

Heat Vulnerability Assessment in the Urban Core of Ile-Ife, Southwest Nigeria

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Abstract

Rapid urbanization in the Sub-Saharan African cities has intensified heat exposure, yet medium-sized cities like Ile Ife remain understudied. This study assesses heat vulnerability in the urban core of Ile-Ife, Nigeria, and develops a spatially explicit Heat Vulnerability Index (HVI) to identify priority areas for targeted interventions. Landsat 8 Level-2 satellite imagery for 2015 and 2025 was used to derive the Land Use/Land Cover and Land Surface Temperature which was combined with household survey data to capture sensitivity and adaptive capacity. The HVI was constructed by integrating exposure (LST), sensitivity (demographic factors) and adaptive capacity (socioeconomic factors) indicators using an equal-weighting approach. Results revealed that land use changed between 2015 and 2025, with built-up areas increasing from 25.05% to 37.87% while vegetation cover declined from 50.99% to 47.38%. Mean Land Surface Temperature rose by approximately 2.69°C over the ten-year period. The HVI ranged from 0.40 to 0.82, with a mean of 0.65. It showed that 69.3% of the households were vulnerable, with about 2.79% being very highly vulnerable. Neighborhoods including Eleyele, Ireemo, Sabo and Modakeke were identified as highly vulnerable priority areas. The study concludes that heat vulnerability in Ile-Ife is driven by rapid urbanization, rising temperatures, low income and inadequate urban planning. The findings highlight the urgent need for interventions to reduce heat exposure, enhance adaptive capacity, and protect vulnerable populations in medium-sized Nigerian cities.

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Keywords: Heat Vulnerability, Land Surface Temperature, Urbanization, Geospatial Technologies.

Résumé

L'urbanisation rapide des villes d'Afrique subsaharienne a intensifié l'exposition à la chaleur ; pourtant, les villes de taille moyenne comme Ile-Ife restent peu étudiées. Cette étude évalue la vulnérabilité à la chaleur dans le centre urbain d'Ile-Ife, au Nigeria, et élabore un indice de vulnérabilité à la chaleur (IVC) spatialement explicite afin d'identifier les zones prioritaires pour des interventions ciblées. Des images satellitaires Landsat 8 (niveau 2) de 2015 et 2025 ont été utilisées pour déterminer l'occupation et l'utilisation du sol ainsi que la température de surface du sol (TSS) ; ces données ont été combinées à celles issues d'enquêtes auprès des ménages pour appréhender la sensibilité et la capacité d'adaptation. L'IVC a été construit en intégrant des indicateurs d'exposition (TSS), de sensibilité (facteurs démographiques) et de capacité d'adaptation (facteurs socio-économiques) selon une méthode de pondération égale. Les résultats révèlent une évolution de l'occupation du sol entre 2015 et 2025 : les zones bâties sont passées de 25,05 % à 37,87 %, tandis que le couvert végétal a diminué, passant de 50,99 % à 47,38 %. La température moyenne de surface du sol a augmenté d'environ 2,69 °C au cours de cette décennie. L'IVC variait de 0,40 à 0,82, avec une moyenne de 0,65. L'étude montre que 69,3 % des ménages sont vulnérables, dont environ 2,79 % présentent une très forte vulnérabilité. Les quartiers d'Eleyele, Iremo, Sabo et Modakeke ont été identifiés comme des zones prioritaires à forte vulnérabilité. L'étude conclut que la vulnérabilité à la chaleur à Ile-Ife est exacerbée par l'urbanisation rapide, la hausse des températures, les faibles revenus et une planification urbaine inadéquate. Ces résultats soulignent l'urgence d'interventions visant à réduire l'exposition à la chaleur, à renforcer la capacité d'adaptation et à protéger les populations vulnérables dans les villes nigérianes de taille moyenne.

Mots-clés : Vulnérabilité à la chaleur, Température de surface du sol, Urbanisation, Technologies géospatiales

Introduction

Climate change and the consequent rising temperatures are resulting in the increasing frequency, intensity and duration of heat events globally. Heat vulnerability reflects the intersection of environmental heat exposure and the physiological or socio-economic susceptibility of residents to extreme temperature events (Li *et al.* 2024; Weber *et al.* 2015). It is the degree to which a community, population, or system is exposed to extreme heat and how limited it may be in coping with the harmful outcome (Niu *et al.* 2021). Urbanization amplifies local heat exposure through the urban heat island effect. Rising temperatures are more intense in cities where the effects of population, impervious surfaces, human wastes and emissions from cars, homes and industries intensifies local warmings. Growing cities in the tropics are particularly vulnerable considering their characteristic higher temperature added to rising population, with many cities having weak urban planning systems. In Nigeria, studies have shown that many cities exhibit urban heat island conditions, with the urban areas being warmer than surrounding rural areas (Olorunfemi *et al.*, 2020; Obe *et al.*, 2023; Oluwadare *et al.*, 2025). Urban zones near city centers often show the strongest heat intensities (Simwanda *et al.*, 2019). Higher impervious surface cover is consistently associated with higher land surface temperature, while green spaces have a mitigating effect (Anyakora *et al.*, 2025). In Lagos, highly urbanized areas show high heat stress with critical heat risk zones concentrated in dense urban classes, particularly informal settlements (Obe *et al.*, 2023).

Warming and increased heat is recognized as public health threat (Ellena *et al.*, 2020; Pasquini *et al.*, 2020). Excessive heat can cause several health problems ranging from mild to life-threatening illnesses like severe dehydration, low blood pressure, worsening of respiratory conditions such as asthma and even decline in mental health (Ebi *et al.*, 2021). Zhao *et al.*, (2024) found that between 1990 and 2019, extreme heat was linked to roughly 236 deaths per 10million persons worldwide, with Europe accounting for the largest fatalities. The ability to adjust to heat stress depends on multiple factors including socio-economic status, housing population and quality, age and health conditions (Caruso & Candore, 2025; Kenny *et al.*, 2010; Slesinski *et al.*, 2025).

Heat vulnerability is widely understood as a function of exposure, sensitivity, and adaptive capacity and this framework is now central to urban heat assessment (Abrar *et al.*, 2022; Parker *et al.*, 2025). Reviews of assessment methods show that effective studies combine demographic and socioeconomic variables, health and medical-resource indicators, and natural and built-environment characteristics, because these factors shape both susceptibility to heat and the capacity to cope with it (Ellena *et al.*, 2020). However, in many cities, comprehensive vulnerability

assessments remain limited. Assessing heat vulnerability using integrated approaches combine socio-economic factors as well as other indicators (health, accessibility, infrastructure availability, etc.) using geospatial technologies can help authorities identify hotspots and prioritise interventions in planning, service delivery and blue-green infrastructure development (Agbelade, 2025; Parker *et al.*, 2025)

For Ile-Ife, these gaps justify a localised assessment of the urban core. A city-specific analysis can reveal how land cover, settlement structure, population characteristics and access to adaptive resources combine to produce uneven heat vulnerability and also provide local evidence for heat management, urban design guidance, and targeted adaptation in similar sized cities (Olorunfemi *et al.*, 2020; Guo *et al.*, 2022; Obe *et al.*, 2023). This study therefore utilizes geospatial technologies to examine heat vulnerability in the urban core of Ile-Ife through a spatial framework that integrates exposure with demographic sensitivity and adaptive capacity. By identifying the neighbourhoods and populations at risk, it can support more equitable and evidence-based urban climate adaptation in Nigeria.

Methodology

Study Area

The urban core of Ile Ife comprises majorly the Ife Central and Ife East Local Government Areas of Osun State, southwestern Nigeria. The area lies approximately between latitudes 7°25'N and 7°35'N, and longitudes 4°30'E and 4°40'E (Figure 1). Ile Ife is situated approximately 90 kilometers south of Osogbo, the capital of Osun State. The urban core covers a significant portion of the total land area of Ile Ife. It is characterized by high population density, extensive built-up areas and intense economic activities. Recent estimates suggest the population has grown to over 600,000 with an annual growth rate of about 3% (Ajala *et al.*, 2024). The population is predominantly Yoruba, with a rich cultural heritage that dates back centuries (Ogundiran, 2012).

Ile Ife experiences a tropical climate characterized by distinct wet and dry seasons. The rainfall pattern is bimodal with two peak periods occurring in June -July and September-October. Mean monthly temperature ranges from 25°C to 35°C. The hottest months are typically February to April, with maximum temperatures sometimes exceeding 37°C. The coolest months are July and August, when cloud cover and rainfall moderate temperatures (Fayose, 2025). The natural vegetation consists of moist semi-deciduous forest, characterized by a mixture of evergreen and deciduous tree species. Common tree species include iroko, mahogany, and various species of *Terminalia*, *Ceiba*, and *Ficus* (Mukaila *et al.*, 2022). The economy of Ile Ife is diverse, with

activities ranging from traditional occupations (farming, wood works, etc.) to modern services (education, health care, hospitality, etc.). Education is the largest employer and economic driver in the area, with Obafemi Awolowo University and similar institutions attracting students, academics, support staff and visitors.

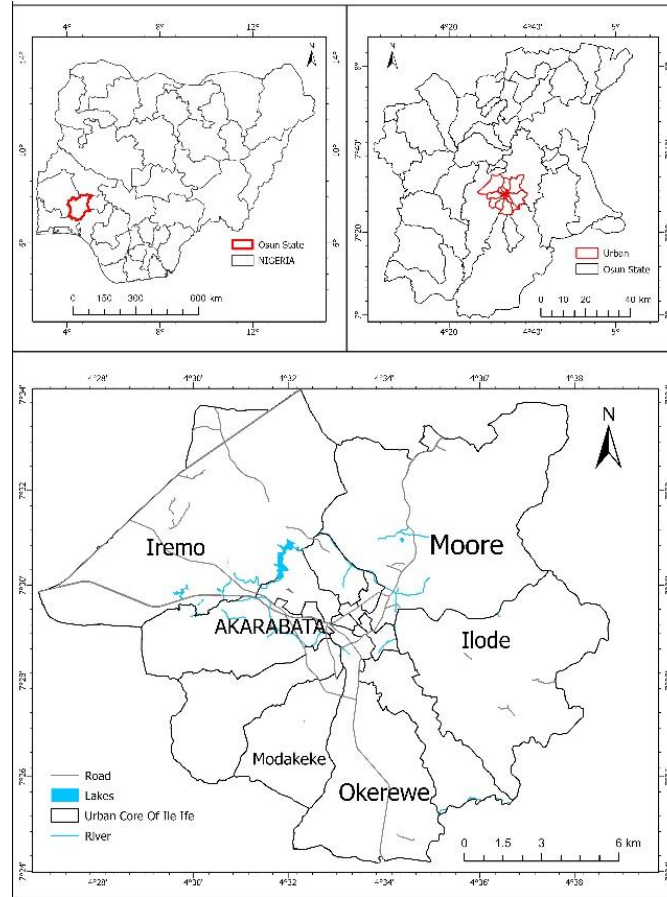


Figure 1: The study area map showing the urban core area of Ile-Ife

Materials and Methods

Landsat OLI-TIRS Level-2 data was used to analyze Land Use/ Land Cover (LULC) and Land Surface temperature (LST). Landsat Level-2 products provide Surface Reflectance for Bands 1-7 at 30m resolution. Various studies have utilized Landsat satellite datasets for LULC classification, spectral indices and Land Surface Temperature analysis (Agbelade, 2025; Oluwadare *et al.*, 2025). Dry season images (January) was acquired for 2015 and 2025 from the United States Geological Survey Earth Explorer. Imageries used had less than 10% cloud cover to ensure consistency and clarity. Administrative boundaries for Ile-Ife Central and East LGAs were sourced from the National Space Research and Development Agency (NASRDA) and OpenStreetMap.

The imageries were subsetting to extract the study area using the administrative boundary. Land Use/Land Cover classification was performed for the area using supervised classification with the Maximum Likelihood Classification algorithm. The classification identified four LULC classes based on the Anderson, (1976) Classification system. The classes used were: Built-up Areas including buildings, roads and other impervious surfaces, Vegetation including forest, woodland, and other vegetated areas, Bare Land including areas with no or sparse vegetation, and Water Bodies including rivers, streams, ponds and other water features. Training samples were collected for each LULC class using high-resolution imagery and field knowledge as reference. Classification accuracy was assessed using a confusion matrix and Kappa coefficient as was used in Abbas & Jaber, (2020), with validation samples collected independently from the training samples. LST was extracted directly from the Landsat Level-2 Surface Temperature band, eliminating the need for complex retrieval algorithms. The temperature in Kelvin was calculated using the appropriate scale factor, then converted to Celsius (Agbelade, 2025). Pixels identified as clouds or shadows in the Quality Assessment band were masked out. The thermal band was resampled to 30m resolution using bilinear interpolation to match the multispectral bands.

Household questionnaire surveys were carried out to collect information on demographic characteristics including age, gender, household size and composition, socioeconomic status including income, education, employment. Other information collected with the questionnaire were housing characteristics (building materials, ventilation), access to cooling, health status (pre-existing conditions and heat-related symptoms), coping behaviors (actions taken during heat events), awareness (knowledge of heat risks, warning systems and perceptions of heat vulnerability) and adaptation needs. The sample size was calculated using the Cochran formula (Cochran & Cochran, 1977) with a 95% confidence level, estimated proportion of 0.5 for maximum variability, and a margin of error of 0.067. With a population of approximately 600,000, the calculated sample size was 215 households. A stratified random sampling method was used to identify households. The survey was administered by trained enumerators using structured questionnaires. Quality control measures included enumerator training, pilot testing of the questionnaire, supervision of data collection, and data validation and cleaning using the min-max normalization for sensitivity and adaptation capacity. The survey data was linked to spatial locations using GPS coordinates collected during the survey, enabling mapping of Heat Vulnerability Index (HVI) scores across the study area, spatial analysis of vulnerability patterns, and identification of high-risk neighborhoods.

The Heat Vulnerability Index was constructed using indicators derived from both satellite data and household surveys, following the methodology of Niu *et al.*, (2021) and Reid *et al.*, (2009). Exposure indicators was based on the Land use/cover and Land Surface Temperature. Sensitivity indicators was derived from survey data based on proportion of elderly population aged 65 years and above in household, proportion of child population aged under 10 years in household and presence of individuals with pre-existing health conditions. Adaptive Capacity indicators was derived from survey data such as household income, education level of household head, housing quality, access to cooling including fans and air conditioning, and availability and reliability of electricity. All indicators were normalized to a common scale of 0 to 1 using min-max normalization. For indicators where higher values indicate lower vulnerability, such as income and education, the normalized values were inverted. The HVI was calculated using an equal-weighting approach following the IPCC framework. The HVI was classified into five categories: Very Low ranging from 0.00 to 0.20, Low ranging from 0.21 to 0.40, Moderate ranging from 0.41 to 0.60, High ranging from 0.61 to 0.80, and Very High ranging from 0.81 to 1.00.

Results

Analysis of Land Use/Land Cover for the study area revealed significant changes between 2015 and 2025. The LULC classification identified four classes: Built-up Areas, Vegetation, Bare Land, and Water Bodies. Figure 2 show the changes in the land use/cover in the urban core of Ile-Ife in 2015 and 2025. In 2015, built-up areas covered about 25% (59.93km²) while bare land made up 24% (56.93km²) of the area. Built-up areas were concentrated in the central urban core, particularly around the city center and major commercial districts. However, the area was predominantly characterized by vegetation which covered 51% (122km²). The waterbody in the area was relatively small and covered only 0.17% (0.41km²) of the area. By 2025, Built-up areas expanded considerably to cover 38% (92km²) of Ile-Ife. This expansion is attributed to rapid urbanization driven by population growth, economic development, and infrastructure expansion. Vegetation cover declined correspondingly to 47% (115.1km²), with many areas converted to built-up or bare land. Bare land also decreased to 14.64% (35.55km²) while waterbodies remained mostly unchanged at 0.11% (0.26km²).

Vegetation declined from approximately 50.99% to 47.38% of the study area, while built-up areas increased from 25.05% to 37.87% over the ten years as shown in Table 1. This represents a 53.51% increase in built-up area, reflecting rapid urbanization in the study area. Bare land decreased from

23.79% to 14.64%, indicating that previously bare areas were being developed. Water bodies remained relatively stable with minor fluctuations.

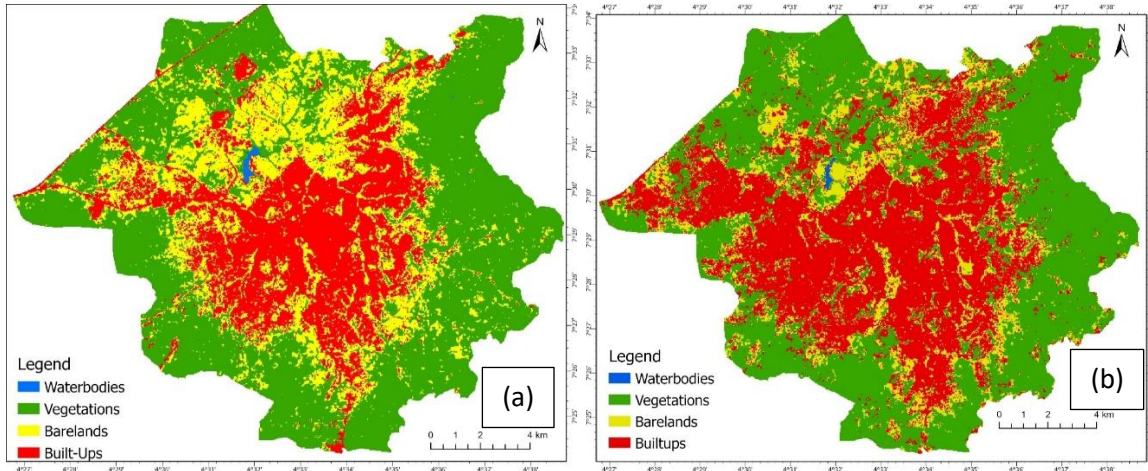


Figure 2: Land Use/Land Cover Map of the Study Area for (a) 2015 and (b) 2025

Table 1: Land Use/Land Cover Statistics for 2015 and 2025

Land Cover Type	2015 (km ²)	2015 (%)	2025 (km ²)	2025 (%)	Change (km ²)
Water Bodies	0.41	0.17	0.26	0.11	-0.15
Vegetation	122.00	50.99	115.10	47.38	-6.90
Bare Land	56.93	23.79	35.55	14.64	-21.38
Built-up	59.93	25.05	92.00	37.87	+32.07
Total	239.27	100.00	242.91	100.00	-

The rapid growth of the built up areas in the 10-year period has significant implications for surface temperatures and heat vulnerability, as the conversion of vegetated surfaces to impervious surfaces reduces evapo-transpirative cooling and increases heat absorption and storage. The Land Surface Temperature (LST) Analysis show spatial and temporal temperature variations between 2015 and 2025. In 2015, LST values ranged from approximately 25.62°C to 31.36°C, with a mean LST of approximately 28.49°C. The spatial distribution showed higher temperatures in built-up areas and bare land, while vegetated areas and water bodies exhibited lower temperatures. The spatial pattern of LST in 2015 revealed higher temperatures concentrated in the urban core, with lower temperatures in areas with greater vegetation cover (Figure 3a). The urban heat island effect is evident, with built-up areas showing temperatures several degrees higher than surrounding vegetated areas. In 2025, LST values ranged from approximately 27.39°C to 34.94°C, with a mean

LST of approximately 31.18°C (Figure 3b). This represents a significant increase in mean LST over ten years, consistent with the LULC changes and urbanization trends observed. The spatial extent of high-temperature areas expanded considerably, reflecting the spread of built-up areas.

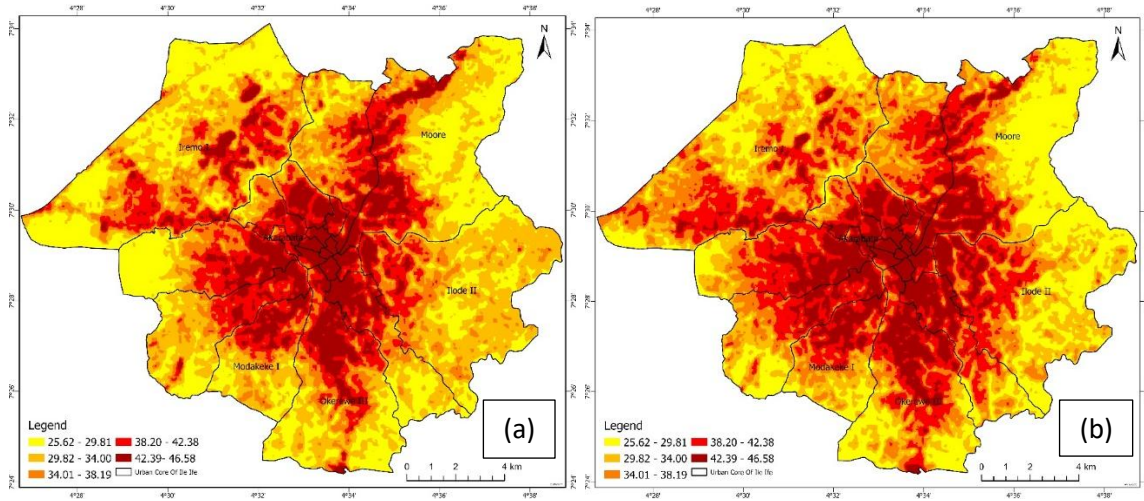


Figure 3: Land Surface Temperature (LST) Distribution for Ile-Ife in (a) 2015 and (b) 2025.

Table 2 indicates that the mean LST increased by approximately 2.69°C over the ten years, with maximum temperatures increasing by 3.58°C. The standard deviation also increased, suggesting greater spatial variability in temperatures as urban areas expanded and created more heterogeneous surface conditions. This represents a significant warming trend in the study area.

Table 2: Land Surface Temperature Statistics for 2015 and 2025

Statistic	LST 2015	LST 2025	Change
Minimum (°C)	25.62	27.39	+1.77
Maximum (°C)	31.36	34.94	+3.58
Mean (°C)	28.49	31.18	+2.69
Standard Deviation	2.87	3.39	+0.52

This pattern is consistent with the urban heat island effect, where impervious surfaces absorb and retain more heat than natural surfaces. The LST change map in Figure 4 reveals areas of significant temperature increase between 2015 and 2025, concentrated primarily in areas that experienced urban expansion. These areas have undergone conversion from vegetated or bare land to built-up

areas, resulting in increased surface temperatures and intensification of the urban heat island effect.

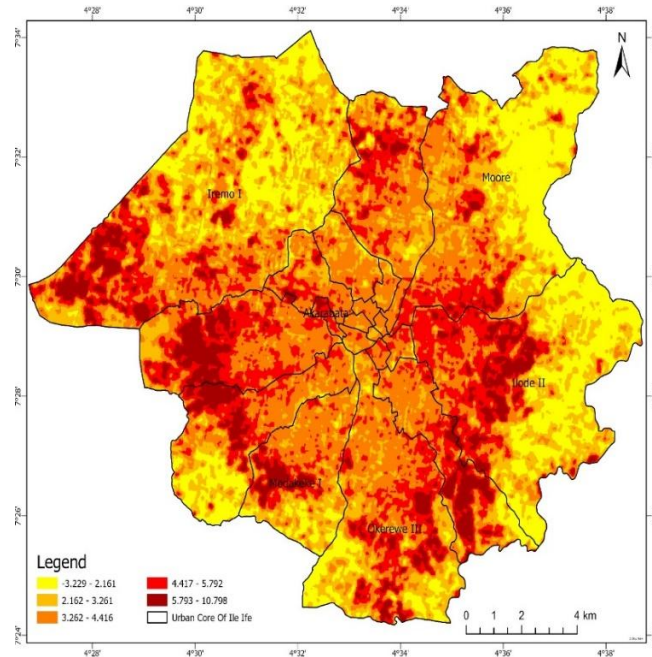


Figure 4: Land Surface Temperature Change Map (2025 - 2015) Showing Areas of Temperature Increase and Decrease

The largest temperature increases were observed in the urban edge where new development has been most intense. These areas with temperature increase of between 4.4°C and 11°C covered approximately 26.4% (62.97km^2) of Ile-Ife. Areas with the lowest change in temperature were most areas that remained vegetated, particularly in the fringes of the study area. These areas had temperature change between -3°C and 2°C and made up about 19% (46.57km^2). About 54% (129.73km^2) of the area exhibited low to moderate increase in temperature, between 2°C and 4°C . These areas were mostly built-up areas whose characteristics did not change over the study period. This distribution confirms that while warming is widespread, the intensity of thermal stress is particularly concentrated in zones where land cover conversion has been most aggressive.

The household survey provided comprehensive data on demographic characteristics, socioeconomic status, housing conditions, health impacts, and coping mechanisms. The survey revealed that the majority of households were headed by individuals in the working age group of 31 to 50 years. The average household size was approximately five persons, with 45.58% of households having 4-6 members. This demographic structure is typical of Nigerian urban areas, with extended family systems and multigenerational households being common. The survey revealed significant socioeconomic diversity across the study area. Household income varied

considerably, with a substantial proportion of households reporting monthly incomes below 50,000 NGN. Education levels ranged from no formal education (6.98%) to university degrees (20.93%), with the majority of household heads having completed secondary school (36.28%) or higher. Employment patterns showed a mix of formal employment (24.19%), self-employment (45.58%) and informal sector activities, with a significant proportion of respondents engaged in outdoor work such as trading and manual labor. Housing tenure varied, with a mix of home ownership (39.53%), rental (45.58%) and family property (14.89%).

The survey highlighted variations in housing quality and access to cooling. Roofing materials included corrugated metal, zinc, concrete, and asbestos, with metal roofs being most common. Wall materials included concrete block, mud, and brick, with concrete block being prevalent in urban areas. Floor materials included concrete, tile, and mud, with concrete being most common. Windows and ventilation varied, with many houses having four or more windows, but a significant proportion having limited cross-ventilation. Access to cooling was limited, with many households lacking fans or air conditioning. Electricity availability varied, with many households having unstable electricity and frequent outages.

The survey found heat-related health impacts among respondents. The most commonly reported symptoms during hot weather included excessive sweating, heat rash, headache, dizziness and difficulty breathing. Many respondents reported experiencing multiple symptoms simultaneously. Pre-existing health conditions such as high blood pressure, diabetes and asthma were reported by a significant proportion of respondents, potentially increasing their sensitivity to heat stress. The survey revealed a range of coping mechanisms employed by residents during hot weather. The most common coping strategies included drinking more water, using fans, taking cold showers or baths, opening windows and doors, going outside for a breeze, wearing light clothing and staying under shade. However, many respondents reported that they simply endured the heat due to limited access to cooling. Respondents expressed needs for stable electricity, access to fans and air conditioning, tree planting and more open spaces for ventilation.

Sensitivity scores were calculated based on the proportion of vulnerable populations, including children under 10 and the elderly aged 65 and above, income levels, health conditions and outdoor work exposure. The sensitivity score ranged from 0.10 to 0.50, with higher scores indicating greater sensitivity to heat stress. The mean sensitivity score was 0.29, suggesting that the study population has moderate sensitivity to heat. Households with elderly members, children, chronic health conditions and low income showed higher sensitivity scores. Adaptive capacity scores were

calculated based on income, access to fans and air conditioning, electricity availability, ventilation and access to information. The adaptive capacity score ranged from 0.90 to 1.00, with higher scores indicating greater adaptive capacity and lower vulnerability. The mean adaptive capacity score was 0.99, suggesting high adaptive capacity among the study population. However, this high value may indicate that the scoring system needs to be reviewed, as it suggests almost all households have near-maximum adaptive capacity. This could be because the survey questions may not have fully captured the limitations in adaptive capacity, or because respondents may have overestimated their coping abilities.

The HVI for 2025 ranged from 0.40 to 0.82, with a mean of 0.65. The index showed that 69.3% of the households were highly vulnerable, with about 2.79% of household being very highly vulnerable. About 26.98% of households we found to be moderately vulnerable. No households were classified as Low or Very Low vulnerability. Neighborhood-level analysis shows spatial variations in 2025 HVI with higher vulnerability observed in areas that experienced significant temperature increases and urban expansion. Eleyele, Sabo and Parakin emerged as high-vulnerability neighborhoods, while Moore and some parts of Okerewe showed lower vulnerability.

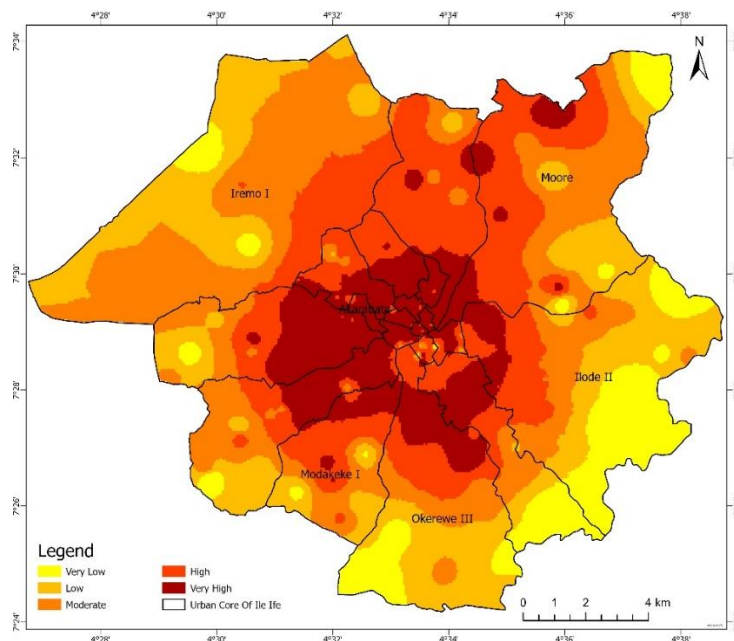


Figure 4.7: Spatial Distribution of Heat Vulnerability Index (HVI) for 2025

Discussion

Transformation of the Urban Core

The analysis of Land Use/Land Cover changes between 2015 and 2025 revealed a significant transformation of the urban core of Ile-Ife. The 53.51% increase in built-up area reflects the growing population pressure and economic activities in the city, particularly driven by the presence of Obafemi Awolowo University and the commercial significance of the area. This rate of urban expansion is consistent with trends observed in other Nigerian cities, for instance, Adesina *et al.*, (2026) documented similar patterns in Abuja, while Olorunfemi *et al.*, (2020) found built up to be expanding with significant reduction in vegetation land cover classes in Ekiti State, Nigeria. Similarly, Koko *et al.*, (2020) found an almost 400% increase in the extent of built up areas in Zaria from 1990 to 2020. However, the rate observed in Ile-Ife (53.51% over ten years) is notably higher than the national average, suggesting that secondary cities are experiencing accelerated urbanization that may outpace planning and infrastructure development.

The corresponding decline in vegetation cover from 50.99% to 47.38% of the study area was observed. This loss of green spaces has significant implications for the urban microclimate, as vegetation plays a critical role in regulating surface temperatures through evapotranspiration and shading (Hesslerová *et al.*, 2019; Ma *et al.*, 2025). The reduction in vegetation cover observed in this study mirrors trends documented in other Nigerian cities including Lagos (Obe *et al.*, 2023), Abuja (Mshelia *et al.*, 2024), Ekiti (Olorunfemi *et al.*, 2020) and Osogbo (Oluwadare *et al.*, 2025).

The LULC change analysis reveals that urbanization in Ile-Ife has been particularly concentrated in the central urban core, with gradual expansion into peripheral areas. This pattern is consistent with the findings of Adesina *et al.*, (2026) in Abuja, where urban growth was concentrated in the city center with peripheral expansion driven by infrastructure development and residential construction. The spatial pattern of urbanization observed in Ile-Ife suggests that the city is experiencing both infill development within existing urban areas and outward expansion into peri-urban zones. This dual pattern of urbanization presents unique challenges for heat vulnerability management, as infill development reduces remaining green spaces within the city, while outward expansion consumes agricultural land and increases commuting distances, potentially exacerbating heat exposure for low-income residents who cannot afford housing in cooler, greener areas. Without adequate green infrastructure, the urban core of Ile-Ife is likely to experience continued warming, with associated health and economic consequences for residents. This finding underscores the urgent need for urban planners to prioritize green space preservation and creation in their development strategies.

Relationship Between Land Cover Change, LST and Heat Vulnerability

The mean LST increased by approximately 2.69°C over the ten years, with maximum temperatures increasing by 3.58°C. This rate of warming is similar to global average as noted by Houghton, (2001) and reflects the combined effects of global climate change and local urbanization. The spatial pattern of LST reveals a clear relationship with land cover, with built-up areas consistently showing the highest temperatures and vegetated areas the lowest. The areas of greatest LST increase between 2015 and 2025 correspond to areas that experienced significant urban expansion and vegetation loss. This pattern is consistent with the urban heat island effect, where impervious surfaces such as concrete, asphalt and buildings absorb and retain more heat than natural surfaces (Akomolafe *et al.*, 2020; Yang *et al.*, 2021; Zemba, 2010). The relationship between LST and land cover observed in this study is consistent with findings from other studies. In Lagos, Obe *et al.*, (2023) found that areas with high vegetation cover in had lower LST values compared to densely built-up areas. Similarly, the study by Fu & Weng, (2016) found high intensity urban areas to have the largest mean LST. The consistency of these findings underscores the universal importance of vegetation in mitigating urban heat.

The implications of rising LST for human health and well-being are significant. Exposure to high temperatures is associated with a range of health problems, including heat exhaustion, heat stroke, dehydration, and exacerbation of cardiovascular and respiratory conditions (Ebi *et al.*, 2021; Niu *et al.*, 2021). Vulnerable populations, including the elderly, children and individuals with pre-existing health conditions are particularly at risk. The increasing LST in the urban core of Ile-Ife therefore represents a growing public health threat that requires urgent attention. The household survey revealed variations in sensitivity to heat across the study population. Households with elderly members, children, chronic health conditions, and low income showed higher sensitivity scores, reflecting their increased susceptibility to heat stress. This finding is consistent with literature on heat vulnerability, which consistently identifies age, health status, and socioeconomic status as key determinants of sensitivity (Niu *et al.*, 2021; Reid *et al.*, 2009). The relatively narrow range of sensitivity scores suggests that while there is variation in sensitivity across the population, most households exhibit moderate to high sensitivity, indicating widespread vulnerability to heat stress.

The Heat Vulnerability Index developed in this study integrates exposure, sensitivity, and adaptive capacity. The HVI ranged from 0.40 to 0.82, with a mean of 0.65. The high percentage of households that were found to be the most vulnerable indicates a good proportion of Ile-Ife residents are at critical risk of heat-related impacts and require intervention. This finding is consistent with the observed trends in LST and LULC studies, as the emergence of Very High

vulnerability corresponds to areas that experienced the most significant temperature increases and urban expansion. The neighborhood-level assessment revealed significant spatial variations in HVI, with higher vulnerability observed in areas with higher LST, higher population density, lower socioeconomic status and limited adaptive capacity. The neighborhoods with the highest HVI values, including Eleyele, Iremo, Sabo and Modakeke are characterized by dense built-up areas, limited green spaces and high concentrations of vulnerable populations. These areas should be prioritized for interventions to reduce heat vulnerability. The spatial pattern of vulnerability observed in this study is consistent with findings from other studies in Sub-Saharan African cities. In Lagos, (Obe *et al.*, 2023) found that heat risk was predominantly concentrated in densely populated, low-income neighborhoods. Similarly, Oluoma *et al.*, (2025) found that heat risk in Kinshasa was concentrated in the central urban core, with lower risk in peri-urban areas. These patterns suggest that heat vulnerability in African cities is strongly associated with urbanization, socioeconomic inequality and limited adaptive capacity.

Conclusion and Recommendations

This study successfully assessed heat vulnerability in the urban core of Ile-Ife, integrating Landsat Level-2 satellite imagery, household survey data and spatial analysis techniques. The study addressed the research objectives by determining and mapping LULC characteristics, identifying demographic and socioeconomic factors contributing to vulnerability, developing and validating a Heat Vulnerability Index.

The study found that the urban core of Ile-Ife experienced significant urban expansion between 2015 and 2025, with built-up areas increasing by 53.51%. The conversion of vegetated and agricultural land to built-up areas has reduced the cooling capacity of the landscape and intensified the urban heat island effect. Land Surface Temperature increased significantly over the ten-year period, with mean LST rising by 2.69°C. The spatial pattern of LST reveals a clear urban heat island effect, with built-up areas consistently showing higher temperatures than vegetated areas. A large proportion of households were classified as High or Very Highly vulnerability, indicating that some households are at critical risk of heat-related health impacts. Vulnerability is not uniformly distributed across the study area. Higher vulnerability is concentrated in urban core areas with high population density, limited vegetation, and lower socioeconomic status. Neighborhoods such as Eleyele, Iremo, Sabo and Modakeke emerged as high-vulnerability areas. These spatial patterns underscore the importance of considering both exposure and social vulnerability in heat vulnerability assessment.

The study contributes to the growing body of knowledge on heat vulnerability in Sub-Saharan African cities, addressing the research gap on medium-sized cities. The findings highlight the urgent need for interventions to reduce heat exposure, enhance adaptive capacity, and protect vulnerable populations in Ile-Ife and other medium-sized Nigerian cities. The findings of this study have significant policy implications for urban planning, public health, and climate adaptation in Ile-Ife and other medium-sized Nigerian cities. The increasing vulnerability to heat observed in this study underscores the urgent need for interventions to reduce heat exposure, enhance adaptive capacity and protect vulnerable populations. Strategic interventions may consider improving urban green spaces and establishing green infrastructure, improve adaptive capacity of residents, create awareness and ensure adequate planning of the growing urban area.

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