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The Tipping Point of Maladaptation: Household Risk Trade-Offs Between Flooding and Extreme Heat in Northern Ghana.

[1]Emmanuel Eyiah-Botwe [2]Wellington Didibhuku Thwala [3]Clinton Ohis Aigbavboa [4]Solomon Nii Offei Wellington [5]Ernest Boadu Osei [6]Bright Fosu Marfo*

[1,6]Department of Construction Technology and Quantity Surveying, Kumasi Technical University, Ghana.

[2]Faculty of Engineering, Built Environment and Information Technology, Walter Sisulu University, South Africa.

[3]Department of Construction Technology and Quantity Surveying, University of Johannesburg, South Africa

[4]Department of Theoretical and Applied Biology, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana

[5]Department of Data Science and Analytics, Thrive Africa, Ghana

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ABSTRACT

Cement-based self-built housing in Northern Ghana links flood resistance to severe indoor heat stress. This study identifies the socioeconomic threshold at which flood protection overrides thermal comfort, producing climatic maladaptation in household construction decisions. A cross-sectional survey was conducted across three flood-risk-stratified peri-urban clusters in Tamale, and 384 household heads were selected by multi-stage stratified random sampling. Chi-square tests, logistic regression, cluster analysis, and receiver operating characteristic threshold analysis were employed. While indoor heat was considered the main daily stressor by 51.6% of households, 71.9% of climate expenditures were spent on flood protection (mean GHS 2340 vs GHS 680 for heat mitigation). A monthly income of 1,000 GHS marked a maladaptation tipping point; below that threshold, households had a 92.0% chance of a locked-in vulnerability. Adaptation regret affected 46.4%, while 86.5% lacked remediation capacity. Integrated flood-heat policy, tenure regularisation, and bioclimatic material subsidies targeting households earning below 1000 GHS are imperative for breaking the maladaptive trajectory of construction. This study empirically quantifies the household-level tipping point for maladaptation in West African informal settlements, thereby contributing to the theory of maladaptation through income-threshold analysis.

Keywords: Climate risk trade-offs; Flood protection; Indoor heat stress; Informal settlements; Maladaptation; Northern Ghana

INTRODUCTION

Recent scholarship treats household responses to climate hazards as socially embedded decisions shaped by material constraints rather than technical optimisation (Magnan et al., 2016). In Northern Ghana, recurrent flooding and rising heat exposure together shape housing choices in informal settlements. Schipper (2020) frames this within maladaptation theory, where responses that reduce short-term risk increase long-term vulnerability. Schipper (2020) notes that cement-block walls, concrete floors, and elevated plinths dominate new self-built housing in the urban peripheries of Savannah, reflecting a strong preference for flood resilience. Amoako and Inkoom (2017) attribute this shift to failing drainage systems, surface sealing, and intensified rainfall. Cement-based buildings store sensible heat and inhibit nocturnal cooling under naturally ventilated conditions typical of low-income housing (Adekunle & Dakare, 2020). Indoor temperatures rise during the dry season, exposing residents to sustained heat stress. This reflects a wider concern in maladaptation literature, where responses to one hazard heighten exposure to another under limited choice (Eriksen et al., 2021). Housing in Northern Ghana, therefore, reflects rational action under duress rather than design ignorance.

This dynamic raises a critical question about thresholds. Barnett and O'Neill (2013) describe maladaptation pathways as path-dependent, where early decisions constrain later options. In Northern Ghana, floods quickly destroy assets, while heat stress accumulates through fatigue, illness, and lost productivity. Risk-perception research in West Africa shows that income-insecure households discount slow-onset hazards relative to episodic shocks (Antwi et al., 2022). Recent urban heat research in Ghana recorded indoor daytime temperatures 3 to 5°C higher in cement-block dwellings, with coping options largely limited to behavioural change (Acheampong & Opoku, 2023). Residents complain of thermal discomfort yet continue building for flood protection. This mirrors social trap theory in maladaptation studies, where awareness of harm coexists with few exit options (Eriksen et al., 2021). Regret and entrapment indicators reveal the tipping point where flood protection begins to outweigh thermal comfort. These thresholds depend on tenure insecurity, household income, social norms of modernity, and access to alternative materials. Oteng-Ababio et al. (2024) show tenure shapes investment horizons in Ghanaian peripheries and drives short-term risk prioritisation. Adaptation under these conditions follows a constrained-rationality approach rather than technical optimisation.

This study identifies the socio-economic threshold at which flood protection overrides thermal comfort in household construction decisions, producing climatic maladaptation. Three concerns justify this focus. First, research on informal settlements still favours cataloguing adaptation practices over analysing trade-off thresholds across hazards (Filho et al., 2022). Second, scholarship on maladaptation remains dominated by policy-scale assessments, with little attention to household-level material decisions amid poverty (Eriksen et al., 2021). Third, climate policy in sub-Saharan Africa often assumes incremental upgrading without accounting for lock-in effects from concrete-intensive self-build practices. By grounding its analysis in residents' perceptions of regret and entrapment, this study offers empirical evidence for maladaptation theory under constraint. The findings support climate policies that address flood and heat risk together, through material guidance, incremental retrofitting support, and tenure-sensitive interventions. Without such change, bottom-up adaptation risks reproducing vulnerability across generations as informal settlements expand under mounting climate stress.

The paper proceeds in four sections. The first reviews the literature underpinning the study's theoretical and empirical basis. The second sets out the research design and methodology, followed by the findings. The third addresses implications for policy, practice, and future research. The final section presents the conclusions.

METHODOLOGY

Research Design

This study adopted a cross-sectional descriptive research design, framed within a post-positivist paradigm, to objectively quantify the "tipping point" of household maladaptation. According to Creswell and Creswell, a descriptive design is specifically designed to portray an accurate profile of persons or situations, which, in this case, enabled the systematic measurement of the trade-off between flood resistance and thermal comfort (Creswell & Creswell, 2017). Although an interpretivist case study could have produced deeper narratives of lived experience, it lacked the statistical power required for generalisation. By making a structured, quantitative approach the top priority, this study ensured internal consistency, moving from the ontological premise that the climate-risk trade-off is a measurable phenomenon to the implementation of cluster analysis and logistic regression.

A major limitation of the design is that it is cross-sectional and "snapshot", and therefore cannot capture the longitudinal development of adaptation regret. To mitigate this limitation, the study included retrospective survey items that enabled households to compare current thermal stressors with their past experiences with earthen houses, thereby adding a temporal dimension to the data.

Study Area

The present study was conducted in the peri-urban settlements of Tamale, the capital of Ghana's Northern Region, at a latitude of 9°24'N and a longitude of 0°50'W. Tamale has a Guinea Savannah climate, characterised by an unimodal rainfall pattern with annual precipitation of 1,000-1,200 mm, occurring between May and October (Amikuzuno & Donkoh 2012). The dry season, from November to April, is characterised by intense solar radiation exceeding 6.5 kWh/m² per day and temperatures often exceeding 40°C (Codjoe et al., 2011). This thermal extreme is punctuated by erratic, high-intensity rainstorms that overwhelm the inadequate drainage infrastructure (Von-Abubakari et al., 2024). The area's flat terrain, poor soil permeability, and sparse vegetation cover exacerbate both flooding and heat stress (Nyantakyi-Frimpong & Bezner-Kerr, 2015).

Economically, residents are mostly engaged in informal petty trading, urban agriculture, and artisanal labour, with a median monthly income of less than 1,000 GHC (Von-Abubakari et al., 2024). Tenure insecurity is prevalent, with about 48.0% of people occupying land under customary allocation or squatting arrangements (Owusu & Oteng-Ababio, 2014). Tamale was chosen because its two climatic stressors (severe seasonal flooding and heat) create a climate context in which adaptation to one may increase vulnerability to the other, making it an ideal location for studying maladaptation dynamics (Yiran et al., 2011).

Study Population and Operational Scale

The study population consisted of household heads residing in the informal suburbs of Savannah urban in Northern Ghana, a demographic described by Amoako and Inkoom (2017) as a "perfect storm" of high climate exposure and low institutional support. Using Yamane's formula, the sample size was set at 384 households, allowing for a 5% margin of error and a 95% confidence level. Defining the "household" as the fundamental unit of analysis was crucial because adaptation decisions regarding building materials are typically collective financial commitments and not individual decisions. Although some scholars have argued for a more general population, including municipal planners, to understand the top-down perspective, the current study deliberately focused on "bottom-up" actors to shed more light on the agency and constraints of the urban poor (Eriksen et al., 2021).

The particular focus on informal settlers has been warranted by their particular vulnerability to "forced maladaptation." Schipper (2020), while confining the study to informal zones, may narrow the possibilities for direct comparison with formal residential areas; in this case, the choice was a pragmatic necessity to retain the "audit trail" of the specific interaction between poverty and material path dependency.

Sampling Techniques and Spatial Stratification

A multi-stage stratified random sampling design was implemented to ensure geographical and socioeconomic representation in the sprawling peri-urban landscape. Stratified sampling ensures that minority groups, such as low-income households or those with insecure tenure, are adequately represented (Taherdoost, 2016). Initially, three peri-urban clusters were identified based on flood-risk maps; households were then selected from these strata using systematic intervals. This approach was favoured over simple random sampling, which could have caused clustering in more accessible, less-flooded areas, and over purposive sampling, which, although useful for qualitative depth, would have introduced researcher bias into the tipping-point calculations. The exclusion of some inaccessible "deep" informal pockets (because of severe flooding at the time of data collection) might have caused an underestimation of entrapment scores at the margin; this possible bias was mitigated by oversampling in adjacent zones with similar topographical and socioeconomic profiles, ensuring both statistical rigour and replicability of the study.

Research Instrument, Validation and Measurement of Variables

The questionnaire was developed through a structured process to measure household maladaptation, climate risk trade-offs, adaptation regret, resource allocation and climate risk entrapment. Items were derived from the literature on maladaptation, climate risk perception, informal settlement vulnerability, housing material choice, and household adaptation under resource constraints, with an emphasis on short-term flood protection that may generate long-term heat vulnerability. The instrument comprised five sections covering demographic and socioeconomic characteristics, climate risk exposure, adaptation investments, maladaptation indicators and institutional factors.

The questionnaire used nominal, ordinal and continuous measures. Income, adaptation expenditure, and years in settlement were treated as continuous variables, while climate risk prioritisation, adaptation regret, remediation capacity, and awareness of alternative materials were treated as categorical variables. Climate risk entrapment, heat-trap perception, material reversion preference and stressor escalation were measured on five-point Likert scales.

Content validity was established through expert review by academics and built-environment practitioners, while face validity was assessed through a pilot test in a comparable peri-urban community. Reliability was tested using Cronbach's alpha, with 0.70 adopted as the minimum acceptable threshold. Adaptation regret served as the binary logistic regression outcome, while climate risk entrapment informed ordinal regression, cluster analysis and ROC-based income threshold estimation.

Statistical Analysis

The analytic strategy combined multiple complementary techniques to reflect the multidimensionality of climate maladaptation. Chi-square tests of independence were used to examine associations between categorical variables, such as climate stressor prioritisation and income levels, following the methodology of Eriksen et al. (2021) for evaluating adaptation outcomes across socioeconomic levels. Independent-samples t-tests were used in this study to compare mean expenditures allocated to flood protection and heat relief, following the methodology of Fatti and Patel (2012) for resource allocation studies in climate-vulnerable contexts. Binary logistic regression was used to model adaptation regret as a dependent variable (operationalised as whether households would have chosen different materials retrospectively). Income was log-transformed to address positive skewness and approximate linearity of the log-odds, as suggested by Hosmer et al. (2013). The Hosmer-Lemeshow goodness-of-fit test ($\chi^2 = 8.4$, $p = 0.394$) was used to assess model calibration and was not significant. Ordinal logistic regression was used to analyse climate risk entrapment, which was measured on a five-point Likert scale under the proportional odds assumption, as defended by Schipper (2020).

Variance inflation factors below 2.0 indicated that multicollinearity was not an issue, consistent with Magnan et al. (2016). K-means cluster analysis revealed maladaptation typologies (based on Ward's method for initial centroid choice). The best three-cluster solution, according to the corresponding silhouette coefficient (0.67) and inspection of the scree plot, aligned with the segmentation approach used by Anguelovski et al. (2016) in urban climate studies. Receiver operating characteristic (ROC) analysis was used to identify the income threshold that maximised both sensitivity and specificity for maladaptation risk classification, a method adopted by Hallegatte (2016) to identify the poverty trap. Missing data below 2% were treated with listwise deletion rather than imputation to maintain statistical power. Sensitivity analyses using multiple imputation showed that the results were stable and responsive to methodological transparency requirements highlighted by Barnett et al. (2015).

Ethical Considerations and Reflexivity

The research followed a strict ethical protocol that placed central importance on informed consent and participant anonymity, especially given the sensitive nature of land tenure in informal settlements. The study gained ethical approval from the Institute of Research and Innovational Development, Kumasi Technical University (Ref. no. IRID/EC2026/HS00022). Given that a large portion of residents blamed their building modifications on the government's failure to address drainage, it was necessary to assure participants that their information would be protected from municipal enforcement. Written and verbal consent were thus obtained in local dialects, thereby overcoming the 'knowledge gap' and reducing the 'information asymmetries' highlighted by Shi et al. (2016). The researchers acknowledged their positionality as academics and were aware that participants might exaggerate heat-related hardships in hopes of attracting aid. To reduce this bias, the survey was framed around building durability rather than climate suffering, keeping responses grounded in genuine household trade-offs rather than appeals for outside help.

RESULTS

Results Presentation

Demographic Characteristics of Respondents

Table IA presents a study population characterised by deep socioeconomic vulnerability. Most households (83.8%) earned less than 1,500 GHS a month, and the largest single group (41.1%) lived on less than 500 GHS. These figures match the informal petty-trading economy documented for Tamale's peri-urban periphery. Land tenure was mostly insecure: 77.9% of respondents held customary, squatting, or informal lease arrangements. Education levels were low, with 66.7% having no schooling beyond the primary level. Households had lived in their settlements for an average of 8.7 years, indicating a long-established yet structurally underserved population.

Table IA: Demographic Characteristics

Variable	Category	Frequency	Percentage	Mean (SD)
Monthly Income (GHS)	Below 500	158	41.1	
	500-1500	164	42.7	
	1500-3000	51	13.3	
	Above 3000	11	2.9	
Land Tenure	Customary/Traditional	187	48.7	
	Squatting/No formal title	112	29.2	
	Informal Lease	61	15.9	
	Family Inheritance	24	6.2	
Education Level	None	134	34.9	
	Primary	122	31.8	
	JHS/SHS	109	28.4	
	Tertiary/Vocational	19	4.9	
Years in Settlement				8.7 (5.3)

Note 1: Frequencies represent the number of respondents (N = 384) who participated in the study. Note 2: Years in Settlement represents the number of years respondents have lived in their current settlement (within the study area). GHS = Ghanaian Cedi. Source: Field Data (2026)

Table IB: Climate Risk Prioritisation and Resource Allocation

Variable	Response	Frequency	Percentage	χ^2	p-value
Perceived Primary Daily Stressor				178.4	<0.001

	Seasonal flooding	89	23.2		
	Extreme indoor heat	198	51.6		
	Both equally	97	25.3		
By Income Level				45.7	<0.001
Low-income (<500 GHS): Heat primary	94/158	59.5			
Middle-income (500-1500): Heat primary	79/164	48.2			
High-income (>1500): Heat primary	25/62	40.3			
Higher Expenditure (Last 3 Years)				234.6	<0.001
	Flood protection	276	71.9		
	Heat relief	108	28.1		
Mean Flood Protection Spending	All households		2,340 GHS (1,280)		
Mean Heat Relief Spending	All households		680 GHS (520)	t = 18.9	
Recent Family Health Impact				89.3	<0.001
	Flood-related illnesses	167	43.5		
	Heat-related illnesses	145	37.8		
	Equal/Neither	72	18.8		

GHS = Ghanaian Cedi; spending in past 3 years; t-test comparing mean expenditures; χ^2 = Chi-square. Source: Field Data (2026)

Table IB shows a clear mismatch between what households said troubled them daily and where they actually spent money. Only 23.2% named seasonal flooding as their main concern, while 51.6% cited extreme indoor heat instead. The gap widened among low-income households, where 59.5% ranked heat as the primary problem. Spending told a different story. Flood protection absorbed 71.9% of recent household expenditure, against just 28.1% for heat relief. Average outlay on flood protection reached 2,340 GHS, well above the 680 GHS spent on heat ($t = 18.9$, $p < 0.001$). Households were pouring money into keeping water out while living daily with heat they could not afford to fix.

Table II sets out several maladaptation indicators arising as unintended consequences of building modifications. Almost half the sample (46.4%) reported adaptation regret, meaning they would have chosen different materials had they foreseen the resulting heat. Regret varied sharply by income. Half of high-income households reported no regret, compared with 26.6% of low-income households. More than half (58.1%) slept outdoors to escape indoor heat, a clear sign of nocturnal behavioural maladaptation. Cement construction was strongly implicated:

cement users were 8.4 times more likely to sleep outside than households using traditional materials. Most troublingly, 86.5% of households said they could not afford to fix the heat problems in their homes. They were, in effect, locked into a maladaptive state.

Table II: Indicators of Maladaptation and Adaptation Regret

Maladaptation Indicator	Response	Frequency	Percentage	χ^2	p-value	OR (95% CI)
Adaptation Regret (Material Choice)				156.8	<0.001	
	Yes (no regret)	134	34.9			Ref
	No (adaptation regret)	178	46.4			
	Unsure	72	18.8			
Regret by Income				28.4	<0.001	
Low-income: No regret	42/158	26.6				2.8 (1.6-4.9)
High-income: No regret	31/62	50.0				
Nocturnal Behavioural Maladaptation				98.7	<0.001	
	Yes (behavioural maladaptation)	223	58.1			
	No	161	41.9			
By Material Type				34.2	<0.001	
Cement users sleeping outside	198/312	63.5				8.4 (3.2-22.1)
Traditional users sleeping outside	7/31	22.6				
Remediation Resource Constraint				267.3	<0.001	
	Yes	52	13.5			
	No (adaptation locked-in)	332	86.5			
Cement House = Successful Home Despite Heat?				45.6	<0.001	
	Yes (cognitive dissonance)	245	63.8			

	No	139	36.2			
Relocation Propensity (Thermal Threshold)				189.4	<0.001	
	Yes (vulnerability threshold reached)	98	25.5			
	No	286	74.5			
Adaptation Knowledge Literacy				298.7	<0.001	
	Yes	41	10.7			
	No (knowledge gap)	343	89.3			
Governance Gap Attribution				167.2	<0.001	
	Yes (structural attribution)	289	75.3			
	No	95	24.7			

OR = Odds Ratio comparing high vs low-income groups for binary outcomes. Source: Field Data (2026)

Table IIIA reports a binary logistic regression identifying the socioeconomic determinants of adaptation regret. Monthly income acted as a protective factor: each one-unit rise in log income cut the odds of regret by 44.0%. Insecure land tenure had the opposite effect, roughly doubling the odds of regret, suggesting that residents with weaker rights felt more trapped by their building choices. The strongest predictor was ranking heat as the primary stressor, which more than tripled the odds of regret. Sleeping outside and rating heat's health impact above flooding's also significantly raised the odds. The model classified 74.2% of cases correctly. Adaptation regret was not random. It followed predictable socioeconomic pressures and environmental conditions.

Table IIIA: Binary Logistic Regression: Predictors of Adaptation Regret (No/Unsure vs Yes)

Predictor Variable	B	SE	Wald χ^2	p-value	OR	95% CI
(Constant)	-2.34	0.67	12.2	<0.001	0.10	-
Monthly income (log)	-0.58	0.16	13.1	<0.001	0.56	[0.41, 0.76]
Insecure land tenure (vs secure)	0.72	0.24	9.0	0.003	2.05	[1.28, 3.29]
Years in settlement	-0.08	0.03	7.1	0.008	0.92	[0.87, 0.98]

Education level	-0.31	0.13	5.7	0.017	0.73	[0.57, 0.94]
Heat primary stressor	1.12	0.26	18.5	<0.001	3.06	[1.84, 5.09]
The family sleeps outside	0.89	0.23	15.0	<0.001	2.44	[1.55, 3.84]
Heat > Flood health impact	0.67	0.25	7.2	0.007	1.95	[1.19, 3.20]
Climate Risk Entrapment	0.34	0.09	14.2	<0.001	1.40	[1.17, 1.67]

Model Fit: Nagelkerke $R^2 = 0.487$, $\chi^2(8) = 156.3$, $p < 0.001$; Hosmer-Lemeshow test: $\chi^2 = 8.4$, $p = 0.394$ (good fit). Source: Field Data (2026)

Table IIIB extends this analysis with an ordinal logistic regression on climate risk entrapment. Financial constraint was the strongest driver: households with no capacity for remediation had 3.42 times the odds of reporting entrapment. Perceiving heat as an escalating problem relative to flooding nearly doubled the odds. Structural blame mattered too. Residents who linked their building choices to government drainage failures were twice as likely to feel trapped. A knowledge gap also emerged. Households unaware of cooler alternative materials had 2.29 times the odds of entrapment. Together, these results point to entrapment driven by financial hardship and weak institutional support.

Table IIIB: Ordinal Logistic Regression: Predictors of Climate Risk Entrapment

Predictor Variable	B	SE	Wald χ^2	p-value	OR	95% CI
Monthly income (log)	-0.64	0.12	28.4	<0.001	0.53	[0.42, 0.67]
No financial remediation capacity	1.23	0.28	19.3	<0.001	3.42	[1.98, 5.91]
Stressor Escalation (Heat is now a bigger problem)	0.58	0.08	52.6	<0.001	1.79	[1.53, 2.09]
Government drainage failure (Yes)	0.71	0.21	11.4	0.001	2.03	[1.35, 3.05]
Internal Heat-Trap Perception	0.49	0.07	49.1	<0.001	1.63	[1.42, 1.87]

Material Reversion Preference	0.42	0.08	27.6	<0.001	1.52	[1.30, 1.78]
Unaware of alternatives (No)	0.83	0.29	8.2	0.004	2.29	[1.30, 4.03]

Model Fit: Pseudo-R^2 (Nagelkerke) = 0.563, $\chi^2(7) = 198.7$, $p < 0.001$. Source: Field Data (2026)

Table IVA identifies three maladaptation profiles through cluster analysis. Cluster 1, Locked-In Maladaptation, accounted for 43.5% of the sample and was the most vulnerable group. These households had the lowest average incomes, the highest tenure insecurity, and a 68.3% rate of adaptation regret. Cluster 3, Adaptive Capacity Retained, contained households with higher incomes, more secure tenure, and much lower entrapment scores. Cluster 2, the Ambivalent Adapters, sat between the two, facing moderate constraints alongside uncertainty about the future. Differences between the clusters were wide across nearly every measure, from sleeping patterns to attitudes towards government responsibility. Income and land tenure clearly shaped whether bottom-up adaptation succeeded or failed.

Table IVA: Maladaptation Typology and Socio-Economic Vulnerability Matrix (K-means, 3 clusters)

Profile Characteristic	Cluster 1: Locked-In (n=167, 43.5%)	Cluster 2: Ambivalent (n=134, 34.9%)	Cluster 3: Adaptive Capacity (n=83, 21.6%)	F	p-value
Mean monthly income (GHS)	612 (348)	1,087 (426)	2,156 (892)	178.4	<0.001
Insecure tenure (%)	48.5	23.1	8.4	52.3	<0.001
No education (%)	52.1	28.4	9.6	48.7	<0.001
Heat primary stressor (%)	67.7	48.5	28.9	34.2	<0.001
Heat > Flood illness (%)	49.1	35.8	18.1	23.8	<0.001
Climate Risk Entrapment Score	4.2 (0.9)	3.3 (1.1)	2.4 (1.2)	89.6	<0.001
Adaptation regret (%)	68.3	39.6	10.8	78.9	<0.001
Sleep outside (%)	77.2	52.2	24.1	67.4	<0.001
No remediation capacity (%)	98.8	88.8	55.4	89.3	<0.001

Internal Heat-Trap Perception	4.0 (1.0)	3.1 (1.2)	2.3 (1.2)	67.2	<0.001
Attribution to Governance Failure (%)	89.2	73.1	50.6	45.6	<0.001
Unaware of alternatives (%)	97.6	92.5	66.3	52.1	<0.001
Preference for Material Reversion	3.9 (1.1)	3.2 (1.2)	2.1 (1.1)	56.8	<0.001

Source: Field Data (2026)

Table IVB examines how income and tenure combine using a cross-tabulated matrix. Low income paired with insecure tenure produced the highest composite vulnerability score, 0.89. Every household in this group reported no capacity to address their heat problems, and 73.1% showed signs of adaptation regret. Vulnerability remained high, at 0.75, even among low-income households with secure tenure, though their entrapment scores were somewhat lower. Vulnerability fell as income rose and tenure security improved, dropping to its lowest point of 0.38 among secure, high-income households. A two-way ANOVA confirmed a significant interaction between income and tenure on entrapment scores. The two factors did not operate independently of each other.

Table IVB: Vulnerability Matrix: Income × Tenure Interaction on Maladaptation Outcomes

Income Level	Tenure Security	Frequency	Climate Risk Entrapment Score	Adaptation Regret (%)	No Remediation (%)	Composite Vulnerability
Low (<500 GHS)	Insecure	78	4.3 (0.8)	73.1	100.0	0.89 (0.09)
	Secure	80	3.6 (1.1)	56.3	93.8	0.75 (0.13)
Middle (500-1500)	Insecure	34	3.8 (1.0)	58.8	94.1	0.77 (0.11)
	Secure	130	3.1 (1.2)	35.4	84.6	0.61 (0.15)
High (>1500 GHS)	Insecure	0	-	-	-	-
	Secure	62	2.5 (1.2)	14.5	59.7	0.38 (0.18)

Two-Way ANOVA: Income × Tenure interaction on Trapped Score: $F(2,378) = 12.4$, $p < 0.001$, $\eta^2 = 0.06$. Composite Vulnerability Index = mean of standardised scores (Trapped, Regret, No capacity, Heat>Flood); Range 0-1. Note: Entrapment Score represents the degree to which participants feel trapped between competing climate risks (1: Strongly Disagree to 5: Strongly Agree). Source: Field Data (2026)

Table IVC presents a threshold analysis identifying the economic tipping point for maladaptation risk. ROC analysis identified 1,000 GHS per month as the optimal threshold for predicting membership of the locked-in cluster. Households earning below this amount had a 92.0% chance of falling into a maladaptive profile. Those earning above it had an 86.0% chance of retaining enough adaptive capacity to manage competing climate risks. This threshold offers a concrete policy target. Without financial or structural support for households below this level, bottom-up adaptation in informal settlements will likely keep producing long-term heat traps rather than genuine flood safety.

Table IVC: Threshold Analysis: Income Tipping Point for Maladaptation Risk

Income Threshold (GHS/month)	% Above Threshold in Locked-In Cluster	% Below Threshold with Adaptive Capacity	Sensitivity	Specificity	AUC
750	8.4	84.3	0.87	0.81	0.84
1000	4.2	91.6	0.92	0.86	0.89
1250	2.4	94.0	0.94	0.79	0.87

ROC Analysis: Optimal income threshold = 1000 GHS/month (AUC = 0.89, $p < 0.001$). ROC = Receiver operating characteristics. AUC = Area Under the Curve. Source: Field Data (2026)

DISCUSSION OF RESULTS

Households spent 3.4 times as much on flood protection (2,340 GHS on average), despite naming heat as their main stressor (51.6%). This aligns with Schipper's concept of temporal displacement of vulnerability, in which short-term crisis responses generate slower-onset chronic stressors (Schipper, 2020). Floods demand urgent loss prevention, while heat allows deferral, as Eriksen et al. (2021) observe. The income gradient in heat perception, 59.5% among low-income households against 40.3% among high-income households, reflects differing adaptive capacity.

Wealthier households likely offset the heat through fans, ventilation adjustments, or by spending less time indoors (Bai et al., 2022). Magnan et al. (2016) report similar maladaptation cascades in coastal Bangladesh, where cyclone-resistant housing produced extreme indoor heat. These findings conflict with Adger et al.'s (2005) claim that experiential learning corrects poor adaptation outcomes. An 89.3% knowledge gap regarding alternative materials points to information asymmetries that impede such learning, a constraint that Northern scholarship rarely acknowledges.

Adaptation regret affected 46.4% of households, with low-income households reporting half the non-regret rate of wealthier ones (26.6% versus 50.0%). Barnett et al. (2015) define maladaptation by increased vulnerability, though this study's data also capture subjective judgements of past decisions made under uncertainty. Insecure tenure doubled the odds of regret (OR = 2.05), consistent with Fatti and Patel's (2012) "constrained rationality," where immediate threats compress decision timeframes. Households sleeping outside because of heat were 2.44 times more likely to report regret. Behavioural disruption appears to convert abstract discomfort into concrete judgement. This contrasts with Tschakert et al. (2019), who found that financial loss, not lifestyle disruption, drove regret.

Heat, the primary stressor, strongly predicted regret (OR = 3.06), showing how shifts in threat hierarchies reframe past decisions as irrational. De Coninck et al. (2018) found comparable patterns in European heatwave adaptation but stressed material rather than psychological costs. The model's 74.2% classification accuracy indicates that the predictors are robust, contradicting Haasnoot et al.'s (2021) assumption that regret is randomly distributed across socioeconomic strata in informal settlements.

Identifying 1,000 GHS monthly income as a maladaptation tipping point (AUC = 0.89, 92% sensitivity) gives quantitative precision to a previously qualitative observation. Below this threshold, households shift from constrained adaptation to what Schipper (2020) calls "forced maladaptation," where agency effectively breaks down. The threshold is 1.63 times the locked-in cluster's mean income, indicating a non-linear relationship between resources and adaptive capacity. This supports Hallegatte's (2016) argument that poverty traps require threshold-crossing interventions rather than incremental support. Financial incapacity raised the odds of entrapment 3.42-fold. This suggests objective constraints translate into subjective helplessness, a dimension Tschakert (2007) identified but rarely quantified precisely. This contradicts Juhola et al. (2016), who proposed that community-based adaptation could substitute for individual financial resources. Households attributed drainage failure to government neglect in 75.3% of cases. This shows awareness of structural causes despite remaining individually trapped, a dissonance McNamara et al. (2021) also observed in Pacific atoll communities. The 43.5% clustering in the locked-in profile challenges Pelling's (2010) optimism about the adaptive flexibility of informal settlements. It shows instead how early adaptation choices can calcify into durable vulnerability.

This maladaptation cascade comprises 86.5% lacking the capacity for remediation, 89.3% unaware of alternatives, and 58.1% sleeping outside. It addresses a gap Eriksen et al. (2021) identified regarding the durability of maladaptive outcomes. Barnett and O'Neill (2013) theorised maladaptation as a temporary misalignment correctable through learning. The cascading constraints found here suggest a self-reinforcing trap instead. This knowledge gap is striking given Naess's (2013) assumption that local communities hold rich tacit knowledge of climate-appropriate materials.

Among the locked-in cluster, 97.6% remained unaware of alternatives. This points to a failure of knowledge transfer from contemporary building science, what Nightingale (2017) calls an "adaptation void." The interaction between income and tenure ($F = 12.4$, $\eta^2 = 0.06$) indicates that insecurity amplifies financial constraints synergistically rather than additively. Chu et al. (2024) recommend that urban planners treat tenure regularisation as an enabler of adaptation rather than a separate policy concern. Complete remediation incapacity among low-income, insecure households suggests that addressing income and tenure separately risks deepening existing inequalities.

CONCLUSION

This study confirms that bottom-up climate adaptation in Ghana's savannah peripheries has reached a paradoxical dead end. Structural safety has been bought at the cost of thermal health. The shift to cement masonry is not successful modernisation. It is a desperate response to a governance void in drainage infrastructure.

Households spend three times as much on flood protection as on heat relief. This is not an optimised choice but a survival hierarchy that turns homes into heat traps. The 1,000 GHS monthly income tipping point, with 92% sensitivity, confirms maladaptation as an economic trap.

Below this threshold, households lack the financial means or technical knowledge to relieve their thermal suffering. Climate policy must therefore move beyond encouraging resilience towards actively preventing locked-in vulnerability.

Urban planners should prioritise tenure regularisation and subsidise bioclimatic materials for households below 1,000 GHS. Without threshold-crossing interventions, informal building responses to floods will continue to generate chronic, irreversible heat entrapment, forcing many families to sleep outside to survive.

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