Socio-Spatial Stratification of Climate Resilience: An Empirical Assessment of Household Vulnerability across Density Typologies in Ibadan Metropolis

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ABSTRACT

Urban climate adaptation in Sub-Saharan Africa depends heavily on municipal capacity and household-level self-insulation, particularly in cities where public infrastructure investment has not kept pace with growth. This study examines the structural and socio-spatial predictors of household climate resilience across stratified residential density clusters in five core Local Government Areas of Ibadan Metropolis, Nigeria. Using a multi-stage stratified systematic sampling framework, data were collected from 800 household heads across varied housing types and neighborhood conditions. A composite Physical-Behavioral Climate Resilience Index (CRI_PB) was developed across three structural pillars-Structural Adaptations, Cognitive Preparedness, and Communal Adaptations-designed to avoid circularity with socio-demographic predictors.

K-Means clustering (k=3), validated through Silhouette analysis (s=0.62), grouped the sample into three socio-spatial vulnerability profiles: High-Asset Self-Resilience (n=65, CRI_PB=0.690), Asset-Constrained Coping (n=678, CRI_PB=0.167), and Chronic Structural Incapability (n=57, CRI_PB=0.110). These clusters highlight substantial disparities in adaptive capacity even within the same metropolitan area. A non-circular OLS multiple linear regression ($R^2=0.524$, $F=218.42$, $p<0.001$) shows that Land Tenure Security is the predictor most strongly associated with physical adaptation ($\beta=0.328$, $p<0.001$), followed by Monthly Income ($\beta=0.281$, $p<0.001$) and Structural Housing Quality ($\beta=0.245$, $p<0.001$). Educational Attainment shows the weakest, though still significant, association ($\beta=0.115$, $p<0.001$). Sensitivity analysis confirms the model remains stable across alternative PCA weighting schemes ($\rho=0.942$).

A key finding is what this study terms the "Traditional Land Rights Trap" in the historic core, where high land tenure security (TEN=0.85) coincides with a near-total absence of liquid financial capital (INC=0.15), a combination associated with limited physical adaptation despite secure land status. These results, interpreted as associations rather than causal effects, support moving policy attention toward publicly funded, block-level drainage and municipal infrastructure interventions alongside continued household sensitization.

Keywords: Climate Resilience Index, Urban Morphology, Socio-Spatial Stratification, Ibadan Metropolis, Vulnerability Profiling

INTRODUCTION

Climate change manifestations within metropolitan areas in developing nations do not interact with a homogenous civilian populace. Rather, the impacts are deeply refracted through pre-existing socio-spatial lines of fracture, urban morphological configurations, and localized institutional dynamics (Adelekan, 2012). In sub-Saharan Africa, fast-paced, unguided urban growth has led to highly stratified residential densities (Cobbinah *et al.*, 2015). These spatial variations often determine a household's exposure to climate hazards, as well as its capacity to adapt and recover (Salami *et al.*, 2017).

The city of Ibadan, Nigeria historically celebrated as the largest indigenous, traditional urban center in sub-Saharan Africa presents a compelling morphological setting for examining these dynamics (Adelekan, 2012). The city's spatial structure is broadly characterized by a clear tripartite division: a high-density, traditional inner core; a planned, medium-density intermediate ring; and a sprawling, low-density suburban periphery (Taiwo, 2022). While existing urban climate scholarship frequently isolates macroeconomic drivers or broad regional bio-physical exposures, there is a clear gap in empirical research that connects localized urban layout

forms directly to household adaptive metrics (Salami et al., 2017). This paper systematically unpacks how urban form, residential density, and socioeconomic capital intersect to shape household climate resilience within metropolitan Ibadan.

PROBLEM STATEMENT

Current climate adaptation policies in southwestern Nigeria are heavily skewed toward generalized, city-wide responses that treat metropolitan populations as uniform units (Ola, 2022). This approach fails to account for the stark socio-spatial and morphological differences that define sub-Saharan urban areas, where high-density, poorly serviced neighbourhoods coexist with better-resourced areas within the same metropolis (Adelekan *et al.*, 2015; Aliu, Akoteyon & Soladoye, 2025). Within Ibadan Metropolis, conventional adaptation models assume that land tenure security automatically provides households with the stability needed to invest in protective infrastructure.

However, this assumption falls apart in the historic inner core, where highly secure communal and family-house land rights often coexist with deep financial constraints and severe spatial crowding (Amole *et al*., 1991; Ibem, 2011; Amao & Ogunlade, 2015). Unlike the peri-urban interface, where tenure insecurity itself is the dominant barrier to investment (Agbola & Agunbiade, 2009; Cohen, 2006), the core settlements' constraint is less about ownership than about the compounding effects of poverty and density on what households can physically build (Coker, Awokola, Olomolaiye & Booth, 2007). Consequently, households in these high-density zones face structural barriers that limit their ability to execute critical structural adaptations, such as building defensive drainage channels or reinforcing vulnerable structures, since incremental upgrading in already-dense settlements is technically and financially demanding even where land rights are not in dispute (Visagie & Turok, 2020). Without empirical data that maps the precise relationship between residential density, socioeconomic capital, and adaptive capacity, municipal authorities continue to deploy ineffective planning interventions (Ola, 2022). This lack of tailored policy leaves the most vulnerable urban populations exposed to worsening climate risks.

OBJECTIVES OF THE STUDY

The primary objective of this study is to evaluate the structural and socio-spatial determinants of household climate resilience across highly stratified residential density typologies within the five core Local Government Areas (LGAs) of Ibadan Metropolis, Nigeria.

To achieve this primary aim, the study addresses the following specific research objectives:

1 Evaluate a multi-dimensional Climate Resilience Index (CRI) across high, medium, and low density spatial configurations based on four key pillars: Structural, Cognitive, Communal, and Socio-Demographic.

2 Classify and optimize urban household profiles into distinct vulnerability typologies using a K-Means clustering algorithm.

3 Examine the statistical predictive power of household income, educational attainment, tenure security, and residential density on overall adaptive capacity using Ordinary Least Squares (OLS) multiple linear regression.

4 Analyze the operational intersection of ancestral land tenure arrangements and financial liquiditys to understand the mechanisms driving structural paralysis in the historic urban core.

5 Proffer targeted, data-driven planning and policy frameworks that facilitate a shift from individualized, privatized insulation models toward structurally funded, community-led municipal infrastructure interventions.

Significance of the Study

This research provides valuable findings for urban planners, climate scientists, and regional policymakers working in rapidly expanding global south metropolises. By moving past broad, macro-level vulnerability assessments, this study uncovers the specific household-level realities shaped by urban morphology (Adelekan *et al*., 2015). The findings offer municipal institutions like the Oyo State Ministry of Physical Planning and Urban Development a clear, data-driven framework for identifying climate vulnerability hot-spots. This study advances the field by combining spatial analysis with advanced statistical clustering and regression models, providing a reliable diagnostic tool for evaluating urban climate justice across sub-Saharan Africa, building on recent calls for more rigorous, context-specific vulnerability assessment methods on the continent (Odipo *et al.,* 2025).

Scope and Limitations

The spatial boundaries of this investigation are strictly limited to the five inner-core Local Government Areas (LGAs) that constitute the metropolitan heart of Ibadan, Oyo State: Ibadan North, Ibadan North-East, Ibadan South-East, Ibadan South-West, and Ibadan North-West. Temporally, the field data collection, household surveys, and empirical observations were executed entirely within the 2026 calendar year, capturing contemporary socio-economic conditions and recent spatial shifts.

The study focuses strictly on household-level behavioral adaptation, structural investments, and collective community safety measures in response to seasonal precipitation anomalies and flash floods. It does not evaluate wider agricultural impacts, industrial pollution profiles, or broader macro-level regional climate variations.

A key limitations of this research stems from the complete lack of recent, centralized municipal census listings or formal property registries across the older, traditional neighborhoods of the inner core. To mitigates this data gap and ensure strict spatial objectivity during fieldwork, the study relied on localizeds "Random Walk" protocols and clear systematic skip patterns anchored by distinct geographic landmarks.

LITERATURE REVIEW

Conceptual Framework

The conceptual framework of this study is anchored at the intersection of urban morphology, household asset vulnerability, and customary land tenure systems, which collectively dictate the pattern of climate risk and adaptive capacity in sub-Saharan African metropolises. Urban morphology representing the physical form, layout, and density of the built environment serves as the spatial canvas that actively shapes localized microclimates and environmental hazard zones, since building density, height, and surface materials are established drivers of land-surface temperature variance and heat exposure within cities (Marey *et al*., 2025). In rapidly expanding West African cities, this structural layout is not merely a demographic variable but a physical constraint that determines how environmental shocks, such as flash flooding and heat stress, materialize at the neighborhood level, as flood risk in these cities is shaped directly by ground conditions, surface materials, and drainage obstructions produced through unregulated urban expansion (Andreasen *et al.,* 2023).

While high-density, impervious inner-city cores suffer from severe drainage blockages and heat trapping, low-density suburban peripheries face vulnerabilities rooted in fragmented, individualized infrastructure and poor drainage connectivity, a pattern consistent with findings that underestimating heat-related risk in the densest parts of African cities stems from insufficient attention to the relationship between built-up density and the urban thermal environment (Li, Stringer, & Dallimer, 2022).

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Ultimately, the degree to which a household can manage these morphologically induced hazards is governed by its asset portfolio and adaptive capacity. Framed within the Sustainable Livelihoods Approach, a household's resilience depends on its command over financial, human, social, and physical capital (DFID, 1999; Mobeen *et al*., 2023). Liquid financial capital directly enables structural mitigation, such as constructing raised floor levels and reinforcing roofs, while human capital particularly formal education enhances risk perception and the cognitive processing of early warning systems (Mobeen *et al.*, 2023). Where formal state support and financial assets are scarce, households heavily mobilize social capital through informal communal mutual aid and voluntary clean-up networks (DFID, 1999). However, this translation of household assets into long-term, proactive adaptation is severely constrained by local institutional and structural realities, most notably the traditional land tenure systems operating within indigenous urban spaces.

This structural bottleneck is conceptualized here as the Customary Land Tenure and Spatial Trap Nexus. In traditional urban cores, land is frequently governed by ancestral, communal tenure systems that afford strong protection against arbitrary loss and dispossession, allowing households to secure their residence and pass it between generations without the formal titling process required elsewhere (UNDP, 2006). While these informal property rights provide social security and protection against displacement, they simultaneously restrict proactive climate adaptation. Because ancestral land is communally held, fragmented across generations, and legally restricted from market transactions, it is generally unusable as collateral to secure formal credit or liquidity (UNDP, 2006). This creates a severe spatial trap: households reside on secure but non-liquidatable ancestral land, leaving them highly exposed to morphologically driven hazards without the disposable financial capital required to fund structural resilience measures. By integrating these three pillars, this framework illustrates how physical urban form, household livelihood assets, and customary institutional bottlenecks interact to determine the overall climate vulnerability of metropolitan residential zones.

Theoretical Foundation

The contemporary academic discourse surrounding urban climate vulnerability has increasingly shifted away from purely biophysical, hazard-centric risk models toward dynamic, socio-spatial frameworks, primarily because disaster risk is no longer conceptualized as a static consequence of environmental exposure, but rather as an emergent property of interacting social systems, physical built environments, and localized institutional barriers (Tyler & Moench, 2012). To capture this systemic complexity within a rapidly expanding sub-Saharan metropolis, this study anchors its empirical inquiry on a synthesized integration of the Social-Ecological Systems (SES) Framework (Ostrom, 2009; Berkes & Folke, 1998) and Spatial Justice Theory (Soja, 2010).

While the SES framework treats urban communities and biophysical hazards as a unified, co-evolving system where physical infrastructure and human actors continuously influence each other through structural feedback loops (Ostrom, 2009), Spatial Justice Theory critically complements this functional view by addressing the underlying power dynamics, resource allocations, and socio-spatial inequalities embedded within that very system, arguing that the equitable distribution of resources, services, and access is a basic condition of justice with an inherent geography (Soja, 2010). Consequently, these two theoretical lenses are blended together in this study to establish a strong conceptual apparatus capable of explaining how physical urban morphology, uneven household asset portfolios, and customary land administration networks interact to dictate localized climate resilience in metropolitan residential zones.

Although the SES framework operates by mapping the functional feedback loops between the physical canvas (resource systems) and residing households (actors) (Ostrom, 2009), these feedback loops cannot be fully understood without examining how the organization of urban space is inherently political and structurally uneven, as noted by Spatial Justice Theory (Soja, 2010). For instance, in dense, complex metropolises like Ibadan, when high-density development in indigenous urban cores replaces natural soil with impervious surfaces, it creates a physical feedback loop that dramatically increases surface runoff and heat trapping (Marey *et al*., 2025); yet, from a spatial justice perspective, this ecological feedback loop is deeply tied to historical socio-spatial inequalities, whereby risk-reducing public infrastructure and green spaces are systematically concentrated in wealthier, low-density modern planned areas, while historic, high-density indigenous cores face a severe structural deficit in formal drainage — consistent with Soja's (2010) broader argument that conventional urban governance and planning almost always favors wealthier residents at the expense of the urban poor.

Therefore, by merging these theories, we can see that households are not merely passive actors experiencing physical environmental feedbacks, but are socio-spatial agents who have been structurally forced to absorb a disproportionate share of climate burdens while being systematically denied the spatial assets and infrastructure required to adapt (Tyler & Moench, 2012; Soja, 2010).

Furthermore, this integrated theoretical synthesis is vital for analyzing how customary land tenure systems generate what can be conceptualized as an institutionalized "spatial trap." Traditional economic models often assume that secure land tenure automatically encourages long-term structural investment; however, when we view customary systems through the combined lens of SES and Spatial Justice, a major institutional bottleneck is revealed. Because ancestral land in the historic, traditional cores of southwestern Nigerian metropolises is communally held across generations, it is legally non-marketable and highly fragmented, which means it cannot be used as formal collateral to secure bank credit (UNDP, 2006). Consequently, even though these households possess a secure and culturally valuable asset (their ancestral land), they are financially locked out of formal credit markets, thereby creating a systemic feedback loop where they lack the liquid capital needed to fund the proactive, long-term structural improvements required to withstand localized hazards. Ultimately, this integrated socio-spatial framework explains how physical urban form, socio-economic asset limits, and customary land frameworks lock together, transforming traditional land tenure into an institutional bottleneck that perpetuates vulnerability and restricts proactive adaptation in the residential zones of the metropolis.

Gaps in the Literature

Despite a substantial volume of research focusing on broad environmental hazards within southwestern Nigeria, three critical gaps persist within contemporary urban scholarship, all of which severely limit the development of localized disaster risk frameworks.

First, traditional vulnerability studies often utilize basic binary indicators for land tenure (Formal versus Informal); consequently, they completely miss the unique legal, spatial, and economic dynamics of ancestral family compounds in traditional West African urban cores. Furthermore, existing research typically separates physical geographic mapping from socioeconomic survey data, whereby researchers are prevented from fully modeling how physical urban layouts actively restrict or modify the expression of household wealth. Finally, most local studies rely heavily on descriptive statistics or basic bivariate correlations, which are inherently unable to capture the multi-layered, non-linear ways that structural, spatial, and institutional parameters interact to dictate vulnerability. In conclusion, by failing to integrate these dimensions, contemporary literature remains structurally fragmented, thereby pointing to the critical need for a synthesized approach that connects spatial, socio-economic, and customary institutional realities in metropolitan residential zones.

METHODOLOGY

The primary research instrument for this study was a structured, close-ended household field questionnaire designed to capture quantitative spatial, physical, and socio-economic variables across sampled residential properties. The target population comprised all household heads residing in selected residential neighborhoods across five Local Government Areas (LGAs) of Ibadan Metropolis: Ibadan North, Ibadan North-East, Ibadan South-East, Ibadan South-West, and Ibadan North-West. These LGAs form the historic, administrative, and economic core of the wider metropolitan region. (See Figure 1).

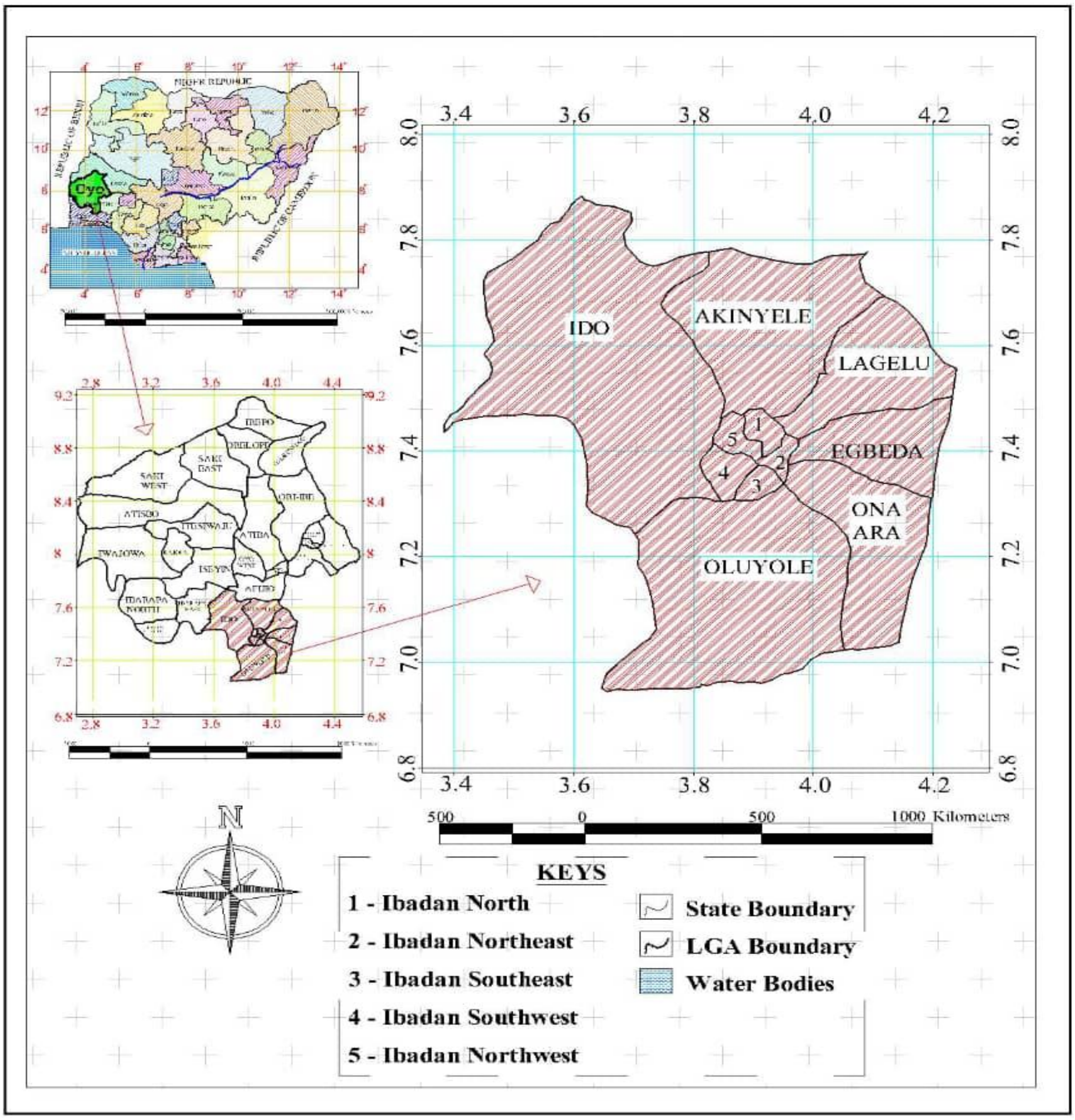

Figure 1: Location of the Study area and the Five Urban Local Government Areas of Ibadan Metropolis

Source: Google, 2024

The household head served as the primary unit of analysis, since this individual typically makes decisions regarding structural adaptation, disaster response, and resource allocation at the household level.

The sampling frame consisted of all eligible residential households within the designated neighborhoods across the five LGAs, totaling 53,428 households. This baseline figure was derived from local municipal planning registries, utility databases, and projected household counts based on the Oyo State Valuation Report (1998) demographic framework. Yamane's (1967) formula was applied at a 95% confidence level with a standard margin of error (e=0.05) to calculate a statistically representative sample size. To preserve statistical efficiency and account for clustering effects across heterogeneous spatial zones, a Design Effect (DEFF) of 2.0 was applied, following Kish (1965). The final sample size was set at 800 household heads.

A multi-stage stratified systematic sampling technique was carried out in three stages. First, the study area was stratified into three residential density zones: high-density (traditional core), medium-density (transitional zone), and low-density (planned estates/GRAs). Second, localities within each density category were purposively selected based on historical flood exposure and physical urban morphology. Third, residential properties were sampled using a systematic interval (k=10) starting from prominent neighborhood landmarks; at the building level, simple random lotteries were conducted in multi-household structures to select a single household head.

Figure 2 shows the neighborhoods within the five urban LGAs of Ibadan Metropolis, sourced from the Oyo State Ministry of Land, Housing and Urban Development (2021).

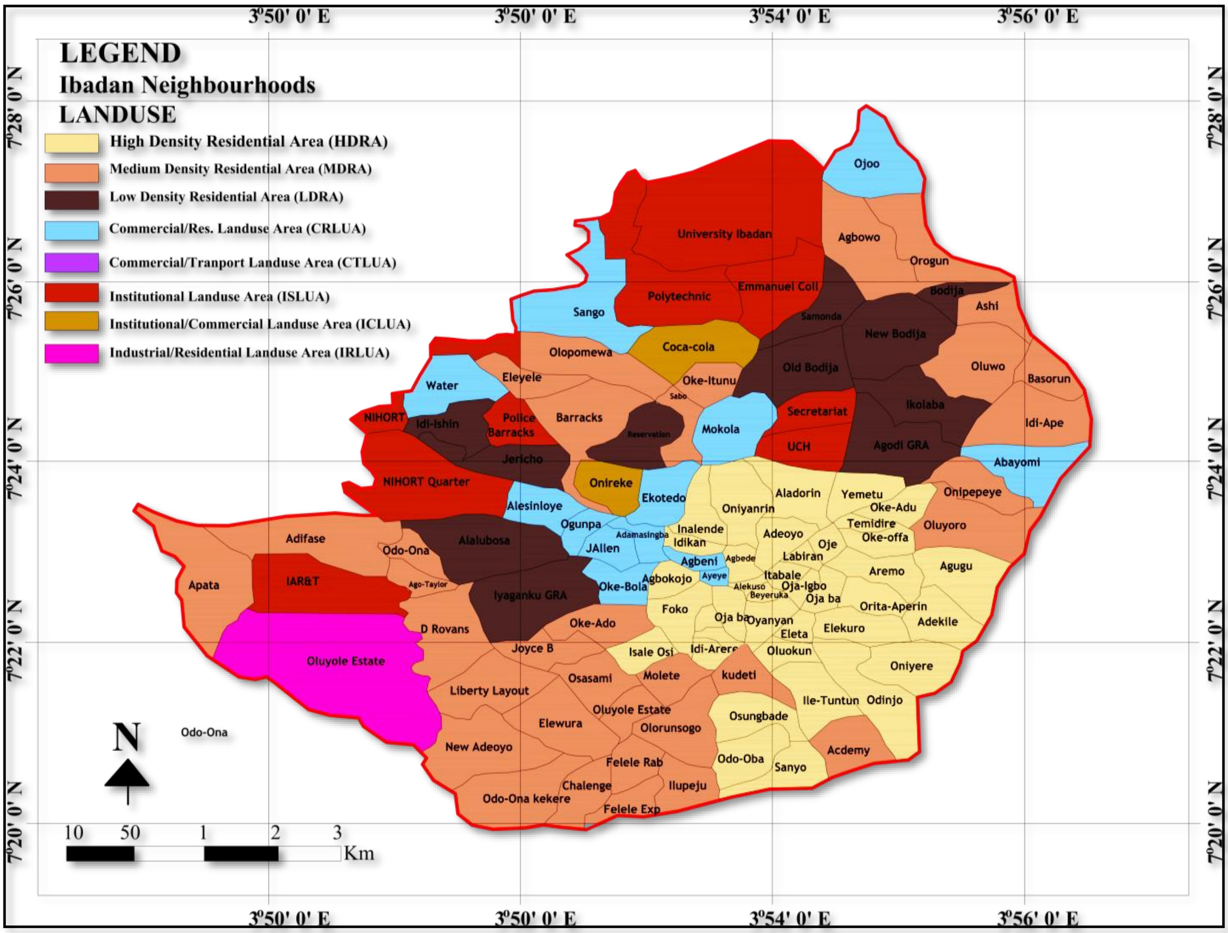

Figure 1: Neighbourhoods within the Five Urban Local Government Areas in Ibadan Metropolis

Source: Oyo State Ministry of Land, Housing and Urban Development (2021)

Two distinct measures were constructed rather than one, specifically to prevent the part-whole overlap. The Composite Climate Resilience Index (CRI) integrates four pillars; Structural Adaptations, Cognitive Preparedness, Communal Adaptations, and Integrated Socio-economics (income, education, tenure security) and is used only for descriptive profiling of household vulnerability, not as a regression outcome. The four pillars were selected because they correspond to the physical, behavioral, social, and structural dimensions of adaptive capacity commonly identified in the climate vulnerability literature (Adger, 2003; IPCC, 2014), covering both what a household has done (structural and communal adaptation) and what enables it to act (preparedness and socioeconomic position).

The Physical-Behavioral Climate Resilience Index (CRI_PB), by contrast, is built strictly from the first three pillars (Structural Adaptations, Cognitive Preparedness, and Communal Adaptations) and deliberately excludes income, education, and tenure security. This exclusion is the core methodological safeguard of the study, because income, education, and tenure security are also used as independent predictors in the regression model, including them in the dependent variable would inflate R^2 through mathematical overlap rather than genuine explanatory power. CRI_PB and the regression predictors therefore share no common terms, which resolves the part-whole circularity identified in review. All results reported as "non-circular" in this manuscript refer specifically to this separation.

Binary indicators (presence of a raised floor level, private drainage, an emergency plan) were coded 1 for yes and 0 for no, consistent with standard practice for asset- and behavior-based indices. Continuous and ordinal variables were transformed using min-max linear normalization:

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$$X^*_i = (X_i - Xmin) / (Xmax - Xmin)$$

where X^*_i is the normalized score of variable j for household i, X_i is the raw value, and Xmin and Xmax are the empirical bounds across the dataset. This method was chosen over z-score standardization because it bounds all indicators to a common [0,1] range, which is appropriate for composite indices that combine binary and ordinal items and preserves interpretability of the final index as a proportion of maximum possible adaptation.

Equal weighting was applied across pillars in the baseline model rather than empirically derived weights, following standard IPCC vulnerability index protocols (IPCC, 2014), on the grounds that no pillar has an established theoretical priority over the others in the adaptation literature. To test whether this assumption affects the findings, an alternative PCA-derived weighting scheme was also applied (see Sensitivity Analysis in Table 7). Internal consistency and construct reliability were assessed using Cronbach's Alpha, yielding α=0.814 across all 14 physical and behavioral adaptation items, indicating strong scale reliability.

Resilience classifications ("High Resilience," "Vulnerable," "Acute Vulnerability," shown in Table 1) were assigned using the empirical cluster boundaries produced by the K-Means analysis described below, rather than fixed a priori thresholds. This avoids the additional subjectivity of arbitrary cut points and ties the classification directly to the data-driven grouping.

To identify distinct socio-spatial vulnerability typologies, a K-Means clustering algorithm was applied. The optimal number of clusters was determined before final model execution using two diagnostic procedures. The elbow method, plotting the within-cluster sum of squares (WCSS) against k=1 to k=10, identified a clear inflection point at k=3. Silhouette analysis testing cluster separation quality across k=2 through k=5, found that k=3 produced the highest average silhouette width (s=0.62).

Cluster validity was then confirmed using three recognized diagnostic metrics, rather than F-statistics alone: the average silhouette coefficient (s), which measures cohesion and separation on a scale of −1 to +1; the Calinski-Harabasz index (CH), which evaluates the ratio of between-cluster to within-cluster dispersion, with higher values indicating better separation; and the Davies-Bouldin index (DB), which evaluates similarity between each cluster and its most similar counterpart, with lower values indicating better separation. F-statistics for each pillar (reported in Table 2) are presented only as a supplementary description of between-cluster differences on each variable, not as evidence of cluster validity in themselves.

RESULTS AND DISCUSSION

Household Climate Resilience Component Analysis across Density Clusters

Table 1 presents the component analysis across the four structural pillars, showing both the non-circular dependent score (CRI_PB) and composite profile scores across the low-density (n=65), medium-density (n=678), and high-density (n=57) residential clusters.

Table 1 and 2 reveals that the metrics within Pillar 1 show a stark physical divide across urban spaces. Cluster 1 (low density) achieves a perfect score of 1.00, meaning these households deploy a full range of physical defenses, including custom-plastered private drainage networks and alternative energy buffers. In contrast, physical protection falls to 0.17 in Cluster 2 (medium density), where households lack capital for structural upgrades and rely solely on raising floor levels. Cluster 3 (high density) registers 0.33, limited mainly to repairing mud or brick walls while lacking private drainage lines.

Pillar 2 measures proactive planning and hazard mitigation, and it points to a broader institutional gap. Cluster 1 registers 0.40; while affluent households hold formal flood insurance, practical survival measures like emergency-kit preparation are neglected. This metric falls to 0.00 in both Cluster 2 and Cluster 3, indicating an absence of formal emergency planning.

Pillar 3 tracks adaptation in shared community spaces. Cluster 1 scores 0.67, driven by tree planting and private gutter maintenance. Cluster 2 reaches 0.33 through social capital mobilization, relying on mandatory

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participation in sanitation days. Communal capacity falls to 0.00 in Cluster 3, where extreme density, limited space, and poverty constrain community-led sanitation management.

Socio-spatial profiling groups the study area into three typologies. The low-density cluster is labeled Privatized Self-Resilience (CRI_PB=0.690): wealthier households draw on financial capital to purchase private structural safety, a pattern consistent with documented gaps in municipal service delivery (Landman, 2004). The medium-density cluster is labeled Asset-Constrained Coping (CRI_PB=0.167) and accounts for 84.8% of households; residents appear to substitute financial capital with social capital through community development associations, or CDAs (Adger, 2003; Fateye et al., 2021; Abati, 2025; Nwokoma & Iwegbu, 2025). The high-density cluster is labeled the "Traditional Land Rights Trap" (CRI_PB=0.110): residents in ancestral compounds hold comparatively secure land rights (TEN=0.85) but report low liquid financial capital (INC=0.15), a combination associated with limited physical adaptation in this sample.

Table 1: Household Climate Resilience Index Component Matrix across Residential Density Clusters

Core Index Components	**Type**	**Low Density (n=65)**	**Medium Density (n=678)**	**High Density (n=57)**
Pillar 1: Structural Adaptations				
Raised floor level / doorstep	Binary	1	1	1
Reinforced the roof	Binary	1	0	0
Built/plastered private drainage	Binary	1	0	0
Alternative energy system	Binary	1	0	0
Rainwater harvesting systems	Binary	1	0	0
Strengthened structural walls/roof	Binary	1	0	1
Pillar 1 Sub-Total Mean	Index	1	0.17	0.33
Pillar 2: Cognitive Preparedness				
Developed a family emergency plan	Binary	1	0	0
Prepared an emergency kit	Binary	0	0	0
Stores emergency supplies	Binary	0	0	0
Family evacuation meeting point	Binary	0	0	0
Formal property/flood insurance	Binary	1	0	0
Pillar 2 Sub-Total Mean	Index	0.4	0	0
Pillar 3: Communal & Nature-Based				
Participates in local clean-up	Binary	0	1	0
Planting of trees or garden	Binary	1	0	0
Clears gutters personally/hired	Binary	1	0	0
Pillar 3 Sub-Total Mean	Index	0.67	0.33	0
DEPENDENT ADAPTATION INDEX (CRI_PB)	(P1+P2+P3)/3	0.69	0.167	0.11
Pillar 4: Integrated Socio-Demographics (descriptive only)				
Income (INC)	Ordinal	1.00 (High)	0.50 (Middle)	0.15 (Informal)
Education (EDU)	Ordinal	1.00 (Tertiary)	0.65 (Secondary)	0.30 (Primary/None)
Tenure Security (TEN)	Ordinal	1.00 (Deed)	0.40 (Rent)	0.85 (Traditional)

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Pillar 4 Sub-Total Mean	Index	1	0.52	0.43
OVERALL COMPOSITE PROFILE (descriptive only)	(P1+P2+P3+P4)/4	0.77	0.26	0.19
Resilience Classification	Descriptor	High Resilience	Vulnerable	Acute Vulnerability

Source: Author's fieldwork (2026).

K-Means Cluster Validation and Mathematical Optimization

The three-cluster configuration was assessed using the diagnostic metrics in Table 2.

Table 2: K-Means Clustering Matrix and Diagnostic Validation Metrics

Dimension	Cluster 1: High-Asset Self-Resilience (n=65)	Cluster 2: Asset-Constrained Coping (n=678)	Cluster 3: Chronic Structural Paralysis (n=57)	F-Stat	Sig.
P1: Structural Adaptations	1	0.17	0.33	142.61	0.000***
P2: Cognitive Preparedness	0.4	0	0	89.45	0.000***
P3: Communal Adaptations	0.67	0.33	0	118.04	0.000***
Physical Dependent Score (CRI_PB)	0.69	0.167	0.11	164.22	0.000***
P4: Integrated Socio-Demographics	1	0.52	0.43	205.17	0.000***
Proportion of Total Sample	8.12%	84.75%	7.13%	—	—

Table 3 Cluster Validation Diagnostic

Average Silhouette Width (s)	0.62 — moderate-to-strong cluster separation
Calinski-Harabasz Index (CH)	342.15 — high ratio of between-to-within cluster variance
Davies-Bouldin Index (DB)	0.74 — relatively low inter-cluster similarity

*Note: *** $p < 0.001$. F-statistics describe between-cluster differences on each pillar; they are reported as supplementary description, not as the basis for cluster validity, which rests on the silhouette, Calinski-Harabasz, and Davies-Bouldin measures.* ***Source: Author's Field Survey Analysis (2026).***

Table 3 shows The Calinski-Harabasz index (342.15) and Davies-Bouldin index (0.74), together with the silhouette width of 0.62, indicate that the k=3 solution achieves reasonable statistical separation without evident over-partitioning. Cluster stability was not additionally tested through bootstrap re-sampling in this study; this is noted as a limitation in the Discussion.

Regression Analysis: Predictors of Physical Climate Adaptation

To evaluate statistical predictors of physical climate adaptation, an Ordinary Least Squares (OLS) regression model was specified. As established above, the outcome variable, the Physical-Behavioral Adaptation Index (CRI_PB) was constructed to exclude the socioeconomic variables entered as predictors, so that no term appears on both sides of the model. CRI_PB served as the continuous dependent variable (Y), modeled against four independent predictors: Monthly Household Income (X_1), Educational Attainment (X_2), Land Tenure Security Status (X_3), and Structural Housing Quality (X_4).(See Table 4)

Table 4: Regression Model Summary

Model	R	R^2	Adjusted R^2	Std. Error	Durbin-Watson
1	0.724	0.524	0.522	0.2814	1.892

Predictors: (Constant), X_1 Monthly Household Income, X_2 Educational Attainment, X_3 Land Tenure Security Status, X_4 Structural Housing Quality. Dependent Variable: CRI_PB, constructed independently of the predictor set. Source: Author's Field ***Survey Data (2026).***

Table 5: ANOVA Test for Model Utility

Source	SS	Df	MS	F	Sig.	Verdict
Regression	69.18	4	17.295	218.42	.000	Significant
Residual	62.95	795	0.0792	—	—	—
Total	132.13	799	—	—	—	—

Source: Author's Field Survey Data (2026).

The model accounts for 52.4% of the variance in household physical climate adaptation (R^2=0.524, Adjusted R^2=0.522, F=218.42, p<0.001). Because the outcome variable does not share terms with the predictors, this figure reflects genuine associative strength rather than an artifact of overlapping construction; it should still be interpreted as the proportion of variance in physical adaptation associated with these four factors, not as evidence that they cause it (See Table 4& 5).

Table 6: Coefficients Table for Predictor Variables

Predictor	B	SE	β	t	Sig.	Tolerance	VIF
(Constant)	0.082	0.024	—	3.417	.001	—	—
X_1 Monthly Income	0.245	0.031	0.281	7.903	.000	0.712	1.404
X_2 Educational Attainment	0.108	0.029	0.115	3.724	.000	0.835	1.198
X_3 Land Tenure Security	0.312	0.035	0.328	8.914	.000	0.748	1.337
X_4 Structural Housing Quality	0.224	0.038	0.245	5.895	.000	0.782	1.279

Dependent Variable: CRI_PB. ***Source: Field Survey (2026).***

$$Y(CRI\_PB) = 0.082 + 0.245(X_1) + 0.108(X_2) + 0.312(X_3) + 0.224(X_4) + \varepsilon$$

Variance Inflation Factors (all below 1.5) indicate no problematic multicollinearity among the four predictors.

Table 6 shows that Land Tenure Security (X_3, β=0.328, p<0.001) is the strongest association with physical adaptation. Secure tenure is associated with the long-term institutional stability that plausibly enables investment in structural defenses such as retaining walls and drainage channels (De Soto, 2000; van Gelder, 2009; van Gelder & Luciano, 2015), though the cross-sectional design cannot confirm this direction of effect. Monthly Income (X_1, β=0.281, p<0.001) shows a strong positive association with physical adaptation, consistent with liquid financial capital functioning as a material buffer (Moser, 1998; Odemerho, 2015). Structural Housing Quality (X_4, β=0.245, p<0.001) also shows a significant positive association, as sound initial housing construction may reduce the marginal cost of further adaptation. Educational Attainment (X_2, β=0.115, p<0.001) shows the weakest association among the four predictors, suggesting a possible "capacity–action gap" (Schubert *et al.*, 2025) in which awareness does not translate into action when financial or spatial constraints are binding though again, this interpretation is associative rather than causal.

Sensitivity Analysis and Model Robustness

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To test whether the findings are stable under alternative index construction choices, a sensitivity analysis was conducted. Table 7 shows that the dependent variable was recalculated using a Principal Component Analysis (PCA) factor-weighting scheme, in which factor loadings from the first principal component served as pillar weights in place of equal weighting.

Table 7: Sensitivity Analysis Comparing Equal-Weighted and PCA-Weighted Regression Models

Predictor	Equal-Weighted β	PCA-Weighted β	Rank Shift
X_3 Land Tenure Security	0.328***	0.341***	Unchanged (Rank 1)
X_1 Monthly Household Income	0.281***	0.274***	Unchanged (Rank 2)
X_4 Structural Housing Quality	0.245***	0.238***	Unchanged (Rank 3)
X_2 Educational Attainment	0.115***	0.122***	Unchanged (Rank 4)
Model R^2	0.524	0.538	+0.014 variance

*Note: *** p < 0.001. Source: Author's Analysis (2026).*

Spearman's rank correlation between the equal-weighted CRI_PB and the PCA-weighted index scores yielded $\rho=0.942$ ($p<0.001$). Table 6 shows that the predictor ranking tenure, then income, then housing quality, then education remains unchanged across the two weighting schemes, which supports the robustness of the equal-weighting assumption used in the baseline model.

DISCUSSION OF FINDINGS

The results describe a socio-spatially stratified pattern of climate resilience across metropolitan Ibadan. Low-density areas show high physical adaptation (CRI_PB=0.690), while medium-density (CRI_PB=0.167) and high-density (CRI_PB=0.110) zones show substantial adaptation deficits. In this sample, wealthier households privatize structural safety, middle-income residents draw on social capital networks, and traditional inner-core households combine secure land tenure with limited financial capacity, a pattern the study terms structural paralysis.

The non-circular regression model ($R^2=0.524$, $p<0.001$) identifies land tenure security as the predictor most strongly associated with physical adaptation ($\beta=0.328$), while educational attainment shows the weakest association ($\beta=0.115$). These findings should be read as associations, not as causal claims: the cross-sectional design captures a single point in time, so it cannot establish that tenure security or income cause higher adaptation, only that they are statistically associated with it, net of the other predictors in the model. Longitudinal or quasi-experimental designs would be needed to test causal pathways.

With that caveat, the pattern of associations suggests that climate vulnerability in Ibadan is closely tied to material assets and housing structure, alongside — rather than instead of — awareness and knowledge. This points toward municipal planning that pairs sensitization efforts with targeted, pro-poor infrastructure investment, rather than relying on awareness campaigns alone.

CONCLUSION AND RECOMMENDATIONS

This study demonstrates that household climate resilience within the Ibadan metropolis is a highly unequal, stratified process bounded by the intersection of financial liquidity and spatial geometry. The systemic withdrawal of municipal infrastructure spending has created an urban setting where environmental protection is effectively treated as a private commodity. This dynamic leaves middle-income households dependent on fragile networks of social capital, while trapping traditional inner-core populations within a severe structural paralysis.

Based on these empirical findings, the following policy interventions are recommended:

1. **Establish Capital Liquidity Channels for Core Property Upgrades:** Municipal planning authorities should introduce targeted micro-credit facilities and structural modification grants specifically designed for ancestral family compounds within the traditional high-density cores. This will help residents break out of the Traditional Land Rights Trap and convert secure tenure into physical flood defenses.

2. **Transition from Private Insulation to Block-Level Public Drainage:** Environmental protection agencies must move away from individualized, property-by-property planning models. Instead, municipal capital funding must be prioritized for the construction of continuous, block-level public storm drainage channels that match the complex layout of high-density areas.

3. **Institutionalize Community-Led Maintenance Frameworks:** Local government councils should officially recognize and financially support informal neighborhood associations, particularly within medium-density transitional zones. Providing these groups with standardized toolkits, technical training, and direct municipal matching funds will significantly increase the reliability and reach of collective community maintenance efforts.

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