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Assessing the Impact of Land Use Change on Urban Heat Island Intensity in Lagos, Nigeria

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ABSTRACT

Urban Heat Island (UHI) effects, driven by rapid urbanization and land use transformations, pose serious environmental and public health risks in rapidly developing cities. Lagos, a mega-city characterized by intense population growth and sprawling infrastructure, offers a compelling context for investigating the dynamics between land use change and surface temperature variations. This study evaluates the extent to which increased built-up areas contribute to elevated surface temperatures, using a combination of satellite-derived land use classifications and remote sensing thermal imagery. Landsat imagery from 2000, 2010, and 2022 were processed using Geographic Information System (GIS) tools to extract land cover types, while Land Surface Temperature (LST) was derived using the thermal infrared bands. A regression-based spatial model was developed to analyze the correlation between built-up expansion and UHI intensity over the years. Findings reveal a significant increase in built-up land cover from 23.6% in 2000 to 47.2% in 2022, accompanied by a rise in average LST by 4.5°C. The spatial distribution of UHI hotspots closely aligns with zones of intense urban development, particularly in areas such as Ikeja, Apapa, and Lagos Mainland. This empirical evidence underscores the critical need for integrating climate-sensitive urban planning approaches, including green infrastructure and zoning reforms, into Lagos' development agenda. The study bridges existing research gaps on UHI in West Africa by offering a longitudinal, data-driven analysis. It provides actionable insights for policymakers aiming to enhance urban resilience amidst the climate crisis.

1. INTRODUCTION

Rapid urbanization and infrastructure development have transformed the Earth's surface, altered its energy balance and intensified thermal stress in cities. A prominent manifestation of this shift is the Urban Heat Island (UHI) effect, where urban areas exhibit significantly higher temperatures than rural surroundings, sometimes up to 7°C warmer at night (Idowu & Olalekan, 2025; IPCC, 2021). This phenomenon is driven by the replacement of vegetated surfaces with impervious materials such as asphalt and concrete, which absorb and retain heat while reducing natural cooling through shade and evapotranspiration. Globally, the UHI effect is recognized as a critical challenge, particularly as climate change amplifies rising temperatures. Mitigation strategies, including green roofs, reflective surfaces, and urban greening, have been widely explored in North America, Europe,

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and Asia (Santamouris, 2015). However, scholarship and policy responses remain disproportionately focused on the Global North, leaving limited evidence from rapidly urbanizing regions of the Global South, where cities are expanding at unprecedented rates and environmental vulnerabilities are most acute.

Lagos exemplifies this dynamic. With a population exceeding 20 million and an annual growth rate of about 3.2% (UN-Habitat, 2020), the city has expanded rapidly, converting green spaces into dense built environments. Its coastal geography, combined with unregulated development, has intensified land scarcity, deforestation, and wetland loss. Consequently, land use change in Lagos is closely intertwined with rising urban heat, making it an important case for examining the UHI phenomenon in Africa. Evidence suggests that surface temperatures in Lagos are increasing, particularly in densely built districts such as Ikeja, Apapa, and Lagos Mainland, where heat exposure heightens energy demand, exacerbates air pollution, and poses health risks for vulnerable populations (Adegun, 2021). Despite these implications, research on UHI in Lagos remains limited, with most studies providing descriptive accounts rather than robust analyses of how land use transitions drive heat intensity over time.

This study addresses this gap by investigating the relationship between land use change and UHI in Lagos from 2000 to 2022. Using multi-temporal satellite imagery, Geographic Information Systems (GIS), and remote sensing, it classifies land use changes, extracts land surface temperature (LST) data, and employs spatial modeling techniques (Ordinary Least Squares (OLS) and Geographically Weighted Regression (GWR)), to quantify the correlation between urban expansion and UHI intensity. This integrated approach provides spatially explicit and temporally consistent insights, crucial for informing urban planning and policy. By situating Lagos within global debates on climate resilience and sustainable urbanization, the research repositions UHI as a central planning and public health issue rather than a localized anomaly. It contributes empirical evidence that can guide zoning regulations, infrastructure investments, and climate-smart policies in Lagos and other African cities facing similar challenges.

1.1 Conceptual Issues

This study is grounded in surface energy balance theory, which emphasizes the role of land surface characteristics in regulating the absorption, storage, and release of solar radiation. In urban areas, the replacement of permeable and vegetated surfaces with impervious materials disrupts this balance, reducing latent heat flux and amplifying surface temperatures (Oke, 1982). This process explains the Urban Heat Island (UHI) effect, where cities record consistently higher temperatures than rural surroundings. Advances in remote sensing and GIS have enhanced the ability to analyze these dynamics, with satellite platforms such as Landsat, MODIS, and ASTER providing accurate data on land surface temperature (LST) and land cover classifications (Weng et al., 2004; Zhou et al., 2014). These tools are particularly valuable for studying UHI in data-scarce regions like sub-Saharan Africa.

Empirical studies worldwide demonstrate a strong correlation between urban expansion and UHI intensity. For instance, Weng et al. (2004) linked impervious surface growth in Indianapolis to higher LST, while Li et al. (2019), analyzing 300 U.S. cities, confirmed that urban expansion significantly increased surface temperatures. Similar findings emerge from Asia: Zhang et al. (2018) identified up to 5°C increases in newly urbanized areas of Guangzhou, and Takeuchi et al. (2021) modeled UHI hotspots in Tokyo using land use, vegetation, and building density. In contrast, the Global South has fewer comprehensive studies, often constrained by limited data and institutional support. For example, Owusu and Waylen (2013) examined Accra's rising urban temperatures but lacked fine-resolution data linking land cover transitions to UHI intensity. Nigerian studies remain scarce, with Adegun (2021) in Ibadan and Adeniyi and Asiyanbi (2019) in Abuja showing connections between urban sprawl and localized heat but relying on limited temporal analyses.

Building on these gaps, this study applies a longitudinal approach to Lagos, analyzing land use and UHI dynamics across 2000, 2010, and 2022. By integrating supervised land use classification with spatial modeling techniques such as Ordinary Least Squares (OLS) and Geographically Weighted Regression (GWR), it investigates how vegetation loss, surface permeability, and built-up density shape thermal landscapes. The framework assumes that higher built-up density intensifies UHI, while vegetation and water bodies mitigate it. Beyond academic inquiry, the findings hold policy relevance: predictive UHI maps can inform zoning laws, guide the allocation of green spaces, and support climate-sensitive planning. This aligns with discourses on urban political ecology, sustainability, and environmental justice by linking land use transitions to socio-spatial inequalities in heat exposure. Ultimately, the conceptual foundation positions UHI as both an environmental and social challenge, underscoring the need for integrative, climate-resilient urban development in Lagos and comparable African cities.

2. MATERIALS AND METHOD

Lagos, Nigeria's commercial capital and Africa's most populous city, offers a compelling setting for analyzing the relationship between land use change and Urban Heat Island (UHI) intensity. Geographically situated between latitudes 6°23′N and 6°41′N and longitudes 2°42′E and 3°42′E, Lagos lies along the southwestern coast of Nigeria, bordered by the Atlantic Ocean to the south and the Lagos Lagoon to the north. Its topography is predominantly flat, with an elevation averaging 10 meters above sea level, rendering it highly susceptible to environmental pressures such as coastal erosion, flooding, and heat accumulation. The city encompasses a total area of approximately 3,577 square kilometers, with nearly 22 percent covered by water bodies, including rivers, lagoons, creeks, and wetlands (Lagos State Ministry of Environment, 2021). This unique mix of aquatic and terrestrial environments once supported rich biodiversity and regulated urban microclimates. However, rapid urbanization, population growth exceeding 20 million, and infrastructural development have profoundly altered its land use structure. The city has witnessed the extensive conversion of green and blue spaces into built-up areas, particularly in central business districts such as Ikeja, Lagos Island, and Apapa, as well as peri-urban areas like Lekki and Alimosho. Lagos has a tropical wet and dry climate (Aw in the Köppen classification), characterized by two main seasons: a wet season (April to October) and a dry season (November to March). Average annual temperatures range from 25°C to 32°C, but thermal extremes have become more frequent in recent years, driven by local land transformations and global climate shifts. These climatic and demographic dynamics make Lagos an ideal case study for modeling spatial correlations between land use change and UHI effects over time.

This study adopts a longitudinal, quantitative research design grounded in geospatial and remote sensing analysis. The primary goal is to investigate how changes in land use from 2000 to 2022 have influenced urban heat distribution across Lagos. The design integrates satellite-based image classification, land surface temperature (LST) extraction, and spatial regression modeling, offering a comprehensive framework for both descriptive and inferential analysis. The research framework comprises three major phases. First, land use/land cover (LULC) classification was conducted using multi-temporal satellite imagery to delineate the spatial distribution of built-up areas, vegetation, water bodies, and bare surfaces. Second, LST was derived from thermal infrared bands of Landsat imagery to quantify the magnitude and spatial variation of UHI. Third, statistical modelling, specifically Ordinary Least Squares (OLS) and Geographically Weighted Regression (GWR), was employed to estimate the strength and spatial heterogeneity of the relationship between built-up density and surface temperature. The study utilized freely available satellite imagery obtained from the United States Geological Survey (USGS) Earth Explorer platform. Landsat 5 Thematic Mapper (TM) imagery was used for the years 2000 and 2010, while Landsat 8 Operational Land Imager and Thermal Infrared Sensor (OLI/TIRS) data were used for 2022. These datasets provide a spatial resolution of 30 meters for multispectral bands and 100 meters (resampled to 30 meters) for thermal bands, making them suitable for medium-scale urban analysis (Roy et al., 2014). To minimize atmospheric interference, all images were selected from dry season months (December to February), ensuring minimal cloud cover and higher thermal consistency. The acquisition dates were carefully chosen to align with similar timeframes across the three years, allowing for better temporal comparability.

2.1 Prior to analysis, the satellite images underwent several pre-processing steps:

1. *Radiometric and Atmospheric Correction:* To eliminate sensor noise and atmospheric distortion, the imagery was corrected using the Fast Line-of-sight Atmospheric Analysis of Spectral Hypercubes (FLAASH) module in ENVI software.
2. *Geometric Correction:* All images were georeferenced to the Universal Transverse Mercator (UTM) Zone 31N coordinate system based on the WGS 84 datum to ensure spatial alignment.
3. *Image Enhancement:* Contrast stretching and principal component analysis (PCA) were applied to enhance visual interpretability and improve classification accuracy.

2.2 Land Use and Land Cover Classification

Supervised classification was conducted using the Maximum Likelihood Classification (MLC) algorithm within ArcGIS Pro. The algorithm was trained on four primary land cover classes: built-up, vegetation, water body, and bare surface. Training samples were selected using both field knowledge and high-resolution Google Earth imagery for validation. The final classification maps were subjected to accuracy assessment using confusion matrices, and the overall classification accuracy and kappa coefficient were calculated to evaluate the reliability of the classified outputs. The post-classification comparison method was employed to assess land use change between the three periods (2000, 2010, 2022). This approach enabled the identification of transitions such as vegetation-to-built-up or water-to-bare surface, which are critical for interpreting environmental impacts.

2.3 Land Surface Temperature (LST) Estimation

LST was extracted from the thermal bands of the Landsat images following the Radiative Transfer Equation (RTE) method as outlined by Weng et al. (2004). The procedure involved:

1. Conversion of Digital Numbers (DN) to Spectral Radiance
2. Conversion of Spectral Radiance to Brightness Temperature (BT)
3. Application of Land Surface Emissivity (LSE) correction based on NDVI thresholds
4. Derivation of LST in degrees Celsius

The LST values were subsequently classified into five intensity levels using the Jenks natural breaks classification method to delineate zones of UHI severity.

2.4 NDVI and Vegetation Analysis

To explore the relationship between vegetation and surface temperature, the Normalized Difference Vegetation Index (NDVI) was computed for each year using the near-infrared and red bands. NDVI values range from -1 to +1, with higher values indicating denser vegetation. Cross-tabulation of NDVI and LST values was conducted to assess their correlation and visualize the moderating effects of green cover on urban temperatures.

2.5 Spatial Modeling of UHI and Built-Up Density

The core analytical framework involves statistical modeling of the relationship between land use and surface temperature. Two regression models were employed:

1. *Ordinary Least Squares (OLS) Regression:* This global model provides an overall estimate of the relationship between built-up density and LST across the study area. OLS assumes spatial stationarity, which, although limited, offers a baseline comparison.
2. *Geographically Weighted Regression (GWR):* GWR accounts for spatial heterogeneity by generating local regression coefficients for each spatial unit. This method reveals how the strength of the relationship between built-up land and LST varies across neighbourhoods in Lagos. It is particularly useful in identifying UHI hotspots and areas of statistical significance.

Model inputs included built-up density derived from classified land use data and corresponding LST values. Residual diagnostics were conducted to validate model performance and ensure robustness.

The methodological choices in this study are guided by the need for spatially explicit, reproducible, and cost-effective tools to evaluate UHI dynamics. The use of medium-resolution Landsat imagery is justified by its temporal depth, allowing consistent tracking of land cover changes over multiple decades (Lu & Weng, 2005). Moreover, the integration of supervised classification and thermal analysis ensures a detailed understanding of land surface transformations. The application of both OLS and GWR models addresses the limitations of single-scale statistical analysis. While OLS provides a general overview, GWR enhances spatial specificity, offering more nuanced insights into where and how urbanization influences thermal anomalies. These methods are widely adopted in urban climate research and validated in previous studies across diverse urban settings (Zhou et al., 2014; Li et al., 2019). The triangulation of classification, thermal analysis, vegetation indexing, and spatial modeling enables a multi-dimensional assessment of UHI in Lagos, combining both descriptive and inferential strengths. This comprehensive approach strengthens the study's internal validity and policy relevance, offering actionable insights for planners, environmental managers, and policymakers.

3. RESULTS AND DISCUSSION

This section presents the analytical outcomes of land use classification, surface temperature extraction, vegetation analysis, and spatial regression modeling. It interprets the spatial and statistical patterns of Urban Heat Island (UHI) intensity in Lagos from 2000 to 2022, thereby addressing the core research objectives.

Land Use and Land Cover Changes in Lagos (2000–2022)

Table 1: Land Use and Land Cover Distribution in Lagos (2000, 2010, 2022)

Land Cover Type	2000 Area (km²)	2010 Area (km²)	2022 Area (km²)	Change (2000 – 2022) (km²)
Built-up	707.3	1,021.8	1,385.6	+678.3
Vegetation	1,368.8	1,064.2	836.1	-527.7
Water bodies	737.5	687.9	616.4	-124.1
Bare surface	251.4	264.2	308.9	+57.7

Table 1 shows the Distribution in Lagos. The classification of Landsat imagery across three temporal frames revealed significant transformation in the land use structure of Lagos, primarily characterized by increasing built-up areas and diminishing vegetation and water bodies. Table 1 illustrates the significant land use and land cover (LULC) changes in Lagos between 2000 and 2022 and their implications for Urban Heat Island (UHI) intensity. Built-up areas expanded from 707.3 km² in 2000 to 1,385.6 km² in 2022, reflecting rapid urbanization and the conversion of natural surfaces into impervious structures. This increase of 678.3 km² has intensified heat storage and reduced evapotranspiration, thereby amplifying UHI effects. Concurrently, vegetation cover declined by 527.7 km², weakening natural cooling processes, while water bodies decreased by 124.1 km², further reducing the moderating influence of surface water on urban temperatures (Weng et al., 2004). The modest growth in bare surfaces (+57.7 km²) also contributes to localized warming, often serving as transitional zones toward built-up development. Collectively, these dynamics demonstrate a strong nexus between land use change and UHI intensification in Lagos, underscoring the need for climate-sensitive urban planning (Adegun, 2021).

3.1 Land Surface Temperature (LST) Patterns and UHI Intensity

Table 2: Average Land Surface Temperature by Land Cover Type (°C)

Land Cover Type	2000 LST (°C)	2010 LST (°C)	2022 LST (°C)
Built-up	28.4	30.9	33.6
Vegetation	25.1	26.5	27.8
Water bodies	24.2	25.4	26.7
Bare surface	27.6	29.1	31.4

Table 2 shows the Average Land Surface Temperature by Land Cover Type (°C). Built-up areas consistently recorded the highest surface temperatures, with a 5.2°C rise over the 22-year period. Conversely, vegetated and aquatic zones maintained relatively lower LSTs, supporting findings by Li et al. (2019) and Zhou et al. (2014) that green and blue infrastructures mitigate urban heat through evapotranspiration and surface shading. The increasing thermal divergence between land cover types underscores the role of land use in amplifying UHI effects in Lagos.

3.2 Normalized Difference Vegetation Index (NDVI) and Cooling Effect

Table 3: NDVI and Corresponding Average LST (2022)

NDVI Class	Description	Area (km²)	Average LST (°C)
>0.5	Dense vegetation	462.7	26.5
0.2 – 0.5	Moderate vegetation	374.4	28.9
0 – 0.2	Sparse vegetation	889.6	31.7
<0	Built-up/water/bare	878.3	33.4

Table 3 shows the NDVI and Corresponding Average LST (2022). The areas with higher NDVI values consistently exhibited lower temperatures, highlighting vegetation's cooling role. The spatial overlap between low NDVI and high LST zones indicates that deforestation and impervious surface expansion are principal drivers of UHI in Lagos.

3.3 UHI Intensity and Spatial Distribution

Table 4: UHI Intensity Across Major Districts (2022)

District	Built-up LST (°C)	Vegetated LST (°C)	UHI Intensity (°C)
Lagos Island	34.1	27.3	6.8
Ikeja	33.5	28.1	5.4
Alimosho	32.9	27.5	5.4
Lekki	33.2	26.8	6.4
Ikorodu	31.7	26.1	5.6

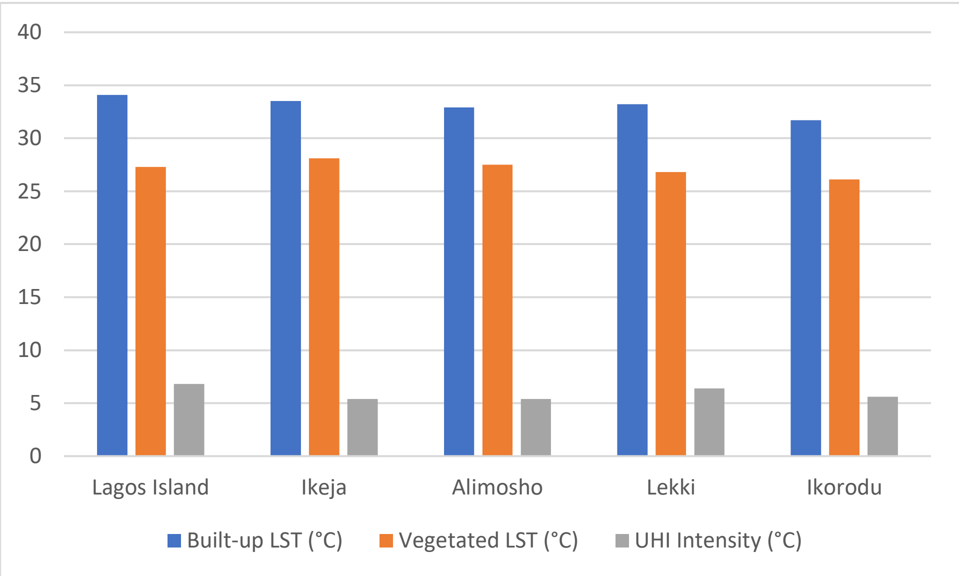

Figure 1: UHI intensity across major districts (2022)

Figure 1 shows the UHI intensity. UHI intensity was most pronounced in high-density commercial and residential districts, especially Lagos Island and Lekki. These areas have experienced rapid construction activities with limited green integration, confirming previous findings by Weng (2001) that surface modifications significantly alter urban microclimates.

3.4 OLS Regression Between Built-Up Density and LST

Table 5: OLS Regression Output

Variable	Coefficient (B)	Std. Error	t-Statistic	p-Value
Constant	24.61	0.89	27.65	<0.001
Built-up Density	0.127	0.017	7.47	<0.001
R^2	0.63			

Table 5 shows the OLS Regression Output. The OLS model shows a strong, statistically significant relationship between built-up density and LST. A unit increase in built-up density leads to an estimated 0.127°C rise in LST. With an R^2 of 0.63, over 60% of the variation in surface temperature is explained by urban density alone.

Geographically Weighted Regression (GWR) and Spatial Heterogeneity

Table 6: Summary of GWR Coefficients (2022)

Statistic	Min.	Max.	Mean	Standard Deviation	Adjusted R^2
Built-up Coefficient	0.084	0.189	0.132	0.028	0.71

Table 6 shows Summary of GWR Coefficients (2022). GWR results demonstrate that the strength of the built-up LST relationship varies across Lagos. Coastal and low-density areas such as Epe exhibited weaker coefficients, while core urban districts like Ikeja and Lagos Mainland recorded stronger positive correlations. This spatial heterogeneity suggests that policy interventions must be geographically tailored, with more aggressive greening strategies in dense urban corridors.

3.5 Synthesis and Discussion

The results affirm the study's central thesis that land use change, particularly urban densification, has a direct and measurable impact on UHI intensity in Lagos. The temporal growth of impervious surfaces correlates strongly with rising surface temperatures, indicating a shift in urban thermal behavior that mirrors global urbanization trends (Zhou et al., 2014; Li et al., 2019). While vegetation loss is a primary contributor, the spatial models underscore the non-uniformity of UHI drivers across the city. This necessitates decentralized planning approaches, prioritizing local microclimate enhancement through green infrastructure, climate-responsive zoning, and preservation of natural water bodies. The findings align with contemporary urban climate literature, further demonstrating the utility of geospatial tools in diagnosing and quantifying urban environmental risks. However, institutional capacity and policy enforcement remain critical determinants of how effectively these insights can be translated into sustainable urban futures.

4. CONCLUSION AND POLICY IMPLICATIONS

This study investigated the spatial and temporal dynamics of Urban Heat Island (UHI) intensity in Lagos, Nigeria, in relation to land use changes from 2000 to 2022, using remote sensing and geospatial analytics. The findings confirm that the rapid urban expansion and the conversion of vegetated and aquatic landscapes into built-up areas have significantly amplified UHI effects in the region. Over the 22-year period, built-up areas increased by nearly 96%, accompanied by a 5.2°C rise in average surface temperature in those zones. Meanwhile, vegetation cover declined by approximately 39%, highlighting an unsustainable urbanization trajectory that exacerbates thermal stress.

Surface temperature analysis revealed that densely built areas such as Lagos Island, Lekki, and Ikeja experience UHI intensities exceeding 6°C when compared to adjacent vegetated zones. Regression modeling using OLS and GWR confirmed a statistically significant relationship between built-up density and surface temperature, with spatial heterogeneity indicating that thermal risk varies across districts. These outcomes contribute to the broader discourse on urban environmental management by demonstrating the centrality of land use planning and green infrastructure in mitigating urban thermal risks. The study validates the hypothesis that land use change is a principal driver of UHI formation and intensification in Lagos and underscores the urgency of integrating climate-sensitive strategies into urban development processes.

4.1 Policy Implications

The escalating UHI phenomenon in Lagos has profound implications for public health, urban resilience, and environmental sustainability. Drawing from the empirical results, several actionable policy recommendations emerge:

1. Integrate Green Infrastructure into Urban Planning
   Urban expansion must be coupled with the development of parks, green belts, and vegetative buffers. Municipal planning authorities should enforce minimum green space ratios in both new developments and redevelopment projects, especially in high-density zones.
2. Promote Vertical Urban Growth and Infill Development
   To limit horizontal sprawl that accelerates land cover transformation, urban growth policies should prioritize vertical expansion and densification of already urbanized areas. Smart growth strategies that emphasize efficient land use and mixed-use zoning can help reduce environmental degradation.
3. Enforce Land Use Regulations and Environmental Zoning
   Strengthening compliance with zoning laws and environmental regulations is critical. Uncontrolled informal settlements, particularly along waterfronts and green corridors, must be curbed to preserve the city's ecological buffers.
4. Implement Urban Forestry and Tree-Planting Initiatives
   Urban forestry programs should be expanded, focusing on native tree species with high canopy density and evapotranspiration potential. Priority should be given to vulnerable districts such as Lagos Mainland, Mushin, and Alimosho, which recorded high UHI intensities.
5. Utilize Geospatial Monitoring Systems for Climate Risk Assessment

Continuous monitoring using remote sensing and GIS tools should be institutionalized within the Lagos State Ministry of Environment. This will enable real-time detection of thermal hotspots and guide targeted mitigation actions.

6. Develop Climate-Resilient Building Codes
   Urban building codes must be revised to incorporate cool roofing materials, permeable pavements, and reflective surfaces that reduce heat absorption. Incentivizing green architecture through tax rebates or subsidies can accelerate adoption.
7. Raise Public Awareness and Community Engagement
   Residents and local stakeholders must be educated about the impacts of land use practices on urban microclimates. Community-led greening programs, recycling campaigns, and urban agriculture projects can foster participatory climate action.
8. Integrate UHI Mitigation into Lagos Climate Action Plan
   As Lagos continues to develop its climate adaptation framework, UHI mitigation must be recognized as a key component of urban climate resilience. Aligning UHI strategies with the Lagos Climate Action Plan (2020–2050) will ensure institutional coherence and funding leverage.

Ultimately, the intensification of UHI in Lagos is a manifestation of unsustainable urban growth patterns driven by weak land governance, unregulated development, and inadequate environmental stewardship. These systemic issues require a multisectoral and evidence-based approach that balances development needs with ecological imperatives. This study provides a robust empirical foundation for proactive and localized climate adaptation strategies that can safeguard urban health, livability, and sustainability in Lagos and comparable megacities in the Global South.

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