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INTEGRATING COMMUNITY OPEN SPACES INTO CLIMATE-RESPONSIVE GREEN INFRASTRUCTURE SYSTEMS: EVIDENCE FROM SEMI-ARID KATSINA, NIGERIA

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Abstract

Rapid urbanization and vegetation loss in semi-arid Nigerian cities have intensified the Urban Heat Island (UHI) effect, worsening thermal stress and climate vulnerability. While green infrastructure (GI) is increasingly recognized as a vital climate adaptation strategy, little research has explored how fragmented community open spaces can be integrated into cohesive urban green networks within Sahelian cities. This study investigates the role of community open spaces in strengthening climate resilience through an integrated GI framework in Katsina, Nigeria. Using a mixed-methods, multi-scalar approach, we combined remote sensing and GIS analysis with field-based surveys. Land Surface Temperature (LST), Normalized Difference Vegetation Index (NDVI), and land use/land cover data derived from MODIS and Landsat imagery (1984–2024) were analyzed alongside household questionnaires (n = 832), key informant interviews, and field observations. Correlation and trend analyses examined the relationship between vegetation cover and urban thermal dynamics. The results reveal a strong inverse relationship between vegetation density and surface temperature; greened areas recorded temperature reductions of up to 4°C compared to densely built-up zones. However, the effectiveness of existing open spaces is severely constrained by spatial fragmentation, land encroachment, weak institutional coordination, and limited public awareness. To address these challenges, this study proposes a decentralized “Green-Linkage” framework. By reconnecting fragmented community open spaces into an integrated GI network, this model offers a scalable, community-driven strategy to enhance climate resilience in semi-arid African cities.

Keywords: Climate Resilience, Community Open Spaces, Green Infrastructure, Semi-Arid Urbanism, Urban Heat Island

1.0 INTRODUCTION

Rapid urbanization has become a major driver of environmental transformation, particularly in developing regions where urban expansion often exceeds ecological and infrastructural planning capacity. The growth of impervious surfaces, including roads, buildings, and industrial infrastructure, disrupts the natural surface energy balance by increasing solar heat absorption while reducing evapotranspiration and long-wave radiation loss (Jacob, 2015). These changes contribute to rising urban temperatures, environmental degradation, and greater exposure to climate risks. Consequently, Land Surface Temperature (LST) has become an important indicator for assessing urban environmental change because it reflects thermal

conditions at the earth–atmosphere interface and influences ecological, physical, and atmospheric processes (Abubakar et al., 2024).

A major outcome of this transformation is the Urban Heat Island (UHI) effect, where urban areas experience higher temperatures than surrounding rural environments. This phenomenon is largely associated with the replacement of vegetation by impervious materials with high heat retention and low albedo (Sulaiman et al., 2025). In semi-arid African cities, limited vegetation cover, prolonged dry seasons, and weak environmental governance further intensify these conditions. Vegetation helps regulate urban microclimates through shading and evapotranspiration, reducing both surface and ambient temperatures. As a result, the relationship between vegetation cover and urban thermal conditions, commonly assessed using the Normalized Difference Vegetation Index (NDVI) and LST, has become central to urban climate research. Studies consistently show a strong inverse relationship between vegetation density and urban temperature, with greener areas recording lower temperatures than densely built environments (Abubakar et al., 2024; Parah & Amba, 2025).

Nigeria is experiencing one of the fastest urbanization rates in Africa, leading to rapid land-use change, vegetation loss, and increasing thermal vulnerability (Sulaiman et al., 2025). Urban growth has transformed natural landscapes, agricultural land, and riparian corridors into built environments, intensifying the UHI effect and reducing ecological resilience. Katsina Metropolis exemplifies these trends, recording a 142.4% increase in built-up area and an LST rise of more than 17°C between 1986 and 2014 (Jacob, 2015). Similar patterns are evident in Kaduna Metropolis, where settlement expansion and vegetation removal have significantly increased daytime LST values (Abubakar et al., 2024). Across Nigerian cities, declining vegetation cover has contributed to the emergence of urban thermal hotspots (Sulaiman et al., 2025). Rising temperatures also increase cooling energy demand, worsen air quality, and elevate heat-related health risks, particularly in semi-arid northern Nigerian cities where climate-responsive planning remains inadequate (Abubakar et al., 2024).

In response, green infrastructure (GI) has gained recognition as a key strategy for strengthening urban climate resilience through the integration of ecological systems into urban planning and design. Urban green spaces, including parks, wetlands, green corridors, street trees, and community open spaces, function as natural cooling systems that regulate microclimates, enhance biodiversity, improve stormwater management, and support environmental quality. Nature-Based Solutions (NBS), such as rain gardens, bioswales, permeable pavements, and urban afforestation, are increasingly promoted as sustainable climate adaptation measures (Granados Aragonet et al., 2025). However, implementation in many African cities remains limited by financial constraints, weak policy enforcement, institutional fragmentation, and outdated planning systems (Thorn et al., 2021). In Katsina, these challenges are further compounded by land encroachment, weak community participation, and poor public perceptions of urban vegetation, which undermine the preservation and effectiveness of green spaces (Sa'ad et al., 2026).

Although previous studies have explored urbanization, vegetation decline, and UHI dynamics in Nigerian cities, limited attention has been given to fragmented community open spaces as interconnected climate-regulating components of GI systems. Existing research largely emphasizes macro-scale land-use and thermal changes while overlooking socio-spatial, climatic, and governance dimensions. Consequently, there remains a limited understanding of how fragmented community open spaces can be strategically connected and managed to improve climate resilience in rapidly urbanizing semi-arid cities. Addressing this gap, this study investigates the integration of community open spaces into urban green infrastructure for climate resilience in Katsina, Nigeria. Using a multi-scalar mixed-methods approach that combines remote sensing,

GIS-based spatial analysis, field observations, and community surveys, the study proposes a decentralized “Green-Linkage” framework aimed at reconnecting fragmented open spaces into an integrated urban green infrastructure network capable of enhancing thermal regulation and supporting climate-responsive urban development.

2.0 LITERATURE REVIEW

2.1 Urbanization and the Urban Heat Island (UHI) Effect

Urbanization is a major driver of environmental transformation, particularly in rapidly growing cities of the Global South. The replacement of natural land surfaces with impervious materials such as asphalt, concrete, and roofing systems alters surface energy balance by increasing heat absorption and reducing evapotranspiration, thereby intensifying urban thermal conditions and contributing to the Urban Heat Island (UHI) effect (Jacob, 2015). In semi-arid African cities, UHI intensity is further aggravated by sparse vegetation, prolonged dry seasons, and weak environmental governance. Rapid urban growth and inadequate ecological planning have increased exposure to thermal stress and climate-related vulnerabilities (Sulaiman et al., 2025).

While early UHI studies focused mainly on urban–rural temperature differences, recent research emphasizes the influence of socio-spatial inequalities, planning deficiencies, and governance structures on thermal vulnerability. In Nigeria, studies consistently show a strong relationship between urban expansion and rising land surface temperatures (LST). For example, Katsina Metropolis experienced a 142.4% increase in built-up area between 1986 and 2014, alongside an LST rise exceeding 17°C (Jacob, 2015). Similar patterns were observed in Kaduna Metropolis, where vegetation loss and settlement expansion significantly increased daytime LST values (Abubakar et al., 2024). However, much of this research focuses heavily on thermal statistics while giving limited attention to the structural causes of ecological fragmentation and unequal green-space distribution.

2.2 Vegetation Dynamics, NDVI, and Urban Thermal Regulation

Vegetation is essential for moderating urban microclimates through shading and evapotranspiration. Consequently, the relationship between vegetation cover and thermal dynamics, often examined using the Normalized Difference Vegetation Index (NDVI) and LST datasets, remains central to urban climate research. Existing studies consistently reveal a strong inverse relationship between vegetation density and urban temperature, indicating that declining green cover intensifies localized heat stress (Abubakar et al., 2024).

In Kaduna Metropolis, a significant negative correlation ($r = -0.704$) was identified between NDVI and daytime LST, confirming the substantial contribution of vegetation decline to urban heat accumulation (Abubakar et al., 2024). Similarly, studies across Nigerian cities indicate that areas with high Urban Green Infrastructure (UGI) coverage can maintain surface temperatures up to 3.5°C lower than densely built-up areas (Parah & Amba, 2025). In contrast, cities such as Kano, Lagos, and Abuja increasingly experience severe thermal hotspots associated with vegetation loss and persistent “browning” trends (Sulaiman et al., 2025).

Despite these findings, much of the literature remains technically descriptive, concentrating mainly on remote sensing outputs and temperature measurements. Limited attention has been given to how vegetation fragmentation affects the functionality of urban green systems at neighbourhood and community scales.

Consequently, while many studies identify thermal hotspots, they provide limited insight into how urban green spaces can be strategically connected to improve long-term climate resilience.

2.3 Green Infrastructure and Nature-Based Solutions for Climate Resilience

The increasing severity of UHI effects has shifted urban climate discourse toward Green Infrastructure (GI) and Nature-Based Solutions (NBS) as integrated climate adaptation strategies. GI emphasizes the multifunctional role of ecological systems in thermal regulation, biodiversity conservation, stormwater management, and environmental improvement. Urban green spaces such as parks, wetlands, street trees, green corridors, and community open spaces are increasingly recognized as critical elements of climate-responsive urban systems.

Nature-Based Solutions, including rain gardens, bioswales, permeable pavements, and urban afforestation, are increasingly promoted as sustainable alternatives to purely engineered adaptation measures (Granados Aragonez et al., 2025). These approaches help reduce heat stress while also addressing flooding, ecosystem degradation, and public health concerns. Similarly, passive cooling strategies incorporated into urban and architectural design have shown strong potential for lowering indoor temperatures and reducing energy demands in African cities.

Nevertheless, the implementation of GI across many African cities remains fragmented. Studies identify financial limitations, institutional fragmentation, weak policy enforcement, and outdated planning systems as major barriers to effective green infrastructure delivery (Thorn et al., 2021). As a result, many adaptation projects remain isolated interventions rather than integrated ecological systems, reducing their long-term effectiveness because of poor spatial connectivity, inadequate maintenance, and weak integration into formal planning frameworks.

2.4 Governance Challenges and Community-Scale Green Space Integration

Governance challenges remain a critical but underexplored aspect of urban climate resilience. In many rapidly urbanizing African cities, weak institutional coordination and ineffective planning controls have accelerated the loss of urban green spaces and constrained climate-responsive development. In Katsina, green-space decline has been linked not only to urban expansion but also to outdated master plans, poor environmental awareness, weak governance systems, and limited community participation (Sa'ad et al., 2026).

Socio-cultural perceptions also affect the sustainability of urban greenery. In many communities, vegetation is often regarded primarily as a source of fuel or fodder rather than as essential climate infrastructure. Such perceptions weaken public support for urban greening initiatives and reduce long-term stewardship of green spaces. Although existing studies acknowledge these governance and socio-cultural barriers, they rarely incorporate them into broader climate adaptation frameworks. Consequently, urban climate resilience is often treated mainly as a technical issue rather than a socio-ecological and institutional challenge.

Another important gap concerns scale and spatial integration. Most UHI mitigation studies focus either on city-wide assessments or isolated site-specific interventions, leaving a limited understanding of how fragmented community open spaces collectively function within urban ecological systems. Yet neighbourhood parks, peri-urban buffers, undeveloped urban plots, and green corridors can serve as important localized climate assets when strategically connected. Studies increasingly argue that ecological connectivity is essential for urban resilience because isolated green patches often fail to deliver sustained environmental benefits (Granados Aragonez et al., 2025).

2.5 Conceptual Gap and Study Positioning

Although previous studies establish strong links between urbanization, vegetation decline, and rising urban temperatures, limited attention has been paid to integrating fragmented community open spaces into cohesive urban green infrastructure systems. Existing research largely prioritizes macro-scale thermal analysis while underemphasizing socio-spatial connectivity, governance structures, and community participation as key determinants of climate resilience.

This study addresses these limitations by adopting a multi-scalar approach that integrates climatic analysis, socio-spatial evaluation, and governance considerations. Unlike earlier studies that treat urban greenery as isolated landscape elements, the study proposes a decentralized “Green-Linkage” framework that positions community open spaces as interconnected climate-regulating infrastructure. Through the integration of remote sensing, GIS analysis, field observations, and community-level assessments, the study contributes to ongoing discussions on climate-responsive urban planning, ecological connectivity, and community-based resilience strategies in semi-arid African cities.

3.0 METHODOLOGY

3.1 Research Design and Study Scope

This study adopts a mixed-methods case study design to examine the integration of community open spaces into urban green infrastructure (GI) systems for enhancing climate resilience in Katsina Metropolis, Nigeria. Katsina Metropolis serves as the primary study area, while evidence from Kaduna and other Nigerian cities is used only as supporting literature context.

The methodology combines geospatial analysis, field observations, and community-level assessments to examine the relationships between vegetation cover, urban thermal conditions, and the functionality of community open spaces. The framework is aligned with the study objectives by:

- a. Mapping land-use and vegetation dynamics;
- b. Assessing urban thermal variation using Land Surface Temperature (LST);
- c. Identifying spatial and governance barriers affecting community open spaces; and
- d. Developing an integrated Green-Linkage framework for climate-responsive urban planning.

3.2 Study Area

Katsina Metropolis is located in northwestern Nigeria within the semi-arid Sudan Savannah ecological zone. The city is characterized by high temperatures, low rainfall, prolonged dry seasons, and rapid urban expansion, making it vulnerable to Urban Heat Island (UHI) effects and climate-related environmental stress. Population growth and unregulated development have contributed to vegetation loss, land-use conversion, and increased thermal exposure (Jacob, 2015).

The study focuses on selected community open spaces across residential, institutional, peri-urban, and mixed-use districts. These include neighbourhood parks, undeveloped public plots, green corridors, recreational fields, and vegetated buffers identified through GIS screening and field reconnaissance. The unit of spatial analysis is the community open space and its surrounding urban fabric within the metropolitan boundary.

3.3 Data Sources and Acquisition

The study integrates remote sensing data, GIS datasets, field observations, and socio-environmental survey data. Multi-temporal satellite imagery from Landsat 5 TM, Landsat 7 ETM+, and Landsat 8 OLI/TIRS covering 1986–2024 was used for land-use/land-cover (LULC) classification and thermal analysis. MODIS NDVI and LST products supported the analysis of vegetation and thermal trends over time (Abubakar et al., 2024).

Additional datasets, including administrative boundaries, road networks, and land-use maps, were obtained from Katsina State planning authorities, while Google Earth imagery supported validation. Climatic data such as rainfall and atmospheric temperature were sourced from the NASA POWER database.

- a. Primary socio-environmental data were collected through questionnaires, interviews, and field observations:
- b. Household Questionnaires: A total of 832 questionnaires were administered using stratified random sampling to capture variations in residential density and socio-spatial conditions. The survey examined perceptions of urban heat, access to community open spaces, environmental awareness, and attitudes toward urban greenery.
- c. Key Informant Interviews: Eighteen semi-structured interviews were conducted with planners, environmental officers, community leaders, and municipal officials involved in land administration and environmental management.
- d. Focus Group Discussions (FGDs): Two FGDs involving 8–10 participants each explored experiences of environmental change, governance challenges, and barriers to green space management.

3.4 Image Processing and Land Use/Land Cover Classification

Satellite imagery underwent radiometric, atmospheric, and geometric corrections to ensure consistency across time periods. Image processing and spatial analyses were conducted using ArcGIS 10.7 and Google Earth Engine.

LULC classification employed a supervised maximum likelihood classification algorithm suitable for heterogeneous urban land covers. The classified categories included built-up areas, dense vegetation, sparse vegetation, bare surfaces, farmland, and water bodies.

Ground-truthing was carried out using GPS-referenced sample points collected during field surveys. Classification accuracy was assessed using an error matrix and Kappa statistics, producing overall accuracy values between 86% and 91% and Kappa coefficients ranging from 0.82 to 0.88, indicating high reliability.

3.5 Retrieval of NDVI and Land Surface Temperature (LST)

Vegetation dynamics were evaluated using the Normalized Difference Vegetation Index (NDVI) derived from the red and near-infrared bands of Landsat imagery. NDVI values were used to assess vegetation density and spatial distribution.

LST was derived from thermal infrared bands through standard remote sensing procedures involving the conversion of Digital Numbers (DN) to spectral radiance, calculation of brightness temperature, and emissivity correction to generate surface temperature values in degrees Celsius (Sulaiman et al., 2025). The relationship between NDVI and LST was then analyzed to assess the cooling effects of vegetation and community open spaces.

3.6 Spatial and Statistical Analysis

Spatial analysis examined the distribution, connectivity, and thermal performance of community open spaces within Katsina Metropolis. GIS-based proximity and network analyses were used to evaluate ecological linkages between fragmented green spaces and surrounding urban districts, forming the basis for the proposed Green-Linkage framework.

Statistical analyses were conducted using SPSS and ArcGIS spatial statistics tools. Pearson Product-Moment Correlation analysis examined the relationship between NDVI and LST, while linear regression assessed the influence of vegetation loss on the increase in LST. Questionnaire responses were analyzed using descriptive statistics, whereas interview and FGD data were interpreted through thematic analysis focusing on governance challenges, land encroachment, and community perceptions of urban greenery.

3.7 Methodological Integration

The study adopts an integrated socio-ecological framework linking urban form, vegetation dynamics, thermal conditions, and governance systems. Remote sensing and GIS techniques provide empirical evidence of land-cover change and thermal patterns, while surveys and interviews explain the socio-cultural and institutional factors influencing the effectiveness of community open spaces as climate-regulating infrastructure.

The integration of spatial and social datasets enables a comprehensive understanding of how fragmented community open spaces can strengthen urban climate resilience through coordinated planning, governance, and ecological connectivity. This combined methodology supports the development of a decentralized Green-Linkage framework for climate-responsive urban planning in semi-arid cities.

4.0 RESULTS AND DISCUSSION

4.1 Land Use Transformation and the Decline of Community Open Spaces

Spatial analysis revealed major land-use transformation in Katsina Metropolis between 1986 and 2024, marked by rapid urban expansion and a significant reduction in vegetated areas. Built-up areas increased by approximately 142.4%, largely through the conversion of agricultural land, undeveloped plots, and community open spaces into residential and commercial developments (Jacob, 2015). This trend reflects broader patterns of uncontrolled urbanization in semi-arid Nigerian cities, where population growth and increasing land demand often exceed the capacity of formal planning systems.

The findings further showed that many communities' open spaces have become fragmented, disconnected, and increasingly vulnerable to encroachment. Instead of functioning as an integrated ecological infrastructure, several now exist as isolated residual spaces surrounded by dense development, reducing ecological connectivity and limiting their microclimatic benefits. This decline is linked to weak planning enforcement, outdated policies, and competing pressures for urban land development (Sa'ad et al., 2026).

Field observations and interviews indicated that informal land conversion and incremental residential growth significantly contributed to the loss of open spaces in low- and medium-income areas. Residents associated urban expansion with declining environmental quality, reduced recreational spaces, and increasing thermal discomfort, reinforcing arguments that climate vulnerability in rapidly urbanizing African cities is closely connected to uneven urban development and inadequate ecological planning systems.

4.2 Spatial Distribution and Accessibility of Community Open Spaces

The study identified considerable spatial inequality in the distribution and accessibility of community open spaces across Katsina Metropolis. Open spaces were concentrated mainly in planned institutional and low-density residential areas, while densely populated neighbourhoods had limited access to functional green spaces. GIS proximity analysis revealed that many high-density communities were located beyond walkable distances from public open spaces, reducing opportunities for thermal relief and social interaction during extreme heat.

This uneven distribution reflects wider socio-spatial inequalities within urban planning systems, where low-income and informal settlements often face greater exposure to climate risks due to inadequate access to environmental infrastructure. The findings, therefore, indicate that climate resilience in Katsina is both an ecological and spatial justice issue shaped by urban exclusion and unequal infrastructure provision.

Questionnaire responses showed that residents valued community open spaces for shade, social interaction, and thermal comfort. However, their accessibility and usability were limited by poor maintenance, insecurity, inadequate landscaping, and land encroachment. About 68% of respondents considered existing spaces poorly managed or underutilized, while 74% expressed concern over the continuous conversion of open land into built development. These perceptions suggest that the effectiveness of community open spaces depends not only on their existence but also on governance quality, maintenance, and public accessibility.

4.3 Vegetation Dynamics, NDVI, and Urban Thermal Patterns

NDVI analysis showed a continuous decline in vegetation density across the metropolis, especially in rapidly urbanizing districts. Areas with dense vegetation consistently recorded lower Land Surface Temperature (LST) values than built-up zones, confirming the cooling role of urban vegetation through shading and evapotranspiration (Abubakar et al., 2024). Statistical analysis revealed a strong inverse relationship between NDVI and LST, indicating that vegetation loss directly increases urban thermal intensity.

Built-up surfaces and bare land recorded the highest temperatures, with mean values exceeding 36°C, whereas vegetated areas and community open spaces exhibited comparatively lower temperatures. Community open spaces with higher vegetation density functioned as localized cooling nodes capable of moderating surrounding microclimates. In several neighbourhoods, interconnected open spaces reduced localized surface temperatures by approximately 3.5–4°C compared to adjacent dense urban areas.

These findings support existing evidence that ecological connectivity improves the climatic performance of urban green infrastructure (Parah & Amba, 2025). However, the study further demonstrates that isolated or degraded open spaces provide weaker cooling effects than interconnected and well-vegetated spaces. This highlights that climate resilience depends not only on the quantity of urban greenery but also on its spatial configuration, accessibility, and ecological continuity.

4.4 Governance Fragmentation and Institutional Constraints

Qualitative findings identified governance fragmentation as a major barrier to effective urban green infrastructure management in Katsina Metropolis. Interviews with planning officials and community leaders revealed that weak institutional coordination, outdated planning policies, and inconsistent development control mechanisms have contributed to the progressive loss of community open spaces.

Respondents noted that planning regulations concerning public open spaces are rarely enforced consistently, particularly in peri-urban and rapidly developing areas. Informal settlement growth and incremental land subdivision often occur without adequate environmental consideration, leading to the gradual encroachment of designated open areas. These governance failures align with findings from other sub-Saharan African cities, where fragmented institutional systems undermine climate-responsive urban planning (Thorn et al., 2021).

The study also found limited public participation in urban environmental governance. Community members reported minimal involvement in decisions related to open-space management, urban greening initiatives, and land-use planning. This weak participatory structure reduces local stewardship and contributes to the deterioration of public green spaces. In addition, socio-cultural perceptions of vegetation as ornamental or economically expendable continue to weaken support for urban greening policies in some communities (Sa'ad et al., 2026).

The findings therefore suggest that urban climate resilience cannot be achieved through technical interventions alone, such as tree planting or landscape beautification. Effective resilience requires integrated governance systems that combine spatial planning, institutional coordination, community participation, and long-term ecological management.

4.5 Implications for Climate Resilience and Urban Green Infrastructure Planning

The results demonstrate that community open spaces are critical yet underutilized components of climate resilience infrastructure in Katsina Metropolis. Although existing green spaces provide measurable cooling benefits, their fragmented distribution, weak governance, and declining accessibility reduce their effectiveness in mitigating thermal stress.

The study advances a decentralized “green-linkage” framework in which community open spaces are connected through green corridors, vegetated buffers, street landscaping, and neighbourhood-scale ecological networks. This approach moves beyond isolated greening interventions toward integrated urban ecological systems capable of improving thermal regulation, ecological continuity, and social accessibility simultaneously.

The findings also reveal that climate resilience is closely linked to governance, equity, and spatial inclusion. Neighbourhoods with limited access to functional community open spaces experienced greater exposure to thermal discomfort and environmental degradation, reinforcing patterns of socio-spatial vulnerability. Consequently, climate-responsive urban planning in semi-arid African cities must prioritize equitable access to ecological infrastructure alongside broader environmental management objectives.

The study contributes to emerging urban climate scholarship by demonstrating that community open spaces are not merely recreational amenities but essential socio-ecological infrastructure capable of supporting localized cooling, environmental sustainability, and climate adaptation when strategically integrated into urban planning systems. This perspective is particularly relevant for rapidly urbanizing semi-arid cities facing increasing thermal stress, land-use pressure, and governance fragmentation.

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This study examined the integration of community open spaces into urban Green Infrastructure (GI) systems to enhance climate resilience in the Katsina Metropolis, Nigeria. Using a mixed-methods approach involving remote sensing, GIS-based spatial analysis, field observations, household surveys, and stakeholder interviews, the study explored the links between urban expansion, vegetation change, thermal conditions, and the governance of community open spaces. The findings revealed that rapid urbanization and uncontrolled land-use change have significantly reduced vegetation cover and fragmented community open spaces, intensifying Urban Heat Island (UHI) effects and increasing thermal vulnerability.

The study established a strong inverse relationship between vegetation density and land surface temperature (LST), confirming the role of vegetated community open spaces in moderating localized temperatures through shading and evapotranspiration. However, their effectiveness was limited by fragmentation, weak spatial connectivity, poor governance, land encroachment, and unequal distribution across neighbourhoods. Densely populated and lower-income areas experienced lower access to functional community open spaces and greater exposure to thermal stress, underscoring the socio-spatial nature of climate vulnerability in semi-arid cities.

Beyond demonstrating the relationship between vegetation loss and rising urban temperatures, the study contributes to urban climate resilience scholarship by conceptualizing community open spaces as interconnected socio-ecological infrastructure rather than isolated recreational areas. The findings show that the climate performance of urban greenery depends not only on vegetation quantity but also on ecological connectivity, accessibility, governance quality, and integration within urban planning systems. This strengthens existing GI discourse by emphasizing decentralized, neighbourhood-scale ecological networks as key components of urban resilience in rapidly urbanizing semi-arid environments.

Methodologically, the study contributes an integrated socio-ecological assessment framework that combines climatic, socio-spatial, and governance analyses. Unlike conventional UHI studies focused mainly on thermal mapping and remote sensing, this research incorporated community perceptions and institutional assessment to provide a broader understanding of urban climate vulnerability. The proposed “Green-Linkage” framework offers a practical and scalable approach for connecting fragmented community open spaces into cohesive urban ecological systems that support localized climate adaptation.

The findings have significant implications for climate-responsive urban planning and policy in Nigeria and other semi-arid African cities. The study demonstrates that urban climate resilience cannot rely solely on isolated greening projects or aesthetic landscaping interventions. Instead, it requires integrated planning systems that prioritize ecological connectivity, equitable access to environmental infrastructure, participatory governance, and long-term environmental management. Community-integrated GI is therefore essential for reducing urban heat stress while improving environmental equity, public health, and urban liveability in rapidly expanding cities.

Overall, the study contributes to ongoing debates on climate adaptation in African urban contexts by showing that community open spaces can function as decentralized climate infrastructure when effectively integrated into urban planning systems. In semi-arid cities facing rising temperatures, rapid urbanization, and ecological degradation, community-scale GI provides a viable pathway toward climate-resilient and socially inclusive urban development.

5.2 Recommendations

Based on the findings, the study recommends several measures to strengthen climate resilience through community-integrated green infrastructure in Katsina Metropolis and comparable semi-arid African cities.

1. **Development of an Integrated Urban Green Infrastructure Policy:** Urban planning authorities should establish comprehensive green infrastructure (GI) policies that integrate community open spaces into climate-responsive urban development frameworks, with emphasis on ecological connectivity, neighbourhood accessibility, and long-term environmental sustainability.
2. **Protection and Restoration of Community Open Spaces:** Existing community open spaces should be protected against encroachment and uncontrolled land conversion through stricter enforcement of land-use regulations and development control measures. Degraded spaces should also be rehabilitated through urban afforestation, landscape restoration, and ecological enhancement programmes.
3. **Creation of Ecological Green-Linkage Networks:** Urban planners should develop interconnected green corridors linking parks, neighbourhood open spaces, institutional landscapes, and peri-urban buffers to strengthen ecological continuity and improve localized cooling effects across the metropolis.
4. **Community Participation and Environmental Stewardship:** Local communities should actively participate in the planning, management, and maintenance of community open spaces. Participatory governance can enhance environmental stewardship, increase public awareness, and improve the long-term sustainability of urban greening initiatives.
5. **Climate-Responsive Planning for Informal and High-Density Areas:** Future urban development policies should prioritize equitable access to green infrastructure in densely populated and low-income neighbourhoods that are more vulnerable to thermal stress. Community-scale greening initiatives should therefore be integrated into informal settlement upgrading and neighbourhood redevelopment programmes.
6. **Strengthening Institutional Coordination:** Effective climate resilience planning requires stronger collaboration among urban planning agencies, environmental authorities, local governments, and community organizations to ensure consistent implementation of green infrastructure policies and environmental management strategies.
7. **Future Research Directions:** Future studies should investigate the long-term climatic performance of interconnected community open spaces using higher-resolution thermal datasets, microclimatic simulations, and longitudinal socio-environmental monitoring. Comparative studies across semi-arid African cities could further improve understanding of how governance systems influence the effectiveness of community-integrated green infrastructure.

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