Urban Expansion and the Urban Flood Paradox: Spatial Dimensions of Climate Vulnerability in Kitui Town, Kenya

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Abstract

Rapid urbanization is transforming the physical and environmental characteristics of towns across sub-Saharan Africa, and poorly planned expansion can increase exposure to climate-related hazards. In arid and semi-arid lands (ASALs), where water resources are scarce and episodic intense rainfall interacts with rapid land-use change, this challenge is acute, yet few studies have integrated spatial, climatic, household, and governance evidence for secondary ASAL towns in Kenya. This study examined the spatial dimensions of urban expansion and their implications for climate vulnerability in Kitui Town, eastern Kenya, between 2005 and 2025. A mixed-methods design was used, combining remote sensing and Geographic Information System (GIS) analysis of Landsat imagery for 2005, 2015, and 2025; climate records for 2000–2025; a household survey of 384 households; 20 key informant interviews; and four focus group discussions. Built-up land increased from 12.18 km² in 2005 to 41.74 km² in 2025 (242.69%), while cropland, wetlands/swamps, and forest declined by 29.02%, 24.31%, and 19.45%, respectively. Mean annual temperature rose from 22.9°C to 24.6°C and was very strongly correlated with built-up expansion (r = .984, R^2 = .969). The study also identified an Urban Flood Paradox, in which flood risk increased despite declining or increasingly erratic rainfall: 83% of households reported increased flash flooding and 71% linked it to the loss of wetlands and natural drainage areas. Governance gaps were evident, as 41.7% of respondents were unaware of zoning regulations and only 10.9% perceived planning policies as consistently enforced. The study concludes that rapid and inadequately regulated urban expansion has intensified environmental and climate vulnerability in Kitui Town by replacing permeable surfaces and ecological buffers with impervious development. It recommends stronger development control, protection of wetlands and riparian areas, GIS-based development monitoring, expanded urban green infrastructure, and the adoption of Sustainable Urban Drainage Systems (SUDS).

Keywords: *urban sprawl, land-use and land-cover change, climate vulnerability, urban heat island, urban flooding, sustainable urban drainage, Kitui Town, Kenya ASALs*

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1.0 Introduction

Urbanization is one of the defining transformations of the twenty-first century, with more than half of the world's population now living in urban areas (United Nations, 2019). Towns and cities concentrate labour, markets, infrastructure, and investment, and can therefore act as engines of regional development. These benefits are not automatic, however. Where expansion outpaces spatial planning, infrastructure provision, and development control, urbanization can generate new forms of vulnerability. The Intergovernmental Panel on Climate Change (IPCC, 2023) identifies urban areas as important sites of both climate risk and adaptation, since changes in the built environment interact with climatic change to increase exposure to heat, flooding, and water scarcity. Urban growth modifies natural drainage, vegetation cover, soil permeability, and local energy balances, so its environmental effects cannot be separated from the spatial form through which it occurs.

Regionally, these challenges are pronounced in sub-Saharan Africa, where urbanization is rapid but planning and infrastructure systems often struggle to keep pace. Many African cities and secondary towns have expanded horizontally into peri-urban farmland, wetlands, and river corridors, replacing natural systems with roads, buildings, and other impervious surfaces. The United Nations Human Settlements Programme (UN-Habitat, 2023) stresses the role of nature-based solutions and ecological systems in strengthening urban climate resilience. In Kenya, Abuje et al. (2020) assessed the vulnerability of Nairobi to the effects of climate change between 1984 and 2016, reflecting growing interest in how urban change shapes climate risk. At a broader level, Nagendra et al. (2018) argue that urban knowledge remains dominated by research from the global north and call for more research on urbanization in the global south.

Locally, Kenya reflects this wider pattern. Although Nairobi and Mombasa have attracted most attention, secondary towns are increasingly important centres of population growth, commerce, and service provision (World Bank, 2023). Devolution under the 2010 Constitution has strengthened county headquarters as administrative and economic hubs, and county investment in offices, roads, markets, and housing can stimulate expansion and alter surrounding land use. Kitui Town, the headquarters of Kitui County in eastern Kenya, lies within an arid and semi-arid environment characterized by high temperatures, variable rainfall, periodic drought, and intense rainfall events. Although the town is not associated with the persistent rainfall of highland areas, intense storms can cause significant flash flooding where drainage channels have been modified, wetlands filled, and impervious surfaces expanded.

This illustrates what the present study terms the Urban Flood Paradox: a situation in which flood vulnerability increases as a result of urban land transformation despite the absence of a corresponding increase in total rainfall. The hydrological response of a landscape depends not only on the quantity of rainfall but also on the condition of the surface that receives, stores, and transports it. Wetlands, vegetation, and agricultural soils absorb and temporarily retain water, whereas concrete, asphalt, rooftops, and compacted soils reduce infiltration and accelerate runoff (McGrane, 2016). Urban expansion may also raise local temperatures, because replacing vegetation and farmland with buildings and paved surfaces increases heat absorption and reduces shading and evapotranspiration, which can produce an Urban Heat Island (UHI) effect. In Kitui, where ambient temperatures are already high, additional warming may heighten thermal stress and the demand for water and cooling, with the heaviest burden falling on low-income households and people living in poorly ventilated buildings.

Despite these concerns, limited empirical attention has been given to the relationship between rapid spatial expansion and climate vulnerability in secondary ASAL towns in Kenya. Existing studies have documented urban growth, climate change, flooding, and environmental degradation separately, but few integrate remote sensing, climate data,

household experiences, and governance factors within a single analytical framework. Kitui Town has expanded markedly over the past two decades into areas that previously supported farming, vegetation, and wetlands, yet the effectiveness of planning in guiding this growth has not been established. The concern is not urbanization itself but the spatial and regulatory manner in which it occurs, because vulnerability can remain hidden during moderate rainfall and become visible only during intense storms.

"Unregulated urban expansion raised flood risk in Kitui Town even as rainfall declined"

The study was guided by Urban Ecology Theory and the climate vulnerability framework associated with the IPCC. Urban Ecology Theory, rooted in the work of Park et al. (1925), conceptualizes the city as a complex ecosystem in which social, economic, institutional, and environmental processes interact to shape spatial development through competition, succession, and spatial differentiation. It is useful for Kitui because decisions on land ownership, infrastructure, investment, and regulation determine where development occurs and which ecological functions are displaced, particularly in peri-urban zones where farmland, vegetation, and housing compete for space. The climate vulnerability framework defines vulnerability in terms of exposure, sensitivity, and adaptive capacity. Within this framework, development in flood-prone areas increases exposure, the removal of wetlands and vegetation increases sensitivity, and weak planning institutions reduce adaptive capacity. Together, the two perspectives guided the study to examine how human decisions about land modify the consequences of climatic trends, rather than treating climate hazards as purely meteorological phenomena.

The main objective of this study was to examine the relationship between urban spatial expansion and climate vulnerability in Kitui Town between 2005 and 2025. Specifically, the study sought to: (i) determine the extent and spatial pattern of land-use and land-cover changes; (ii) examine the relationship between urban expansion and temperature trends; (iii) assess the influence of land-cover change on flood vulnerability; and (iv) evaluate the effectiveness of planning and development control. The findings are intended to help county governments, planners, and environmental managers in secondary ASAL towns integrate climate adaptation into spatial planning.

2.0 Materials and Methods

Research Design

A mixed-methods design was adopted, combining quantitative spatial and climatic analysis with household survey data and qualitative evidence from key informants and focus groups. The design was appropriate because climate vulnerability is both a measurable environmental phenomenon and a socially experienced condition: remote sensing can demonstrate the physical transformation of the landscape, while household and qualitative data show how residents experience heat, flooding, land-use change, and planning practice. The design also allowed triangulation, whereby findings from independent sources were cross-checked to strengthen accuracy and depth.

Study Area and Population

The study was conducted in Kitui Town, the headquarters of Kitui County in eastern Kenya, which lies approximately between 37°55′ and 38°05′ E and 1°15′ and 1°30′ S. The investigation focused on rapidly developing peri-urban areas, namely Kyanika, Wikililye, Syongila, Mutune, and Ithookwe. Kitui lies within Kenya's ASAL zone, with relatively high temperatures, variable rainfall, and occasional intense precipitation capable of generating rapid surface runoff. The town has expanded in response to its growing administrative, commercial, educational, residential, and transport functions, with consequent changes to the surrounding agricultural and ecological landscapes.

Sampling and Sample Size

A descriptive household survey was conducted among 384 households, selected through a multi-stage stratified random sampling procedure that ensured representation of the selected rapidly urbanizing areas. Twenty key informants, including physical planners, environmental experts, and other individuals with knowledge of urban development and environmental management, were purposively selected. Four focus group discussions were also held with residents.

Data Collection

Multi-temporal Landsat imagery for 2005, 2015, and 2025 (Landsat TM, ETM+, and OLI datasets appropriate to the respective periods) was used to examine land-use and land-cover (LULC) change. Image processing was undertaken using ENVI 4.7 and ArcGIS Pro. Supervised classification, comprising image preprocessing, selection of training samples, classification, and post-classification analysis, was used to categorize the landscape into seven LULC classes. Meteorological data for 2000–2025 on mean annual air temperature and rainfall were obtained from the Kitui Meteorological Station.

A questionnaire administered to the 384 households collected information on residents' observations of urban expansion, flooding, temperature change, and environmental degradation, as well as their awareness of planning regulations and perceptions of policy enforcement. Twenty key informants were interviewed, and the four focus group discussions captured residents' accounts of urban expansion, flooding, heat, wetland loss, drainage change, and development practices.

Data Analysis

Changes in the spatial extent of built-up land, cropland, wetlands/swamps, forests, and other land-cover categories between the initial and final periods were calculated to establish the magnitude and direction of landscape transformation. Temperature trends were compared with changes in built-up land, and correlation and regression analysis were used to examine the strength and direction of the relationship. Household survey data were summarized using descriptive statistics. Qualitative data were organized thematically around the major themes that emerged from the spatial and quantitative analyses.

Limitations

This study has some limitations. Correlation does not by itself establish causation, so the relationship between built-up expansion and temperature is interpreted as an association within the study area rather than proof that urban expansion alone caused the observed warming, since temperature is also influenced by regional climate change, atmospheric circulation, vegetation loss, and urban morphology. Household findings rely on residents' perceptions, which may differ from measured conditions. The decline in forest cover was not statistically significant and is interpreted with caution. In addition, the study covers a single secondary town, which may limit generalizability to other ASAL settings.

3.0 Results and Discussion

Land-Use and Land-Cover Change

GIS analysis revealed substantial transformation of the Kitui Town landscape between 2005 and 2025. As shown in Table 1, built-up land expanded from 12.18 km² to 41.74 km², a net increase of 29.56 km² or 242.69%. The largest expansion occurred during 2005–2015, coinciding with increasing investment in, and the changing administrative and economic significance of, county headquarters.

The expansion of built-up land was accompanied by reductions in cropland (from 89.35 km² to 63.42 km²; −29.02%), wetlands/swamps (from 23.90 km² to 18.09 km²; −24.31%), and forest (from 9.05 km² to 7.29 km²; −19.45%). The changes in built-up land, cropland, and wetlands were statistically significant ($p < .001$, $p < .001$, and $p = .032$, respectively), whereas the decline in forest cover was not ($p = .121$) and should be read as indicative only.

Table 1

Land-Use and Land-Cover Changes in Kitui Town, 2005–2025

LULC category	2005 area (km²)	2025 area (km²)	Change (km²)	Change (%)	p-value
Built-up	12.18	41.74	+29.56	+242.69	< .001
Cropland	89.35	63.42	−25.93	−29.02	< .001
Wetland/Swamp	23.90	18.09	−5.81	−24.31	.032
Forest	9.05	7.29	−1.76	−19.45	.121

Note. Percentage change = (2025 area − 2005 area) ÷ 2005 area × 100. The change in forest cover was not statistically significant. Source: Research data (2026).

Urban expansion therefore occurred largely through the conversion of permeable or ecologically productive surfaces. This matters for climate vulnerability because land-cover types perform different environmental functions: croplands and vegetated areas allow some infiltration and provide ecological services, while wetlands temporarily store excess water, slow runoff, and support natural drainage. The spatial findings were supported by household perceptions, as approximately 91% of respondents reported noticeable expansion of urban development within their neighbourhoods. This convergence between remotely sensed evidence and residents' observations strengthens the conclusion that urban expansion has been a prominent feature of Kitui's recent development.

These results are consistent with McGrane (2016), who notes that urbanization can substantially modify hydrological processes through changes in surface permeability, drainage, and runoff. They also respond to the call by Nagendra et al. (2018) for more evidence from urbanizing settings in the global south, to which Kitui adds a secondary ASAL town.

Urban Expansion and the Thermal Environment

Meteorological data showed that mean annual temperature rose from 22.9°C in 2005 to 24.6°C in 2025, an increase of approximately 1.7°C (Table 2). Correlation analysis showed a very strong positive relationship between built-up growth and temperature increase (r = .984; R^2 = .969), and the reported regression estimate suggested a rise of approximately 0.055°C for each additional square kilometre of built-up land.

Table 2

Built-up Expansion and Mean Annual Temperature, 2005–2025

Indicator	2005	2025	Change
Built-up land (km²)	12.18	41.74	+29.56
Mean annual temperature (°C)	22.9	24.6	+1.7

Note. Pearson correlation between built-up land and mean annual temperature: r = .984, R^2 = .969. Estimated increase of 0.055°C per additional km² of built-up land. Temperature data: Kitui Meteorological Station. Source: Research data (2026).

The magnitude of this association is noteworthy, but it should be interpreted carefully because temperature is influenced by multiple factors, including regional climate change, atmospheric circulation, vegetation loss, land-surface characteristics, and urban morphology. The correlation therefore indicates a strong association between urban expansion and temperature change, not that built-up expansion was the sole cause of warming. Nevertheless, the land-cover changes provide a plausible mechanism for localized warming: converting vegetated and open surfaces to buildings and paved areas reduces shading and evapotranspiration while increasing heat storage, which can contribute to an urban heat island effect.

The household findings reinforce this interpretation. Approximately 80% of participants reported that the town had become noticeably hotter, with many attributing the

change to tree removal, increased construction, and the spread of iron-roofed buildings. The thermal implications are particularly significant in an ASAL environment, where residents already experience high temperatures and additional warming may increase thermal stress, energy consumption, water demand, outdoor labour productivity losses, and the uninhabitability of poorly designed buildings. Urban greening can therefore serve as both an environmental and a climate-adaptation strategy: protecting existing vegetation and planting trees along roads and in public spaces, residential areas, schools, and institutional compounds would contribute to shading and evaporative cooling.

The Urban Flood Paradox

A further key finding was the emergence of what this study terms the Urban Flood Paradox. Residents reported increasing flash-flood events even though rainfall was increasingly variable and, during some periods, declining. Table 3 shows that 83% of households had experienced increased flash flooding and that 71% explicitly associated the increase with the loss of wetlands and swamps. This finding shows why flood vulnerability should not be assessed from rainfall totals alone, because the hydrological consequences of rainfall depend on the condition of the receiving landscape. Three mechanisms help to explain the paradox.

Table 3

Household Perceptions of Urban Change, Heat, Flooding, and Planning Enforcement

Perception	Respondents (%)
Noticed urban expansion within their neighbourhood	≈ 91
Reported that the town had become noticeably hotter	≈ 80
Experienced increased flash flooding	83
Associated increased flooding with loss of wetlands and swamps	71
Unaware of zoning regulations	41.7
Perceived planning policies as consistently enforced	10.9

Note. Household survey (N = 384 households). Values for urban expansion and heat are approximate, as reported. Source: Research data (2026).

Mechanism 1: Expansion of Impervious Surfaces

The 242.69% expansion of built-up land substantially increased the proportion of surfaces that do not readily absorb rainfall. Roofs, roads, parking areas, paved compounds, and compacted surfaces rapidly transfer water into drainage channels. Rainfall that would previously have infiltrated the soil or been stored in vegetation and wetlands is therefore converted into surface runoff, and where drainage infrastructure is insufficient, the water accumulates quickly and produces flash flooding. This pattern is consistent with the hydrological effects of urbanization described by McGrane (2016).

Mechanism 2: Wetland Loss

Wetlands declined by 24.31%, from 23.90 km² to 18.09 km². Wetlands function as natural storage areas that absorb and temporarily retain water during heavy rainfall, reducing the speed and volume of runoff reaching downstream areas; when they are filled or built upon, this buffering function is weakened. Focus group participants identified flooded areas as former seasonal drainage or wetland locations on which houses and other structures had since been built. This suggests that some flood events represent the reoccupation of natural drainage pathways rather than entirely new environmental processes.

Mechanism 3: Declining Vegetation Cover

Forest cover declined by 19.45%, although, as noted, this change was not statistically significant and is indicative only. Vegetation contributes to hydrological regulation through interception, infiltration, root development, and soil stabilization, so its loss can increase runoff and erosion, particularly where soils become compacted. The combined effects of wetland loss, vegetation reduction, and impervious-surface expansion create a landscape with a

reduced capacity to absorb and store stormwater.

The paradox therefore arises from the interaction between climate variability and land transformation: even if total annual rainfall does not increase, a more impervious landscape responds to individual storms with faster and larger runoff. For ASAL towns, adaptation should address not only the prediction of rainfall but also how development modifies the pathways through which rainfall becomes flooding.

Governance and Planning Gaps

The study identified a significant gap between planning frameworks and their implementation. Although Kitui County has spatial planning instruments intended to guide development, 41.7% of respondents were unaware of zoning regulations and only 10.9% perceived planning policies as consistently enforced (Table 3). These findings indicate that planning effectiveness involves more than the existence of policies, since regulations require institutional capacity, public awareness, monitoring, enforcement, and administrative commitment.

The study further found that the Physical Planning Department had approximately seven technical staff responsible for a county of about 30,496 km², which limits regular field inspection and development monitoring. Where inspection capacity is limited, unauthorized construction may proceed without timely intervention, particularly in fast-growing peri-urban areas where development outpaces institutional response. Zoning and building regulations are therefore not merely administrative tools but climate-risk management mechanisms, because protecting drainage corridors, wetlands, riparian zones, and open spaces reduces exposure to hazards and preserves ecological functions. Weak enforcement can thus transform a planning problem into a climate-risk problem.

Integrated Findings and Implications

Taken together, the findings show that urban expansion, environmental degradation, climate exposure, and institutional capacity are interconnected. The rise in built-up land cannot be interpreted apart from the decline in wetlands, forests, and cropland; the results indicate a transition from a relatively permeable landscape to a more impervious urban system. This transition can contribute to localized warming, accelerate runoff, and remove natural water-storage capacity, while weak development control allows further construction in sensitive areas and limited public awareness reduces residents' capacity to recognize or challenge inappropriate development.

These processes can form a self-reinforcing vulnerability cycle: expansion creates demand for land and infrastructure, ecological areas are converted to meet it, the resulting landscape is more exposed to heat and flooding, and rising vulnerability generates demand for costly engineered interventions. Climate vulnerability in Kitui Town is therefore not simply an external consequence of global climate change but is partly produced through local decisions about where, how, and under what conditions development occurs. This is consistent with the climate vulnerability framework, in which the changing land surface increases exposure and sensitivity while weak planning capacity constrains adaptive capacity.

The findings also demonstrate the value of integrating remote sensing with community-level evidence: satellite imagery establishes the magnitude of landscape change, whereas household surveys and focus groups reveal how that change is experienced. Their implications extend beyond Kitui, since secondary towns across Kenya and Africa are likely to keep expanding. If growth follows patterns of horizontal sprawl, wetland conversion, inadequate drainage, and weak development control, vulnerability may rise even where towns are not regarded as high-risk flood environments. Planning in ASAL towns should therefore integrate climate adaptation from the outset and treat wetlands, vegetation, and open spaces as components of urban infrastructure rather than as undeveloped land awaiting conversion, in line with the emphasis of UN-Habitat (2023) on nature-based solutions.

4.0 Conclusion

This study examined the spatial dimensions of urban growth and climate vulnerability in Kitui Town between 2005 and 2025. Built-up land increased by 242.69%, from 12.18 km² to 41.74 km², while cropland and wetlands declined significantly by 29.02% and 24.31%, respectively, and forest cover declined by 19.45%, marking a transition from a relatively permeable landscape to an increasingly impervious one. Mean annual temperature rose by 1.7°C and was very strongly associated with built-up expansion (r = .984), although this association should not be read as proof of a single causal mechanism. The study identified an Urban Flood Paradox, in which flood vulnerability increased despite variable and, at times, declining rainfall, explained by impervious-surface expansion, wetland loss, vegetation reduction, and inadequate drainage capacity. The low level of perceived enforcement and the limited awareness of zoning regulations show that urban climate vulnerability is also a governance issue. The study therefore concludes that rapid and inadequately regulated urban expansion is an important amplifier of climate vulnerability in Kitui Town, and that addressing it requires an integrated approach combining spatial planning, ecological conservation, climate adaptation, infrastructure development, public participation, and institutional strengthening. By combining satellite-based analysis, meteorological records, and community-level evidence, the study also offers a more complete picture of urban vulnerability in a secondary ASAL town than any single data source could, and it advances the Urban Flood Paradox as a concept for explaining rising flood risk under stable or declining rainfall.

5.0 Recommendations

Based on the conclusions drawn from the study, the following recommendations are proposed:

1. The County Government of Kitui should progressively adopt Sustainable Urban Drainage Systems (SUDS) as part of urban infrastructure development, including retention ponds, infiltration trenches, permeable pavements, rain gardens, detention basins, and bioswales. These measures slow runoff, increase infiltration, reduce peak flows, and complement conventional drainage, and new public and private developments should incorporate stormwater-management measures appropriate to their scale and location.
2. The remaining 18.09 km² of wetland/swamp area should be identified, mapped, and incorporated into the town's ecological protection framework by the County Government and the relevant environmental authorities, with development in wetlands and natural drainage corridors strictly controlled. Riparian and seasonal watercourse buffer zones should also be mapped and protected in accordance with applicable Kenyan environmental and planning requirements.
3. The County Government should establish an urban greening programme targeting at least 50,000 indigenous and climate-suitable trees by 2030, prioritizing streets, public open spaces, schools, health facilities, markets, residential neighbourhoods, and degraded ecological areas. Tree planting should be accompanied by long-term maintenance arrangements so that survival, not only the number of seedlings planted, is secured.
4. The Physical Planning Department should be adequately staffed and equipped to conduct regular inspections of construction activities, and development approvals should incorporate assessment of drainage, flood exposure, vegetation, and wetland proximity. A GIS-based development-monitoring system should be established to support real-time identification of unauthorized construction and land-use change.
5. Planning authorities should strengthen public awareness of zoning regulations, flood-risk areas, wetland protection, and development requirements, and should incorporate public participation into local planning processes. Community-based

environmental monitoring could complement formal inspection, particularly in rapidly expanding peri-urban areas.

6. Future spatial plans for Kitui and comparable towns should explicitly integrate climate-risk assessments, with flood-prone areas, ecological corridors, wetlands, drainage networks, and heat-sensitive locations mapped and built into development-control decisions, so that climate adaptation is treated as a core component of spatial planning rather than a separate environmental programme.
7. For future research, scholars should extend the analysis to other secondary ASAL towns, add intermediate image dates and rainfall–runoff modelling, and use land-surface temperature data to strengthen causal inference on the thermal effects of urban expansion. Adopting these recommendations would help secondary ASAL towns grow in ways that protect ecological buffers, reduce flood and heat exposure, and build lasting climate resilience.

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