Assessing Household Vulnerability to Climate Risks in Mukuru Special Planning Area (Spa), Nairobi:
A Mixed-Methods Spatial Analysis

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Abstract

Households in Nairobi's Mukuru Special Planning Area (SPA) face overlapping vulnerabilities driven by poverty, insecure tenure, and recurrent climate hazards. Guided by the Sustainable Livelihoods Framework and Social-Ecological Systems theory, this mixed-method spatial analysis combined 376 household surveys, six focus group discussions, and GIS mapping. Results show that flood exposure (β = 0.47), improved sanitation (β = −0.21), and income (β = −0.16) were the strongest determinants of household vulnerability, collectively explaining over 90% of its variance. Households relying on informal employment and living in flood-prone zones faced heightened risks, while access to sanitation, secure tenure, and early preparedness substantially reduced exposure. Findings underscore that resilience in Mukuru is infrastructural, social, and institutional, calling for participatory, household-centred planning that links service provision, tenure security, and adaptive capacity-building to equitable climate resilience.

INTRODUCTION

Globally, almost one billion people live in urban informal settlements, increasing their exposure and vulnerability to climatic, technological, and environmental risks (UN-Habitat, 2020; Frumkin et al., 2021). The rapid and unchecked pace of urbanisation has resulted in dense populations with poor infrastructure, insecure tenure, and socio-economic marginalisation (Brookings Institution, 2022). In Nairobi, more than 60 per cent of the population resides in informal areas covering less than 10 per cent of the city's land area, leading to overcrowding, fragile housing, and poor access to sanitation, water, and drainage (Kenya National Bureau of Statistics [KNBS], 2019; Amnesty International Kenya, 2018). These structural injustices reinforce cycles of poverty and heighten vulnerability to floods, heat, and disease (Dodman, Archer, & Satterthwaite, 2019).

To address these systemic weaknesses, in 2017, the Kenyan government gazetted Mukuru Informal Settlement as a Special Planning Area (SPA) under the Physical and Land Use Planning Act (2019). The SPA was created to enable participatory, spatially aware, and household-based planning (Muungano wa Wanavijiji, 2019; World Bank, 2020). Although these innovations were made in the planning domain, there remains a shortage of empirical data on how vulnerability is spatially and socially distributed throughout the SPA (Warah, 2023).

This study seeks to fill that gap by assessing household vulnerability to climate risk across economic, environmental, health, and social dimensions using a mixed-methods spatial analysis. Specifically, the study aims to:

i. Identify and map the spatial distribution of household vulnerability within Mukuru SPA;
ii. Examine the key socio-economic and environmental determinants influencing vulnerability; and
iii. Evaluate the implications of household-level vulnerability for urban resilience and climate-justice planning in Nairobi's informal settlements.

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By integrating household data, spatial analysis, and community narratives, the study contributes to ongoing debates on social vulnerability mapping, participatory planning, and equitable adaptation in African cities (Friend, Desai, & Parnell, 2024; Bulkeley, Edwards, & Fuller, 2023).

Figure 1 shows the boundary of the Mukuru SPA, key physical features, transportation networks, and the rivers (Ngong and Nairobi Rivers) that define the settlement's spatial extent. The inset maps indicate the location of Mukuru within Nairobi County, Kenya, and Africa.

THEORY

Social Vulnerabilities in Mukuru

The households in the Mukuru Special Planning Area (SPA) have overlapping and reinforcing vulnerabilities, which increase their susceptibility to climate-related hazards and decrease their ability to adapt. Poor infrastructure, fragile livelihoods, and socio-political marginalisation continue to increase climate hazards even in the aftermath of Mukuru's designation as a Special Planning Area in 2017 (Amnesty International Kenya, 2018; Warah, 2023). These vulnerabilities are multidimensional, meaning that they involve economic, environmental, health, and social aspects that interact on both spatial and temporal levels (Friend et al., 2024). Over 80% of the families in Mukuru depend on informal or casual jobs —the livelihoods that are unstable and can be easily affected by extreme weather conditions such as floods or extended heat waves (Mitlin & Satterthwaite, 2013; UN-Habitat, 2020). This economic insecurity reduces households' ability to save, invest in adaptive housing, or purchase basic services during crises. The rental rates are also very high, with more than 40% of earnings spent on housing, and the price of water and sanitation services is more than 142% higher than in the formal neighbourhoods (World Bank, 2020). This is consistent with what Satterthwaite et al. (2020) mean by the so-called poverty penalty, in which poor urban households pay a disproportionate amount for poor-quality services.

Social vulnerability, as shown in **Figure 2** in Mukuru, is characterised by tenure insecurity, limited participation in decision-making, and weak institutional governance. Nearly all structure owners lack formal tenure documentation, which discourages long-term investments in housing
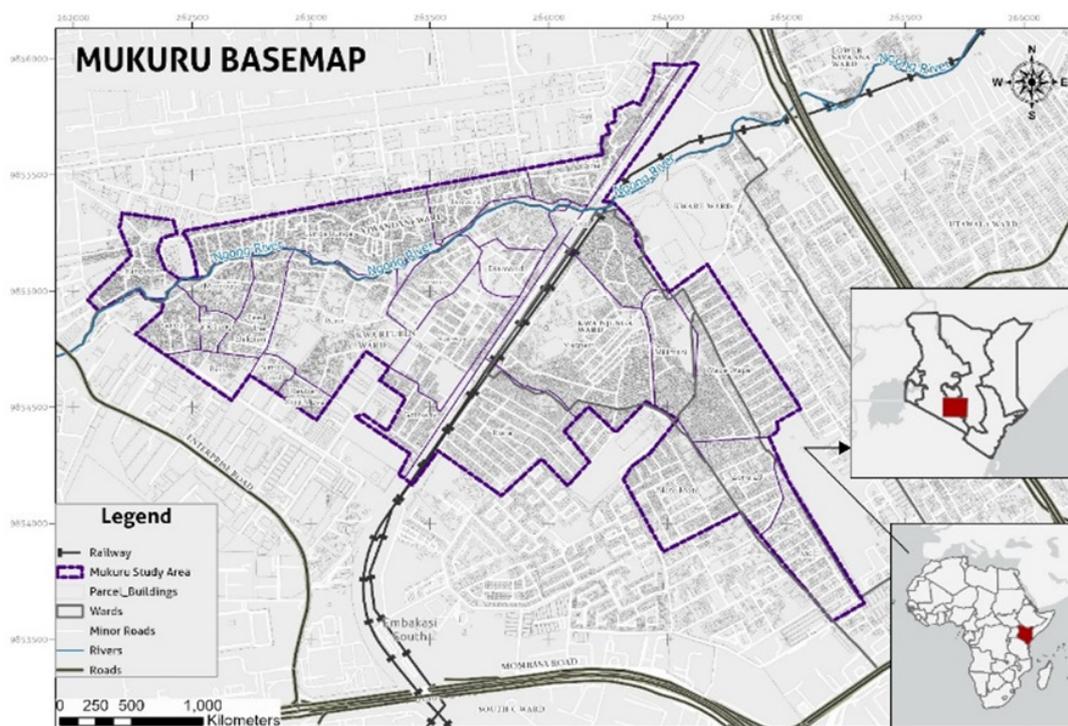

FIGURE 1
Basemap of Mukuru Special Planning Area (SPA), Nairobi County
Source: Author's cartographic compilation using GIS data from Nairobi City County (2025)
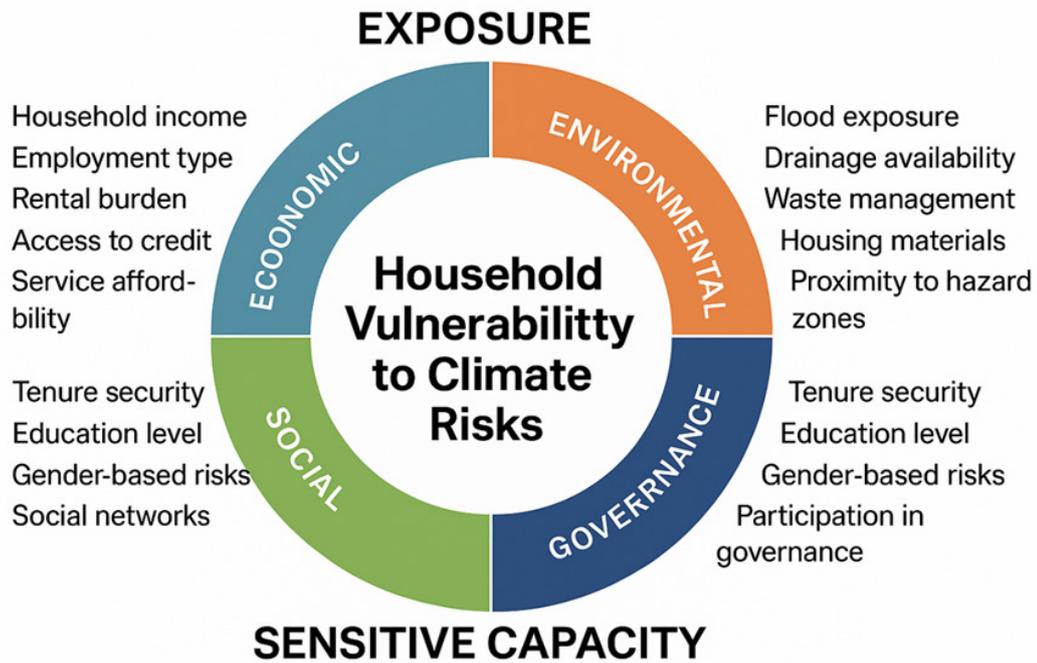
FIGURE 2
Conceptual model of multidimensional household vulnerability in Mukuru Special Planning Area (SPA)
Source: Author's design, 2025, adapted from Scoones (2015), Meerow et al. (2016), and Truelove (2021).

improvement or drainage infrastructure (Yang & Lin, 2018). Gender and age inequalities compound this vulnerability, with women and youth disproportionately affected by unemployment, gender-based violence, and exposure to unsafe sanitation facilities (UN-Habitat, 2020; Huchzermeyer, 2021). Limited representation of informal residents in SPA planning processes has also undermined trust in governance, weakening collective adaptive capacity (Dodman et al., 2019; Anguelovski et al., 2022).

Climate-related household vulnerabilities in Mukuru, as indicated in **Figure 2**, are multidimensional, spatially differentiated, and structural. Economic precarity, environmental degradation, limited access to health care, and weak governance interact to amplify exposure and limit adaptive capacity. Addressing these challenges requires integrated interventions that combine tenure regularisation, infrastructure investment, and inclusive climate governance, aligning with the principles of climate justice and sustainable urban development (Bulkeley et al., 2023; Friend et al., 2024). **Figures 3a** and **b** illustrate the extent of riparian-reserve encroachment and the resulting

flood exposure in Mukuru SPA, showing how informal housing has expanded into restricted river corridors and how storm water spreads across these settled areas during heavy rains.

Urban Acupuncture, a concept coined by architect Lerner (2018), refers to small, strategic interventions in the urban fabric that catalyse broader social, environmental, and economic transformations. It's about doing "less but impactful" localised, context-sensitive projects that catalyse resilience and regeneration. Urban acupuncture draws on the idea that informal settlements are complex, networked systems in which local changes can create non-linear, positive cascade effects when correctly located and timed. Lerner's vernacular is metaphorical, but more recent academic work frames these effects within resilience and socio-ecological systems theory. Integrating Climate Resilience and Urban Acupuncture is further broken down in **Table 1**.

Theoretical Framework
The paper incorporated three complementary theoretical frameworks, namely: Sustainable Livelihoods Framework (SLF), Social-Ecological

Figure 3a
Housing structures built on Riparian reserve

Figure 3b
The red arrow indicates the extent of water that covers the area during heavy rains

FIGURE 3
Encroachment on Riparian Reserves and Floodwater Extent in Mukuru SPA
Source: Field survey, Mukuru SPA (2025).

TABLE 1
Integration of climate-resilient planning and urban acupuncture approaches for adaptive and inclusive urban development

Dimension	Climate Resilient Planning Focus	Urban Acupuncture Approach	Integration Outcome
Scale	City-wide and systemic	Site-specific and micro	Multi-scalar resilience through localized nodes of adaptation
Goal	Reduce vulnerability, enhance adaptability	Spark regeneration and social cohesion	Climate-responsive regeneration
Method	Policy, infrastructure, data-driven planning	Tactical, participatory design	Contextual, community-embedded adaptation
Example	Green infrastructure networks	Pocket wetlands, micro parks	Micro green buffers that reduce flooding & heat
Social Element	Inclusion & equity	Empowerment through local action	Social resilience through place-making

Source: Author's compilation (2025), adapted from Lerner (2014) and World Bank (2020)

Resilience Theory (SER), and Political Ecology (PE). The combination of these theories gives a multidimensional approach to the analysis of vulnerability in informal urban situations.

The sustainable livelihoods framework (SLF) discusses how individuals globally live, work, and make their living in a way that is friendly to, and sustainable for, the environment. It describes the determinant of a household's adaptive capacity as access to assets, including human, social, natural, physical, and financial ones (Scoones, 2015). Asset accumulation is often constrained in informal settlements by systemic inequalities and insecure tenure. The merits of the framework are that it connects household resources to resilience, but it fails to acknowledge structural obstacles such as governance failures and land politics (Satterthwaite et al., 2020).

Social-Ecological Resilience Theory (SER) posits that adaptive feedback is the primary driver of resilience between human and environmental systems (Meerow et al., 2016). It is a theory that emphasises interdependence between ecological and social processes and underestimates power relations and institutional vulnerability within urban informality. Using SER in Mukuru helps conceptualise resilience as both structural and behavioural adjustment (Friend et al., 2024).

The theory of Political Ecology (PE) positions vulnerability within the relationships of power, governance, and unequal dynamics (Truelove, 2021). It highlights the significance of planning regimes and land politics in deciding who is at risk of environmental problems. Although PE can be essential for providing insight into the structural reasons behind vulnerability, it offers very few operational tools to planners. It is significant to ensure that the vulnerability of households is not only considered a social consequence but a factor of political exclusion in the system, and

that governance plays a key role in improving the quality of informal settlements.

These frameworks, combined, informed the variable choice and analysis —the relationship between access to assets, adaptive behaviour, governance, and vulnerability outcomes. The presented theoretical synthesis is representative of the existing African resilience literature that focuses on community agency, institutional change, and spatial equity (Opiyo et al., 2021). Informality, therefore, should not be reduced to the spatial margins of urban administration only. Planning for resilience for urban systems must involve grappling with this complexity if resilience is to reflect equity and social justice (Hebinck et al., 2021).

Figure 4 illustrates how three theoretical lenses—Sustainable Livelihoods Framework (SLF), Social-Ecological Resilience Theory (SER), and Political Ecology (PE)—interact to explain household vulnerability to climate risks. The SLF emphasises
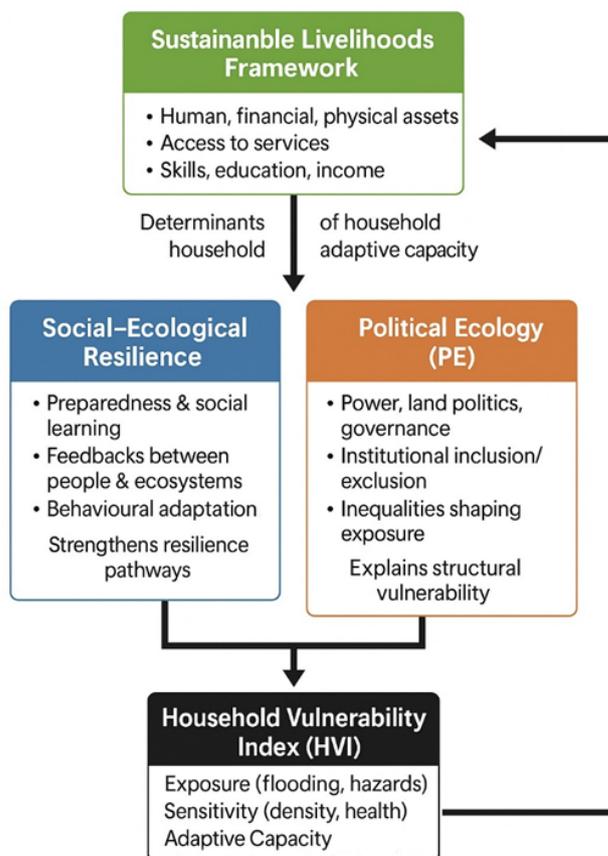

FIGURE 4
Conceptual link between theoretical frameworks and Household Vulnerability Index (HVI)
Source: Author's design, 2025, adapted from Scoones (2015), Meerow et al. (2016), and Truelove (2021)

the role of livelihood assets in determining adaptive capacity, while SER highlights preparedness, learning, and feedback mechanisms that strengthen resilience. PE situates vulnerability within governance and power relations that influence access to resources and protection from environmental risks. Together, these theories converge to form a multidimensional understanding of vulnerability, showing that effective resilience strategies must integrate assets, adaptive behaviours, and equitable governance systems.

RESEARCH METHODS

Research Approach and Sampling

This cross-sectional mixed-methods study integrated quantitative, qualitative, and spatial approaches to examine household vulnerability to climate risks in Mukuru Special Planning Area (SPA). The mixed-methods approach enhanced validity by combining numerical analysis with community narratives, consistent with the participatory ethos of the SPA (Creswell & Creswell, 2018; Lines & Makau, 2018). Quantitative data were used to compute the Household Vulnerability Index (HVI) and identify statistical determinants, while qualitative insights contextualised adaptive practices and lived experiences. Informality, insecure tenure, poor drainage, high density, and frequent flooding (NEMA, 2022) typify this settlement. The study targeted 376 household heads as primary respondents and adopted a stratified proportional random sampling approach, with each of the three sub-areas forming a stratum. These were selected based on estimated population size, and within each stratum, systematic random sampling was used to ensure representation across gender and socioeconomic groups.

Data Collection and Analysis Techniques

Data collection, conducted between May and September 2025, followed a structured three-phase approach. The preparatory stage involved tool pre-testing, enumerator training, and securing ethical clearance. The Quantitative Phase consisted of structured household surveys administered directly to respondents across the study area. The Qualitative Phase comprised six Focus Group Discussions (FGDs) with youth, women, and community leaders to map hazards, document lived experiences, and identify community coping mechanisms.

A Spatial Mapping Phase complemented these methods through GPS-based transect walks used to locate flood-prone areas, unsafe zones, and patterns of service access in Mukuru SPA.

Quantitative analysis relied on descriptive statistics to summarise household characteristics, exposure, and preparedness levels. Multiple regression analysis was employed to examine how key predictors—such as income, flooding experience, sanitation access, household size, education, preparedness, and tenure security—influenced household vulnerability. ANOVA tests were used to assess whether vulnerability significantly differed across the three settlement zones or household categories. SPSS (Version 26) was used to analyse the data.

Qualitative data from FGDs were transcribed and thematically analysed to capture governance issues, tenure insecurity, gendered exposure, and adaptive strategies.

This integrated and participatory mixed-method approach ensured that both empirical evidence and community perspectives informed the understanding of household vulnerability and resilience within the Mukuru SPA.

Household Vulnerability Index

The Household Vulnerability Index (HVI), summarised in **Table 2**, provides a composite measure of household exposure, sensitivity, and adaptive capacity within Mukuru SPA. The index was computed on a normalised 0–1 scale, where higher values indicate greater vulnerability. A five-level equal-interval classification was applied to group households into: not vulnerable (0.00–0.20), slightly vulnerable (0.21–0.40), moderately vulnerable (0.41–0.60), highly vulnerable (0.61–0.80), and extremely vulnerable (0.81–1.00).

This classification follows established composite index methodologies used to assess multidimensional vulnerability by integrating exposure, sensitivity, and adaptive capacity. Instrument validity was strengthened through pre-testing with 20 households and expert review, while reliability tests returned Cronbach's alpha values above 0.7.

TABLE 2
Household Vulnerability Index (HVI) categories and interpretation

Index Range (HVI)	Category	Interpretation
0.00 – 0.20	Not Vulnerable	The household has strong adaptive capacity, low exposure, and minimal sensitivity.
0.21 – 0.40	Slightly Vulnerable	The household experiences mild risk factors but maintains reasonable coping ability.
0.41 – 0.60	Moderately Vulnerable	The household faces noticeable exposure and sensitivity with limited adaptive capacity.
0.61 – 0.80	Highly Vulnerable	The household is significantly exposed and sensitive, with weak coping mechanisms.
0.81 – 1.00	Extremely Vulnerable	The household is at critical risk, with very high exposure and little to no adaptation.

Source: Field survey, Mukuru SPA (2025)

Ethical Approval and Consent

Ethical clearance was granted by the Jomo Kenyatta University of Agriculture and Technology (JKUAT) Ethics Review Board and the National Commission for Science, Technology and Innovation (NACOSTI). Informed consent was obtained from all respondents prior to participation, and confidentiality was maintained throughout data collection and analysis.

RESULTS

The findings, structured around four key dimensions of vulnerability—environmental, economic, health, and social, were supported by both regression and spatial analyses. Quantitative results are enriched with qualitative insights drawn from focus group discussions (FGDs) and spatial mapping outputs. Gender and demographic variations are emphasised where applicable.

Environmental Vulnerabilities

Flooding emerged as the most significant environmental stressor, particularly in Mukuru Kwa Reuben (KKR), where 72% of households experienced flood-related damage in the past two years, compared with 58% in Mukuru Kwa Njenga (KKN) and 49% in Viwandani (VWD). GIS mapping confirmed that riparian households in KKR faced almost triple the displacement risk compared to VWD. FGDs revealed that floods disrupted small-scale trading and increased women's caregiving burdens (Douglas et al., 2019). Waste accumulation was also severe, with uncollected waste amounting to 68% in KKN, 61% in KKR, and 47% in VWD households. This is due to blocked drains and water contamination. Inadequate drainage, poor solid waste management, and flood exposure primarily drive environmental vulnerability in Mukuru, with women and low-income tenants facing the greatest risk due to caregiving and asset constraints.

Figure 5 shows that Mukuru Kwa Reuben (KKR) was the most environmentally vulnerable (68%), followed by Mukuru Kwa Njenga (KKN) (61%) and Viwandani (VWD) (47%) due to high uncollected solid waste and drainage blockages.

Overall, these findings highlight that structural service deficits and gendered exposure drive spatially uneven environmental vulnerability across the SPA.

Economic Vulnerabilities

Economic vulnerabilities in Mukuru are characterised by precarious livelihoods, high living costs, and limited savings capacity, intensifying dependency on informal social safety nets and networks. The average monthly household income reported was KES 6,800–8,100, which is less than a quarter of Nairobi's formal settlements (KNBS, 2019). Dependence on informal labour was highest in KKN (85%), followed by KKR (82%) and VWD (67%). Rent consumed over 40% of household income for more than half of respondents, while water costs were 2–3 times higher than in formal areas (**Figures 6a, b, c, d** and **e**). FGDs indicated that women traders and casual workers were most affected by income volatility, often resorting to credit from social safety nets such as informal savings groups (chamas).
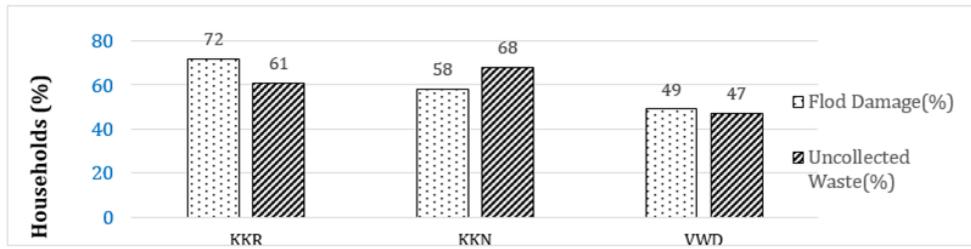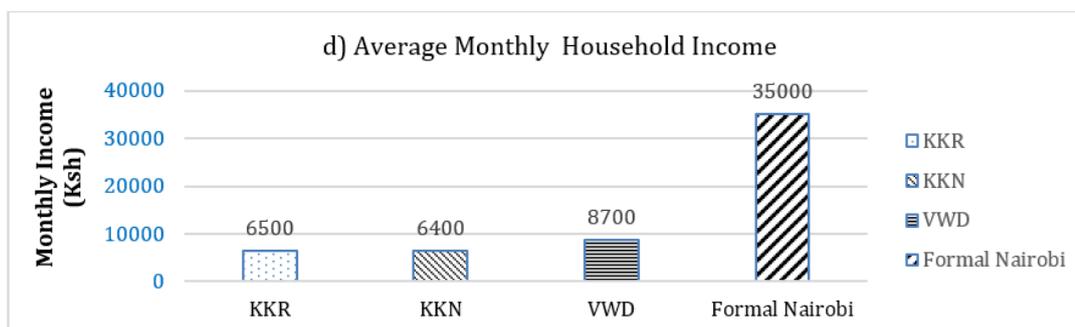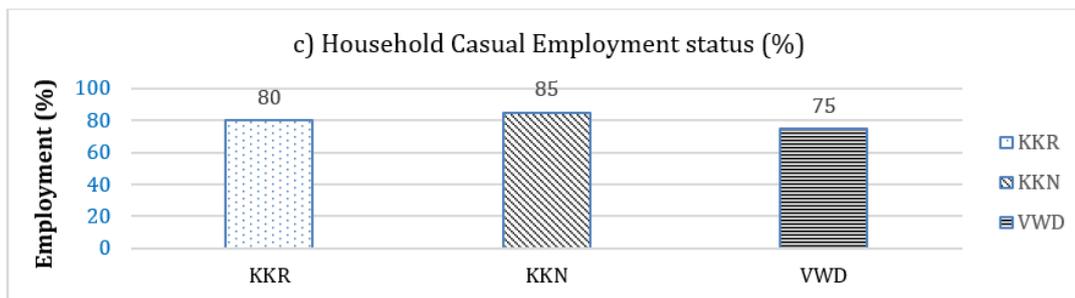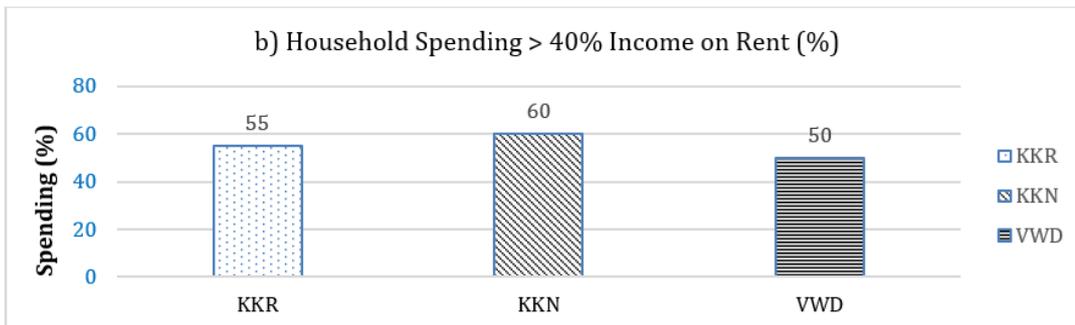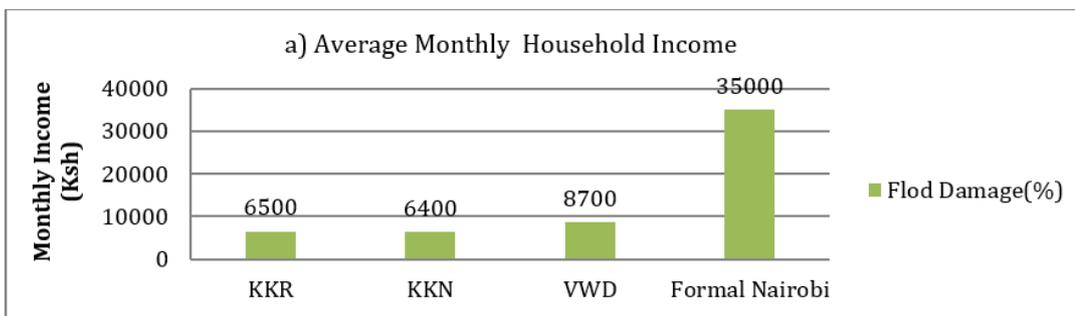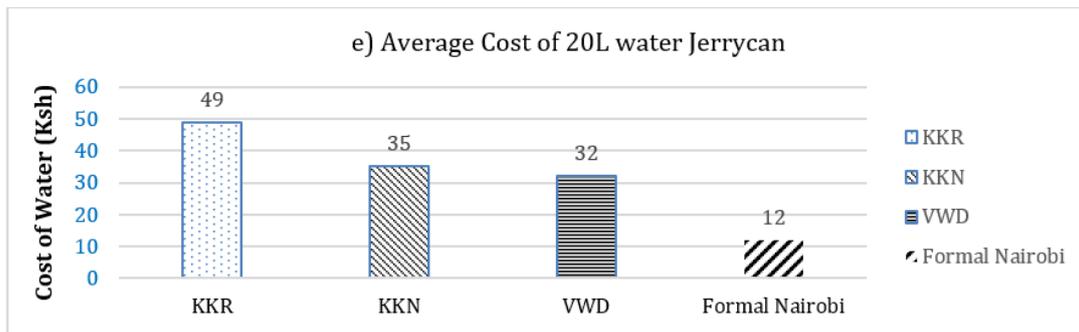
FIGURE 5
Environmental Vulnerability in Mukuru Regions
Source: Field survey, Mukuru SPA (2025)

FIGURES 6 a, b, c, d and e
Economic Vulnerability across Mukuru Sub-regions
Source: Field survey, Mukuru SPA (2025)

The **Figures 6 a, b, c, d** and e: indicate that:

i. The income of households in informal settlements is well below that of formal estates.
ii. Casual labour dominates employment, especially in KKN (85%).
iii. Rent occupies a significant portion of income, the highest percentage in KKN (61%).
iv. Water costs are significantly higher in informal places (KES 30-50 per 20L) than in formal Nairobi (KES 10-15).

Economic insecurity and high living costs are central to vulnerability, reinforcing household dependence on informal labour and unstable income streams.

Access to improved sanitation remained low— 15–24% of households reported access, while over 70% relied on shared pit latrines. Overcrowding was pervasive, with 54–73% of households having more than four occupants per room (**Figures 7a, b, c** and **d**). FGDs noted that women and children faced safety risks when using shared sanitation at night. The prevalence of waterborne diseases such as cholera and diarrhoea was highest in KKR (33%) and KKN (29%).

Access to improved sanitation in KKR was 20%, KKN 17%, and VWD 24%. Shared latrines: KKR 70%, KKN 78%, VWD 64%. Waterborne diseases: KKR 37%, KKN 32%, VWD 18%. Overcrowding: KKR 66%, KKN 73%, VWD 54%. This poor sanitation, overcrowding, and gendered safety risks amplify health vulnerabilities, especially among women and children in flood-prone areas. Health vulnerability is shaped by environmental degradation, unsafe sanitation, and gendered exposure, linking household well-being to infrastructure inequities.

Approximately 90% of households lacked formal tenure documentation, deterring investment in drainage or durable housing. Education gaps were also evident with 38% of children in KKN not enrolled in school compared to 22% in VWD. Crime, gender-based violence, and insecurity were more prevalent in KKN. Women's participation in governance was minimal, with 85% of respondents reporting exclusion from SPA planning processes. Social vulnerability is entrenched in tenure insecurity, limited representation, and gender inequities that restrict community participation and adaptive capacity.

Multiple Regression Analysis of Household Vulnerability Index (HVI)
The multiple regression model explained 90.6% of the variance in the Household Vulnerability Index (HVI) (R^2 = 0.906, p < .001). Flood exposure (β = 0.468, p < .001) and household size (β = 0.105, p < .01) significantly increased vulnerability, while income, sanitation access, education, preparedness, and tenure security had negative coefficients, reducing vulnerability. Hotspot mapping revealed high-risk clusters along riparian zones in KKN and KK, while VWD exhibited moderate vulnerability due to better job access and NGO presence. Vulnerability was highest among female-headed households and large families (**Table 3**).

The model explains about 90.6 % of the variation in the Household Vulnerability Index (HVI), meaning the selected predictors collectively provide a very strong explanation of household
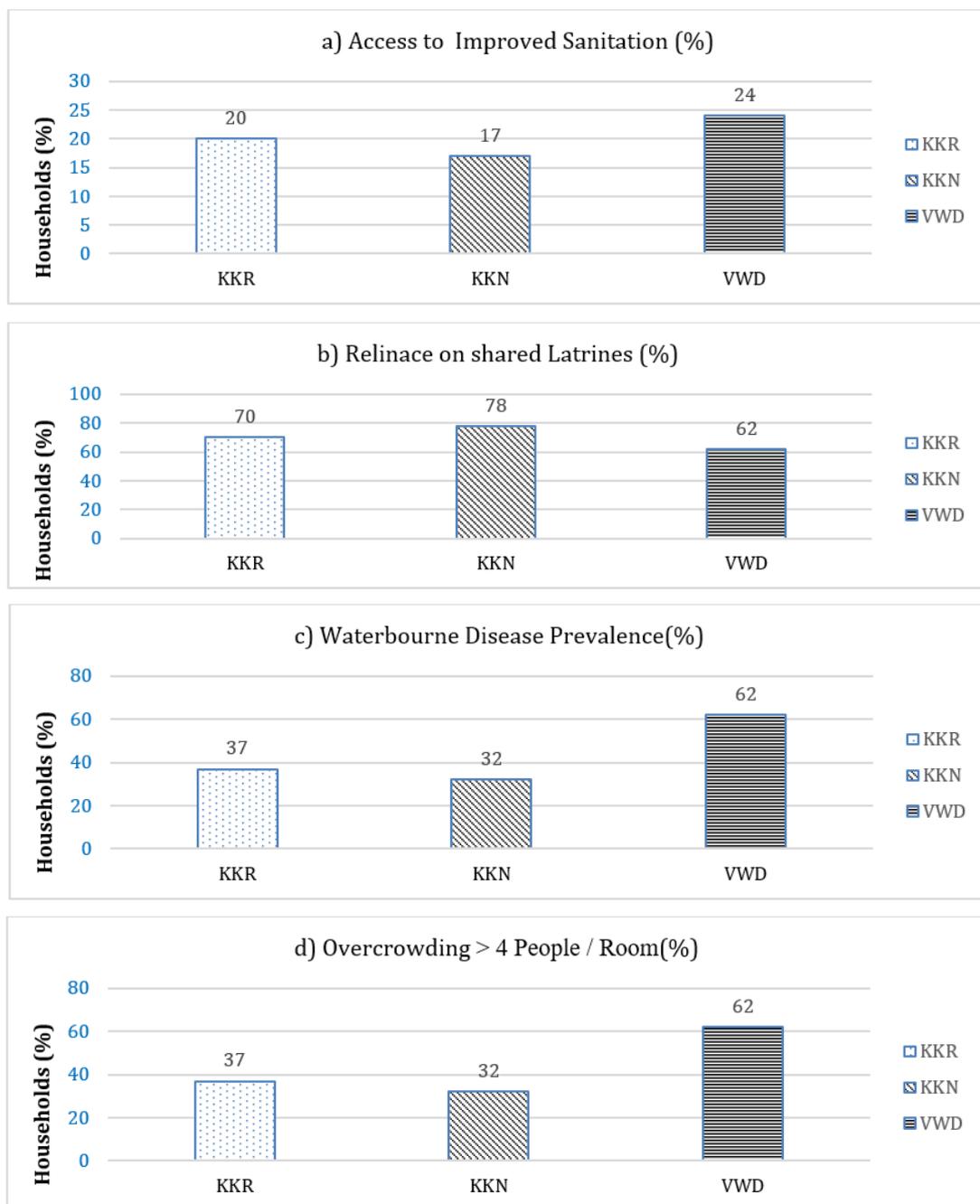
FIGURES 7 a, b, c, and d
Health Vulnerability by Region
Source: Field survey data, Mukuru SPA (2025).

TABLE 3
Model summary showing the relationship between predictor variables and the Household Vulnerability Index(HVI)

Model	R	R²	Adjusted R²	Std. Error of Estimate	Durbin–Watson
1	0.952	0.906	0.904	0.034	2.03

Source: Field survey, Mukuru SPA (2025)

vulnerability patterns.

Table 4 presents the results of the Analysis of Variance (ANOVA), indicating that the regression model predicting household vulnerability in Mukuru SPA is statistically significant, with the predictors collectively explaining a substantial proportion of the observed variance in the Household Vulnerability Index (HVI).

The ANOVA confirms the regression model is highly significant ($F = 582.1$, $p < .001$), meaning the set of predictors—collectively has a meaningful influence on household vulnerability in Mukuru SPA.

Table 5 presents the coefficients of the multiple regression model used to predict household vulnerability in the Mukuru Special Planning Area (SPA). The analysis identifies the relative influence of economic, environmental, and social factors

on the Household Vulnerability Index (HVI). Positive coefficients, such as flood exposure and household size, indicate variables that increase vulnerability, while negative coefficients—including income, sanitation, preparedness, education, and tenure security—represent factors that reduce vulnerability. These results highlight that improved sanitation, higher income, and secure tenure substantially strengthen household resilience against climate-related risks.

Flood exposure is the strongest positive predictor of household vulnerability, with households in flood-prone areas facing higher environmental and infrastructural risks. Conversely, access to sanitation, prior preparedness, and higher income are significant negative predictors, indicating that better sanitation, preventive measures, and financial resources reduce vulnerability. Education has a modest but meaningful effect, enhancing awareness and adaptive behaviors. Household size

TABLE 4
ANOVA results showing the significance of predictor variables influencing the Household Vulnerability Index (HVI)

Source	df	SS	MS	F	Sig.
Regression	7	0.584	0.0834	582.1	.0001
Residual	368	0.061	0.00017	—	—
Total	375	0.645	—	—	—

Source: Field survey, Mukuru SPA (2025)

TABLE 5
Coefficients of the regression model predicting the Household Vulnerability Index (HVI)

Predictor	B	Std. Error	Beta	t	Sig.	95% CI for B
(Constant)	0.120	0.014	—	8.57	.000	[0.092, 0.148]
Income (KES)	-3.3×10^{-6}	5.0×10^{-7}	−0.162	−6.60	.000	$[-4.3 \times 10^{-6}, -2.3 \times 10^{-6}]$
Flood Exposure (1/0)	0.204	0.005	0.466	40.8	.000	[0.194, 0.214]
Sanitation Improved (1/0)	−0.101	0.004	−0.210	−25.3	.001	[−0.109, −0.093]
Household Size	0.0092	0.001	0.107	9.20	.001	[0.0073, 0.0111]
Education Level (Years)	−0.0024	0.001	−0.043	−2.12	.034	[−0.0047, −0.0002]
Early Warning Systems (1/0)	−0.082	0.006	−0.169	−13.6	.000	[−0.094, −0.070]
Tenure Security (1/0)	−0.047	0.005	−0.092	−9.40	.000	[−0.057, −0.037]

Source: Field survey data analysis, Mukuru SPA (2025)

slightly increases vulnerability, as larger families experience greater dependency and resource pressures during crises.

The results presented in **Table 6** indicate that all key regression assumptions were satisfied. The Variance Inflation Factor (VIF) values below 5 confirm that multicollinearity was not present among the predictors. The Breusch–Pagan and Jarque–Bera test results further verify that the residuals are both homoscedastic and normally distributed. These findings confirm that the regression model is statistically robust, reliable, and suitable for interpreting the determinants of household vulnerability in Mukuru SPA. Statistical and spatial analyses collectively demonstrate that vulnerability in Mukuru is multi-scalar—driven by flood exposure, economic precarity, and gendered social inequities. Overall, these patterns confirm that vulnerability in Mukuru is multi-scalar, shaped by the interplay of physical exposure, economic precarity, and gendered social inequities.

Cross-Cutting Vulnerability Drivers in Mukuru SPA

i. *Tenure Insecurity*: Over 90% of structure owners lack formal land rights (94% KKR; 91% KKN; 89% VWD). **Figure 8** shows that

Mukuru kwa Reuben has 94% insecurity, Mukuru kwa Njenga has 91%, and Viwandani has 89%.

ii. *Infrastructure Gaps*: Limited piped water, poor drainage, and inadequate health facilities.

iii. *Environmental Risks*: Floods, heatwaves, and poor waste management exacerbate exposure.

iv. Social Inequality: Women, children, the elderly, and people with disabilities face disproportionate risks.

v. *Educational vulnerability*: It was most acute in KKN, where 38% of children were reported as not enrolled in school, compared to 27% in KKR and 22% in VWD. Parents cited lack of fees, distance to schools, and opportunity costs of child labour as barriers.

vi. *Crime and insecurity*: It also emerged as a critical social vulnerability. Survey and FGD evidence revealed higher incidences of theft, assault, and gender-based violence in KKN compared with the other sites. Participants highlighted weak policing and mistrust of formal governance institutions as barriers to safety.

Figure 8 presents the proportion of households experiencing tenure insecurity across the three sub-regions of Mukuru SPA, revealing consistently high levels of insecure land tenure in all areas.

TABLE 6
Model diagnostics confirming the validity and reliability of the regression model

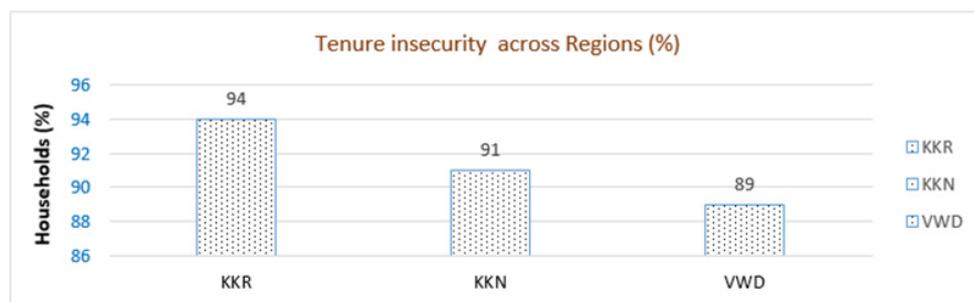| Diagnostic Test	Statistic / p-value	Interpretation
VIF Range: 1.01–1.09	< 5	No multicollinearity detected
Breusch–Pagan Test: p = 0.23	> .05	Homoscedasticity confirmed
Jarque–Bera Test: p = 0.36	> .05	Residuals approximately normal

Source: Field survey data analysis, Mukuru SPA (2025)

FIGURE 8
Tenure insecurity across regions (%)
Source: Field survey, Mukuru SPA (2025)

Tables **7** and **8** compare key economic and health-related indicators across Mukuru Kwa Reuben (KKR), Mukuru Kwa Njenga (KKN), and Viwandani (VWD). **Table 7** highlights economic disparities—lower incomes, high reliance on casual work, heavy rent burdens, and higher water costs—showing greater economic vulnerability than in formal Nairobi areas. **Table 8** presents health-related vulnerabilities, including limited access to improved sanitation, high dependence on shared latrines, elevated waterborne disease cases, and severe overcrowding. These indicators reveal significant gaps from WHO standards and demonstrate how poor services and crowded living conditions heighten health risks in Mukuru.

Analysis of the Household Vulnerability Index (HVI)

The Household Vulnerability Index (HVI) results in **Table 2** provide an integrated picture of how exposure, sensitivity, and adaptive capacity combine to shape household vulnerability across Mukuru SPA. The five-level classification—ranging from not vulnerable to extremely vulnerable—shows a clear gradient of risk that reflects both household-level conditions and broader structural inequalities within the settlement.

Households falling within the 0.00–0.20 (Not Vulnerable) category exhibit strong adaptive capacity, supported by relatively stable income sources, better access to sanitation, smaller household sizes, and greater preparedness. These households experience minimal exposure to climate hazards and are therefore better positioned to cope with shocks.

The 0.21–0.40 (Slightly Vulnerable) group faces mild but noticeable risk factors, such as occasional flood exposure or moderate economic strain, yet retains sufficient coping mechanisms to minimise negative impacts.

Households categorised as 0.41–0.60 (Moderately Vulnerable) show increased sensitivity to environmental and economic disruptions. Limited access to sanitation, inconsistent income, and moderate exposure to flooding reduce their ability to recover from climate-related events, making them more susceptible to prolonged hardship.

The 0.61–0.80 (Highly Vulnerable) category reflects households significantly exposed to hazards such as frequent flooding, poor drainage, and overcrowding. Their coping mechanisms are

TABLE 7

Economic indicators by region showing income disparities, employment type, rent burden, and water costs

Indicator	KKR	KKN	VWD	Formal Nairobi
Avg. monthly income (KES)	7,200	6,800	8,100	15,201
Households in casual employment	82 %	85 %	67 %	32 %
Rent burden > 40 % income	55 %	61 %	51 %	25 %
Avg. cost of 20 L water (KSh)	50	35	30	10–15

Source: Field survey, Mukuru SPA (2025).

TABLE 8

Health-related vulnerabilities by region, indicating sanitation access, shared-latrine dependence, disease prevalence, and overcrowding levels

Indicator	KKR	KKN	VWD	WHO / Urban Standard
Access to improved sanitation	20 %	15 %	24 %	> 75 %
Reliance on shared latrines	71 %	76 %	64 %	< 20 %
Waterborne disease prevalence	33 %	29 %	18 %	< 5 %
Households > 4 persons per room	66 %	73 %	54 %	≤ 2

Source: Field survey, Mukuru SPA (2025).

weak, often due to insecure tenure, low income, and heavy reliance on shared sanitation facilities. These conditions greatly heighten their risk of displacement, illness, and economic instability.

Households classified as 0.81–1.00 (Extremely Vulnerable) face the most critical risk. They experience severe exposure to climate hazards and have minimal adaptive capacity, often compounded by large household sizes, high poverty levels, chronic sanitation challenges, and very limited access to protective infrastructure or early warning systems. These households are least equipped to respond to or recover from climatic shocks.

Overall, the HVI results reveal that vulnerability in Mukuru SPA is not evenly distributed but varies across households depending on their socio-economic status, environmental exposure, and ability to adapt. The index therefore provides a practical basis for prioritising interventions—directing urgent support to those in the highly and extremely vulnerable categories, while strengthening resilience among moderately vulnerable households through targeted improvements in sanitation, income stability, preparedness, and tenure security.

CONCLUSION

This study concludes that household vulnerability in the Mukuru Special Planning Area (SPA) is multidimensional—rooted in economic precarity, environmental exposure, health insecurity, and governance inequities. Drawing on the Sustainable Livelihoods Framework (SLF), Social-Ecological Resilience Theory (SER), and Political Ecology (PE), the analysis revealed that vulnerability is not only a matter of exposure to hazards but also a consequence of structural and institutional constraints. Key determinants included income, sanitation, education, preparedness, and tenure security, collectively explaining over 90 percent of the variance in household vulnerability. These findings confirm that building resilience requires strengthening household assets, community networks, and governance mechanisms simultaneously.

Policy acupuncture refers to focused, high-impact micro-interventions that stimulate broader systemic resilience within informal urban

contexts. Borrowing from the concept of urban acupuncture—small, catalytic actions that trigger positive transformation—this study identifies localized interventions capable of generating wide-scale impact on climate adaptation and social inclusion. Such approaches align with Kenya's National Climate Change Action Plan (NCCAP 2023–2027), the UN-Habitat New Urban Agenda, and the Sustainable Development Goals (SDGs 1, 6, 11, and 13) on poverty reduction, sanitation, sustainable cities, and climate action.

At the policy level, geographically differentiated strategies are recommended to match the distinct vulnerability profiles of Mukuru's sub-areas. In Mukuru Kwa Reuben (KKR), intensive flood mitigation and drainage restoration should be prioritised due to high exposure and housing fragility. In Mukuru Kwa Njenga (KKN), rapid sanitation and education scaling are critical for addressing overcrowding and dependency ratios. In Viwandani (VWD), gradual tenure regularization and community upgrading are key to long-term stability and investment in durable housing.

Short-term actions (1–3 years) should focus on restoring riparian zones, expanding drainage, scaling up affordable toilets, improving hygiene campaigns, and strengthening early warning systems for flood and disease preparedness. Long-term measures (4–10 years) should institutionalize tenure reforms, promote women's cooperatives and microenterprises, and entrench participatory governance through inclusive SPA committees. These interventions collectively reinforce equitable and accountable resilience governance while strengthening community empowerment.

Four cross-cutting insights emerge from this research.

First, climate justice should prioritize vulnerable and female-headed households in service delivery and spatial upgrading.

Second, resilience planning must embed participatory risk mapping and community data within policy frameworks to ensure responsiveness to local realities.

Third, institutional coordination should be enhanced through collaboration among county

authorities, civil society, and residents for sustained SPA implementation.

Finally, monitoring and evaluation systems must link local resilience indicators to SDG and NCCAP performance targets to ensure transparency and accountability.

The findings align with Kenya's national and international commitments to climate adaptation and inclusive urban governance. Future research should adopt longitudinal designs to capture seasonal and temporal variations in vulnerability and expand gender-disaggregated analyses. Integrating citizen-generated data into formal urban planning can deepen accountability and sustain adaptive governance.

In essence, achieving climate resilience in Mukuru SPA requires bridging community-driven action with institutional reform—transforming localised household adaptation into a scalable, equitable, and sustainable urban resilience model aligned with global development goals.

RECOMMENDATIONS

The lens of the three guiding frameworks—the Sustainable Livelihoods Framework (SLF), Social-Ecological Resilience Theory (SER), and Political Ecology (PE)—is used to explain how household vulnerability in Mukuru SPA is shaped by the interactions among social, economic, and environmental factors. It also integrates gender, governance, and methodological reflections. The findings reveal that vulnerability is both structural and behavioural, arising from inequalities in access to livelihood assets, exposure to hazards, and limited institutional capacity to respond.

Households with higher income, education, and secure tenure exhibited greater adaptive capacity, demonstrating that socio-economic stability and secure tenure enhance resilience. Conversely, low income, overcrowding, and inadequate sanitation intensified exposure and sensitivity. These conditions affirm that vulnerability in informal settlements is socially and politically produced rather than purely environmental. The results align with Satterthwaite et al. (2020), who emphasise that resilience in African cities depends on the capacity to prepare, respond, and recover through institutional and behavioural adaptation.

For Mukuru SPA, the findings underscore that targeted interventions—such as community awareness, early warning systems, improved sanitation, and tenure regularisation—are critical in reducing household vulnerability while complementing infrastructural improvements.

Interpreting Household Vulnerability through Theoretical Lenses

The findings confirm that vulnerability in Mukuru SPA is multidimensional and embedded within structural inequities. The SLF highlights that limited access to financial, human, and physical assets weakens adaptive capacity, leaving households dependent on unstable informal livelihoods. The SER framework demonstrates that social learning, preparedness, and cooperative networks enhance adaptation by fostering feedback and recovery mechanisms. Political Ecology situates these outcomes within broader governance failures and urban inequalities, showing that insecure tenure and weak accountability perpetuate exposure. Collectively, these frameworks illustrate that vulnerability is an outcome of restricted assets, insufficient social capital, and institutional exclusion.

Interpretive synthesis: Together, the three frameworks show that vulnerability is not simply a response to climate risks but a reflection of systemic inequities, governance asymmetry, and limited opportunities for collective action.

Environmental and Health Dimensions

The environmental and health outcomes reveal how physical and social factors converge to heighten risk. Flood exposure and poor drainage degrade infrastructure, while weak waste management and water contamination exacerbate disease prevalence. Health vulnerability is compounded by gendered exposure—women and children face heightened risks when accessing shared sanitation, reinforcing social inequality. The SER framework supports hybrid interventions that integrate green infrastructure, improved sanitation, and environmental restoration to enhance adaptive capacity. The SLF perspective suggests that strengthening human capital through education and public health measures can substantially reduce vulnerability across households.

Economic and Social Dimensions

Economic fragility in Mukuru is rooted in

dependence on informal employment, income volatility, and minimal savings. These conditions deepen social vulnerability and restrict household adaptation. The SER framework identifies community-based savings groups (chamas) and local solidarity networks as vital coping mechanisms that promote resilience through self-organisation. Political Ecology interprets economic precarity as a manifestation of structural exclusion from formal markets and credit systems. Empowering small enterprises, improving financial access, and promoting gender-inclusive livelihoods can therefore disrupt the cycle of dependency and improve adaptive resilience.

Interpretive synthesis: Economic insecurity and social marginalisation reinforce one another, creating cyclical vulnerability. Strengthening household income sources and community safety nets offers a pathway toward sustainable resilience.

Governance, Gender, and Institutional Gaps
Governance asymmetry remains one of the most significant drivers of vulnerability. The study found that limited community participation—especially by women and tenants—undermines the legitimacy and inclusiveness of the SPA planning process. Political Ecology links this exclusion to entrenched power relations that favour elite-driven decision-making. Integrating marginalised voices into planning and budgeting processes is essential for equitable outcomes. These gendered and governance patterns confirm that resilience is co-produced through institutional inclusion and everyday adaptation. Building climate resilience, therefore, requires participatory institutions that value local knowledge and gender-balanced leadership.

Study Limitations and Theoretical Integration
Although the study's cross-sectional design limits temporal analysis, its mixed-method approach—combining regression, spatial mapping, and qualitative inquiry—strengthens interpretive validity. Integrating the SLF, SER, and PE frameworks provides a comprehensive analytical lens that connects micro-level adaptation with macro-level governance reform. This theoretical synthesis demonstrates that resilience in informal settlements depends on enhancing household assets (SLF), promoting adaptive self-organisation (SER), and reforming power structures (PE).

Theoretical–practical integration: Strengthening climate resilience in informal settlements requires bridging household-level adaptation (SLF and SER) with institutional reform and social justice (PE). Mukuru's SPA process illustrates how participatory data and inclusive planning can embed resilience principles into urban governance systems (Lilford et al., 2017).

This study demonstrates that household vulnerability in Mukuru SPA results from the intersection of economic precarity, environmental risk, gender inequity, and governance asymmetry. Resilience-building must therefore go beyond physical infrastructure to address social justice, empowerment, and participatory governance. By linking SLF's emphasis on assets, SER's focus on adaptive behaviour, and PE's critique of governance inequality, the study provides a holistic framework for designing equitable, gender-sensitive, and sustainable climate resilience strategies for Nairobi's informal settlements.

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