

## ENHANCING URBAN FOOD SECURITY THROUGH CLIMATE-MITIGATION PRACTICES IN LOKOJA, NIGERIA: A SIMULATION-BASED GEOSPATIAL AND MULTI-CRITERIA ASSESSMENT 2000-2025

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### Abstract

Rapid urbanization can simultaneously increase greenhouse-gas emissions, reduce ecosystem services, intensify heat and flood exposure, and weaken access to affordable food. This study developed a simulation-based framework to evaluate climate-mitigation practices that strengthen household food security in Lokoja, Nigeria, over the period 2000–2025. The analytical design integrates six Landsat epochs, geographic information system-based land-use/land-cover classification, the Normalized Difference Vegetation Index, land surface temperature, an 800-household structured questionnaire distributed across 20 neighborhoods, logistic regression, and an Analytic Hierarchy Process-based multi-criteria analysis. The results indicate that built-up land expanded from 39.60 km<sup>2</sup> in 2000 to 156.80 km<sup>2</sup> in 2025 (+296.0%), while vegetation declined from 306.40 km<sup>2</sup> to 204.50 km<sup>2</sup> (-33.3%) and cropland/gardens declined by 15.8%. Across neighborhoods, 2025 land surface temperature was strongly associated with built-up share ( $r = .99$ ) and inversely associated with NDVI ( $r = -.98$ ). In the household scenario, 42.8% of respondents were moderately or severely food insecure, 36.3% practiced some form of urban agriculture, and 31.5% reported recent flood exposure. Adjusted logistic estimates associated urban-agriculture participation with lower odds of food insecurity (OR = 0.53, 95% CI [0.38, 0.74]), whereas low income (OR = 2.88), flood exposure (OR = 2.14), and each 1°C increase in land surface temperature (OR = 1.21) were associated with higher odds. Multi-criteria analysis prioritized fruit-tree agroforestry and household gardening (35.4%), followed by urban forestry and street-tree corridors (24.7%), grassed green infrastructure and rain gardens (18.3%), cereal/open-field farming (11.8%), and climate-smart irrigated vegetables (9.8%). The findings support a differentiated neighborhood portfolio that combines food-producing green infrastructure, heat mitigation, flood-sensitive design, livelihood support, and land-use regulation.

**Keywords:** Urban Agriculture; Climate Mitigation; Food Security; Land-Use/Land-Cover Change; Land Surface Temperature; Analytic Hierarchy Process; Lokoja

### Introduction

Urban food security has become inseparable from the environmental performance of cities. Urban expansion alters surface energy exchange, replaces vegetated and agricultural land with impervious materials, concentrates vulnerable populations, and increases dependence on long food-supply chains. The Intergovernmental Panel on Climate Change (IPCC, 2022) identifies urban heat, flooding, infrastructure disruption, livelihood insecurity, and unequal access to services as

interacting risks in rapidly growing settlements. These risks are particularly consequential in African cities, where planning institutions often face fast land conversion, infrastructure deficits, informality, poverty, and limited fiscal capacity.

Urban and peri-urban agriculture offers a potentially important response because it can produce food close to consumers while contributing shade, evapotranspiration, soil infiltration, biodiversity, employment, and social cohesion. The Food and Agriculture Organization of the United Nations (FAO, 2016) and the High-Level Panel of Experts on Food Security and Nutrition (HLPE-FSN, 2024) emphasize that urban food systems must be treated as linked spatial, economic, nutritional, and governance systems rather than as isolated production activities. Reviews show that urban agriculture can improve access to fresh food and livelihoods, but its benefits depend on land tenure, water quality, soil safety, crop choice, institutional support, and integration with urban plans (Ifatimehin & Musa, 2008; de Bon et al., 2010; Hamilton et al., 2014; Mok et al., 2014; Orsini et al., 2020).

The national context reinforces the urgency of this integrated perspective. FAO (2025) projected that 30.6 million people in Nigeria could face acute food and nutrition insecurity during the June–August 2025 lean season. Although acute insecurity is not evenly distributed, food-price inflation, income instability, transport costs, climate shocks, insecurity in producing regions, and supply-chain disruption transmit vulnerability into cities. Urban households that purchase most of their food are particularly sensitive to declining real income, while low-income neighborhoods often experience higher exposure to heat, poor drainage, flood loss, inadequate water supply, and limited green space.

Located at the confluence of the Rivers Niger and Benue, Lokoja combines strategic transport functions, administrative expansion, residential growth, floodplain occupation, and pronounced seasonal thermal stress. Earlier remote-sensing research showed that changes in land cover were associated with rising surface temperature in Lokoja (Ifatimehin et al., 2009). More recent flood studies have documented the exposure of residential, commercial, agricultural, and open-space land uses, particularly along the Kabawa–Adankolo, Gadumo, and Ganaja axes (Duchi et al., 2020; Nazir et al., 2024). These conditions create a strong case for policies that generate co-benefits rather than treating food, land, heat, flooding, and livelihoods as separate sectors.

Green infrastructure can reduce urban temperatures through shade and evapotranspiration. A systematic review found that urban green sites were generally cooler than comparable non-green sites (Bowler et al., 2010), while strategic frameworks stress that the type, location, scale, and maintenance of greenery determine its performance (Norton et al., 2015). Remote sensing provides a consistent way to track the relationship between vegetation abundance and land surface temperature, with NDVI commonly used as an indicator of vegetative condition and surface cooling capacity (Weng et al., 2004). However, biophysical evidence alone cannot identify whether households have land access, water, Labour, knowledge, or incentives to adopt food-producing green practices.

Multi-criteria decision analysis is therefore useful because it makes trade-offs explicit. The Analytic Hierarchy Process (AHP) converts pairwise judgments into priority weights and provides a consistency test for the resulting preference structure (Saaty, 2008). Applied to urban food-security planning, it can integrate food contribution, heat reduction, income generation, land feasibility, flood and water management, and cost. Such integration is especially important where the highest-need neighborhoods may not have the largest available plots, and where interventions must vary between dense urban cores, planned residential districts, flood-prone riverine communities, and expanding peripheral settlements.

Despite growing scholarship on Lokoja's land-cover change, thermal conditions, and flooding, there remains limited neighborhood-scale integration of remote sensing, household food-security indicators, and climate-mitigation prioritization. This paper addresses that methodological gap using a dataset constructed around the 20 neighborhoods identified. The simulation is to demonstrate how a complete empirical study could be structured, analyzed, reported, and converted into a spatially differentiated action portfolio.

### ***Aim, objectives and hypotheses***

The aim is to evaluate how urban land transformation and household vulnerability could inform the prioritization of climate-mitigation practices with food-security co-benefits in Lokoja between 2000 and 2025. The specific objectives were to:

- i. quantify hypothetical land-use/land-cover change at five-year intervals from 2000 to 2025;
- ii. assess neighborhood patterns of vegetation condition and land surface temperature;
- iii. estimate the distribution and predictors of household food insecurity, including urban-agriculture participation, income status and flood exposure;
- iv. rank alternative mitigation practices using AHP-based multi-criteria analysis; and
- v. translate the results into a neighborhood-specific implementation portfolio.

Four hypotheses guided the analysis: H1, built-up share is positively associated with land surface temperature; H2, NDVI is negatively associated with land surface temperature; H3, participation in urban agriculture is associated with lower odds of household food insecurity after adjustment for socioeconomic and environmental factors; and H4, the most appropriate intervention differs across neighborhoods because need, land availability, flood exposure, thermal stress and implementation feasibility are spatially uneven.

### **Literature Review and Conceptual Framework**

Urbanization affects food security through multiple pathways. It converts agricultural land, changes employment and income structures, increases dependence on purchased food, alters market access, and creates new spatial inequalities. Abu Hatab et al. (2019) found that urban sprawl in developing countries can undermine agricultural systems through land conversion and fragmentation while also creating new markets and livelihood opportunities. The policy challenge is therefore not to preserve every undeveloped parcel, but to identify land and production systems that provide the greatest combined social and ecological returns.

Urban agriculture is multifunctional rather than a single technology. It includes household gardens, community plots, fruit trees, peri-urban fields, livestock, aquaculture, rooftop or container production, and value-chain activities. In developing-country contexts, the strongest evidence concerns livelihood supplementation, dietary diversity, flexible use of small spaces, and access to fresh vegetables, although health risks may arise from polluted soils, untreated wastewater, agrochemical exposure, and insecure tenure (de Bon et al., 2010; Hamilton et al., 2014). In wealthier settings, urban agriculture is also assessed for social inclusion, education, ecosystem services, and food-system resilience, but questions remain regarding scale, life-cycle emissions, and commercial viability (Mok et al., 2014; Orsini et al., 2020).

Recent evidence on community gardens indicates that they can contribute to food access, social cohesion and resilience, but that benefits are limited when participation is socially exclusive or when gardens are treated as temporary uses awaiting development (Huq & Deacon, 2025). For Lokoja, a practical strategy should therefore combine household-level production with public-

space interventions and formal planning protection. Tropical fruit trees are potentially attractive because they provide edible output, shade and longer-term canopy, while annual vegetables can generate quicker nutritional and income returns. Their suitability nevertheless depends on species selection, rooting space, flood tolerance, water demand, maintenance responsibility and protection from road construction or utility works.

Land-cover change and urban heat are closely related. Impervious surfaces store and re-radiate solar energy, while vegetation cools through evapotranspiration and shading. Weng et al. (2004) demonstrated the value of combining land surface temperature with vegetation-abundance indicators for urban heat-island analysis. In Lokoja, Ifatimehin et al. (2009) reported that earlier built-up expansion corresponded with higher surface temperature, providing a historical basis for extending analysis to 2025. Yet heat mitigation should not be reduced to maximizing NDVI alone: canopy structure, irrigation, patch size, connectivity, location relative to exposed populations, and nighttime ventilation all influence performance (Bowler et al., 2010; Norton et al., 2015).

Flood risk adds another layer of complexity. Urban agriculture on floodplains may preserve permeable land and reduce pressure for permanent structures, but crops, soils and water sources may also be contaminated or destroyed during flood events. Lokoja studies show that farmland and open spaces are among the most inundated land uses, while residential communities along riverine axes experience substantial exposure (Duchi et al., 2020; Nazir et al., 2024). Food-producing green infrastructure in such areas should therefore use flood-compatible design: riparian buffers, seasonal cropping calendars, raised beds where appropriate, safe-water protocols, erosion control, evacuation access, and restrictions on permanent construction.

The conceptual framework treats urban food security as the outcome of interacting household and neighborhood conditions. At the household level, income, food prices, Labour, knowledge, land access and production participation affect food access and dietary diversity. At the neighborhood level, built-up intensity, NDVI, land surface temperature, flood exposure, water availability and open-space distribution shape both vulnerability and feasibility. Governance variables, including zoning, tenure, public works, extension services, market access and maintenance arrangements, mediate the conversion of potential benefits into sustained outcomes. The analytical workflow in Figure 1 links these dimensions.

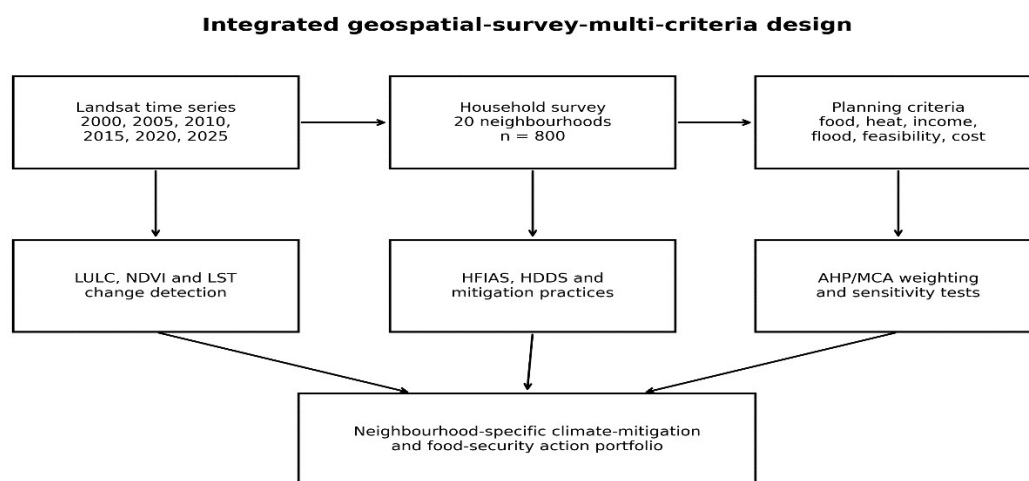


**Figure 1. Integrated analytical framework for linking urban land transformation, household food security and multi-criteria intervention planning.**

## Materials and Methods

### *Study area and neighborhood coverage*

Urban Lokoja, the capital of Kogi State in north-central Nigeria, occupies a strategic confluence setting and includes riverine lowlands, older high-density districts, planned residential areas, institutional and military land, and rapidly expanding peripheral settlements. Following the spatial frame specified, the analytical extent was fixed at 576.58 km<sup>2</sup>. Figure 2, Lokoja shows the neighborhood coverage comprised Felele, Lokongoma, Adankolo, Ganaja, Karaworo, Government Residential Area (GRA), New Layout, Cinema, Kabawa, Gadumo, Marine, Cemetery, Anguwar TV, Cantonment, Otokiti, Barracks, Apansede, Zango, Army Signal and Zone 8.

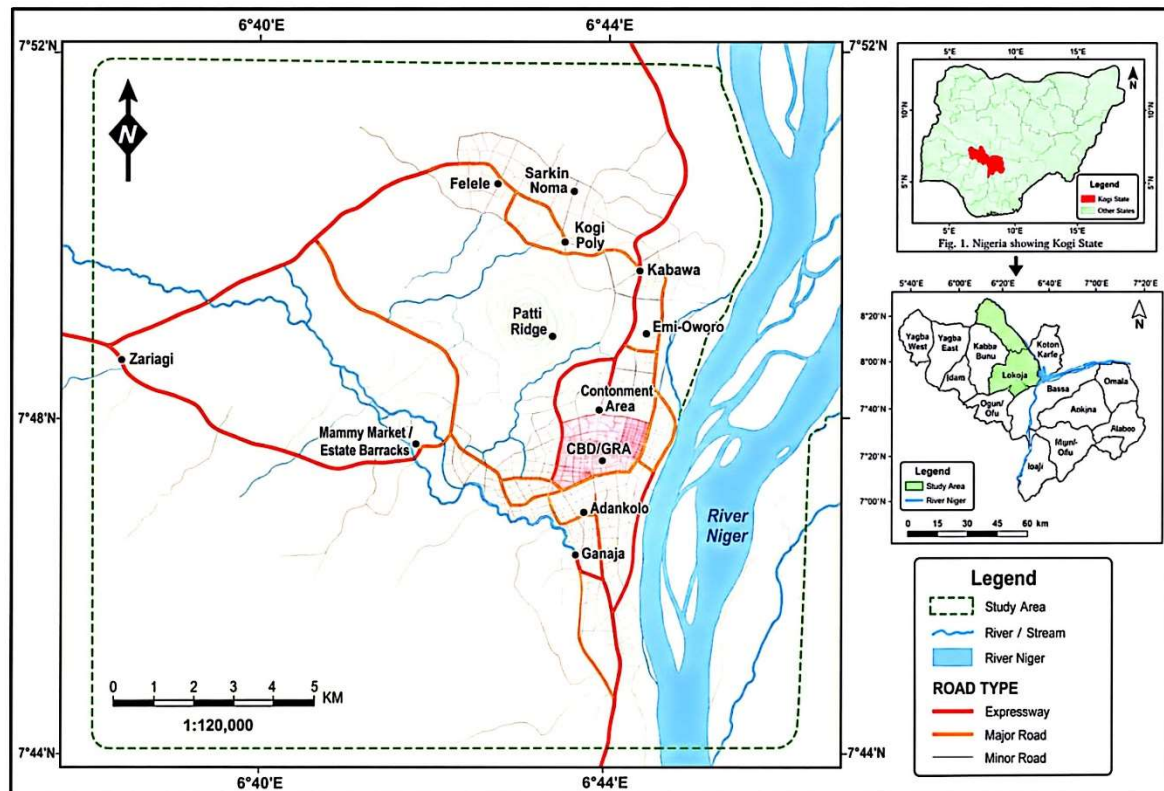


**Figure 2:** Lokoja and its Environs

*Source:* Author Analysis, 2026

### *Research design and simulation disclosure*

A convergent mixed-method design integrated remote-sensing indicators, a cross-sectional household survey, statistical modelling and AHP-based multi-criteria analysis. The temporal analysis covered 2000–2025 at five-year intervals. The household survey represented conditions in 2025, while respondents' flood exposure and mitigation practices were framed with a recent-event recall period. Every numerical observation was generated using bounded distributions and theoretically expected relationships. The simulation was designed to preserve plausible variation without reproducing or implying actual responses from identifiable persons.

### **Earth-observation data and preprocessing**

The empirical workflow uses Landsat Collection 2 Level-2 surface-reflectance and surface-temperature products, which provide globally consistent, atmospherically corrected observations suitable for multi-decadal analysis (U.S. Geological Survey [USGS], 2021). Six dry-season epochs were specified: Landsat 5 Thematic Mapper for 2000 and 2005; Landsat 7 Enhanced Thematic Mapper Plus for 2010; Landsat 8 Operational Land Imager/Thermal Infrared Sensor for 2015 and 2020; and Landsat 9 Operational Land Imager-2/Thermal Infrared Sensor-2 for 2025. Actual implementation should use cloud and shadow masking, sensor-specific scale factors, radiometric quality flags, and compositing where single scenes contain gaps or haze.

All images are projected to a common coordinate reference system and clipped to the 576.58 km<sup>2</sup> study boundary. Bands would be resampled to 30 m, and co-registration are checked before change detection. Field GPS points, high-resolution reference imagery and stratified random samples support the classification training and accuracy assessment. The accuracy levels in Table 1 were set above commonly accepted thresholds for regional land-cover analysis.

**Table 1: Landsat Epochs and Classification-Accuracy Statistics.**

| <i>Epoch</i> | <i>Primary sensor</i>  | <i>Overall accuracy (%)</i> | <i>Kappa</i> | <i>Validation points</i> |
|--------------|------------------------|-----------------------------|--------------|--------------------------|
| 2000         | Landsat 5 TM           | 87.4                        | 0.84         | 300                      |
| 2005         | Landsat 5 TM           | 88.1                        | 0.85         | 300                      |
| 2010         | Landsat 7 ETM+         | 89.0                        | 0.86         | 300                      |
| 2015         | Landsat 8 OLI/TIRS     | 90.2                        | 0.88         | 320                      |
| 2020         | Landsat 8 OLI/TIRS     | 91.1                        | 0.89         | 320                      |
| 2025         | Landsat 9 OLI-2/TIRS-2 | 92.0                        | 0.90         | 340                      |

**Source:** Author Computation, 2026

### **Land-use/land-cover classification and change detection**

Five classes were used: built-up land, vegetation, cropland/gardens, bare surface, and water/wetland. A Random Forest classifier was specified because ensemble decision trees can model nonlinear spectral relationships and are comparatively robust to noisy predictors (Breiman, 2001). Predictor bands would include visible, near-infrared, shortwave-infrared and spectral indices. Post-classification comparison was selected for change detection because it yields class-to-class transitions and supports direct calculation of area change.

For class *i*, percentage change was calculated as: Percentage change =  $[(\text{Area}_{2025, i} - \text{Area}_{2000, i}) / \text{Area}_{2000, i}] \times 100$ . The annual absolute rate was the net area change divided by 25 years. Accuracy assessment would report the confusion matrix, producer's accuracy, user's accuracy, overall accuracy and kappa, consistent with established remote-sensing practice (Congalton, 1991).

### **Vegetation condition and land surface temperature**

NDVI was calculated as  $(\text{NIR} - \text{Red}) / (\text{NIR} + \text{Red})$ , where NIR and Red are surface reflectance in the near-infrared and red bands. Higher positive values indicate greater photosynthetically active vegetation. Surface-temperature values would be obtained from Landsat Collection 2 Level-2 products after application of the required scale and offset factors. Neighborhood means would

be extracted from boundary polygons, and Pearson correlations would test the relationships between built-up share, NDVI and land surface temperature. The expected inverse NDVI-temperature relationship is grounded in the cooling function of vegetation and the established use of remotely sensed temperature-vegetation analysis (Weng et al., 2004).

### ***Household survey, sampling and measures***

The household survey contained 800 observations, comprising 40 households in each of the 20 neighborhoods. A multistage design was used: stratification by neighborhood; selection of enumeration areas or streets; systematic household selection; and random selection of an adult household decision-maker. Sample allocation may be adjusted proportionally after reliable population counts become available, while minimum neighborhood samples were retained for comparative analysis.

The questionnaire contained modules on household composition, income category, food expenditure pressure, food production, land and water access, flood experience, perceived heat, mitigation practices, institutional support and willingness to participate in neighborhood projects. Household food access was represented by the Household Food Insecurity Access Scale (HFIAS), which captures anxiety, inadequate food quality and insufficient food quantity over a four-week recall period (Coates et al., 2007). Dietary diversity was represented by a 12-group Household Dietary Diversity Score following FAO guidance (Kennedy et al., 2011).

Urban-agriculture participation was coded 1 when a household reported producing food within or near the city through backyard, container, community, institutional or peri-urban plots, including fruit-tree production. Low-income status and recent flood exposure were binary. Land surface temperature was attached at neighborhood level.

### ***Statistical analysis***

Descriptive statistics summarized household and neighborhood indicators. Pearson correlations assessed bivariate relationships among environmental indicators. A binary logistic regression estimated the adjusted odds of moderate/severe food insecurity as a function of urban-agriculture participation, low-income status, flood exposure and neighborhood land surface temperature. Results are reported as odds ratios with 95% confidence intervals. Because households were nested within neighborhoods, a verified empirical study used cluster-robust standard errors or multilevel logistic regression.

The regression model was specified as  $\text{logit}[p/(1-p)] = \beta_0 + \beta_1(\text{urban agriculture}) + \beta_2(\text{low income}) + \beta_3(\text{flood exposure}) + \beta_4(\text{LST})$ , where  $p$  is the probability of moderate/severe food insecurity. Statistical significance was evaluated at  $p < .05$ , but substantive effect size, confidence intervals and model assumptions were emphasized over binary significance.

### ***Multi-criteria analysis and sensitivity testing***

AHP was used to prioritize five intervention families were derived: fruit-tree agroforestry and household gardening; urban forestry and street-tree corridors; grassed green infrastructure and rain gardens; cereal/open-field farming; and climate-smart irrigated vegetable production. Six criteria were weighted: food contribution (0.27), heat mitigation (0.19), income and livelihood contribution (0.17), land feasibility (0.14), flood and water regulation (0.12), and cost and maintenance (0.11). Pairwise comparisons followed Saaty's 1–9 scale, and the aggregated criteria matrix had a hypothetical consistency ratio of 0.06, below the conventional 0.10 threshold (Saaty, 2008).

Neighborhood priority and feasibility were then calculated from standardized indicators of available non-built land, low-income prevalence, thermal stress, existing urban-agriculture participation, food-insecurity prevalence and water/flood conditions. The composite score ranged from 0 to 100. It was interpreted as a combined indicator of need and implementation potential, not as a cadastral suitability decision. Sensitivity testing perturbed criteria weights by  $\pm 20\%$  in 1,000 simulations and recorded the frequency with which each intervention retained first rank.

## Discussion of Results

### *Land-use/land-cover transformation, 2000 - 2025*

The time series shows a sustained shift from vegetated and agricultural surfaces towards built-up land (Table 2). Built-up area increased from 39.60 km<sup>2</sup> in 2000 to 156.80 km<sup>2</sup> in 2025, a net gain of 117.20 km<sup>2</sup> and a relative increase of 296.0%. The implied average absolute expansion was 4.69 km<sup>2</sup> per year. Vegetation declined by 101.90 km<sup>2</sup> (-33.3%), equivalent to an average loss of 4.08 km<sup>2</sup> per year. Cropland and garden land declined by 22.40 km<sup>2</sup> (-15.8%), while bare surface increased by 9.80 km<sup>2</sup> (+19.1%). Water and wetland area declined by 2.70 km<sup>2</sup> (-7.2%).

The pace of built-up expansion accelerated after 2010: the class gained 24.20 km<sup>2</sup> between 2010 and 2015, 29.70 km<sup>2</sup> between 2015 and 2020, and 30.40 km<sup>2</sup> between 2020 and 2025. Vegetation losses occurred throughout the period rather than as a single abrupt transition. The pattern suggests both outward expansion into peripheral vegetation and incremental infill within the urban fabric.

Table 2: Land-Use/Land-Cover Change in Urban Lokoja, 2000–2025.

| <i>Class</i>            | <i>2000<br/>(km<sup>2</sup>)</i> | <i>2025<br/>(km<sup>2</sup>)</i> | <i>Net change<br/>(km<sup>2</sup>)</i> | <i>Change (%)</i> | <i>Annual change<br/>(km<sup>2</sup>/year)</i> |
|-------------------------|----------------------------------|----------------------------------|----------------------------------------|-------------------|------------------------------------------------|
| <i>Built-up</i>         | 39.60                            | 156.80                           | +117.20                                | +296.0            | +4.69                                          |
| <i>Vegetation</i>       | 306.40                           | 204.50                           | -101.90                                | -33.3             | -4.08                                          |
| <i>Cropland/gardens</i> | 142.00                           | 119.60                           | -22.40                                 | -15.8             | -0.90                                          |
| <i>Bare surface</i>     | 51.20                            | 61.00                            | +9.80                                  | +19.1             | +0.39                                          |
| <i>Water/wetland</i>    | 37.38                            | 34.68                            | -2.70                                  | -7.2              | -0.11                                          |

**Source:** Author Analysis, 2026

### *Neighborhood vegetation and thermal conditions*

Neighborhood land surface temperature in 2025 ranged from 37.1°C in Apansede to 41.2°C in Cinema. NDVI ranged from 0.16 in Cinema to 0.48 in Apansede. Built-up share and temperature were strongly positively correlated ( $r = .99$ ), supporting H1, while NDVI and temperature were strongly negatively correlated ( $r = -.98$ ), supporting H2. The fitted cross-neighborhood relationship in Figure 3 indicates that lower vegetation condition coincided with higher daytime surface temperature.

The highest-temperature cluster comprised Cinema, Karaworo, GRA, New Layout, Kabawa, Marine and Zone 8. These areas did not share the same socioeconomic profile: GRA and Zone 8 had comparatively lower low-income prevalence, whereas Cinema, Karaworo, Kabawa and Marine combined thermal stress with higher food insecurity or flood exposure. This distinction illustrates why heat maps alone are insufficient for equitable intervention planning.

**Table 3: Environmental Indicators by Neighborhood.**

| <b>Neighborhood</b> | <b>Built-up change (%)</b> | <b>Built-up share 2025 (%)</b> | <b>NDVI 2025</b> | <b>LST 2025 (°C)</b> | <b>Flood index</b> |
|---------------------|----------------------------|--------------------------------|------------------|----------------------|--------------------|
| <i>Felele</i>       | 260                        | 54                             | 0.35             | 38.6                 | 0.35               |
| <i>Lokongoma</i>    | 145                        | 72                             | 0.24             | 40.2                 | 0.25               |
| <i>Adankolo</i>     | 175                        | 64                             | 0.29             | 39.8                 | 0.85               |
| <i>Ganaja</i>       | 230                        | 55                             | 0.34             | 38.7                 | 0.95               |
| <i>Karaworo</i>     | 95                         | 76                             | 0.18             | 40.7                 | 0.45               |
| <i>GRA</i>          | 85                         | 78                             | 0.23             | 40.7                 | 0.15               |
| <i>New Layout</i>   | 155                        | 75                             | 0.22             | 40.7                 | 0.20               |
| <i>Cinema</i>       | 70                         | 80                             | 0.16             | 41.2                 | 0.40               |
| <i>Kabawa</i>       | 105                        | 74                             | 0.20             | 40.6                 | 0.75               |
| <i>Gadumo</i>       | 315                        | 50                             | 0.38             | 38.4                 | 0.90               |
| <i>Marine</i>       | 165                        | 68                             | 0.24             | 40.5                 | 0.95               |
| <i>Cemetery</i>     | 120                        | 62                             | 0.28             | 39.4                 | 0.65               |
| <i>Anguwar TV</i>   | 140                        | 70                             | 0.22             | 40.1                 | 0.30               |
| <i>Cantonment</i>   | 125                        | 60                             | 0.30             | 39.1                 | 0.35               |
| <i>Otokiti</i>      | 480                        | 45                             | 0.42             | 38.0                 | 0.45               |
| <i>Barracks</i>     | 210                        | 52                             | 0.36             | 38.7                 | 0.30               |
| <i>Afansede</i>     | 410                        | 38                             | 0.48             | 37.1                 | 0.40               |
| <i>Zango</i>        | 355                        | 44                             | 0.43             | 37.5                 | 0.50               |
| <i>Army Signal</i>  | 190                        | 65                             | 0.28             | 39.5                 | 0.25               |
| <i>Zone 8</i>       | 170                        | 70                             | 0.25             | 40.3                 | 0.20               |

**Source:** Author Analysis, 2026

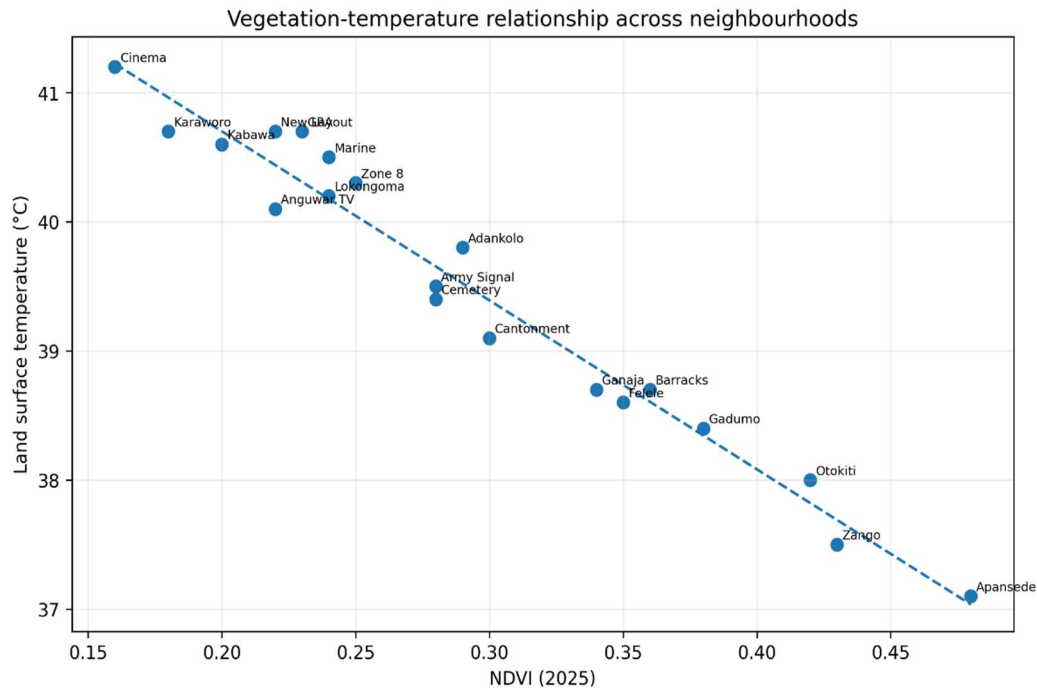


**Figure 3.** Relationship between Neighborhood NDVI and Land Surface Temperature in 2025

**Source:** Author Analysis, 2026

### **Household food security and mitigation practices**

Across the 800-household scenario, 42.0% were classified as low income, 36.2% practised urban agriculture, and 31.5% reported recent flood exposure. Moderate or severe food insecurity affected 42.8% of households. Mean HFIAS was 7.86 (SD = 4.00), while mean household dietary diversity was 6.97 food groups (SD = 1.39).

Neighborhood differences were pronounced (Table 4). Food insecurity was highest in Karaworo, Anguwar TV, Kabawa, Marine and Cinema, while it was lowest in Apansede, Otokiti, Barracks and Zone 8. Existing urban-agriculture participation was highest in Apansede, Zango, Otokiti, Gadumo and Ganaja. The neighborhood correlation between urban-agriculture participation and food insecurity was negative ( $r = -.56$ ), whereas the correlation between low-income prevalence and food insecurity was positive ( $r = .66$ ).

Table 4: Household Food-Security Indicators and Intervention Priorities.

| <b>Neighborhood</b> | <b>Food insecure (%)</b> | <b>Mean HFIAS</b> | <b>Mean HDDS</b> | <b>Urban agriculture (%)</b> | <b>Priority score</b> | <b>Primary action</b>                       |
|---------------------|--------------------------|-------------------|------------------|------------------------------|-----------------------|---------------------------------------------|
| <i>Felele</i>       | 47.5                     | 8.0               | 7.1              | 32.5                         | 57.4                  | Fruit trees + household/community gardens   |
| <i>Lokongoma</i>    | 47.5                     | 8.4               | 6.8              | 32.5                         | 38.7                  | Urban forestry + institutional/home gardens |
| <i>Adankolo</i>     | 45.0                     | 8.2               | 6.9              | 22.5                         | 52.1                  | Flood-compatible gardens + riparian buffers |
| <i>Ganaja</i>       | 47.5                     | 8.5               | 6.6              | 35.0                         | 58.9                  | Flood-compatible gardens + riparian buffers |
| <i>Karaworo</i>     | 50.0                     | 9.0               | 6.8              | 7.5                          | 56.1                  | Container gardens + shaded street corridors |
| <i>GRA</i>          | 30.0                     | 6.8               | 7.1              | 17.5                         | 23.6                  | Urban forestry + institutional/home gardens |
| <i>New Layout</i>   | 37.5                     | 7.7               | 7.0              | 22.5                         | 34.1                  | Urban forestry + institutional/home gardens |
| <i>Cinema</i>       | 60.0                     | 10.0              | 6.5              | 17.5                         | 54.0                  | Container gardens + shaded street corridors |
| <i>Kabawa</i>       | 62.5                     | 9.4               | 6.6              | 22.5                         | 60.4                  | Container gardens + shaded street corridors |
| <i>Gadumo</i>       | 40.0                     | 7.4               | 6.8              | 62.5                         | 58.6                  | Flood-compatible gardens + riparian buffers |

|                    |      |     |     |      |      |                                             |
|--------------------|------|-----|-----|------|------|---------------------------------------------|
| <i>Marine</i>      | 57.5 | 9.3 | 6.9 | 42.5 | 56.2 | Flood-compatible gardens + riparian buffers |
| <i>Cemetery</i>    | 47.5 | 8.1 | 6.7 | 37.5 | 60.1 | Container gardens + shaded street corridors |
| <i>Anguwar TV</i>  | 55.0 | 8.0 | 6.7 | 27.5 | 56.3 | Container gardens + shaded street corridors |
| <i>Cantonment</i>  | 45.0 | 7.8 | 6.8 | 42.5 | 47.9 | Urban forestry + institutional/home gardens |
| <i>Otokiti</i>     | 20.0 | 6.4 | 7.6 | 55.0 | 51.9 | Fruit trees + household/community gardens   |
| <i>Barracks</i>    | 27.5 | 6.7 | 7.2 | 52.5 | 44.7 | Fruit trees + household/community gardens   |
| <i>Apansede</i>    | 27.5 | 6.3 | 7.9 | 75.0 | 62.8 | Fruit trees + household/community gardens   |
| <i>Zango</i>       | 30.0 | 6.8 | 7.3 | 70.0 | 60.7 | Fruit trees + household/community gardens   |
| <i>Army Signal</i> | 40.0 | 7.5 | 7.0 | 30.0 | 37.4 | Urban forestry + institutional/home gardens |
| <i>Zone 8</i>      | 37.5 | 7.2 | 7.2 | 20.0 | 31.2 | Urban forestry + institutional/home gardens |

**Source:** Author Analysis, 2026

### ***Predictors of household food insecurity***

The adjusted logistic model supported H3 (Table 5). Urban-agriculture participants had approximately 47% lower odds of moderate/severe food insecurity than non-participants (OR = 0.53, 95% CI [0.38, 0.74],  $p < .001$ ), conditional on the other variables. Low-income households had 2.88 times the odds of food insecurity (95% CI [2.13, 3.90],  $p < .001$ ), and flood-exposed households had 2.14 times the odds (95% CI [1.55, 2.95],  $p < .001$ ). Each 1°C increase in neighbourhood land surface temperature was associated with 21% higher odds (OR = 1.21, 95% CI [1.06, 1.40],  $p = .007$ ).

Table 5: Logistic Regression Predicting Moderate/Severe Household Food Insecurity (n = 800).

| <b><i>Predictor</i></b>                   | <b><i>OR</i></b> | <b><i>95% CI lower</i></b> | <b><i>95% CI upper</i></b> | <b><i>P</i></b> |
|-------------------------------------------|------------------|----------------------------|----------------------------|-----------------|
| <i>Urban agriculture participation</i>    | 0.53             | 0.38                       | 0.74                       | < .001          |
| <i>Low-income household</i>               | 2.88             | 2.13                       | 3.90                       | < .001          |
| <i>Flood exposure</i>                     | 2.14             | 1.55                       | 2.95                       | < .001          |
| <i>Land surface temperature (per 1°C)</i> | 1.21             | 1.05                       | 1.40                       | 0.007           |

**Source:** Author Analysis, 2026

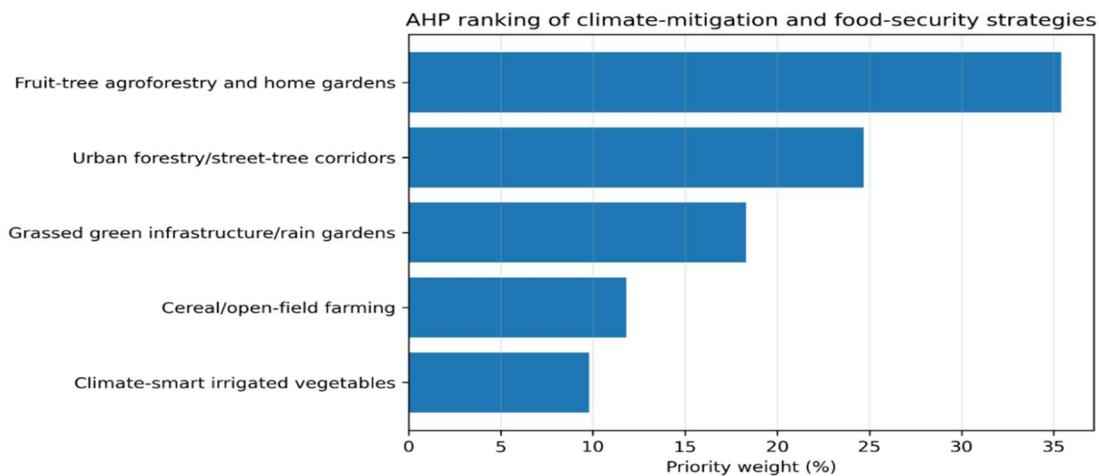


**Figure 4. AHP Ranking of Mitigation Strategies with Food-Security Co-Benefits.**

Source: Author Analysis, 2026

**Note.** OR = odds ratio; CI = confidence interval. Reference categories are no urban agriculture, not low income and no recent flood exposure.

#### **Multi-criteria ranking and neighborhood portfolio**

The AHP results supported H4 by showing a clear ordering of citywide strategy families alongside neighborhood-specific implementation differences. Fruit-tree agroforestry and household gardening received the highest priority weight (35.4%) because it scored strongly on food provision, income, shade, household-scale feasibility and relatively manageable maintenance. Urban forestry and street-tree corridors ranked second (24.7%), reflecting their high heat-mitigation value and suitability for planned districts, road reserves and institutional land. Grassed green infrastructure and rain gardens ranked third (18.3%) because of strong infiltration and flood-management benefits but more limited direct food output.

Cereal and open-field farming ranked fourth (11.8%). Although it can contribute staple food, it generally requires larger contiguous plots and may be less compatible with dense urban land markets. Climate-smart irrigated vegetables ranked fifth (9.8%), not because of low productive potential, but because water quality, infrastructure cost, dry-season reliability, maintenance and flood contamination reduced its relative feasibility in the composite judgment. Sensitivity testing retained fruit-tree agroforestry and household gardening as the first-ranked option in 88.6% of 1,000 perturbed-weight simulations, urban forestry in 9.8%, and grassed green infrastructure in 1.6%.

**Table 6: AHP priorities for climate-mitigation practices with food-security co-benefits.**

| <b>Rank</b> | <b>Alternative</b>                        | <b>Priority weight (%)</b> |
|-------------|-------------------------------------------|----------------------------|
| 1           | Fruit-tree agroforestry and home gardens  | 35.4                       |
| 2           | Urban forestry/street-tree corridors      | 24.7                       |
| 3           | Grassed green infrastructure/rain gardens | 18.3                       |
| 4           | Cereal/open-field farming                 | 11.8                       |
| 5           | Climate-smart irrigated vegetables        | 9.8                        |

Source: Author Analysis, 2026

The composite neighborhood score was highest in Apansede, Zango, Kabawa, Cemetery, Ganaja, Gadumo, Felele, Anguwar TV, Marine and Karaworo (Figure 5). However, the same intervention was not assigned to every high-priority area. Peripheral settlements such as Apansede, Zango, Felele and Otokiti were suited to fruit-tree and garden expansion because of relatively greater land availability and existing participation. Ganaja, Gadumo, Marine and Adankolo required flood-compatible production, riparian buffers and safe-water controls. Dense and vulnerable neighbourhoods such as Cinema, Karaworo, Kabawa and Anguwar TV required small-space production and public shade corridors. Planned and institutional districts, including GRA, New Layout, Lokongoma, Zone 8, Army Signal and Cantonment, were prioritized for street trees, institutional gardens and protection of remaining open space.

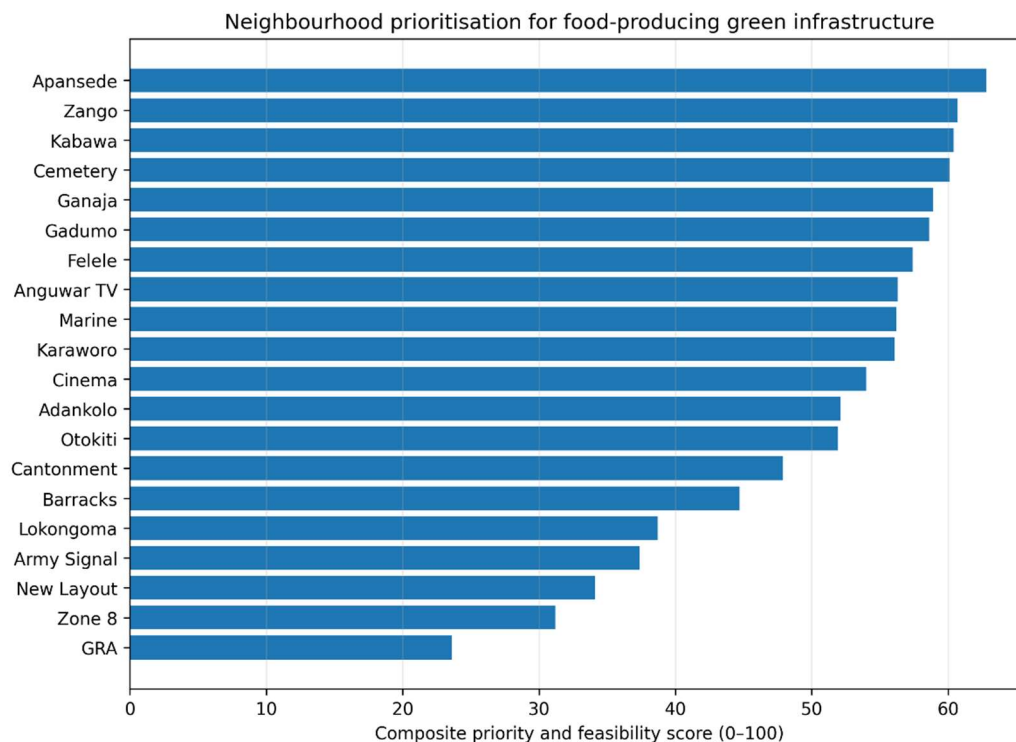


**Figure 5. Composite neighborhood priority and feasibility for food-producing green infrastructure.**

**Source:** Author Analysis, 2026

## Discussion

### *Urban land transformation and thermal stress*

The simulated land-cover trajectory extends the logic of earlier Lokoja research into a 2000 - 2025 analytical frame. The large gain in built-up land and loss of vegetation are consistent with the direction reported by Ifatimehin et al. (2009), although the present values are not observations and cannot be compared as measured rates. The scenario illustrates a common process in rapidly urbanizing cities: peripheral vegetation and agricultural parcels are converted, while remaining open land becomes fragmented and increasingly exposed to speculative development.

The very strong cross-neighborhood associations among built-up share, NDVI and land surface temperature are partly a feature of the constructed dataset, but the underlying mechanism is well supported. Impervious materials reduce evapotranspiration and increase sensible heat storage,

while trees and other vegetation provide shade and latent heat exchange. Weng et al. (2004) showed how remotely sensed temperature and vegetation indicators can reveal this relationship, and reviews confirm the cooling value of well-designed green infrastructure (Bowler et al., 2010; Norton et al., 2015). For Lokoja, the planning implication is not simply to increase citywide vegetation totals; it is to place appropriate canopy and permeable surfaces where thermal exposure and social vulnerability overlap.

Different neighborhood types require different spatial treatments. Dense districts may have insufficient land for conventional plots but can support container gardens, courtyard production, market-edge micro gardens, trellises and shade trees where utilities permit. Planned districts often have road verges, setbacks, institutional compounds and drainage corridors that can host connected canopy. Peripheral settlements may offer larger parcels but face tenure insecurity and rapid conversion. Riverine districts need measures that protect flood conveyance, avoid obstructing drainage, and minimize contamination.

#### ***Food-Security Co-Benefits and Household Vulnerability***

The regression identifies urban-agriculture participation as protective after adjustment for income, flooding and heat. Urban agriculture may improve food access through direct consumption, sale of surplus, expenditure savings, livelihood diversification and social exchange. It may also be endogenous: households with secure land, Labour, water and prior resources are more able to participate. A field study should therefore collect information on plot size, production value, consumption share, market sales, input costs, tenure and duration of participation.

The stronger associations of low income and flood exposure with food insecurity emphasize that production interventions cannot substitute for social protection, safe housing, drainage and income policy. A garden may buffer food expenditure, but it cannot fully offset repeated flood loss, unemployment or severe price inflation. This aligns with the HLPE-FSN (2024) view that urban food security depends on the functioning of the wider food system, not only on local production. The appropriate policy package should combine productive greening with extension, microfinance, input support, market access, cash or food assistance for highly vulnerable households, and measures to reduce disaster losses.

#### ***Multi-Criteria Prioritization and Strategy Trade-Offs***

Fruit-tree agroforestry and household gardens perform well because they combine direct food output with shade, evapotranspiration, carbon storage, amenity and household ownership. Urban forestry performs strongly on heat and ecological functions but may contribute less direct food unless edible species are deliberately included. Grassed green infrastructure and rain gardens are valuable for infiltration and drainage but can become poorly maintained, compacted or converted if institutional responsibility is unclear.

The low ranking of irrigated vegetables is a warning against interpreting productivity alone as suitability. Dry-season irrigation can produce high-value vegetables, yet water scarcity, pumping cost, wastewater contamination and flood-borne pollutants can create health and maintenance risks. Water-quality testing, low-cost drip systems, rainwater harvesting, protected wells, safe compost and extension support would improve performance. Similarly, cereal farming may remain appropriate in peripheral or institutional land but is less suited to dense cores and may provide limited shade per unit area.

Sensitivity analysis is essential because AHP weights reflect judgment. A city administration prioritizing flood reduction might raise the weight of rain gardens, while a nutrition Programme might favor vegetables and fruit. The reported stability of the top-ranked option suggests that fruit-tree and household-garden systems are robust within the preference range, but final weights were elicited from planners, agriculture officers, public-health specialists, community organizations, women's groups, youth groups, landowners and flood-management agencies.

### ***Policy and Implementation Implications***

A practical Programme should be organized as a portfolio rather than a citywide tree-planting campaign. Institutional arrangements are as important as planting. The city requires a land inventory, clear maintenance responsibility, transparent beneficiary selection, water-quality monitoring, horticultural extension, nursery capacity, protection from livestock or vandalism, and procedures for resolving conflicts over public land. Public procurement can create demand by allowing schools, hospitals and government canteens to purchase qualifying local produce where food-safety standards are met. Universities can support monitoring, species trials, remote sensing, soil testing and student-led innovation.

### ***Conclusion and Recommendations***

This study demonstrates how land-cover change, urban thermal conditions, household food insecurity and multi-criteria planning can be integrated for urban Lokoja over the period 2000–2025. The scenario indicates a substantial expansion of built-up land, loss of vegetation and cropland, higher temperatures in less vegetated neighborhoods, and a concentration of food insecurity among low-income and flood-exposed households. Urban-agriculture participation was associated with lower adjusted odds of food insecurity, while AHP prioritized fruit-tree agroforestry and household gardens as the most balanced citywide strategy.

The central policy conclusion is that no single intervention should be applied uniformly. Peripheral neighborhoods require protection of productive land and expansion of fruit trees and gardens; flood-prone communities require safe, seasonal and flood-compatible systems; dense vulnerable districts require small-space production combined with public shade; and planned or institutional areas should deliver street-tree corridors, demonstration gardens and open-space protection. These actions must be supported by land governance, water and soil safety, extension, social protection, monitoring and maintenance finance.

The implementation phased pilots with pre-specified indicators for tree survival, food output, household dietary diversity, income, land surface temperature, flood performance and equitable participation are practicable recommendation that can be adopted. Consequently, climate mitigation can be reframed as a food-security and livelihood strategy while retaining the safeguards required for flood-prone and socially differentiated urban environments.

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