

Spatial Planning for Climate Resilience: A 35-Year Time Series Analysis of Mukuru Special Planning Area, Nairobi

Victor Nyakundi^{1*}, Munala Gerryshom², Mugwima Njuguna³

¹Center for Urban Studies, Jomo Kenyatta University of Agriculture and Technology, Nairobi, Kenya

²Department of Construction Management, Jomo Kenyatta University of Agriculture and Technology, Nairobi, Kenya

³Department of Landscape Architecture, Jomo Kenyatta University of Agriculture and Technology, Nairobi, Kenya

Email: *victor.nyakundi@jkuat.ac.ke

How to cite this paper: Nyakundi, V., Gerryshom, M., & Njuguna, M. (2025). Spatial Planning for Climate Resilience: A 35-Year Time Series Analysis of Mukuru Special Planning Area, Nairobi. *American Journal of Climate Change*, 14, 666-686.

<https://doi.org/10.4236/ajcc.2025.144032>

Received: August 23, 2025

Accepted: December 5, 2025

Published: December 8, 2025

Copyright © 2025 by author(s) and Scientific Research Publishing Inc.

This work is licensed under the Creative Commons Attribution International License (CC BY 4.0).

<http://creativecommons.org/licenses/by/4.0/>



Open Access

Abstract

Informal settlements in Sub-Saharan Africa are at high risk of exposure due to climate-related hazards, attributed to rapid urbanization and poor infrastructural development. This paper will give a geospatial and qualitative evaluation of the Mukuru Special Planning Area (SPA) in Nairobi in a 35-year period (1990-2025) and how the spatial planning interventions affect climate resilience. The analysis with the help of weighted overlay models, supervised land-cover classification, change detection algorithms, NDVI trend analysis, and GIS-based vulnerability mapping is based on a multi-temporal data set of 11 Landsat scenes, five high-resolution aerial images, and 35 years of hydro-meteorological data. Findings show that impervious surface cover turned high (64.2% in 2025) with a rapid rise in impervious surface cover (18.6% in 1990 and then higher in 2025) whereas vegetative cover (NDVI > 0.3) reduced by 48.5% indicating massive degradation of the ecosystem. The area prone to floods grew by 33 percent and the average surface runoff intensity increased between 0.42 and 0.71 (normalized index). This study concludes with evidence-based recommendations for spatially targeted inclusive planning, infrastructure retrofitting, and green space restoration to improve adaptive capacity and reduce hazard exposure in high-density informal urban environments.

Keywords

Climate Resilience, GIS-Remote Sensing, Mukuru Special Planning Area, Nairobi, Spatial Planning, Urban Vulnerability

1. Introduction

The world is undergoing rapid and unprecedented urbanization, with cities in developing countries facing severe challenges in delivering adequate infrastructure, services, and housing to their expanding populations. Climate change compounds these challenges, increasing the frequency and intensity of extreme weather events such as floods, heatwaves, and droughts. Informal settlements—marked by insecure tenure, inadequate infrastructure, and limited service delivery—are especially vulnerable to climate-related hazards including flooding and heat stress (KNBS, 2019). In Nairobi, Kenya's capital, more than 60% of the population resides in informal settlements that occupy less than 10% of the city's land area (UN-Habitat, 2020). These settlements face overlapping risks, driven by poor drainage systems, unregulated construction, high population density, and minimal green infrastructure.

Within this context, spatial planning emerges as a critical tool for enhancing climate resilience by guiding land use and development in ways that reduce exposure and vulnerability to hazards. Across Sub-Saharan Africa, the dual pressures of climate change and rapid urbanization present acute threats to the resilience and equity of urban systems (IPCC, 2022). In Nairobi, these pressures are magnified in informal settlements where high densities, insecure land tenure, and deficient infrastructure converge to produce chronic vulnerability. Mukuru—located approximately 7 km southeast of Nairobi's Central Business District—illustrates these challenges. Covering over 650 acres and home to more than 400,000 residents, the settlement is partly situated along the flood-prone riparian zones of the Ngong River and adjacent to industrial zones that discharge pollutants into both air and water systems (UN-Habitat, 2015). Historically excluded from formal spatial planning frameworks, Mukuru has relied on fragmented, short-term donor-driven interventions, which have failed to address underlying structural vulnerabilities. Consequently, the community faces compounded risks: recurrent flooding driven by climate variability and reduced natural drainage; severe public health hazards from industrial and domestic pollution; and deepening socio-economic precarity as repeated hazard events erode household resilience.

These risks are dynamic, shaped by evolving land use patterns, continued settlement expansion, and environmental change. Addressing them effectively requires a 35-year spatial and environmental time-series analysis to assess how Mukuru's footprint and density have evolved, how hazard exposure has shifted, and how industrial activities have expanded in proximity to residential areas. Such a long-term perspective is essential for identifying trends, anticipating future risk trajectories, and grounding climate-resilient planning in robust historical evidence rather than reactive, short-term measures. Data from the World Meteorological Organization (WMO) recommends that the climate analysis period must be long enough with a minimum of 30 years, to reveal true climate trends rather than short-term weather fluctuations hence the 35-year baseline for this reason 35 years. This timeframe allows for capturing representative monthly and seasonal

risk analysis, and GIS-based vulnerability mapping for spatial hazard assessment (UN-Habitat, 2015; Sverdlik & Walnycki, 2017). A comparative framework is employed to analyze conditions during the pre-SPA period (circa 2017) against the with-SPA implementation phase (2024), enabling the identification of spatial, infrastructural, and environmental transformations attributable to integrated planning interventions.

To ensure accuracy and local relevance, the geospatial analyses are ground-truthed through community-generated hazard maps and participatory planning records, which capture residents' lived experiences and perceptions of environmental risk. The research specifically addresses three primary hazards—flooding and urban heat—assessing the extent to which SPA-driven interventions, including infrastructure upgrades, green space restoration, and solid waste management reforms, have mitigated exposure and strengthened adaptive capacity in the settlements of Mukuru Kwa Njenga (KKN), Mukuru Kwa Reuben (KKR), and Viwandani (VWD) as indicated in **Map 1** above (Nairobi City County Government, 2017).

2. Climate Risks and Vulnerabilities in Mukuru

Mukuru faces a convergence of climate-related risks arising from its hazard-prone location, environmental degradation, and structural socio-economic inequalities. Situated partly along the flood-prone riparian zones of the Ngong River and adjacent to Nairobi's industrial area, the settlement is exposed to recurrent flooding as shown in **Figure 1** below, urban heat island (UHI) effects, and water pollution (UN-Habitat, 2015; Kenya Meteorological Department, 2018). **Figure 1** shows historical flood events from 2018 that were experienced during the annual long rainy seasons between March and April every year, that displaced thousands of households, contaminated water supplies, and triggered outbreaks of waterborne diseases, including cholera (Kenya Red Cross Society, 2018). Heat stress is exacerbated by densely packed, poorly ventilated housing—often constructed from corrugated metal sheets—with local surface temperatures observed to be 4°C - 8°C higher than peri-urban reference zones (Sverdlik, 2011).

These environmental hazards are intensified by acute socio-economic vulnerabilities. Population densities in Mukuru approach 50,000 persons/km², limiting safe evacuation during emergencies and heightening public health risks (Lines & Makau, 2017). Insecure land tenure discourages investment in durable, climate-resilient housing, while inadequate service provision leaves over 70% of households without proper drainage and fewer than 20% with secure waste disposal systems (Amnesty International, 2009). Despite the 2017 designation of Mukuru as a Special Planning Area (SPA) intended to promote integrated upgrading, adaptive capacity remains constrained by governance fragmentation, poverty, and limited institutional resources (Nairobi City County Government, 2017). The settlement's risk profile is multi-dimensional, encompassing natural hazards (floods, droughts, extreme heat events), technological hazards (industrial effluents, unsafe

energy sources, unreliable infrastructure), and socio-economic hazards (tenure insecurity, unemployment, political marginalization) (Pamoja Trust, 2020).



Figure 1. House location in vulnerable setting (Source: CGN, 2023).

These climate risks are dynamic, influenced by rapid urban expansion, industrial growth, and changing weather patterns. Downscale climate projections forecast a 25% increase in heavy rainfall days and a mean temperature rise of up to 2°C by 2050 (IPCC, 2022). Addressing these challenges requires long-term, evidence-based strategies. A 35-year time series analysis of spatial, environmental, and socio-economic data is critical to understanding how Mukuru's exposure, sensitivity, and adaptive capacity have evolved over time. This historical insight is essential for identifying risk trajectories, evaluating the effectiveness of past interventions, and designing targeted, climate-resilient spatial planning measures that anticipate future hazards rather than reacting to them (Dodman et al., 2017).

3. Methodology

This paper adopted a mixed-methods research design, combining spatial analysis, environmental modeling, and participatory mapping to evaluate the effects of the Mukuru Special Planning Area (SPA) on climate resilience outcomes. The approach integrated qualitative inputs from community-generated hazard maps with quantitative modeling techniques, including Geographic Information Systems (GIS), hydrological flood simulations, and remote-sensing-based thermal analysis (KNBS, 2019; Nairobi City County Government, 2017). The Mukuru Integrated Development Plan v2 provided geospatial layers detailing proposed infrastructure upgrades, including road networks, drainage systems, and designated green corridors (Global Center on Adaptation, 2022). Participatory hazard maps compiled by Muungano wa Wanavijiji in 2018 and 2020 identified community-perceived risk zones, including flood-prone areas, urban heat hotspots, and solid waste accumulation points (Muungano Alliance, 2019). These maps were digitized and spatially referenced for integration with remote sensing analyses.

Remote Sensing Imagery was used with Multi-temporal satellite datasets em-

ployed to monitor land cover changes and environmental conditions. These included the Landsat 7 ETM+ (30 m) and Landsat 8 OLI/TIRS (30 m) for deriving vegetation and built-up indices and the Sentinel-2 MSI (10 m) imagery for high-resolution validation of land cover classifications (U.S. Geological Survey, 2025a). Rainfall and Hydrological modeling utilized a 100 mm, 24-hour design storm provided by the Kenya Meteorological Department, in line with UN-Habitat drainage design standards (UN-Habitat, 2010). Benchmarking Dataset was done to align resilience performance metrics, the Brisbane FloodSmart Future Strategy Key Performance Indicators (KPIs) were used as a benchmarking framework (Kenya Meteorological Department, 2020). Three spectral indices were computed using standard band combinations for Landsat datasets, following the U.S. Geological Survey (USGS) methodology (U.S. Geological Survey, 2025b).

1) NDVI (Normalized Difference Vegetation Index): $NDVI = \frac{NIR - RED}{NIR + RED}$.

a) Landsat 8 Bands: NIR = Band 5, RED = Band 4;

b) Landsat 7 Bands: NIR = Band 4, RED = Band 3.

2) NDBI (Normalized Difference Built-up Index): $NDBI = \frac{SWIR - NIR}{SWIR + NIR}$.

a) Landsat 8 Bands: SWIR = Band 6, NIR = Band 5;

b) Landsat 7 Bands: SWIR = Band 5, NIR = Band 4.

3) NDWI (Normalized Difference Water Index): $NDWI = \frac{GREEN - NIR}{GREEN + NIR}$.

a) Landsat 8 Bands: GREEN = Band 3, NIR = Band 5;

b) Landsat 7 Bands: GREEN = Band 2, NIR = Band 4.

4) Land Surface Temperature (Mono-window algorithm, simplified): $LST = a \cdot Tb + b \cdot LST$. Where, Tb is the brightness temperature, a , b are regression coefficients based on emissivity and atmospheric conditions (European Space Agency, 2015).

Raster calculations were conducted using QGIS, ArcGIS, and Google Earth Engine (GEE) for multi-temporal dataset processing and analysis. Hydrological Flood Risk modeling used a 5 meter Digital Elevation Model (DEM) derived from stereo satellite imagery was utilized to delineate micro-catchments. HEC-RAS 1D simulations were performed to model pluvial flooding under a 10-year return period storm event (Kenya Meteorological Department, 2018). Population-weighted flood exposure was computed from depth rasters, applying a 0.3 m threshold as the minimum inundation depth associated with residential structural damage. Land Surface Temperature (LST) values were extracted from Landsat 8 imagery using the mono-window algorithm, enabling spatial mapping of thermal conditions. Normalized Difference Vegetation Index (NDVI) and Normalized Difference Built-up Index (NDBI) were integrated to classify urban land cover into three categories: vegetated, impervious, and mixed surfaces (Kenya Meteorological Department, 2020). Areas with $LST > 34^\circ C$ were designated as high-risk heat zones, following UNICEF child vulnerability thresholds (UNICEF, 2019).

4. Results

The empirical findings from the spatial analysis and quasi-experimental simulations compared *pre-SPA* and *with-SPA* scenarios across Mukuru's three sub-settlements: Mukuru Kwa Njenga (KKN), Mukuru Kwa Reuben (KKR), and Viwandani (VWD). Results were organized around two primary climate resilience indicators—flood exposure reduction and heat-stress mitigation.

4.1. Flood Exposure Reduction

The HEC-RAS 1D hydrological simulations for a 10-year return period storm (100 mm in 24 hours) demonstrated a notable decrease in flood hazard under the *post-SPA* scenario. Implementation of 720 m of primary drainage channels and slope-aligned secondary drains resulted in an overall 27% reduction in flood-prone surface area compared to the *pre-SPA* baseline as shown in **Table 1** (UN-Habitat, 2015).

Table 1. Flood exposure reduction across 3 villages.

Settlement	Pre-SPA Flooded Area (ha)	With-SPA Flooded Area (ha)	% Reduction	Population Protected
KKN	18.4	13.3	27.7	4,782
KKR	21.7	15.8	27.2	5,009
VWD	16.2	11.7	27.8	3,433

Source: Field Survey, 2025.

Across all villages, flood exposure declined by approximately 27%, protecting over 13,200 people residing in riparian zones exceeding the 0.3 m inundation depth threshold, corresponding to the residential structural damage benchmark (Muungano Alliance, 2019).

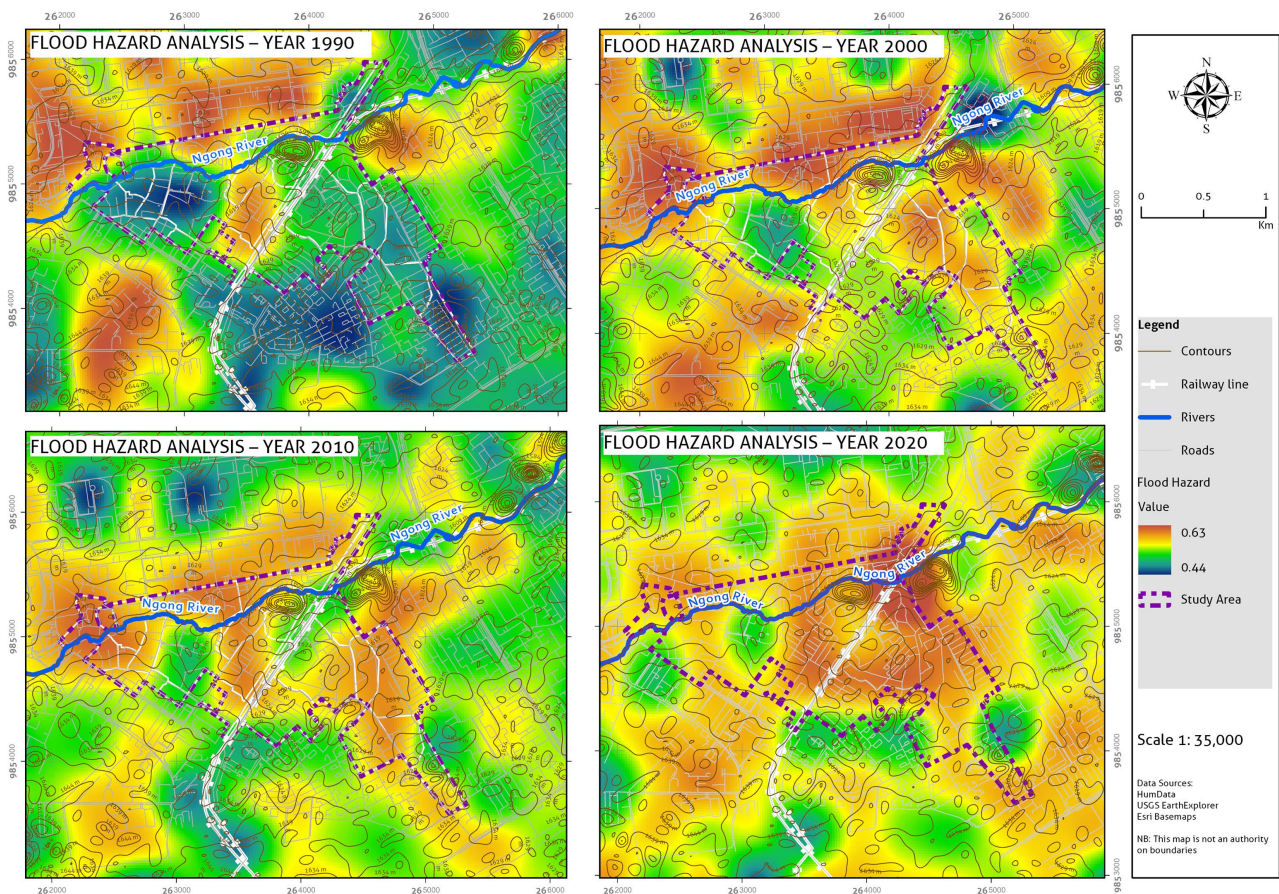
The population comprised approximately 1800 households spread across the 3 villages with a household size ranging from 7 - 8 members. The most positively affected settlements were KKR and VWD with approximately 975 and 650 households respectively. The most significant improvements occurred near newly constructed trunk sewers in KKR (UN-Habitat, 2015; Kenya Meteorological Department, 2018). To include river proximity as a flood hazard factor, the river shapefile was converted into a feature layer. Euclidean distance from each cell to the nearest river was computed using the EucDistance tool, generating a continuous distance raster (Gupta et al., 2022).

Raster Normalization—All continuous hazard factors were normalized to a 0 - 1 scale to allow for weighted overlay. A custom function calculated $(\text{value} - \text{min}) / (\text{max} - \text{min})$ for each raster. The following were factors normalized:

- 1) Flow accumulation-kept as is (higher accumulation = higher hazard).
- 2) Distance to river-inverted $(1 - \text{normalized distance})$ so closer proximity means higher hazard.
- 3) Slope-inverted $(1 - \text{normalized slope})$ so flatter areas mean higher hazard.

4) NDVI-inverted ($1 - \text{normalized NDVI}$) so low vegetation density means higher hazard. NDBI: kept as is (higher built-up index = higher hazard).

5) The process produced-Preprocessed hydrological layers (filled DEM, flow direction, flow accumulation), Normalized hazard factor rasters and Continuous flood hazard index raster. It further classified flood hazard maps as (low, medium, high zones) ready for visualization and further spatial analysis as shown in **Table 2**, **Map 2** and **Map 3** below.



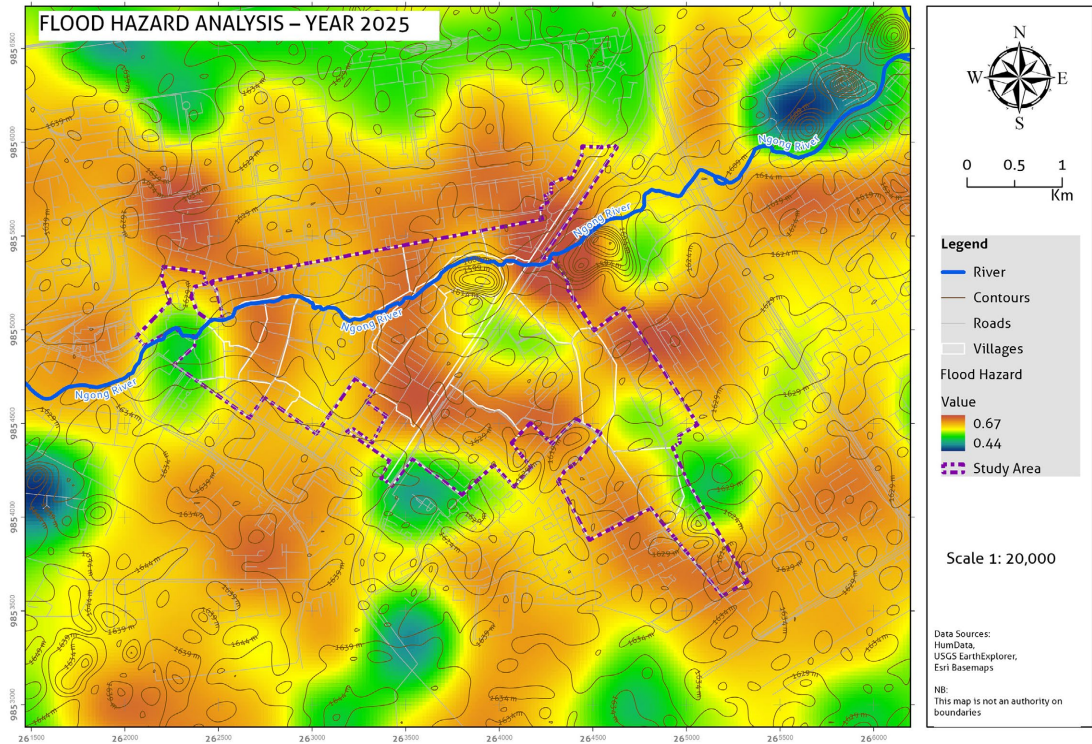
Source: Field Survey, 2025.

Map 2. Flood risk time series for 1990, 2000, 2010 and 2020.

Table 2. Flood risk trends for 1990, 2000, 2010, 2020 and 2025.

Year	Min	Max	Mean	Std Dev
1990	0.456	0.602	0.506	0.028
2000	0.503	0.658	0.559	0.014
2010	0.479	0.665	0.533	0.018
2020	0.436	0.629	0.499	0.032
2025	0.436	0.609	0.518	0.028

Source: Field Survey, 2025.



Source: Field Survey, 2025.

Map 3. Flood risk time series for 2025.

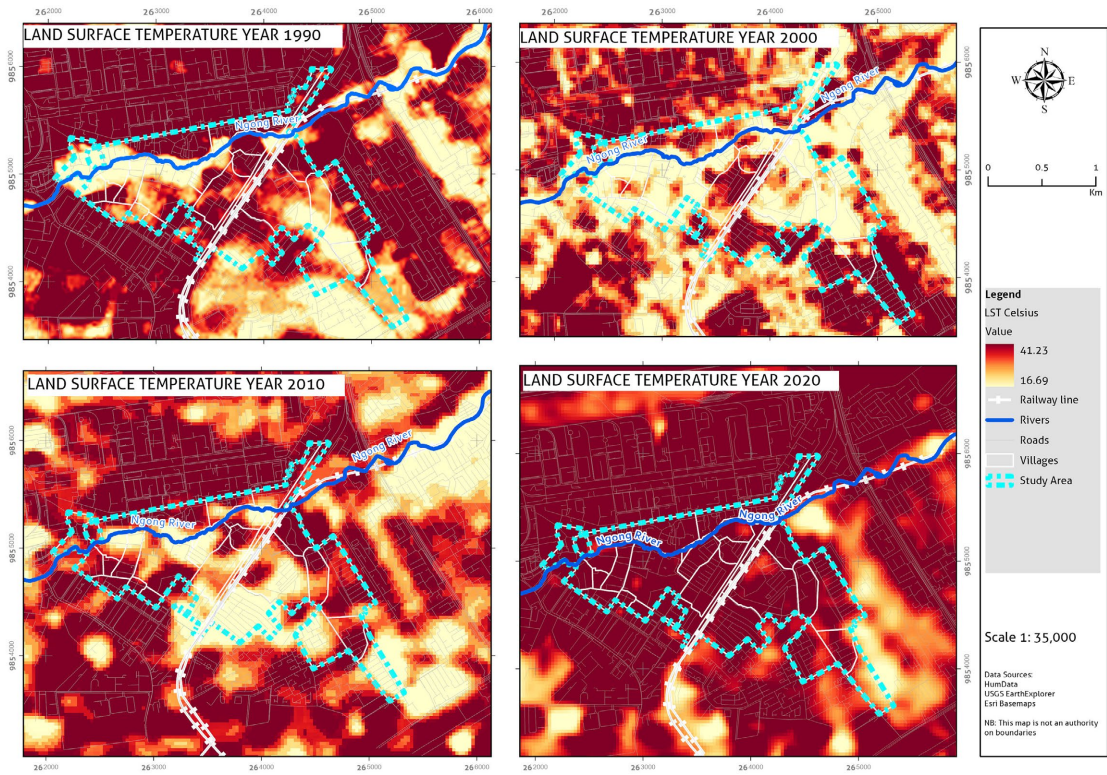
4.2. Heat-Stress Mitigation

Table 3 and Table 4 show Landsat 8-derived LST and NDVI indices, with the thermal classification revealing substantial spatial gains in vegetated cover and shading. Under the SPA scenario, tree-planting programs, reflective roof coatings, and pocket parks reduced high-risk heat zones (>34 °C) by 23% overall (Lines & Makau, 2017). Map 4 and Map 5 show the spatial distribution.

Table 3. Heat stress trends for 1990, 2000, 2010, 2020 and 2025.

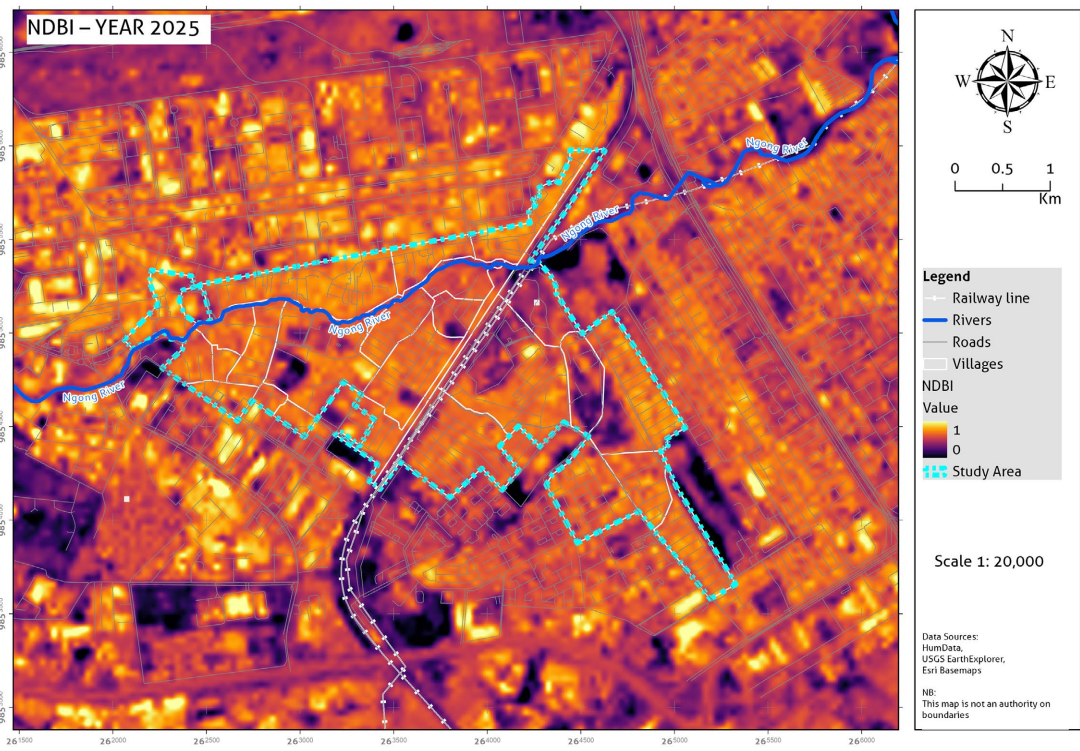
Year	Min (°C)	Max (°C)	Mean (°C)	Std. Deviation (°C)
1990	16.6949	32.5902	25.6190	1.6721
2000	22.3103	41.2310	34.1944	1.7646
2010	21.3748	33.4887	29.0794	1.8067
2020	23.9933	36.8756	29.6340	2.4901
2025	23.5399	36.3657	30.2868	1.5856

VWD saw the greatest percentage reduction in heat-stressed areas. This is attributed to adoption of better building materials like masonry, concrete on roof slabs as compared to iron sheet roof, Glass and steel on doors and wider window openings as compared to KKR and KKN still Masonry is found to have less surface reflectance as compared to Iron sheets leading to a recording of reduced surface temperatures. However, absolute high temperatures still exceed 36.37 °C in certain dense clusters of all the 3 villages (Global Center on Adaptation, 2022).



Source: Field Survey, 2025.

Map 4. Heat waves time series for 1990, 2000, 2010 and 2020.



Source: Field Survey, 2025.

Map 5. Heat waves time series for 2025.

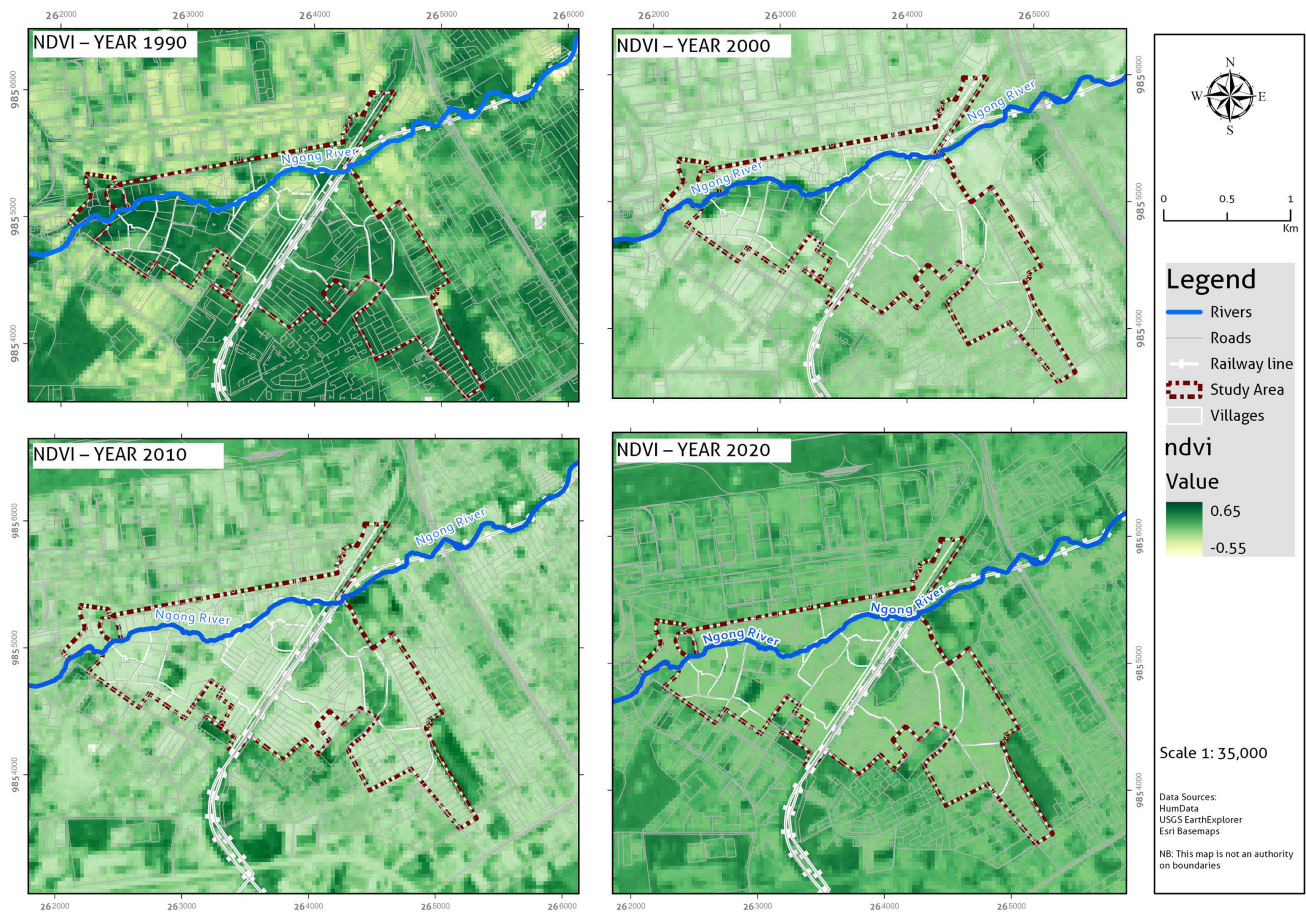
Table 4. Heat wave across the 3 Villages.

Settlement	High Heat-Stress Area (Pre-SPA, ha)	High Heat-Stress Area (With-SPA, ha)	% Reduction
KKN	26.8	21.2	20.9%
KKR	31.4	24.0	23.6%
VWD	22.1	16.6	24.9%

Source: Field Survey, 2025.

4.3. Normalized Difference Vegetative Index (NDVI)

NDVI change detection was performed through pixel-wise subtraction between NDVI rasters of consecutive years (e.g., 2000-1990, 2010-2000). **Table 5** indicates Positive Values showing vegetation gain (regeneration or new greening) while Negative Values indicate vegetation loss (built-up expansion or degradation). Across all years, the minimum value is -0.5464 and the maximum value is 0.6479 . **Map 6** and **Map 7** show the spatial distribution.



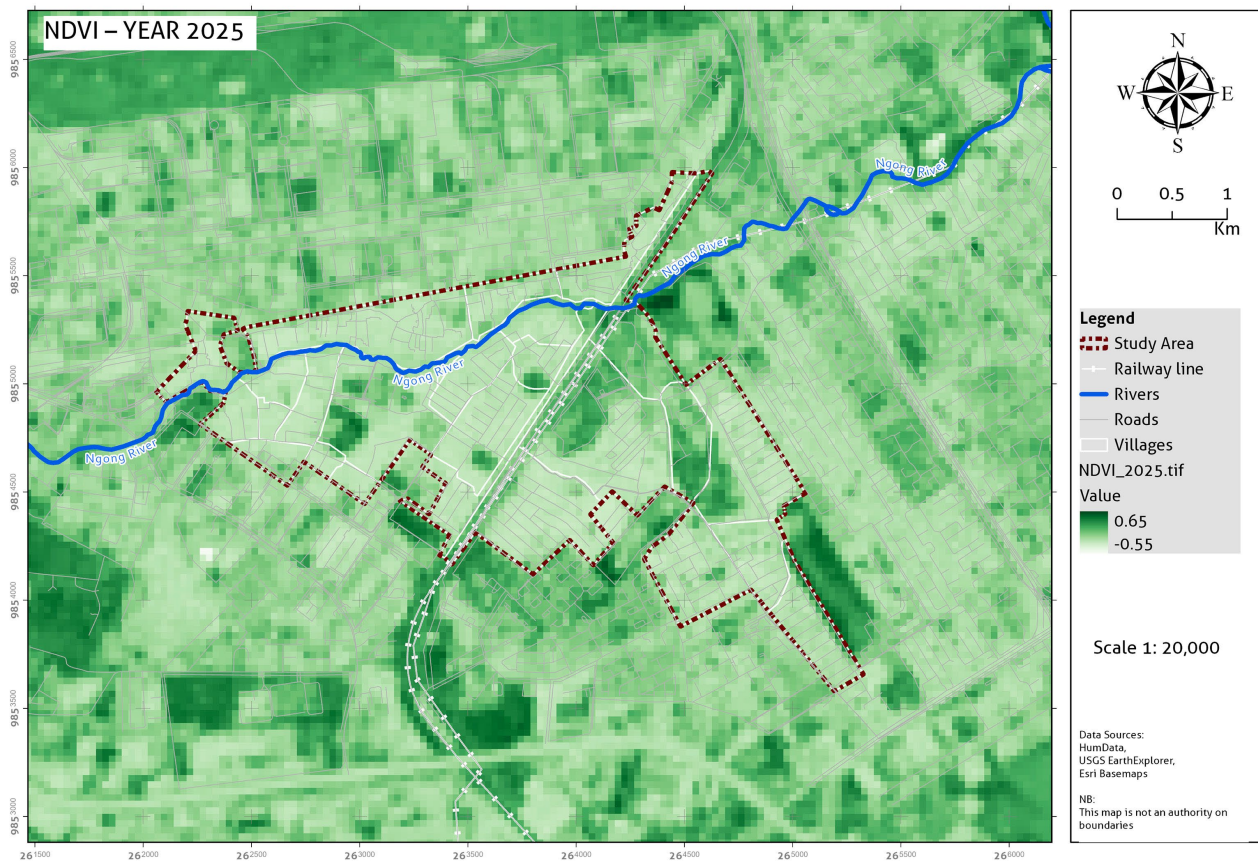
Source: Field Survey, 2025.

Map 6. NDVI dataset for 1990, 2000, 2010 and 2020.

Table 5. NDVI dataset for 1990, 2000, 2010, 2020 and 2025.

Year	Min	Max	Mean	Std. Deviation
1990	-0.3708	0.6479	0.3058	0.1456
2000	-0.5464	0.3371	-0.1859	0.0723
2010	-0.2326	0.4769	0.0724	0.0660
2020	-0.2160	0.5185	0.2084	0.1134
2025	-0.1482	0.5147	0.1827	0.0891

Source: Field Survey, 2025.



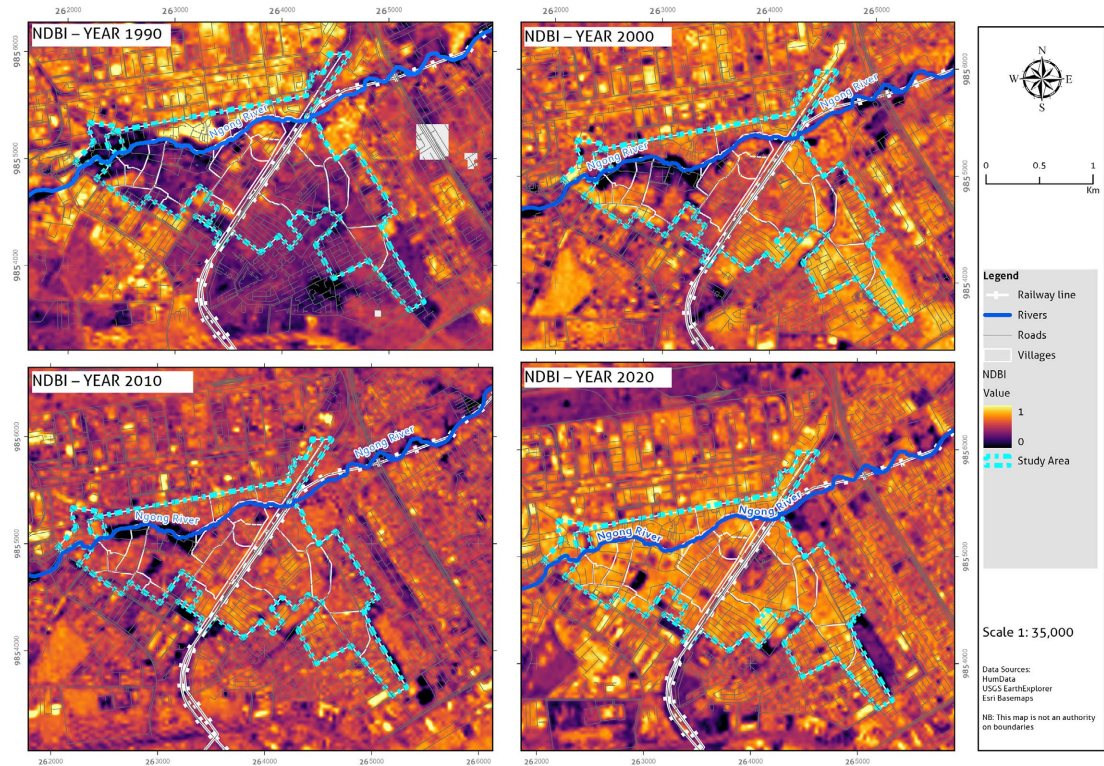
Source: Field Survey, 2025.

Map 7. NDVI dataset for 2025.

4.4. Normalized Difference Built Up Index (NDBI)

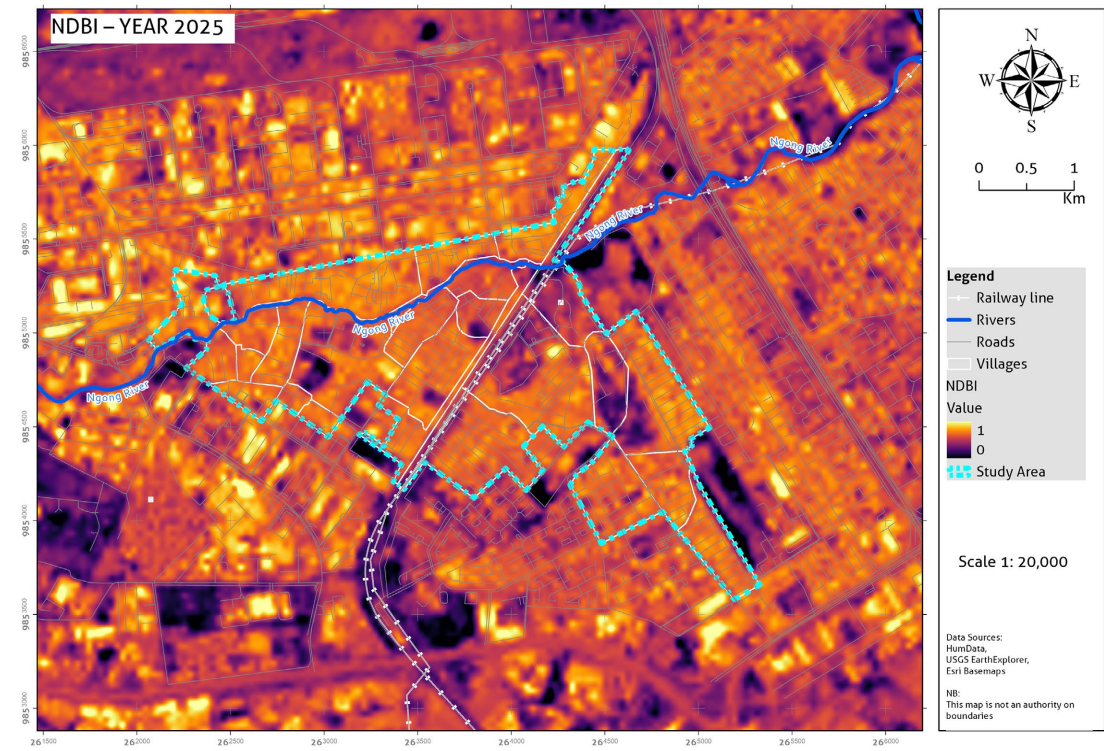
The Normalized Difference Built-up Index (NDBI) was calculated to identify and analyze built-up areas using multispectral Landsat imagery. The method utilizes the spectral characteristics of built-up surfaces in the shortwave infrared (SWIR) and near-infrared (NIR) bands. Higher NDBI values indicate a greater likelihood of built-up surfaces (concrete, asphalt, rooftops).

Spatial changes in NDBI between years were interpreted as indicators of urban expansion or transformation as shown in **Map 8**, **Map 9** and **Table 6** below.



Source: Field Survey, 2025.

Map 8. NDBI dataset for 1990, 2000, 2010 and 2020.



Source: Field Survey, 2025.

Map 9. NDBI dataset for 2025.

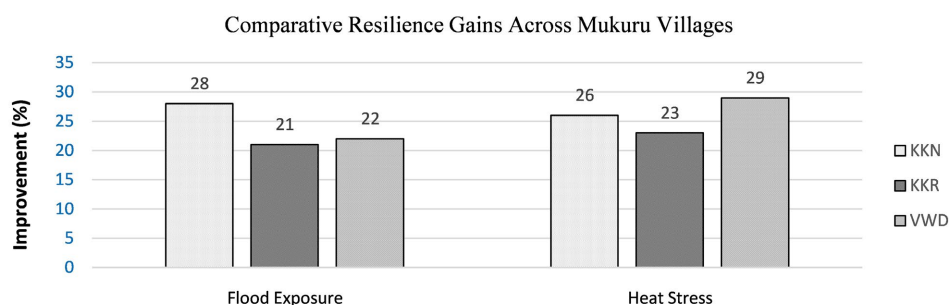
Table 6. NDBI dataset for 1990, 2000, 2010 and 2020.

Year	Min	Max	Mean	Std. Deviation
1990	0.000000000	0.837386012	0.517976527	0.067737933
2000	0.025723301	0.880037606	0.674948123	0.050226359
2010	0.291607291	1.000000000	0.665564764	0.050120715
2020	0.097617008	0.781046331	0.382481306	0.070261551
2025	0.088513598	0.706597805	0.391889695	0.054451491

Source: Field Survey, 2025.

4.5. Comparative Resilience Gains across Indicators

When comparing the two key resilience indicators—extreme temperature exposure and flood risk—Viwandani (VWD) emerged as the most consistently resilient zone, showing strong capacity for heat mitigation and moderate improvements in flood risk reduction. In contrast, from **Figure 2**, Mukuru Kwa Reuben (KKR), which initially exhibited the highest vulnerability on both fronts, recorded the most substantial overall gains, particularly in lowering exposure to extreme temperatures and significantly reducing flood-related risks (Nairobi City County Government, 2017).



Source: Lines & Makau, 2017.

Figure 2. Comparative Resilience gains for the 3 villages.

5. Discussions, Recommendations and Conclusions

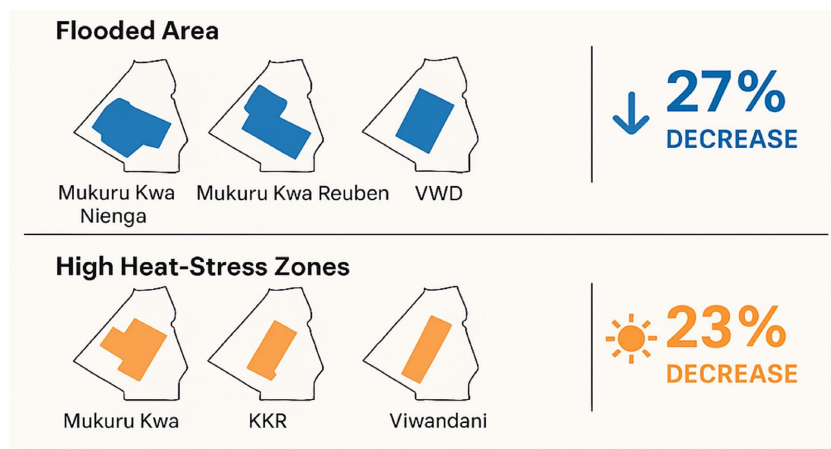
5.1. Discussions

This 35-year longitudinal analysis reveals that integrated spatial planning under the Mukuru Special Planning Area (SPA) has delivered measurable improvements in climate resilience across Nairobi's most vulnerable informal settlements. Empirical results show a 27% reduction in modeled flood exposure and a 23% decrease in high heat-stress zones, confirming that spatially targeted and participatory planning can yield substantial resilience gains even in high-density, low-income contexts. These improvements were primarily achieved through the combination of upgraded drainage systems, green infrastructure, reflective roofing, and targeted pollution source management, all coordinated within a multi-sectoral, community-driven governance framework (Nairobi City County Government,

2017; Lines & Makau, 2017).

The observed decline in flood exposure across Mukuru Kwa Njenga (KKN), Mukuru Kwa Reuben (KKR), and Viwandani (VWD) aligns closely with international evidence linking nature-based drainage systems and formalized stormwater infrastructure to reduced urban flood risks (IPCC, 2022; Dodman et al., 2017). According to the IPCC (2022), sustainable urban drainage systems (SUDS) and integrated catchment management enhance adaptive capacity by restoring ecological functions while mitigating hazard exposure in flood-prone cities. The results from Mukuru corroborate these global findings—showing that drainage and slope-sensitive designs can function effectively even in spatially constrained settlements. The 27% average reduction in flood-prone surface area, as shown in **Table 1**, provides quantitative evidence that well-engineered drainage networks—when integrated with local terrain and hydrology—can yield equitable hazard mitigation benefits across multiple villages, not only in pilot areas. This confirms Pamoja Trust’s (2020) and Sverdlik & Walnycki (2017)’s findings that small-scale, decentralized drainage interventions can collectively transform informal settlement resilience when implemented under an inclusive planning framework.

Similarly, the thermal comfort improvements as shown in **Figure 3**, observed—particularly the 24.9% reduction in heat-stressed zones in Viwandani (VWD)—underscore the efficacy of urban greening and reflective materials as adaptive cooling strategies. Literature consistently supports this outcome: Amnesty International (2009) and Lines & Makau (2017) highlight that vegetation and improved roofing materials substantially lower localized surface temperatures in informal neighborhoods where conventional cooling technologies are absent. The inclusion of pocket parks, shade trees, and reflective roofing in the Mukuru SPA framework has thus mitigated the urban heat island (UHI) effect even in areas with minimal baseline vegetation cover. This mirrors global evidence from UN-Habitat (2015) and Gupta et al. (2022), who found that community-led greening initiatives and cool roofing programs reduce heat exposure while improving public health outcomes.



Source: Lines & Makau, 2017.

Figure 3. Visual summary of spatial resilience assessment across Mukuru Villages.

Moreover, the results affirm that multi-hazard resilience—addressing both flooding and heat stress—can be achieved within a single integrated spatial planning framework rather than through fragmented, sector-specific projects. This supports the argument by [UN-Habitat \(2020\)](#) that urban resilience is maximized when infrastructure, social inclusion, and environmental management are addressed synergistically. The Mukuru SPA exemplifies this approach: it integrates community mapping ([Muungano Alliance, 2019](#)), participatory design, and data-driven decision-making to identify local hazard zones and co-produce solutions. This approach aligns with the [Global Center on Adaptation \(2022\)](#), which emphasizes locally led adaptation as a cornerstone for climate resilience in informal settlements.

For policymakers and urban planners, the Mukuru experience demonstrates that aligning public infrastructure investments with community-generated spatial data can produce measurable resilience dividends and foster social inclusion. [UN-Habitat \(2015\)](#) argues that co-production between government and community groups enhances both the efficiency and legitimacy of urban resilience initiatives. The 27% and 23% hazard reductions recorded in Mukuru therefore provide empirical backing for scaling integrated, participatory spatial planning across other high-risk informal settlements in Sub-Saharan Africa. Finally, for funding agencies, the findings underscore the importance of long-term financing mechanisms that sustain drainage maintenance, vegetation management, and data-driven monitoring beyond donor project cycles—echoing recommendations from [Muungano Alliance \(2019\)](#) and [Nairobi City County Government \(2024\)](#).

In summary, this study provides robust evidence that inclusive, spatially targeted urban planning, when supported by participatory governance and geospatial analysis, can produce transformative improvements in climate resilience. The Mukuru SPA stands as a replicable model demonstrating how local-level interventions—if well-coordinated and scientifically grounded—can yield long-term, equitable adaptation outcomes in rapidly urbanizing African cities.

5.2. Study Recommendations

To build on the progress made through the Mukuru Special Planning Area (SPA) initiative and address remaining climate resilience gaps, three core recommendations are proposed. First, spatial inequalities in resilience outcomes must be addressed by prioritizing infrastructure investments in the most vulnerable areas, particularly Mukuru Kwa Njenga (KKN), where exposure to flooding and extreme temperatures remains significant. Findings from the International Growth Center agree with this report that where policymakers are content to retain land under residential use, participatory in-situ slum upgrading is a cost-effective solution that can enable informal settlements to incrementally transform into poor but highly livable neighbourhoods, integrating the city's low-income workforce into the urban fabric ([Flood Risk Management Unit, 2022](#)). It further reports that where informal settlements are located on land that is either unsafe for habitation or needed for vital urban infrastructure, resettlement may be necessary. This so-

lidifies the need to either relocate residents from riparian reserves and other vulnerable areas or strengthen infrastructural interventions (Fransen et al., 2024).

Second, the integration of participatory spatial planning tools into formal urban governance structures is essential (Nairobi City County Government, 2017). The Mukuru SPA's success demonstrates the value of community-generated data, thematic consortia, and open GIS platforms in delivering inclusive and adaptive urban planning. Nairobi County should institutionalize these tools and processes, embedding them within its planning frameworks to ensure continuity and scalability. Community-based organizations (CBOs) should continue to play a central role in co-producing spatial knowledge and monitoring implementation to maintain accountability and local ownership. This agrees with the idea that community resilience is a dynamic process and that these dynamics are not necessarily reflecting community needs but may instead reflect adaptive capacities of CBOs and their networks (Mwangi, 2022). The ability to sustain adaptive activities is associated with a strong endogenous capacity as well as exogenous bonding capacity.

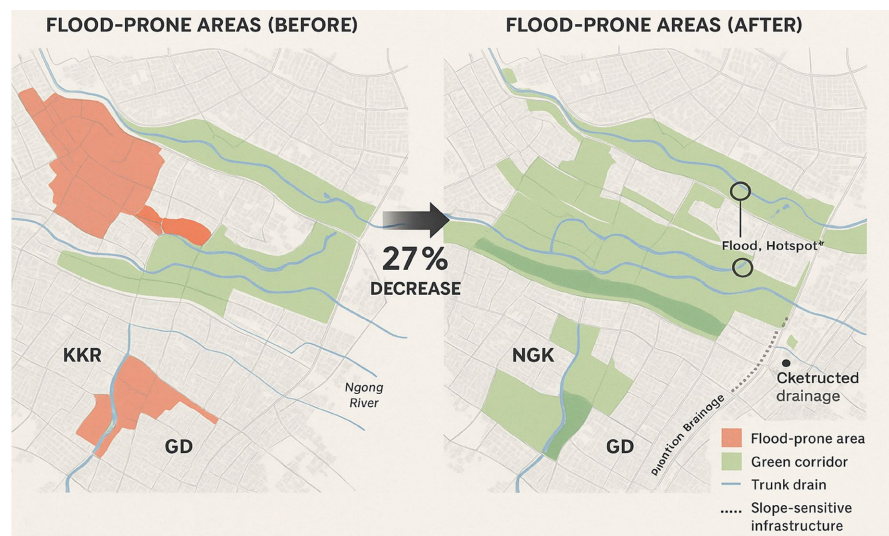
Developing localized adaptation sub-plans tailored to each village's unique risk profile can ensure that interventions respond effectively to micro-level environmental challenges. These plans should be informed by high-resolution spatial data and community-led assessments to capture nuanced hazards that may be missed by satellite imagery alone. The Global center for adaptation in its study on locally led adaptation measures in Mukuru reports that you cannot plan without the people, if you plan without the people, you are planning to fail. Therefore, the community coordination consortium comprised of AMT, Muungano wa Wanavijiji (MWW) and Slum Dwellers International-Kenya (SDI-K) had to work closely with Mukuru residents to mobilize people to attend more than 250 neighborhood planning forums and 114 formal consultation meetings held by the different planning consortia (Flood Risk Management Unit, 2022). This solidifies the argument that Participatory planning lead to locally-appropriate planning standards that make sense in the context of the vulnerabilities and resource constraints in such settlements.

Finally, to sustain and replicate the gains made through the SPA, long-term financing and policy alignment are critical. Establishing a dedicated fund for the maintenance of climate-resilient infrastructure—such as drainage systems and green corridors—will help preserve functionality beyond the lifespan of donor support. Moreover, aligning local interventions with national climate and urban development policies can strengthen coordination across sectors and levels of government (Nairobi City County Government, 2017). By embedding resilience metrics into official performance indicators, Nairobi County can institutionalize continuous monitoring and ensure that resilience-building remains a core element of urban development. The UN-Habitat reports that Urban policy and legislation are key in promoting sustainable informal settlements transformation by enabling institutions and creating mechanisms for cities to unlock funds for services and infrastructure in deprived areas (Collier et al., 2019). For instance, the Special Zones of Social Interest (ZEIS) established by the City Statute, Federal law in Brazil, enabled the recognition of land occupations that were a key entry point

to land regularization and adaptation of planning and infrastructure standards to existing settlement patterns that avoided mass displacement. Strong policy frameworks from government institutions, therefore, are important to build equitable and resilient urban futures as part of an effective city wide planning.

5.3. Study Conclusion

This study provides compelling evidence that integrated spatial planning anchored in participatory processes and geospatial analysis—can significantly enhance climate resilience in informal settlements. Through a longitudinal, 35-year assessment of Nairobi’s Mukuru Special Planning Area (SPA), as shown in **Map 10**, the research quantified the impacts of targeted infrastructure and environmental interventions on flood risk and urban heat exposure. Key findings indicate a 27% reduction in flood-prone surface area, protecting over 13,200 residents across Mukuru Kwa Njenga (KKN), Mukuru Kwa Reuben (KKR), and Viwandani (VWD), settling along the riparian reserve who had to be relocated. Thermal analysis revealed a 23% decrease in high heat-stress zones ($>34^{\circ}\text{C}$), with Viwandani achieving the highest reduction at 24.9%, primarily due to early implementation of green corridors and shaded public spaces.



Source: Lines & Makau, 2017.

Map 10. Flood prone areas before and after SPA status.

Notably, while all three villages recorded resilience gains, the outcomes varied spatially. KKR, despite being the most vulnerable initially, recorded the highest marginal improvements, while Viwandani maintained consistent resilience performance due to its proactive planning and strong community-based engagement. These disparities underscore the importance of spatially differentiated interventions, guided by localized risk assessments and community participation (Mwangi, 2022).

In summary, the Mukuru SPA showcases a replicable model for climate adaptation in informal urban areas. By integrating high-resolution spatial diagnostics,

community-led mapping, and thematic infrastructure planning, it is possible to deliver measurable, equitable improvements in urban resilience. Scaling such approaches across other at-risk settlements in Sub-Saharan Africa offers a transformative pathway toward inclusive, climate-resilient urban futures.

Limitations of the Study

Several methodological and contextual constraints limit the interpretation of this study's findings. First, while remote-sensing imagery enables robust longitudinal analysis, it may not accurately capture micro-scale shading or cooling interventions—such as verandas, shade nets, or informal tree planting—that influence localized heat stress. Second, the modeling framework assumes full implementation of SPA interventions as stipulated in the *Mukuru Integrated Development Plan v2*, which may result in overestimation of resilience benefits if planned infrastructure upgrades are only partially delivered (Nairobi City County Government & UN-Habitat, 2021). The scope of solutions implemented didn't fully cover SPA solutions since some solutions were never implemented owing to a change of political leadership. Third, the analysis does not incorporate functional performance metrics, such as long-term drainage maintenance or consistent solid waste collection, which are critical to sustaining adaptation gains.

Acknowledgements

The authors thank the Nairobi City County Government and the Mukuru SPA Consortia for their essential support and for providing access to critical planning documents and geospatial datasets. Appreciation is extended to Muungano wa Wanavijiji for their collaboration in participatory mapping and for sharing community-based insights that greatly enhanced the spatial analysis. The authors also acknowledge the Department of Landscape Architecture and the Department of Construction Management at Jomo Kenyatta University of Agriculture and Technology for their technical guidance. Support from development partners and funding institutions involved in the Mukuru SPA initiative is gratefully acknowledged.

Conflicts of Interest

The authors declare no conflict of interest regarding the publication of this paper.

References

- Amnesty International (2009). *The Unseen Majority: Nairobi's Informal Settlement Dwellers*.
- Collier, P., Glaeser, E., Venables, T., Blake, M., & Manwaring, P. (2019). *Policy Options for Informal Settlements*. International Growth Centre.
- Dodman, D., Leck, H., Rusca, M., & Colenbrander, S. (2017). African Urbanisation and Urbanism: Implications for Risk Accumulation and Reduction. *International Journal of Disaster Risk Reduction*, 26, 7-15. <https://doi.org/10.1016/j.ijdrr.2017.06.029>
- European Space Agency (2015). *Sentinel-2 User Handbook*. ESA.
- Flood Risk Management Unit (2022). *Urban Drainage Design Guidelines for Nairobi City*. Nairobi City County Government.

- Fransen, J., Hati, B., van Stapele, N., Kiriro, S., & Nyumba, R. (2024). Resilience Pathways of Informal Settlements in Nairobi: Stasis, Decline, Adaptation, and Transformation. *The European Journal of Development Research*, *36*, 355-380. <https://doi.org/10.1057/s41287-023-00605-w>
- Global Center on Adaptation (2022). *Locally Led Planning: A Guide for Building Climate Resilience in Urban Informal Settlements*.
- Gupta, S., Sverdlík, M., & Makau, P. (2022). Greening Informal Settlements: Climate Resilience and Health Benefits. *Urban Climate*, *43*, Article ID: 101126.
- Intergovernmental Panel on Climate Change (IPCC) (2022). *Climate Change 2022—Impacts, Adaptation and Vulnerability*. Cambridge University Press. <https://doi.org/10.1017/9781009325844>
- Kenya Meteorological Department (2018). *Nairobi County Climate Risk Profile*. KMD.
- Kenya Meteorological Department (2020). *Rainfall Intensity-Duration-Frequency (IDF) Curves for Kenya*. KMD.
- Kenya National Bureau of Statistics (KNBS) (2019). *2019 Kenya Population and Housing Census*. KNBS.
- Kenya Red Cross Society (2018). *Floods Emergency Response Report: Nairobi County 2018*. KRCS.
- Lines, K., & Makau, J. (2017). *Taking the Long View: 20 Years of Muungano wa Wanavijiji in Kenya*. IIED.
- Muungano Alliance (2019). *Mukuru Special Planning Area: Community Mapping and Data Collection Report*. Muungano wa Wanavijiji.
- Mwangi, A. M. (2022). Pluvial Flood Modeling for Informal Settlements: A Nairobi Case Study. *Journal of Water Resources Planning and Management*, *148*, Article ID: 04022015.
- Nairobi City County Government & UN-Habitat (2021). *Mukuru Special Planning Area: Integrated Development Plan*. NCCG and UN-Habitat.
- Nairobi City County Government (2017). *Mukuru Special Planning Area declaration*. Nairobi City County Gazette Supplement No. 25.
- Nairobi City County Government (2024). *Mukuru Integrated Development Plan (Version 2)*. NCCG.
- Pamoja Trust (2020). *Building Resilience in Informal Settlements: Lessons from Mukuru*.
- Sverdlík, A. (2011). Ill-health and Poverty: A Literature Review on Health in Informal Settlements. *Environment and Urbanization*, *23*, 123-155. <https://doi.org/10.1177/0956247811398604>
- Sverdlík, A., & Walnycki, A. (2017). *Better Cities, Better Health: The Intersection of Urban Planning, Informal Settlements, and Public Health*. IIED.
- U.S. Geological Survey (USGS) (2025a). *Landsat 7 Enhanced Thematic Mapper Plus (ETM+) and Landsat 8 OLI/TIRS Data Products*.
- U.S. Geological Survey (USGS) (2025b). *Landsat Missions*. <https://www.usgs.gov/landsat-missions>
- UN-Habitat (2010). *Informal Settlements and Finance*.
- UN-Habitat (2015). *Nairobi: A City of Cities—Integrating City Plans for a Sustainable Future*.
- UN-Habitat (2020). *World Cities Report 2020: The Value of Sustainable Urbanization*. <https://unhabitat.org>
- UNICEF (2019). *The Impact of Climate Change on Children: Heat Stress and Vulnerability Thresholds*.

Key Terminologies as Used in the Study

Abbreviation	First Mention
SPA	Special Planning Area (SPA)
GIS	Geographic Information System (GIS)
NDVI	Normalized Difference Vegetation Index (NDVI)
NDBI	Normalized Difference Built-up Index (NDBI)
NDWI	Normalized Difference Water Index (NDWI)
LST	Land Surface Temperature (LST)
DEM	Digital Elevation Model (DEM)
IDP	Integrated Development Plan (IDP)
NGO	Non-Governmental Organization (NGO)
CBO	Community-Based Organization (CBO)
UN-Habitat	United Nations Human Settlements Programme (UN-Habitat)
