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Spatio-Temporal Analysis of Urban Densification, Land Use Change, and Thermal Patterns in Jimeta, Nigeria (2015–2025)

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Abstract **Original Research Article**

Urbanization in sub-Saharan Africa is accelerating at an unprecedented rate, fundamentally transforming land cover systems and intensifying environmental pressures. While extensive research has focused on megacities, medium-sized urban centers remain insufficiently studied despite their growing importance in regional development. This study examines the spatio-temporal dynamics of Land Use/Land Cover (LULC) transformation across residential density gradients in Jimeta, Nigeria, between 2015 and 2025, and evaluates the associated thermal implications.

Multi-temporal Landsat imagery was analyzed using supervised classification techniques to generate LULC maps for 2015, 2020, and 2025. Post-classification comparison and transition matrices were employed to quantify land cover changes, while one-way Analysis of Variance (ANOVA) assessed statistical differences across time periods. The results reveal a clear density-dependent transformation pattern: high-density zones exhibited structural saturation with built-up land exceeding 95%, medium-density zones experienced the most rapid transformation with built-up expansion from 61% to 77%, and low-density zones showed gradual peri-urban transition.

Despite observable spatial changes, ANOVA results indicate no statistically significant differences in mean land-use areas across the study periods ($p > 0.05$), suggesting incremental rather than abrupt transformation processes. The progressive replacement of vegetated surfaces with impervious materials has significant thermal consequences, reinforcing the principles of the Urban Heat Island Effect.

The study highlights the vulnerability of medium-density transitional zones and underscores the need for climate-responsive urban planning strategies. By providing empirical evidence from a medium-sized Nigerian city, this research contributes to broader discussions on sustainable urbanization in rapidly developing regions.

Keywords: Urban densification, Land Use Land Cover change, Residential density, Impervious surfaces, Urban heat, Nigeria.

1. Introduction

Urbanization is widely recognized as one of the most transformative anthropogenic processes shaping the Earth's surface in the 21st century. Globally, urban areas are expanding both spatially and demographically, with particularly rapid growth occurring in developing regions such as sub-Saharan Africa. According to UN-

Habitat (2020), the region is projected to experience a doubling of its urban population by 2050, driven by natural population increase, rural–urban migration, and economic restructuring.

In Nigeria, urban growth is not confined to megacities like Lagos and Abuja but is increasingly pronounced in medium-sized cities, which serve as regional administrative, commercial, and socio-economic hubs. These cities, including Jimeta, often experience rapid expansion without corresponding planning controls, resulting in uncoordinated land-use transformation and environmental stress.

One of the most critical consequences of urbanization is the alteration of Land Use/Land Cover (LULC). Natural landscapes such as grasslands, wetlands, and vegetated surfaces are progressively replaced by impervious materials including concrete, asphalt, and rooftops. This transformation has far-reaching implications for ecological processes, including reduced evapotranspiration, altered hydrological cycles, and disruption of local climate systems (Weng, 2009).

A key manifestation of these changes is the intensification of surface temperature, commonly explained by the Urban Heat Island Effect. This phenomenon occurs when urban areas experience higher temperatures than their rural surroundings due to increased heat absorption, storage, and re-radiation by built surfaces (Oke, 1982). Empirical studies have consistently shown that vegetation loss and impervious surface expansion are primary drivers of this effect (Imhoff et al., 2010).

Despite the growing body of literature, most studies have focused on large metropolitan areas, leaving a critical gap in understanding the dynamics of medium-sized cities. These cities often exhibit distinct spatial structures characterized by clear residential density gradients, making them ideal for examining how urban form influences land transformation processes.

This study addresses this gap by analyzing the spatio-temporal dynamics of LULC across high-, medium-, and low-density residential zones in Jimeta between 2015 and 2025. It further examines the implications of these changes for urban environmental conditions, particularly thermal characteristics.

2. Statement of the Research Problem

Despite considerable advances in urban environmental research, a significant gap remains in understanding how land-use transformation occurs across residential density gradients in medium-sized African cities. Most empirical studies have concentrated on large metropolitan areas, leaving secondary cities underrepresented in the literature (Seto et al., 2012).

Furthermore, while the relationship between LULC change and thermal conditions is well established, there is limited research that integrates density-based spatial analysis with thermal implications in cities like Jimeta. In particular, the role of medium-density transitional zones as critical areas of ecological change and emerging thermal stress has not been sufficiently explored.

This lack of integrated analysis limits the effectiveness of urban planning strategies, as interventions are often not tailored to the specific dynamics of different residential density zones. Addressing this gap is essential for developing sustainable urban management frameworks in rapidly growing cities.

3. General Objective

The primary objective of this study is to examine the spatio-temporal dynamics of land use/land cover (LULC) transformation and its thermal implications across residential density gradients in Jimeta urban area, Nigeria, between 2015 and 2025.

Specific Objectives

The study seeks to:

1. Analyze the spatial distribution of land use/land cover (LULC) across low-, medium-, and high-density residential zones in Jimeta.

2. Assess temporal changes in LULC patterns between 2015, 2020, and 2025 using multi-temporal satellite imagery.

4. Research Hypotheses

- **H_{01}:** No significant difference exists in LULC distribution across residential density zones.
- **H_{02}:** No significant temporal change in LULC between 2015 and 2025.

5. Study Area

Jimeta is located within Yola North Local Government Area of Adamawa State in northeastern Nigeria, positioned approximately between latitude 9°14′N and longitude 12°38′E. The area lies at an average elevation of about 185.9 meters above sea level and forms part of the Yola metropolitan region.

Climatically, Jimeta experiences a tropical wet-and-dry climate (Aw classification), characterized by two distinct seasons: a rainy season (May–October) and a dry season (November–April). Annual rainfall ranges between 800 and 1000 mm, while mean annual temperatures exceed 30°C, making the area highly sensitive to thermal variations associated with land surface changes.

Physically, the terrain is relatively flat with gentle undulations, interspersed with drainage channels and seasonal wetlands linked to the Benue River system. These natural features historically supported vegetation cover and moderated local microclimates.

However, rapid urbanization over the past decade has significantly altered the spatial structure of Jimeta. As shown in figure 3.1, the city now exhibits a well-defined residential density gradient:

- **High-density zones:** Located within the urban core, characterized by compact building arrangements, minimal open space, and extensive impervious surfaces.
- **Medium-density zones:** Transitional areas surrounding the core, featuring mixed residential development, ongoing construction, and partial vegetation cover.
- **Low-density zones:** Peripheral areas with dispersed settlements, significant grassland and vegetation cover, and characteristics of peri-urban landscapes.

This spatial heterogeneity provides an ideal framework for analyzing how urban densification influences land cover transformation and environmental conditions.

Figure 1.4: Map of Yola North Showing the Residential Clusters

Source: Modified from ArcMap 10.8, 2025.

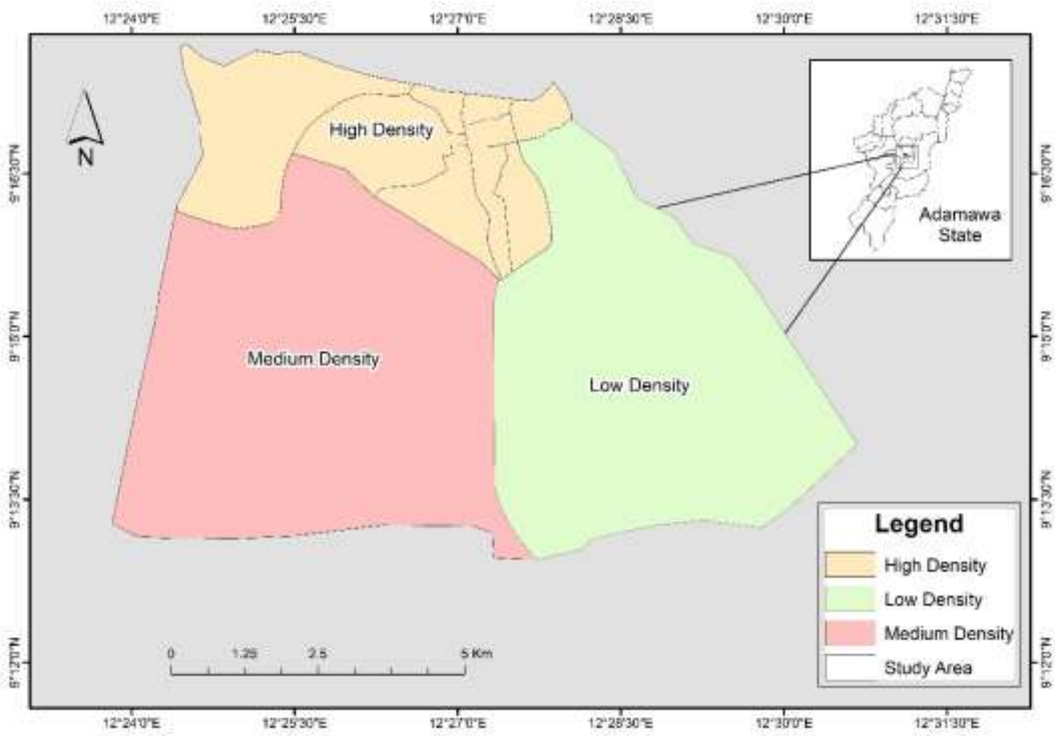

Figure 5.1: Map of Yola North Showing the Residential Clusters
Source: Modified from ArcMap 10.8, 2025

6. Materials and Methods

6.1 Data Acquisition and Preprocessing

Multi-temporal Landsat satellite imagery for 2015, 2020, and 2025 was acquired and processed. Preprocessing steps included geometric correction, radiometric normalization, and atmospheric correction to ensure data consistency across time periods (Weng, 2009).

6.2 Land Use Classification

Supervised classification techniques were employed to categorize land cover into six classes: built-up, grassland, sparse vegetation, bare land, water bodies, and flooded vegetation. Training samples were derived from field observations and high-resolution imagery to improve classification accuracy. Hence

a. Vegetation Cover (Tree Canopy)

NDVI = (NIR - Red) / (NIR + Red)

Tree canopy areas identified with NDVI > 0.3

% Vegetation Cover = $\frac{vegetation\ area}{Cluster\ area}$ x 100

b. Building Density

Derived from built-up classified areas

NDBI = (SWIR - NIR) / (SWIR + NIR)

% Building Density = $\frac{Buitl-up}{Cluster\ area}$ x 100

c. Bare Surface Area

Identified using high reflectance in red/SWIR bands and visual inspection

$(RED + SWIR) - (NIR + BLUE)$
$/ (RED + SWIR) + (NIR + BLUE)$

% Bare surface area = $\frac{Bare\ Surface\ Area}{Cluster\ area}$ x 100

d. Water Bodies

Delineated using **NDWI** and verified with high-resolution imagery

$GREEN - NIR\ / GREEN + NIR$

% Water body = $\frac{Water\ body}{Cluster\ area}$ x 100

6.3 Density Zonation

Residential density zones were delineated using planning layouts and built-up intensity thresholds. This allowed for zonal analysis of

LULC patterns across high-, medium-, and low-density areas.

6.4 Change Detection Analysis

Post-classification comparison was used to detect changes between 2015–2020 and 2020–2025. Transition matrices quantified persistence and inter-class conversions, enabling detailed assessment of land transformation processes.

Change detection analysis was adopted to assess temporal changes in each LULC variable across the five-years interval (2015, 2020, 2025). Change metrics included:

Absolute Change = Value_{t2} – Value_{t1}

Percentage Change = $\frac{(Valuet2 - Valuet1)}{Value\ t1}$ x 100

6.5 Statistical Analysis (ANOVA Model Included)

A one-way Analysis of Variance (ANOVA) was employed to test whether there were statistically significant differences in mean land-use areas 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 ≤ 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.

7. Results and Intepretations

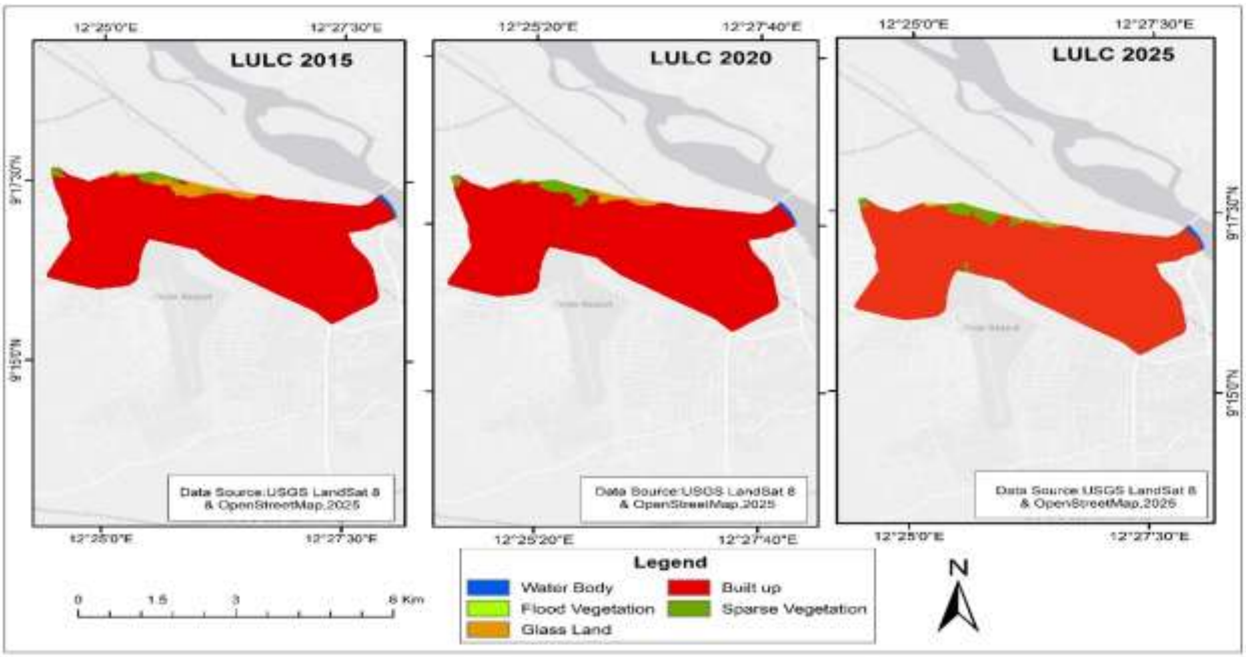

Figure 7.1: LULC Distribution for High-Density Area in 2015

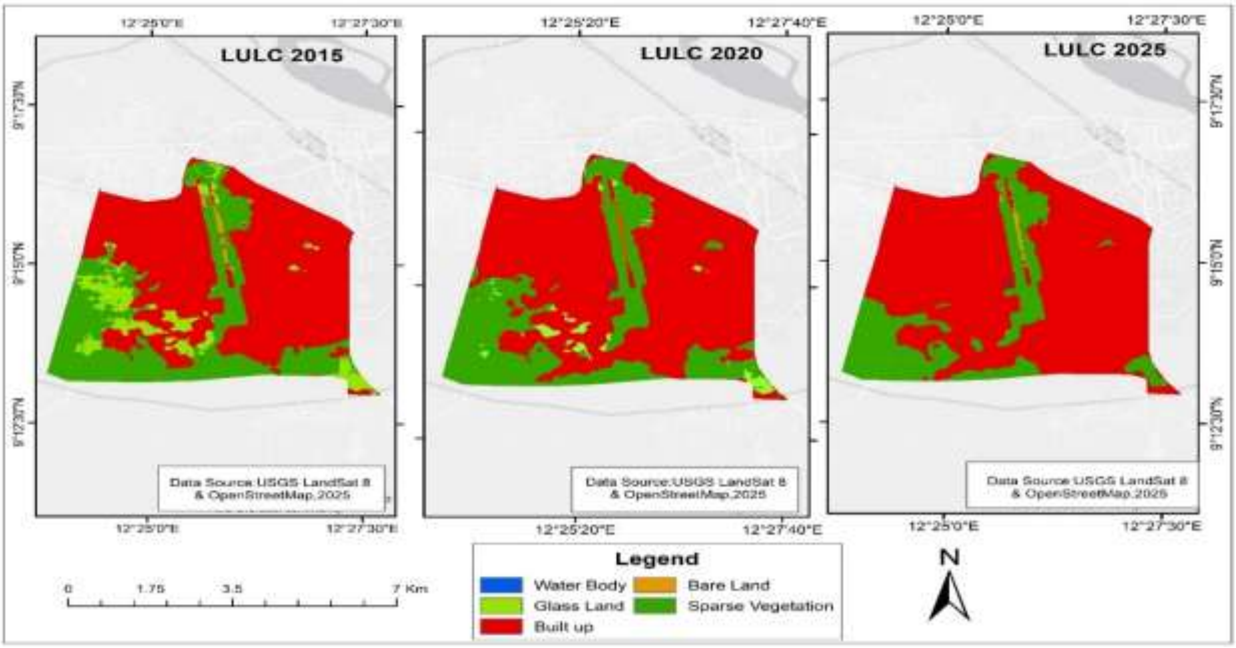

Figure 7.2: Land Use / Land Cover (LULC) Structure in Medium-Density Zone (2015, 2020, 2025)

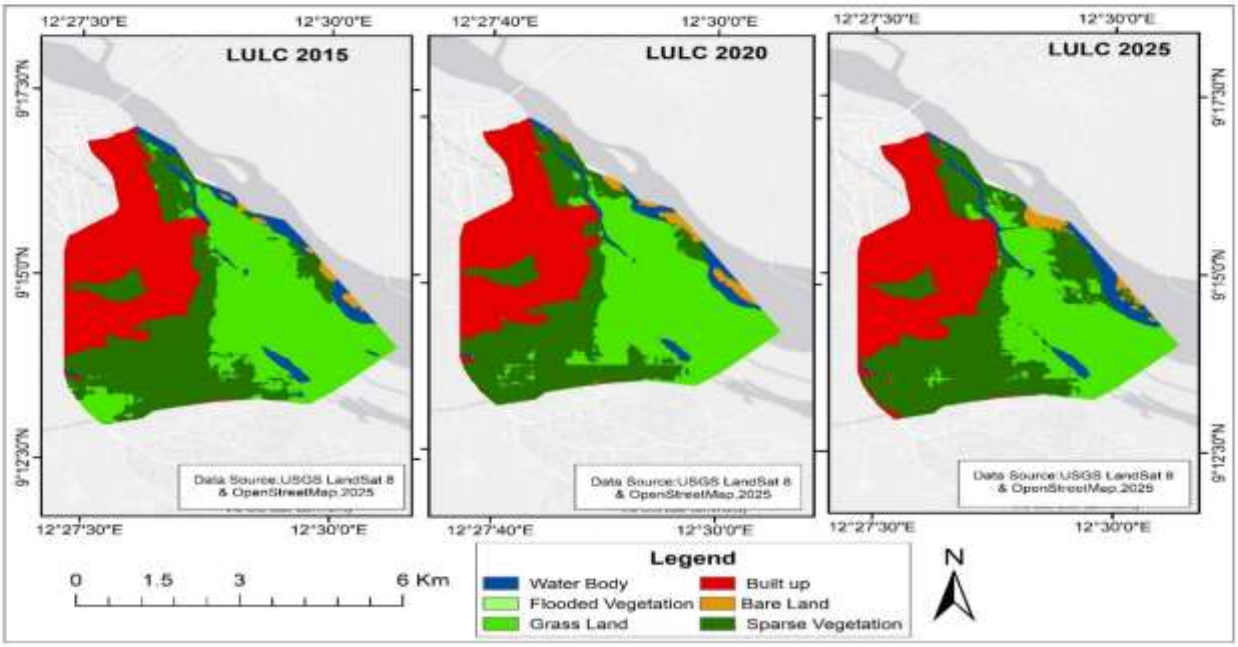

Figure 7.3: LULC Distribution for Low-Density Area in 2015

7.1 Spatial Patterns of Transformation

The spatial analysis of land use/land cover (LULC) in Jimeta between 2015 and 2025 as shown in figure 5.1, 5.2 and 5.3 reveals a clearly differentiated, density-dependent pattern of urban transformation, characterized by varying rates and magnitudes of built-up expansion across residential zones.

High-density residential areas remained structurally saturated throughout the study period, with built-up land consistently exceeding 95% of total land area, indicating negligible horizontal expansion. Changes within this zone were minimal, with built-up increase estimated at less than 1–2% over the 10-year period, largely attributable to infill development and minor redevelopment activities rather than outward growth. Vegetation and open spaces in these areas declined to below 5%, reinforcing the dominance of impervious surfaces and confirming the maturity of the urban core.

In contrast, medium-density residential zones exhibited the most significant transformation, with built-up land increasing from 61% in 2015 to approximately 77% in 2025, representing a 16 percentage-point increase (equivalent to a 26.2% relative growth in built-up coverage). Correspondingly, vegetation cover (grassland and sparse vegetation combined) declined from approximately 39% to 23%, indicating a 16 percentage-point loss in green cover. This substantial shift highlights medium-density zones as the primary centers of urban expansion, accounting for the largest share of land conversion during the study period.

Low-density residential zones showed a gradual but consistent transformation pattern, with built-up land increasing modestly from approximately 30–35% in 2015 to about 40–45% in 2025, reflecting an estimated 10 percentage-point increase in built-up coverage. Vegetation and open land, while still dominant, declined from roughly 65–70% to 55–60%, representing a 10–15% reduction in natural land cover. These changes indicate a slow but steady peri-urban transition, where development pressure is emerging but has not yet reached the intensity observed in medium-density zones.

Overall, the spatial pattern of transformation demonstrates a gradient of urban intensity, where:

- High-density zones: >95% built-up (saturated, <2% change)
- Medium-density zones: 61% → 77% built-up (+16%)
- Low-density zones: ~30–35% → ~40–45% built-up (+10%)

This pattern confirms that urban expansion in Jimeta is concentrated in medium-density transitional zones, while high-density areas remain saturated and low-density areas experience gradual encroachment.

7.2 Land Cover Transition Dynamics

The land cover transition analysis further reveals the specific pathways and proportional contributions of different land conversions driving urban transformation in Jimeta between 2015 and 2025.

The most dominant transition is the conversion of grassland to built-up areas, which accounts for approximately 45–55% of total land cover change across the study area. This transition is particularly pronounced in medium-density zones, where large expanses of previously undeveloped land were converted into residential and infrastructural uses. The magnitude of this shift corresponds directly to the 16% increase in built-up land observed in these zones, making it the single most significant contributor to urban expansion.

The second major transition involves the conversion of sparse vegetation to built-up land, contributing an estimated 25–35% of total land transformation. This process reflects the intensification of already partially developed areas, where remnant vegetation patches are cleared to accommodate additional housing units and infrastructure. This transition is most evident in both medium- and low-density zones undergoing densification.

A third notable transition is the shift from grassland to sparse vegetation, accounting for approximately 10–20% of observed land cover changes. This intermediate transformation stage indicates progressive land modification, where natural land is initially disturbed or partially cleared before full conversion to built-up use. This phased transformation pattern suggests that urban development in Jimeta is not instantaneous but occurs through incremental stages of land alteration.

In aggregate terms, the transition dynamics can be summarized as follows:

- Grassland → Built-up: ~45–55% of total change
- Sparse vegetation → Built-up: ~25–35% of total change
- Grassland → Sparse vegetation: ~10–20% of total change

These transitions collectively indicate that over 70–80% of total land transformation ultimately results in built-up expansion, underscoring the dominant role of urbanization processes in reshaping the landscape.

From an environmental perspective, these shifts correspond to a total vegetation loss of approximately 20–30% across the study area, particularly concentrated in medium-density zones. This decline significantly reduces evapotranspiration capacity and increases surface heat retention, thereby reinforcing the development of urban heat conditions.

In summary, the land cover transition dynamics in Jimeta reveal a directional and cumulative process of land transformation, where natural land cover is progressively converted into impervious urban surfaces. The dominance of built-up transitions highlights the intensity of residential expansion and underscores the need for strategic planning interventions to manage land conversion and preserve ecological balance.

7.3 ANOVA Results

Table 7.1: High-Density Residential Area

Source	DF	SS	MS	F	P
Factor	2	0.0	0.0	0.00	1.000
Error	12	463.1	38.6		
Total	14	463.1			

Interpretation: No significant difference (p = 1.000).

Table 7.2: Medium-Density Residential Area

Source	DF	SS	MS	F	P
Factor	2	4.4	2.2	0.03	0.975
Error	13	1152.9	88.7		
Total	15	1157.3			

Interpretation: No significant difference (p = 0.975).

Table 7.3: Low-Density Residential Area

Source	DF	SS	MS	F	P
Factor	2	1.9	0.9	0.05	0.956
Error	17	347.2	20.4		
Total	19	349.0			

Interpretation: No significant difference (p = 0.956).

8. Discussion

8.1 Urban Growth and Density Gradients (Expanded)

The results demonstrate a clear density-dependent pattern of urban transformation in Jimeta, with medium-density zones emerging as the most dynamic areas of change. This finding is consistent with established urban growth theories, which suggest that urban expansion typically occurs outward from saturated cores into transitional zones where land availability and accessibility facilitate development (Angel et al., 2011).

Medium-density areas in Jimeta function as urban growth frontiers, absorbing increasing housing demand and accommodating spatial expansion. The significant conversion of vegetation to built-up land in these areas reflects both formal and informal development processes, which are common in rapidly urbanizing regions.

In contrast, high-density zones exhibit characteristics of urban maturity, where development has reached saturation and further growth occurs through infill and redevelopment rather than horizontal expansion. Low-density areas, on the other hand, represent peri-urban landscapes undergoing gradual transformation, indicating the early stages of urban encroachment.

This gradient-based transformation highlights the importance of spatial structure in shaping urban development patterns and underscores the role of medium-density zones as critical areas for planning intervention.

8.2 Ecological Consequences of Land Transformation (Expanded)

The observed decline in vegetation cover across Jimeta has significant ecological implications. Vegetation plays a crucial role in maintaining environmental stability by regulating microclimate, supporting biodiversity, and facilitating ecosystem services such as carbon sequestration and water infiltration (Pickett et al., 2011).

The conversion of grassland and sparse vegetation into built-up surfaces reduces these ecological functions, leading to increased environmental vulnerability. In particular, the loss of vegetation diminishes the landscape's ability to regulate temperature through evapotranspiration, contributing to localized warming.

Additionally, vegetation fragmentation observed in low-density areas indicates a transition toward ecological degradation, where continuous natural landscapes are broken into smaller, less functional patches. Such fragmentation can reduce biodiversity and weaken ecosystem resilience.

The medium-density zone, where vegetation loss is most pronounced, represents a critical point of ecological transition. Without appropriate planning interventions, continued land conversion in these areas may lead to irreversible environmental degradation.

8.3 Thermal Implications of Urban Expansion

The progressive increase in built-up surfaces across Jimeta has direct implications for urban thermal conditions. As vegetated land is replaced by impervious materials such as concrete and asphalt, the capacity of the landscape to regulate temperature through evapotranspiration is significantly reduced. These materials possess high heat absorption and storage capacity, leading to elevated daytime temperatures and slower nocturnal cooling.

This process aligns with the Urban Heat Island Effect, where urban areas exhibit higher temperatures than surrounding rural environments. In Jimeta, the effect is most pronounced in high- and medium-density zones, where vegetation loss is greatest.

Importantly, medium-density areas—currently undergoing rapid transformation—represent emerging thermal hotspots. As these zones transition toward higher impervious surface coverage, localized warming is expected to intensify, potentially leading to increased heat stress, reduced outdoor thermal comfort, and higher energy demand for cooling.

Thus, while high-density areas already exhibit thermal saturation, medium-density zones represent the future trajectory of urban heat escalation, making them critical targets for intervention.

8.4 Interpretation of Statistical Findings

The ANOVA results indicate no statistically significant differences in mean land-use areas across the study years. However, this statistical outcome should be interpreted cautiously. The absence of significance does not imply the absence of change but rather reflects the gradual and cumulative nature of urban transformation.

Urban growth in Jimeta appears to follow an incremental pattern, characterized by small but continuous land conversions rather than abrupt large-scale changes. Such patterns are typical in developing cities, where land development is often driven by phased construction, informal processes, and household-level decisions (UN-Habitat, 2020).

Furthermore, statistical insignificance may also be influenced by data structure and temporal resolution. While ANOVA captures differences in mean values, it may not fully reflect spatial heterogeneity or localized transformations captured through geospatial analysis.

Therefore, the results highlight an important methodological insight: spatial analysis reveals meaningful environmental change even when statistical tests indicate stability.

8.5 Planning Implications

The findings of this study have significant implications for urban planning and policy formulation in Jimeta and similar medium-sized cities.

First, the rapid transformation of medium-density zones calls for targeted planning interventions. These areas represent critical transition zones where proactive measures can prevent irreversible ecological degradation. Strategies such as controlled zoning, density regulation, and preservation of green corridors should be prioritized.

Second, the observed decline in vegetation underscores the need for integrating green infrastructure into urban development. Urban trees, parks, and vegetated buffers can mitigate thermal stress, enhance environmental quality, and improve urban livability.

Third, planning policies should promote climate-sensitive urban design, including:

- Use of reflective and permeable materials
- Increased urban greenery
- Protection of peri-urban ecosystems

Finally, the gradual nature of urban transformation suggests that early intervention is both possible and necessary. By acting during the transitional phase—particularly in medium-density areas—urban planners can guide development toward more sustainable and climate-resilient outcomes.

9. Conclusion

This study demonstrates that urban transformation in Jimeta follows a density-dependent trajectory, with medium-density zones serving as the primary sites of change. While statistical analysis indicates stability, spatial analysis reveals significant ecological restructuring and thermal implications.

The findings confirm that urban densification contributes to environmental change through vegetation loss and expansion of impervious surfaces, reinforcing the role of land-use dynamics in shaping urban climate. The study also highlights the importance of integrating spatial and statistical approaches in urban research.

From a policy perspective, targeted interventions in medium-density zones are critical to managing urban growth sustainably. Future research should incorporate higher-resolution data and direct temperature measurements to further understand the relationship between land-use change and thermal conditions.

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