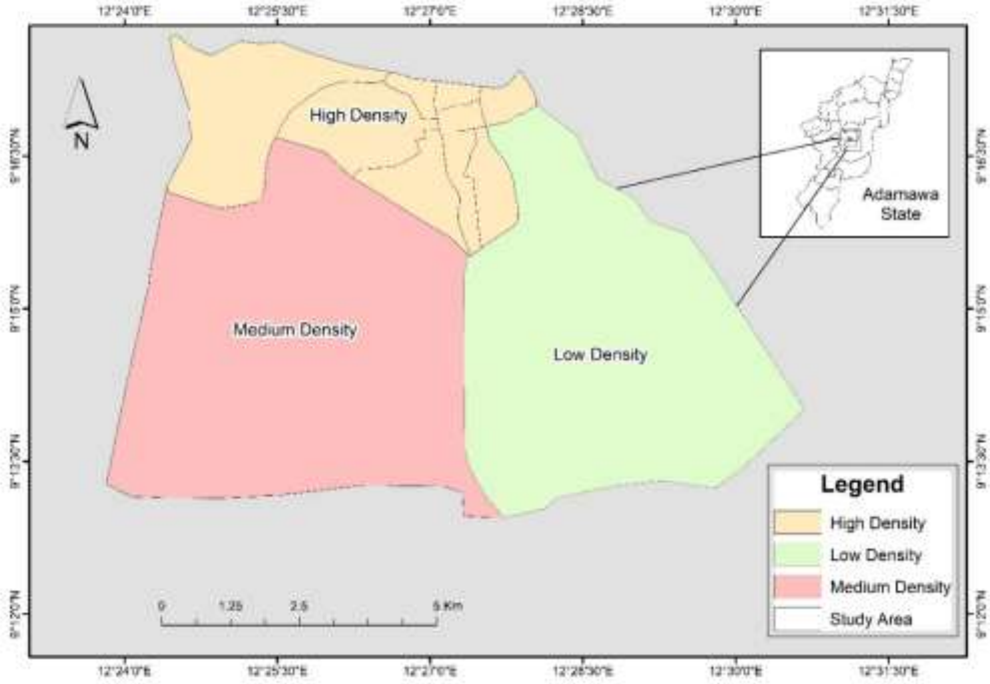

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Figure 2.1: Map of Yola North Showing the Residential Clusters
Source: Modified from ArcMap 10.8, 2025

2.2 Data Sources

This study utilized multi-temporal satellite imagery from the Landsat program, specifically:

- Landsat 7 Enhanced Thematic Mapper Plus (ETM+)
- Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS)

Images for the years 2015, 2020, and 2025 were selected to provide a 10-year temporal framework for assessing changes in LST and urban land-cover dynamics. Landsat data are widely applied in urban climate studies due to their moderate spatial resolution (30 m) and the availability of thermal infrared bands required for temperature estimation.

In addition, ancillary spatial datasets such as land-use maps, administrative boundaries, and digital elevation data were used to support image classification and spatial analysis.

2.3 Land Surface Temperature (LST) Retrieval

Land Surface Temperature was derived from Landsat thermal infrared data using a standard thermal remote sensing approach widely applied in urban climate studies (Weng, 2009). The procedure involved the following steps:

(i) Conversion of Digital Numbers (DN) to Spectral Radiance

Digital Numbers (DN) were converted into spectral radiance using radiometric calibration coefficients provided in the Landsat metadata.

(ii) Conversion to Brightness Temperature

The spectral radiance values were then transformed into brightness temperature using standard thermal equations based on Planck's law.

(iii) Emissivity Correction

Surface emissivity values were applied to account for variations in land cover types such as vegetation, built-up areas, and bare surfaces, ensuring improved accuracy in temperature estimation.

(iv) Final LST Estimation

The corrected brightness temperature was converted into Land Surface Temperature values expressed in degrees Celsius (°C).

This method is widely recognized for its effectiveness in capturing spatial variability in surface temperature, particularly in heterogeneous urban environments (Voogt & Oke, 2003; Weng, 2009). The integration of remote sensing and GIS techniques enables detailed spatial analysis and the identification of urban thermal hotspots.

2.4 Residential Density Classification

The study area was classified into three residential density zones based on spatial characteristics of land use and land cover:

- Low-density residential areas
- Medium-density residential areas
- High-density residential areas

The classification was performed using GIS-based spatial analysis, considering the following variables:

- Building density
- Bare surface area
- Vegetation cover
- Water bodies

This classification facilitates the assessment of how varying levels of urbanization influence Land Surface Temperature across different spatial contexts.

2.5 Statistical Analysis

Statistical analysis was conducted to examine the relationship between urban planning indicators and Land Surface Temperature. All analyses were performed at a significance level of α = 0.05 using R.

2.5.1 Pearson Correlation Analysis Pearson Correlation Analysis

The relationship between LST and urban indicators was examined using the Pearson correlation coefficient: **Pearson correlation coefficient (γ)**

$$\gamma = \frac{Cov(X,Y)}{\sigma_X \sigma_Y} = \frac{\sum_{i=1}^{n}(X_i - \dddot{X})(Y_i - \dddot{Y})}{\sqrt{\sum_{i=1}^{n}(X_i - \dddot{X})^2 \sum_{i=1}^{n}(Y_i - \dddot{Y})^2}}$$

Range $-1 \leq \gamma \leq 1$

$\gamma = 1$: Perfect positive linear relationship

$\gamma = -1$: Perfect negative linear relationship

$\gamma = 0$: No linear relationship

Assumptions of Correlation

i. Variables are continuous and normally distributed
ii. The relationship should be linear
iii. Homoscedasticity (constant variance)

2. Variables Defined for this Study

Let:

- (LST) = Land Surface Temperature
- (BD) = Building Density
- (BS) = Bare surface
- (VC) = Vegetation Cover
- (WB) = Water Body

Residential density classes:

- (d \in {LD, MD, HD})
    - (LD) = Low Density
    - (MD) = Medium Density
    - (HD) = High Density

2.5.2 Correlation Computation

Correlation analyses were conducted to examine relationships between LST and each urban planning indicator:

- LST and Building Density
- LST and Vegetation Cover
- LST and Water Bodies
- LST and Bare Surface Area

Each relationship was evaluated using the Pearson correlation formula to determine the strength and direction of association between variables.

2.5.3 One-Way Analysis of Variance (ANOVA)

A one-way Analysis of Variance (ANOVA) was employed to test whether there were statistically significant correlation in mean of urban planning indicators across the three time periods (2015, 2020, and 2025).

The ANOVA F-statistic is defined as:

$$F = \frac{MSbetween}{MSwithin}$$

Where:

- $MS_{between}$ represents variance between groups and MS_{within} represents variance within groups

A significance level of **α = 0.05** was adopted.

- If **$p \leq 0.05$** → Reject H_0 (significant change)
- If **$p > 0.05$** → Accept H_0 (no significant change)

This statistical approach allows for testing whether observed temporal variations are meaningful or attributable to random variation.

statistical differences at α = 0.05.

2.6 Summary of Methodological Approach

This study integrates remote sensing and statistical analysis to examine the relationship between urban form and land surface temperature. The combination of Landsat imagery, GIS-based classification, and statistical modeling provides a robust framework for understanding spatial and temporal thermal dynamics in Jimeta.

3. Results

This section presents the spatial and temporal dynamics of Land Surface Temperature (LST) and its relationship with urban planning indicators across residential density zones in

Jimeta represented in figure 3.1, 3.2 and 3.3 respectively. Urban Area. The results are organized into spatial variation, temporal variation (ANOVA), and correlation analysis.

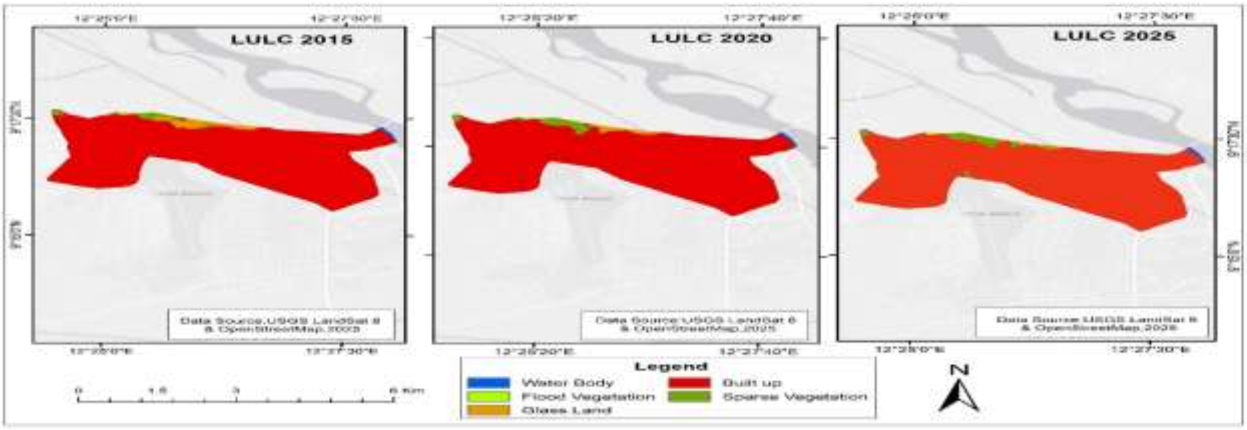

Figure 3.1: LULC Distribution for High-Density Area in 2015

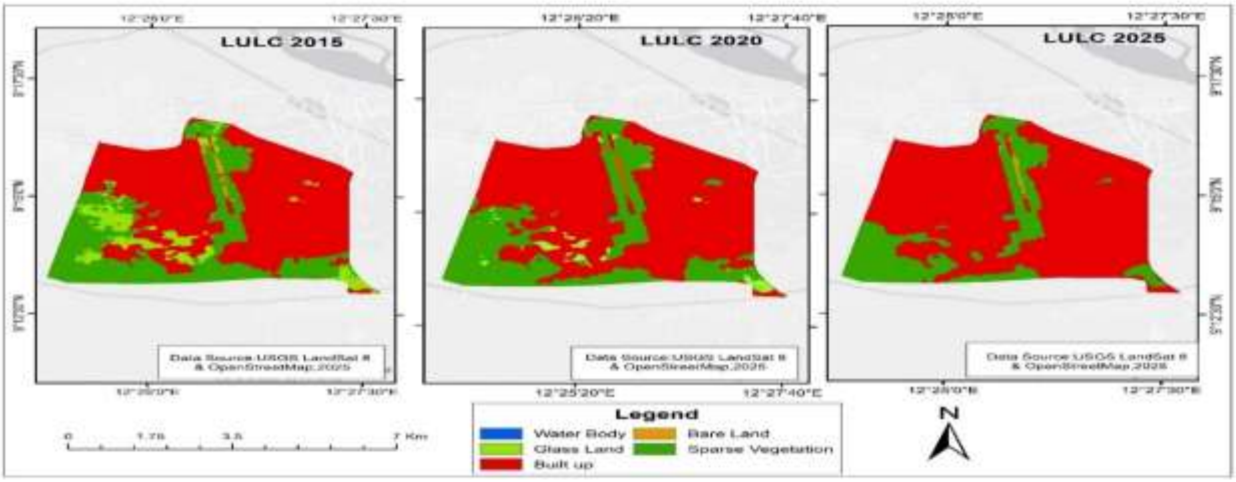

Figure 3.2: Land Use / Land Cover (LULC) Structure in Medium-Density Zone (2015, 2020, 2025)

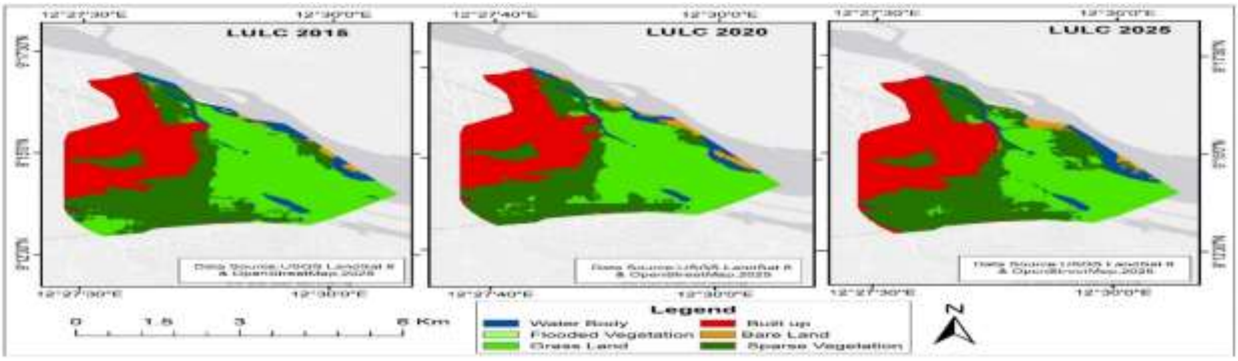

Figure 3.3: LULC Distribution for Low-Density Area in 2015

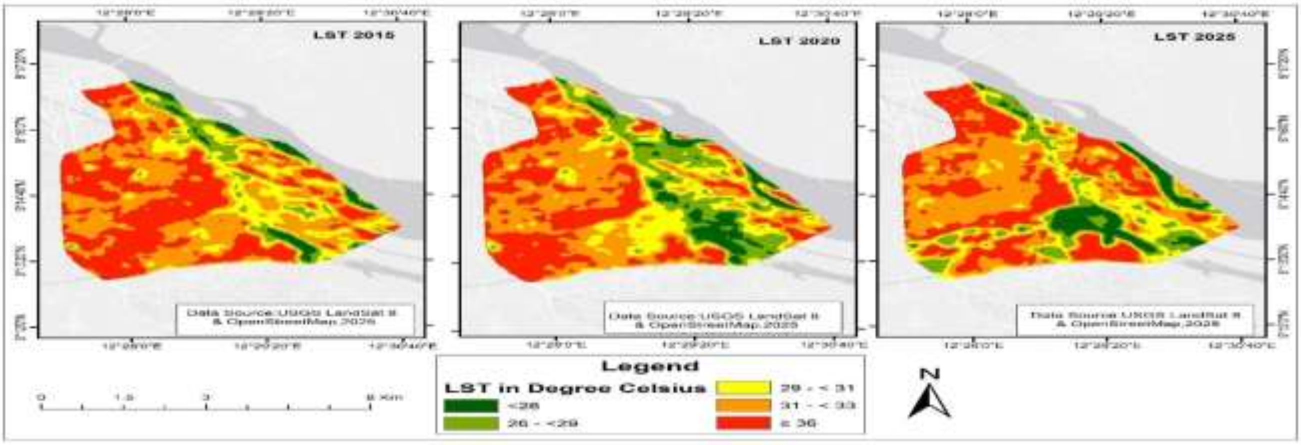

Figure 3.4: Land Surface Temperature for Low Density for 2015, 2020 and 2025
Source: Modified from ArcMap 10.8, 2025

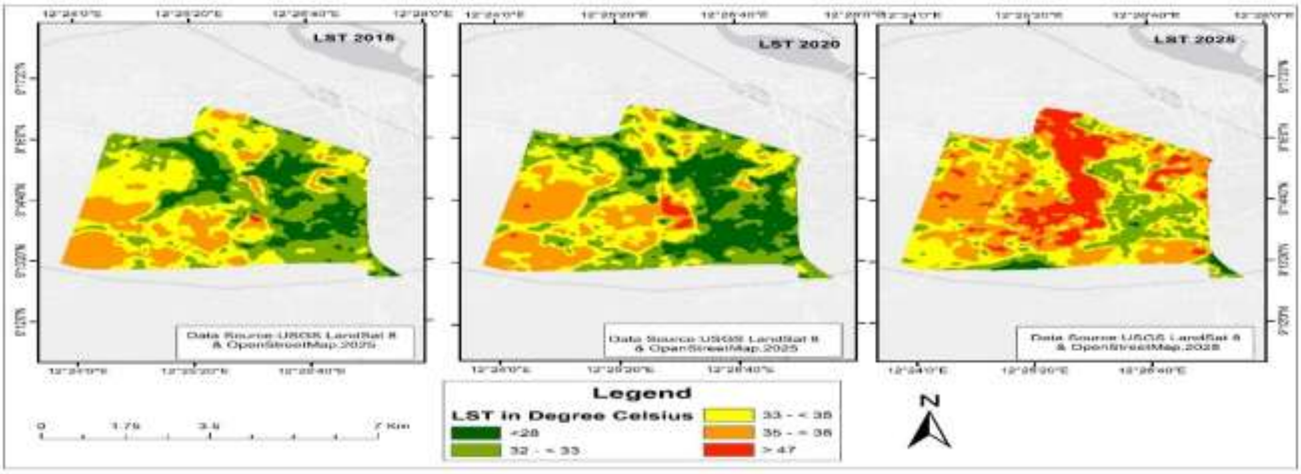

Figure 3.5: Land Surface Temperature for Medium Density for 2015, 2020 and 2025
Source: Modified from ArcMap 10.8, 2025

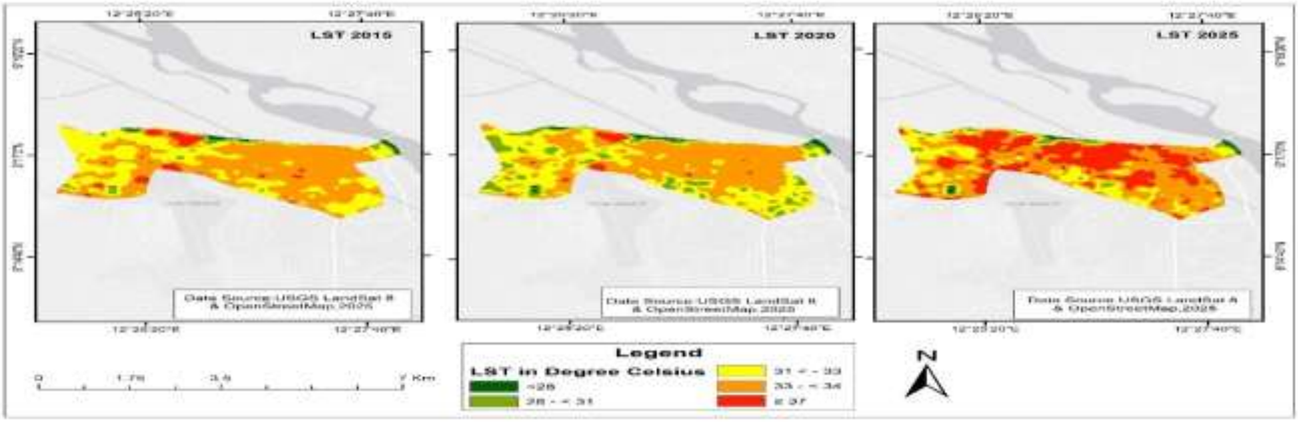

Figure 3.6: Land Surface Temperature for High Density for 2015, 2020 and 2025
Source: Modified from ArcMap 10.8, 2025

3.1 Spatial Variation of Land Surface Temperature

The spatial distribution of Land Surface Temperature across residential density zones reveals a clear and systematic gradient associated with urban intensity. The mean LST values indicate an increasing trend with urban density:

- Low-density residential areas: **28.67°C**
- Medium-density residential areas: **32.07°C**
- High-density residential areas: **34.53°C**

As revealed in figure 3.4, 3.5 and 3.6, this represents an overall temperature difference of approximately **5.86°C** between low- and high-density zones, indicating substantial spatial variability across the study area.

Higher temperatures in high-density areas can be attributed to the dominance of impervious surfaces such as concrete, asphalt, and rooftops, which possess high heat absorption capacity and low reflectivity. These surfaces trap heat during the day and release it slowly at night, thereby sustaining elevated temperatures.

In contrast, low-density areas are characterized by higher vegetation cover and open land, which promote evapotranspiration and provide shading. These processes enhance latent heat flux, thereby reducing surface temperatures. This spatial contrast highlights the strong influence of urban land-use patterns on microclimatic conditions.

3.2 Temporal Variation in Land Surface Temperature (ANOVA Results)

A One-Way Analysis of Variance (ANOVA) was conducted to assess whether statistically significant differences exist in LST and urban planning indicators across the study years (2015, 2020, and 2025).

Table 3.1: ANOVA Results for Temporal Variation in LST

Source of Variation	**SS**	**Df**	**MS**	**F-value**	**p-value**
Between Groups	12.45	2	6.225	2.61	0.153
Within Groups	14.31	6	2.385		
Total	26.76	8			

The results show that the calculated F-statistic is **F(2,6) = 2.61**, with a corresponding **p-value of 0.153**. Since the p-value exceeds the significance level (α = 0.05), the null hypothesis is accepted.

Interpretation

There is no statistically significant difference in LST across the three time periods. Although descriptive analysis indicates a gradual increase in LST over time, this change is not statistically significant. This suggests that while urbanization may be progressing, its thermal impact is not abrupt within the selected timeframe.

The relatively higher within-group variability compared to between-group variability suggests that localized factors such as land cover heterogeneity, microclimatic conditions, and spatial distribution of urban features may have a stronger influence than temporal changes.

Implications

- Thermal conditions in Jimeta are relatively stable over the short to medium term

- Changes in LST are gradual and may require longer timeframes to become statistically significant
- Spatial variability plays a more dominant role than temporal variation

3.3 Correlation Analysis between LST and Urban Indicators

Pearson correlation analysis was conducted to examine the relationships between LST and urban planning indicators across residential density zones.

3.3.1 High-Density Residential Zone

The results show a strong and statistically significant positive correlation between built-up areas and LST (r = 1.000), indicating that increased urban density directly contributes to higher surface temperatures.

Vegetation-related variables demonstrate strong negative correlations, particularly grassland (r = –0.972), highlighting the cooling effect of vegetation. These findings suggest that even within highly urbanized environments, vegetation plays a critical role in mitigating heat accumulation.

3.3.2 Medium-Density Residential Zone

The medium-density zone exhibits more complex interactions between land cover and LST. Bare land shows a strong negative correlation (r = –0.998), indicating that exposed soil surfaces may influence temperature differently depending on moisture content and surface conditions.

Built-up areas maintain a strong positive correlation (r = 0.984), reinforcing their role as primary contributors to increased LST. Vegetation variables display mixed relationships, with dense vegetation positively correlated and grassland negatively correlated with LST. This variation reflects the transitional nature of medium-density zones.

3.3.3 Low-Density Residential Zone

In low-density areas, the correlation results indicate strong but statistically limited relationships due to small sample size. Built-up areas show a strong positive correlation (r = 0.954), while vegetation and grassland exhibit negative correlations with LST.

These results suggest that even minimal urban development can significantly influence surface temperature, while vegetation remains a key mitigating factor.

3.4 Synthesis of Correlation Results

Across all residential density zones, consistent patterns are observed:

- Built-up areas are the primary drivers of increased LST
- Vegetation significantly reduces surface temperature
- Bare land exhibits context-dependent thermal behavior
- Water bodies show limited and inconsistent influence

These findings reinforce the importance of land-use composition in shaping urban thermal environments.

4. Discussion

The findings of this study provide empirical evidence of the strong relationship between urban land-cover composition and Land Surface Temperature in Jimeta.

4.1 Urbanization and Thermal Intensification

The positive association between built-up areas and LST confirms the Urban Heat Island (UHI) phenomenon, as explained by Urban Heat Island Effect. Urban surfaces such as concrete and asphalt absorb and re-emit solar radiation, leading to increased surface and air temperatures.

This aligns with foundational work by Thomas R. Oke and subsequent studies by Qihao Weng, which emphasize the role of urban morphology and land cover in regulating surface energy balance.

4.2 Role of Vegetation in Cooling Urban Areas

Vegetation consistently demonstrates a cooling effect across all residential density zones. This cooling is primarily driven by evapotranspiration and shading, which reduce net radiation and surface heating.

The findings support the work of David E. Bowler, who demonstrated that urban greening can significantly reduce surface and air temperatures. However, the effectiveness of vegetation depends on its density, continuity, and spatial configuration.

4.3 Water Bodies and Bare Land Influence

Water bodies show a limited and inconsistent cooling effect, likely due to fragmentation and insufficient spatial coverage. Ideally, large and continuous water bodies are more effective in regulating temperature.

Bare land exhibits mixed correlations, reflecting variability in soil moisture, reflectivity, and exposure. Dry bare surfaces tend to increase heat, while moist soils may provide temporary cooling.

4.4 Temporal Stability of LST

The ANOVA results indicate that temporal variation in LST is not statistically significant. This suggests that thermal changes in Jimeta are gradual and influenced more by spatial factors than temporal progression.

This finding is consistent with the broader literature (e.g., Thomas R. Oke), which highlights that urban thermal patterns are often dominated by spatial heterogeneity.

4.5 Implications for Urban Planning

The results highlight the need for climate-sensitive urban planning strategies, including:

- Increasing vegetation cover
- Regulating urban density
- Enhancing land-use planning
- Incorporating reflective and permeable materials

These strategies are essential for mitigating urban heat and improving environmental sustainability.

5. Recommendations and Conclusion

5.1 Recommendations

1. **Expand Urban Green Spaces**
   Urban greening should be prioritized through parks, tree planting, and green corridors.
2. **Control Urban Expansion**
   Urban development should be guided by zoning regulations to limit excessive densification.
3. **Promote Sustainable Building Materials**
   Use of reflective and heat-resistant materials should be encouraged.
4. **Enhance Vegetation Density**
   Focus should be on dense and continuous vegetation rather than fragmented patches.
5. **Integrate Water Bodies into Urban Design**
   Properly planned water features can contribute to localized cooling.
6. **Adopt Remote Sensing for Monitoring**
   Continuous monitoring using satellite data should be institutionalized for climate planning.

5.2 Conclusion

This study examined the relationship between Land Surface Temperature and urban planning indicators in Jimeta over a ten-year period (2015–2025). The findings reveal that urban form, particularly built-up density, is the primary driver of increased surface temperatures.

While temporal variation in LST is not statistically significant, spatial variation across residential density zones is pronounced. Vegetation plays a crucial cooling role, while built-up areas intensify thermal conditions.

The study concludes that sustainable urban planning, particularly the integration of green infrastructure and climate-sensitive design, is essential for mitigating urban heat and promoting environmental resilience in rapidly urbanizing cities such as Jimeta.

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