Int. j. adv. multidisc. res. stud. 2026; 6(4):659-674

Received: 28-05-2026
Accepted: 07-07-2026

International Journal of Advanced Multidisciplinary Research and Studies

ISSN: 2583-049X

Assessment of the Impact of Urban Expansion on Thermal Characteristics in Gombe Metropolis Gombe State, Nigeria

[1] Matthew Olumide Adepoju, [2] Hyelpamduwa Yaro, [3] Alaga Taofik Abayomi, [4] Iliya Joshua Jerome, [5] Kenneth Uchua Abaagu, [6] Nasiru Aliyu, [7] Tallen Abubakar Sadiq, [8] Jibrin Abubakar Babayo, [9] Itse Atang, [10] Nenkir Judith Lonse, [11] Manu Othniel Kwardam, [12] Nickson Audu Gabali, [13] Baba-Ali Charles Hena, [14] Iliya Richard Zakwoi, [15] Eunice Elbi, [16] Musa Muhammad Ngudoromma, [17] Felix Sangli Ngantem, [18] Dinnci Jimmy, [19] Muktar Garba, [20] Muhammed Samaila, [21] Abraham Gambo Chandimi, [22] Bada Danladi Su'reh, [23] Jeremiah Zumji Jankanwa, [24] Lakong Timring Wuyep

[1, 3] National Space Research and Development Agency, Obasanjo Space Centre, Lugbe Abuja, Nigeria
[2, 8, 9, 11, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24] North East Zonal Advanced Space Technology Applications Laboratory, Kashere Gombe State, Nigeria
[4] National Centre for Climate Change and Food Security, Mubi Adamawa State, Nigeria
[6] Centre for Geodesy and Geodynamics, Toro, Bauchi State, Nigeria
[5, 7, 10, 12] National Centre for Remote Sensing, Jos Plateau State, Nigeria

Corresponding Author: **Matthew Olumide Adepoju**

Abstract
Urban expansion is rapidly reshaping cities globally, with significant consequences for local environments and human wellbeing. In sub-Saharan Africa, especially Nigeria, this growth is often rapid and unplanned, resulting in marked land use changes and heightened environmental vulnerabilities. This study examines the impact of urban expansion on the thermal characteristics of Gombe Metropolis, the capital of Gombe State, over a 30-year period (1994–2024). Employing multi-temporal Landsat satellite imagery integrated with Geographic Information Systems (GIS) and advanced remote sensing techniques, the research quantifies changes in land use and land cover (LULC) and their influence on land surface temperature (LST), a key indicator of urban heat. Findings indicate that built-up areas increased markedly from 10.8% to nearly 40%, while vegetation cover declined by over 58%. Concurrently, mean annual surface temperatures rose by approximately 1.2°C, with the urban heat island effect intensifying as urban-rural temperature differentials grew from 0.8°C to 1.5°C. Statistical analyses reveal strong positive correlations between increased built-up and bare land areas and elevated temperatures, whereas vegetation and farmland exhibited significant cooling effects. Spatial analysis identifies thermal hotspots concentrated in dense urban cores and rapidly expanding peri-urban zones where natural surfaces have been replaced by impervious materials. The study underscores the environmental and public health implications of unregulated urban sprawl in semi-arid Nigerian cities and advocates for urban greening, climate-sensitive land use policies, and sustained environmental monitoring to promote sustainable urban development. By filling a critical research gap, this work provides empirical evidence linking urban growth to microclimate alteration, offering transferable methodologies and insights for planners addressing similar challenges in rapidly urbanizing contexts across the Global South.

Keywords: Urban Expansion, Gombe Metropolis, Land Use Change, Thermal Environment, Urban Heat Island, Vegetation Loss, Land Surface Temperature, Climate Impact, Sustainable Urban Planning, Nigeria

1. Introduction

Urban expansion is a dominant global phenomenon of the 21st century, fundamentally reshaping landscapes, economies, and human–environment interactions. The rapid growth of cities, both in population and spatial extent, has become a defining feature of contemporary development, with far-reaching implications for environmental sustainability, climate systems, and human wellbeing. According to the United Nations Department of Economic and Social Affairs (UN DESA, 2018), approximately 56.2% of the world's population resides in urban areas, and this proportion is projected to increase to about 68% by 2050. This unprecedented growth is not evenly distributed; rather, it is concentrated in a few countries, notably Nigeria, India, and China, which together are expected to account for roughly 35% of global urban population growth within this period. As cities expand, natural and agricultural lands are increasingly converted into built-up areas dominated by impervious surfaces such as asphalt and concrete, leading to significant alterations in land use and land cover (LULC) patterns and influencing local climatic conditions.

In sub-Saharan Africa, urban expansion is occurring at an even more accelerated pace due to a combination of high natural population growth and sustained rural–urban migration. The region is experiencing one of the fastest urban transitions globally, with UN-Habitat (2020) projecting that Africa's urban population will triple between 2020 and 2050. However, this rapid urbanization is often characterized by inadequate planning and weak regulatory frameworks, resulting in uncoordinated spatial growth, proliferation of informal settlements, and increasing pressure on infrastructure and environmental resources. One of the most significant environmental consequences of this process is the modification of urban thermal environments, particularly through the intensification of the Urban Heat Island (UHI) effect, where urban areas experience higher temperatures than their rural surroundings. This phenomenon is largely attributed to the replacement of vegetated surfaces with heat-absorbing materials and the reduction of natural cooling processes such as evapotranspiration (Oke, 1982; Voogt & Oke, 2003).

Nigeria exemplifies the challenges associated with rapid and largely unplanned urban growth in sub-Saharan Africa. With an annual urban growth rate exceeding 4%, Nigeria is among the fastest urbanizing countries in the world (World Bank, 2021). This growth has led to extensive urban sprawl, characterized by the outward expansion of cities into peri-urban and rural areas. Major cities such as Lagos, Kano, and Abuja have witnessed substantial changes in land use patterns, often resulting in the loss of vegetation, encroachment on agricultural lands, and increased environmental degradation. The expansion of impervious surfaces has contributed to rising land surface temperatures (LST), reduced infiltration of rainfall, and increased vulnerability to environmental hazards such as flooding and heat stress (Akpu *et al*., 2023). The lack of integrated urban planning and effective land management policies further exacerbates these challenges, making Nigerian cities highly susceptible to the adverse impacts of climate variability and change.

Gombe Metropolis, the capital of Gombe State in north-eastern Nigeria, represents a typical example of a rapidly growing mid-sized city experiencing significant urban transformation. Historically, Gombe was a relatively small settlement with slow population growth; however, its designation as a state capital in 1996 triggered rapid demographic and spatial expansion. Balzerek (2003) notes that Gombe's population increased from a few hundred inhabitants in the early 20th century to over 138,000 by 1991, followed by a sharp rise after the creation of Gombe State. Tiffen (2006) further reports that the population grew from 169,894 in 1996 to over 312,000 by 2006, reflecting the city's increasing socio-economic importance. This rapid growth has been accompanied by extensive land conversion, as agricultural lands and natural vegetation are progressively replaced by residential, commercial, and infrastructural developments.

The expansion of Gombe has been largely unregulated, leading to the encroachment of urban development into peri-urban and environmentally sensitive areas. Wakirwa (2015) observes that urban sprawl in Gombe has significantly increased over the years, with built-up areas expanding at the expense of agricultural land. Similarly, Mbaya (2012) highlights the rapid conversion of productive farmland into urban uses, driven by population pressure and increased demand for housing and services. Earlier studies, such as those by Alabi (2009), attribute this trend to unchecked population growth and inadequate urban planning mechanisms. Dabara *et al*. (2012) further demonstrate that rapid urban expansion in Gombe has contributed to environmental challenges, including increased flood risk due to reduced soil permeability and altered drainage patterns. These findings underscore the need for comprehensive assessments of urban growth dynamics and their environmental implications.

Understanding LULC dynamics is essential for effective urban planning and sustainable development. Accurate and up-to-date information on land use patterns enables policymakers and planners to make informed decisions regarding land allocation, infrastructure development, and environmental management. In this regard, Remote Sensing (RS) and Geographic Information Systems (GIS) have emerged as powerful tools for monitoring and analyzing urban expansion and its impacts. Over the past few decades, satellite-based observations have provided valuable data for detecting changes in land cover and assessing their environmental consequences (Wang & Maduako, 2018). Compared to traditional ground-based surveys, remote sensing techniques offer significant advantages in terms of spatial coverage, temporal frequency, and cost-effectiveness (Karimi *et al*., 2018).

The integration of multi-temporal satellite imagery with GIS allows for detailed analysis of urban growth patterns and their relationship with thermal characteristics. For instance, Landsat data have been widely used to map LULC changes and estimate land surface temperature, providing insights into the spatial distribution of urban heat islands and their evolution over time. Studies conducted in various parts of the world have demonstrated strong correlations between increased built-up areas and elevated surface temperatures, as well as the cooling effects of vegetation and water bodies (Weng, 2009; Zhou *et al*., 2014). In the Nigerian context, similar approaches have been employed to examine the environmental impacts of urbanization, highlighting the critical role of geospatial technologies in urban climate studies.

The alteration of natural landscapes due to urban expansion has profound effects on key biophysical processes, including surface albedo, evapotranspiration, heat storage, and anthropogenic heat emissions. The replacement of vegetated surfaces with impervious materials reduces the capacity of the land to reflect solar radiation and dissipate heat, leading to increased surface and air temperatures. This, in turn, contributes to thermal discomfort, higher energy demand for cooling, and increased risks to public health, particularly in hot and semi-arid regions such as Gombe. Furthermore, the concentration of human activities in urban areas often leads to increased emissions of pollutants, which can exacerbate heat retention and degrade air quality (Arnfield, 2003). Given the growing importance of urban climate issues, there is a pressing need for empirical studies that quantify the relationship between urban expansion and thermal characteristics, particularly in rapidly urbanizing regions where data are limited. Despite the increasing body of research on urbanization in Nigeria, relatively few studies have focused specifically on the thermal implications of urban growth in mid-sized cities like Gombe. This represents a critical knowledge gap, as such cities are expected to experience significant population and spatial growth in the coming decades.

In this context, the present study aims to assess the impact of urban expansion on the thermal characteristics of Gombe Metropolis using multi-temporal remote sensing and GIS techniques. By analyzing changes in LULC and land surface temperature over time, the study seeks to provide a comprehensive understanding of how urban growth influences local microclimates. The findings are expected to inform urban planning and policy decisions, particularly in relation to climate-sensitive land use management, urban greening initiatives, and strategies for mitigating the urban heat island effect. Ultimately, this research contributes to the broader goal of promoting sustainable and resilient urban development in Gombe and other rapidly growing cities in sub-Saharan Africa.

1.1 Problem Statement

Urbanization is a major driver of environmental change in sub-Saharan Africa, significantly influencing land use/land cover (LULC) patterns and urban climate systems. In Gombe Metropolis, the capital of Gombe State, rapid and largely unplanned urban expansion has transformed natural landscapes by replacing vegetated surfaces with impervious materials such as buildings and roads. This transformation has been closely linked to changes in local thermal conditions, particularly increasing land surface temperature (LST) and the development of urban heat islands (UHIs), which alter the microclimate and contribute to environmental stress (Balzerek *et al*., 2003; Daramola & Adelekan, 2019).

Gombe has experienced substantial spatial growth over the years, driven by population increase and rising demand for housing and infrastructure. Mbaya (2012), notes that this expansion has resulted in the conversion of productive agricultural land and natural vegetation into built-up areas. Similarly, Wakirwa (2015) reports that the city's urban extent increased significantly from approximately 12.78 km^2 in 1999 to 39.50 km^2 in 2014, largely at the expense of agricultural zones. The loss of vegetation is particularly critical because it reduces natural cooling mechanisms such as evapotranspiration and shading, thereby contributing to higher surface temperatures and increased thermal discomfort.

Empirical studies across Nigerian cities reveal a strong positive relationship between urban expansion and rising temperatures. Adetunji and Aruya (2023) found that in rapidly growing urban areas, mean LST increased substantially over time alongside a sharp rise in built-up land. In the case of Gombe, Bachama *et al*. (2020) identified a clear transition from green cover to urban land uses, which significantly influenced the city's microclimate and intensified heat stress conditions. These findings highlight the environmental consequences of uncontrolled urban growth, particularly in semi-arid regions where baseline temperatures are already high.

Despite the growing body of literature, there remains a significant gap in comprehensive spatial-temporal analyses that integrate LULC changes with surface temperature dynamics in Gombe Metropolis. Many existing studies have focused primarily on urban growth patterns or flood risks (Dabara *et al*., 2012; Balzerek *et al*., 2003), with limited application of remote sensing techniques to examine thermal variations alongside land-use transformations. This lack of integrated analysis restricts the ability of urban planners and policymakers to develop effective, evidence-based mitigation strategies.

In response to this gap, this study seeks to address three key research questions: the rate of urban expansion between 1994 and 2024, the trend of temperature changes over the same period, and the extent to which LULC patterns influence thermal characteristics. By providing a comprehensive assessment, the study aims to support sustainable urban planning and climate-responsive development in Gombe Metropolis.

1.2 Objective

The primary aim of this study is to examine how urban expansion has influenced the thermal characteristics of Gombe Metropolis, with particular emphasis on understanding the relationship between land use/land cover (LULC) dynamics and land surface temperature (LST). Over the past three decades, Gombe has undergone rapid urbanization, resulting in significant transformation of natural landscapes into built-up environments. This study therefore seeks to provide a comprehensive assessment of how these spatial changes have affected temperature patterns and contributed to microclimatic variations, including the development of urban heat island (UHI) effects.

To achieve this aim, the study focuses on three key objectives. First, it assesses the extent and pattern of LULC changes in Gombe Metropolis between 1994 and 2024. This involves identifying how different land cover types—such as vegetation, agricultural land, wetlands, and built-up areas—have evolved over time. By analyzing these changes, the study establishes the magnitude and direction of urban expansion and highlights the rate at which natural land covers have been replaced by impervious surfaces.

Second, the study examines changes in temperature patterns associated with LULC transformations. Using geospatial techniques, it evaluates how variations in land cover influence surface temperature distribution across the study area. This objective is critical in understanding the thermal implications of urban growth, particularly the extent to which the loss of vegetation and increase in built-up areas contribute to rising temperatures and localized heat stress.

Third, the study investigates the relationship between LULC characteristics and LST. Through statistical and spatial analysis, it determines whether significant correlations exist between different land-use types and temperature variations. This is further supported by the formulation of a null hypothesis, which states that there is no significant relationship between LULC changes and LST in Gombe Metropolis. Testing this hypothesis provides a scientific basis for confirming or rejecting the influence of urban land transformation on thermal conditions.

The scope of the study is geographically limited to Gombe Metropolis, including its urban core and surrounding peri-urban areas affected by urban sprawl. It focuses specifically on LULC and LST as key indicators of environmental change. Temporally, the study spans a 30-year period (1994–2024), using four benchmark years 1994, 2004, 2014, and 2024 to capture different phases of urban growth and their thermal impacts. This time frame allows for a consistent and detailed analysis of long-term trends.

The significance of the study lies in its contribution to bridging the gap between urbanization and environmental sustainability. By integrating remote sensing and GIS techniques, it provides empirical evidence on how urban expansion affects temperature patterns. The findings are valuable for urban planners, environmental managers, and policymakers, as they offer insights for developing climate-sensitive strategies such as urban greening, improved land-use planning, and heat mitigation measures.

Furthermore, the study contributes to broader research on urban climatology and climate change adaptation, particularly in rapidly growing cities of the Global South. Its methodology and results can be applied to similar urban contexts, making it relevant beyond Gombe. Ultimately, the research emphasizes the need for sustainable urban development that balances growth with environmental protection, ensuring healthier and more resilient cities for the future.

2. Methodology

This chapter describes the research methodology that will be used to investigate the impact of Urban Expansion on thermal characteristics in Gombe metropolis from 1994 to 2024. The methodological framework is designed to answer the research questions about urban expansion rates, temperature changes, and the relationship between land-use land cover (LULC) patterns and local temperature variations. The study will employ a geospatial approach using remote sensing and Geographic Information System (GIS) techniques to analyze how LULC changes have influenced thermal conditions over three decades in the study area.

2.1 Study Area

Gombe City is located on Latitudes 10°16′48″N and 10°17′24″N and Longitude 11°14′07″E and 11°4′42″E, and has a total land mass 52 Km^2, Gombe city lies at elevation of 461m, 1512.47ft above sea level. Fig 1 shows a map of Gombe city, Nigeria. Gombe is the capital city of Gombe State, north-eastern Nigeria. The city is the headquarters of the Gombe Emirate, a traditional State that covers most of Gombe State (Muhammad *et al.*, 2022).

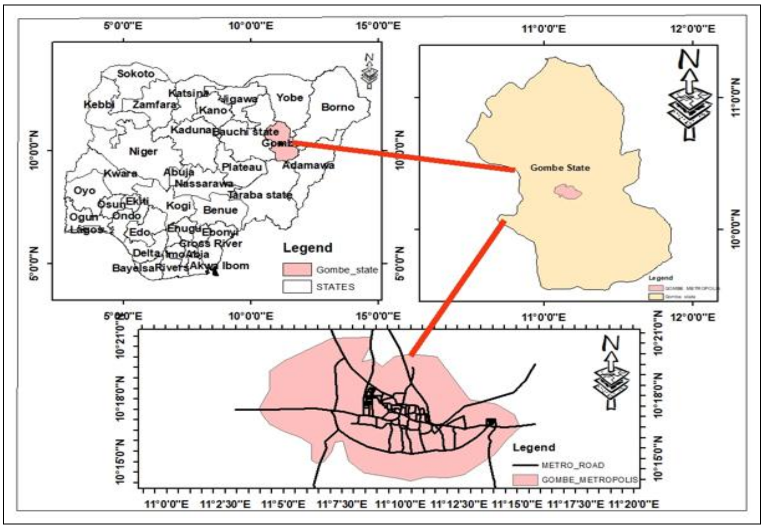

Fig 1: Study Area

The geology of Gombe is largely classified as cretaceous sedimentary sandstone of the Bima formation. Other formations are the Yolde formation and the Pindiga formation. There are granitic intrusions of basement complex exposed at the surface. More so, the upper part of Akko slope are developed in weakly consolidated sandy sediment of tertiary Keri-Keri formation, whereas the towns slope consist of sand and silts stones belonging to the cretaceous Gombe formation. The central part of the town was founded on these older sedimentary rocks (Obiefuna and Sheriff, 2011).

Gombe city has a flat landscape in the north while in the southern parts of the city have isolated hills. The elevation of the plain is at about 600m above sea level, the hills reach between 700-800m. The city has numerous streams that are mostly seasonal and serve as tributaries to the Gongola River. It traverses the city watering most of the northern and north-eastern part of the city before emptying into the river Benue at Numan (Obiefuna and Sheriff, 2011). The soils of Gombe city have exerted an enormous influence on soil development, hence over half of the city (central) that is underlain by Kerri-Kerri formation has swallowed to moderately shallow impoverished soils, with sandy loams on the Iron pan (Adamu, 2017). On the Chad formation in the northern part of the city, the soils are deep but sandy and developed on clay and silky clay (Adamu, 2017). Soils in the eastern part of Gombe city are shallow to deep loamy, sandy, clay, loam and vertisols with cracking clays that have weathered from shale’s (Obiefuna and Sheriff, 2011).

The vegetation in Gombe city is characterized by two vegetation zone (Guinea and Sudan savanna). Vegetation in Gombe city is predominantly wooded shrub land in the central part, with the plant community comprising of *Anogeissus, Combretum, Affrormosia, Detarium*. The northern part of the state exhibits a mosaic of shrubbed grassland and grassed shrub land with the preponderance of Acacia. In the hilly south areas, the vegetation is shrubbed woodland with mostly *Affrormosia and Datarium* (Obiefuna and Sheriff, 2011). The people of Gombe are mostly farmers and civil servants they produce both cash and food crops. Cash crops such as groundnut, cotton, beniseed, soyabean, cowpea etc. Food crops such as cassava, maize, tomato, millet, beans, sorghum, rice, onions, pepper and sugar cane. The people rear cattle, goats, sheep, horses and donkeys. Traditional craft like weaving and local processing of cotton are still practiced. The farmers provide raw materials for agro-based industries like Tomato Company, cotton ginnery and groundnut oil mills in the city. Other industries are cement industries (Ashaka Cement Company), various block industry and other small-scale industries (Obiefuna and Sheriff, 2011).

Gombe city have two distinct climates, the dry season between November and March and the warm, humid rainy season between April and October with an average rainfall of about 850mm (Malik 2004). There is a brief interlude of harmattan occasioned by the Northeast trade wind, with the main features of dust, haze, intensified coldness and dryness (Malik, 2004). The highest daily temperature is about 38^0C which corresponds to the hottest period usually experienced in the months of March to April and the months of December to January are usually very cold with temperature as low as 25^0C (Obiefuna and Sheriff, 2011). Rainfall is one of the key climatic resources of Gombe; the climate of Gombe is characterized by a dry season of six months, alternating with a six months rainy season. As in other parts of the Nigerian Savanna this precipitation distribution is mainly triggered by a seasonal shift of the Inter -Tropical Convergence Zone (ITCZ). For the years 1984 to 2013, the mean annual precipitation is 969.7mm the arrival of the rainy season starts around April or May; however, heavy rainfall may put in an appearance until June or even July. By October, the amounts of rainfall begin to decrease (Yahaya, 2015).

The mean annual temperature is about 32^0C weather tends to be very hot between November and March with average high temperature can reach 32^0C or more. The hamattan wind from around February makes the temperature cooler, although with dusty conditions, whereas relative humidity has some pattern being 90% in August and dropping to less than 10% during the hamattan period (Balzerek *et al*., 2003).

2.2 Research Design

This study will adopt a quantitative, geospatial research design aimed at analyzing the spatial and temporal dynamics of urban expansion and its influence on thermal characteristics - specifically Land Surface Temperature (LST) - in Gombe Metropolis. A combination of remote sensing, Geographic Information System (GIS) techniques and statistical analysis will be used to examine how changes in Land Use and Land Cover (LULC) patterns over time have affected the city's thermal environment. The research will be conducted over a 30-year temporal scope, focusing on four key time points: 1994, 2004, 2014, and 2024. These years were purposefully selected to represent pre-expansion, early-growth, peak-growth, and recent urban development phases, enabling a comprehensive spatiotemporal analysis of urban expansion and associated thermal implications in the study area.

The analytical framework will follow a systematic multi-step approach, including:

1. Satellite Image Acquisition and Preprocessing: Multi-temporal satellite imageries (Landsat series) for the four selected years will be acquired and preprocessed to correct for radiometric and geometric distortions.
2. LULC Classification and Change Detection: Supervised classification using maximum likelihood algorithms will be employed to classify LULC types. Post-classification comparison will be used to detect land use transitions across the selected periods.
3. LST Retrieval: Land Surface Temperature will be extracted from the thermal bands of the Landsat datasets using appropriate algorithms (e.g., mono-window or single-channel methods), with atmospheric corrections applied.
4. Spatial Analysis: The relationship between LULC changes and LST variation will be explored using spatial overlay and zonal statistics in GIS. Heat maps and surface temperature gradient models will be developed to visualize thermal patterns.
5. Statistical Analysis: Pearson correlation and regression models will be employed to evaluate the strength and direction of the relationship between urban expansion (e.g., increase in built-up area) and LST trends.

This integrated geospatial and statistical design will allow for an evidence-based understanding of how rapid urban expansion in Gombe Metropolis has altered its thermal landscape. The approach provides both quantitative measures and spatial visualizations necessary for informing urban planning and environmental management in the region.

2.3 Data Types and Sources

This study will utilize Landsat satellite imagery as the primary data source for analyzing Land Use and Land Cover (LULC) changes and Land Surface Temperature (LST) patterns in the study area. Landsat imagery offers a robust combination of long-term temporal coverage, consistent data quality, and adequate spatial and spectral resolution for environmental monitoring.

A spatial resolution of 30 meters is selected for the multispectral bands because it provides a balance between detail and coverage, making it suitable for urban and environmental studies at regional and city scales such as Gombe metropolis. While higher resolution imagery (e.g., <10m) may offer finer details, Landsat's 30m resolution is sufficient for detecting broad patterns of urban expansion, vegetation change, and surface temperature variation over multi-decadal periods. Furthermore, its compatibility with historical datasets enhances the ability to conduct time-series analysis across decades.

The thermal bands, which are critical for LST estimation, have coarser native resolutions (120m for Landsat 5 and 100m for Landsat 8/9), but are resample to 30m by USGS to align with the multispectral bands, thereby facilitating integrated analysis. All satellite data will be acquired for the dry season month of January. This selection ensures uniform atmospheric conditions, minimizes cloud cover, and avoids seasonal vegetation fluctuations, thereby improving comparability and accuracy in LULC and LST assessments across the years. The satellite images were all acquired from the United States Geological Survey (USGS) Earth Explorer platform, and all data undergo surface reflectance correction to reduce atmospheric distortion and enhance the reliability of spectral measurements.

Table 1: Satellite Data Specifications

Year	Satellite/Sensor	Acquisition Date	Spatial Resolution (m)	Bands Used
1994	Landsat 5 TM	January 1994	30 (Multispectral), 120 (Thermal)	1-7
2004	Landsat 5 TM	January 2004	30 (Multispectral), 120 (Thermal)	1-7
2014	Landsat 8 OLI/TIRS	January 2014	30 (Multispectral), 100 (Thermal)	2-7, 10-11
2024	Landsat 9 OLI/TIRS	January 2024	30 (Multispectral), 100 (Thermal)	2-7, 10-11

The study will also incorporate several supplementary datasets to support the analysis like the administrative boundaries of Gombe metropolis will be obtained from the Gombe State Ministry of Lands and Survey to define the exact study area extent. Ground control points will be collected during field surveys to verify land use classifications and improve accuracy assessment. Historical temperature records from the Nigerian Meteorological Agency (NiMet) will be used to validate the satellite-derived temperature estimates. Population statistics from the National Population Commission will help contextualize urban growth patterns in relation to demographic changes. A digital elevation model (DEM) from the Shuttle Radar Topography Mission (SRTM) will be used to account for topographic effects on temperature patterns.

2.4 Data Processing and Analysis

Several pre-processing steps were applied to the satellite images to ensure data quality and consistency for analysis, including the radiometric calibration process which converts the raw digital numbers to physically meaningful values of surface reflectance. This involve converting to at-sensor radiance and then to top-of-atmosphere reflectance using sensor-specific calibration parameters (Chander *et al*., 2009). Atmospheric correction was applied to remove atmospheric effects from the imagery using the Dark Object Subtraction method for Landsat 5 TM images and the FLAASH module for Landsat 8/9 data (Xu *et al*., 2020).
The images undergo geometric correction to ensure precise spatial alignment between multi-temporal scenes, with a target root mean square error below 0.5 pixels. All images will be clipped to the Gombe metropolis administrative boundary to focus the analysis specifically on the study area. Quality assessment will be performed to identify and mask clouds, cloud shadows, and other artefacts that could compromise analysis results. These pre-processing operations were carried out using ENVI software and ArcGIS Pro to prepare the data for subsequent analysis.
The study also adopts a classification scheme with five LULC classes based on the characteristics of Gombe metropolis and the research objectives as shown in table 2. This classification scheme will allow for detailed analysis of urban expansion patterns and their relationship with thermal characteristics while being appropriate for the semi-arid savannah landscape of Gombe.

Table 2: Land Use Land Cover Classification Scheme

LULC Class	Description
Built-up Area	Residential, commercial, industrial, transportation, and other constructed areas
Vegetation	Trees, shrubs, grasslands, and vegetated areas
Bare Land	Exposed soil, sand, rocks, and areas with no vegetation
Farmland	Cultivated areas and agricultural fields
Water Bodies	Rivers, streams, ponds, and other water features

The study employs a supervised classification approach using the Random Forest algorithm, which has demonstrated robust performance in urban land cover mapping (Belgiu and Drăguţ, 2016). The classification process will begin with the collection of representative training samples for each LULC class using high-resolution reference imagery and ground truth data. For historical images where direct ground truth is unavailable, training samples will be selected from areas with known historical land uses.
The Random Forest classifier was applied with optimized parameters to generate the initial LULC maps for each time period. Post-classification processing will include a majority filter to reduce the salt-and-pepper effect and improve classification coherence. Accuracy assessment will be conducted using an independent set of validation points, with metrics including overall accuracy, user's and producer's accuracies, and the Kappa coefficient calculated to evaluate classification performance.
The area of each LULC class was calculated for each time period to determine the extent and proportion of different land uses and their changes over time. Change matrices will be generated to quantify transitions between LULC classes across the three decades, identifying both the magnitude and direction of land use transformations.
The annual rate of change for each LULC class will be calculated using the standardized formula equation 1 proposed by Puyravaud (2003):

$$r = \left[\frac{1}{(t_2 - t_1)} \times In\left(\frac{A_2}{A_1}\right)\right] \quad (1)$$

Where r represents the annual rate of change, A_1 and A_2 are the areas of a land use class at times t_1 and t_2, respectively. This will quantify the pace of urbanization and other land cover conversions.
Spatial pattern metrics including patch density, mean patch size, and landscape fragmentation index will be calculated using FRAGSTATS software to characterize the structural changes in the urban landscape over time (McGarigal *et al*., 2012).
Urban expansion intensity will be analyzed using the Urban Expansion Intensity Index (UEII) as shown in equation 2 to measure the rate and magnitude of built-up area growth relative to the initial urban extent:

$$UEII = [(ULA_2 - ULA_1)/(ULA_1 \times (t_2 - t_1))] \times 100\% \quad (2)$$

Where ULA_1 and ULA_2 represent urban land area at times t_1 and t_2, respectively.

The thermal bands (Band 6 for Landsat 5 TM and Bands 10-11 for Landsat 8/9 OLI/TIRS) were processed to derive LST values. The processing will follow these steps, conversion of Digital Numbers (DN) to at-sensor spectral radiance using sensor-specific calibration parameters.

Transformation of spectral radiance to at-sensor brightness temperature using the Planck function is given in equation 3 below:

$$TB = K_2/In(\frac{K_1}{L\lambda} + 1) \tag{3}$$

Where TB is the brightness temperature in Kelvin, K_1 and K_2 are calibration constants specific to each Landsat sensor, and $L\lambda$ is the spectral radiance.

Calculation of land surface emissivity (LSE) based on the Normalized Difference Vegetation Index (NDVI) threshold method given in equation 4 (Sobrino *et al*., 2004):

$$\varepsilon = \varepsilon v \times Pv + \varepsilon s \times (1 - Pv) + d\varepsilon \tag{4}$$

Where ε is the land surface emissivity, εv and εs are the emissivities of vegetation and soil respectively, Pv is the vegetation proportion derived from NDVI, and $d\varepsilon$ represents the cavity effect.

Derivation of final LST using the emissivity-corrected land surface temperature equation was obtained using equation 5:

$$LST = TB/\left[1 + \left(\lambda \times \frac{TB}{\rho}\right) \times In(\varepsilon)\right] \tag{5}$$

Where λ is the wavelength of emitted radiance, and ρ is a constant derived from Planck's constant, Boltzmann constant, and the speed of light (1.438×10^{-2} mK).

To ensure reliability of the LST results, the satellite-derived LST values will be validated against ground-based temperature measurements from the Nigerian Meteorological Agency (NiMet) using correlation analysis and root mean square error calculation. Temporal normalization will be applied to account for diurnal and seasonal variations in temperature, enabling more accurate comparison between different time periods. Topographic corrections using the SRTM DEM will be implemented to minimize the influence of elevation differences on temperature patterns. Calculation of urban heat island intensity (UHII) by comparing mean LST values between built-up areas and surrounding non-urban areas for each time period: UHII = LST(urban) - LST(rural). Zonal statistics to quantify mean, minimum, maximum, and standard deviation of LST for each LULC class, enabling assessment of how different land covers influence thermal conditions.

Buffer analysis to examine how LST varies with distance from the urban core, using concentric buffer zones at 1 km intervals from the city center. Trend analysis to identify statistically significant warming or cooling trends across the 30-year study period using pixel-based linear regression of LST values against time. Hot spot analysis was used to identify statistically significant hot and cold spots within the urban landscape and track their spatial evolution over time.

Several statistical techniques was employed to quantify the relationships between land use patterns and thermal characteristics such as Pearson correlation analysis to measure the strength and direction of relationships between the proportion of different land use types and LST. Multiple linear regression to develop predictive models of LST based on LULC composition, with the general form: $LST = \beta_0 + \beta_1X_1 + \beta_2X_2 + ... + \beta_nX_n + \varepsilon$ Where $X_1, X_2, ..., X_n$ represent the proportions of different LULC types, $\beta_0, \beta_1, \beta_2, ..., \beta_n$ are regression coefficients, and ε is the error term. Analysis of Variance (ANOVA) to test for significant differences in mean LST values between different LULC classes and time periods was used and Principal Component Analysis (PCA) to explore multivariate relationships between LULC patterns, LST, and other variables such as population density and elevation.

The study utilized a suite of specialized software packages for geospatial analysis and statistical computation such as ENVI 5.6 for satellite image preprocessing and LST retrieval, ArcGIS Pro 3.0 for LULC classification, change detection and spatial analysis. FRAGSTATS 4.2 for landscape pattern analysis and R Statistical Software for statistical modeling and data visualization. Lastly, Google Earth Engine for supplementary analysis and verification.

3. Results and Discussion

This section presents the LULC distribution in Gombe Metropolis across four study years: 1994, 2004, 2014, and 2024. Each map is discussed independently to highlight key land cover characteristics and transitions for that decade.

3.1 Spatial Distribution and Temporal Changes of LULC

The 1994 LULC map represents the pre-urban expansion condition of Gombe Metropolis. At this stage, the landscape was largely natural and undeveloped.

Vegetation dominated the area, covering approximately 90,086 hectares (49.3%), primarily composed of savannah woodland, shrubs, and open grassland. These green spaces served essential ecological functions such as microclimate regulation and soil protection. Farmlands accounted for 69,153 hectares (37.9%), indicating that agriculture was the primary land use for livelihood, especially on the outskirts of the town. Built-up areas were minimal, covering only 19,665 hectares (10.8%), concentrated within the historical urban core, such as areas around Gombe town center and key administrative zones. Bare surfaces were negligible, occupying just 3,653 hectares (2.0%), likely representing exposed soil, dry riverbeds, and undeveloped rocky outcrops. This map reflects a typical low-density, agriculturally supported settlement surrounded by expansive natural vegetation.

By 2004, noticeable spatial transformations had begun to reshape the landscape of Gombe Metropolis. Vegetation decreased to 75,557 hectares (41.4%), a reduction of 14,529 hectares from 1994, indicating ongoing deforestation and degradation of natural areas. Farmland slightly declined to 61,482 hectares (33.7%), likely due to early-stage urban encroachment and road construction. Built-up areas expanded modestly to 22,621 hectares (12.4%), marking the beginning of linear and concentric urban growth extending outwards from the core. Bare surfaces rose sharply to 22,897 hectares (12.5%), signalling land clearance for construction, erosion-prone surfaces, or incomplete building sites. The 2004 map signals the transition from a primarily rural landscape to a peri-urban setting, where development pressure began to alter the ecological balance of the region.

A more intensified phase of land use transformation was evident in 2014. Built-up areas surged to 40,815 hectares (22.4%), nearly doubling within a decade. This growth corresponded with infrastructural expansion, increased migration, and economic development across the city. Vegetation declined further to 41,403 hectares (22.7%), a reduction of almost 45% from the 1994 baseline.

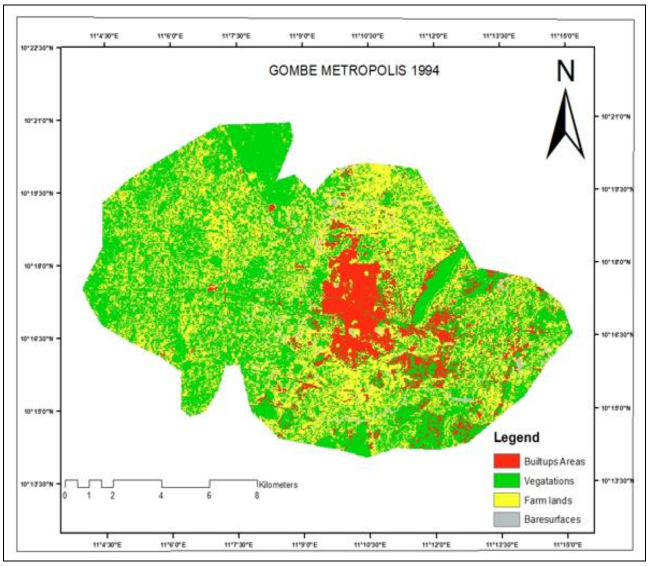

Fig 2: LULC Map of Gombe Metropolis in 1994

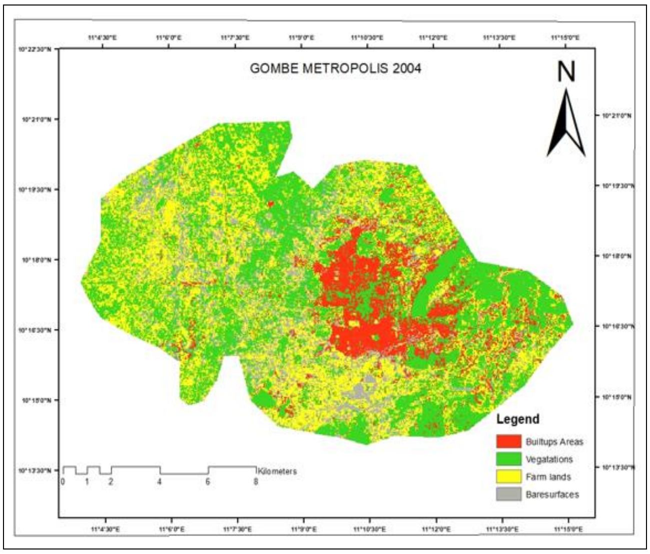

Fig 3: LULC Map of Gombe Metropolis in 2004

The remaining vegetation was now largely fragmented and scattered across the urban fringe. Farmlands increased temporarily to 74,095 hectares (40.6%), possibly due to a surge in urban agriculture or reclassification of transitional lands. However, this expansion may also reflect informal land-use adaptation. Bare surfaces increased modestly to 26,244 hectares (14.4%), indicating that large portions of land were actively being converted or prepared for urban development. This period represents a tipping point in the landscape, with aggressive land conversion leading to a shrinking ecological base and the emergence of patchy, disconnected green spaces. By 2024, Gombe Metropolis had evolved into a predominantly urban landscape. Built-up areas dominated the land cover, reaching 72,512 hectares (39.7%), signifying a dramatic transformation from a rural town to a highly urbanized city over three decades. Vegetation declined further to 37,700 hectares (20.6%), which represents a staggering loss of over 52,000 hectares (58%) since 1994.

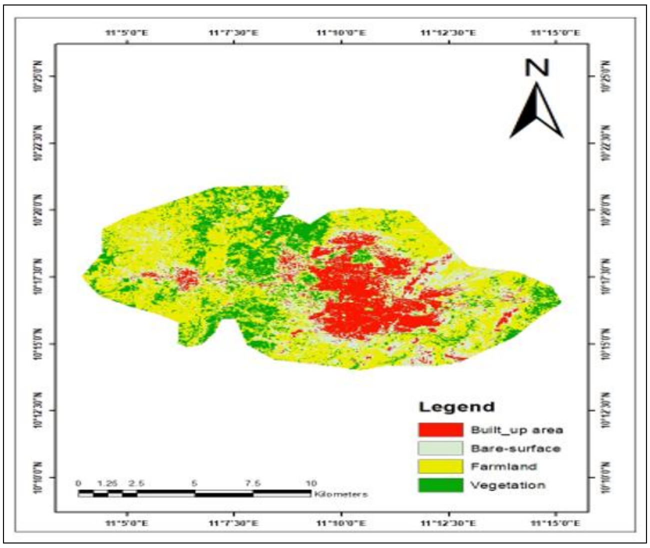

Fig 4: LULC Map of Gombe Metropolis in 2014

Farmlands decreased sharply to 41,119 hectares (22.5%), as agricultural lands were increasingly absorbed by the expanding city. Bare surfaces peaked at 31,226 hectares (17.1%), highlighting extensive land clearing, construction, and surface exposure. The 2024 map depicts a critical scenario in which natural land cover has been heavily compromised, raising serious concerns about environmental degradation, reduced ecological resilience, and rising urban heat risks. Over the 30-year period, built-up areas increased by more than 52,000 hectares, representing a 268.7% rise, while vegetation declined by 58.2%, losing over half of its original area. Farmlands initially rose but later declined drastically, and bare surfaces increased eightfold, reflecting both developmental and environmental stress on the urban ecosystem. These figures reveal the intensity of human-induced landscape transformation, underscoring the urgent need for sustainable urban planning, land-use regulation, and ecological conservation in Gombe Metropolis. Table 3 provides a consolidated comparison of land cover changes over the four decades.

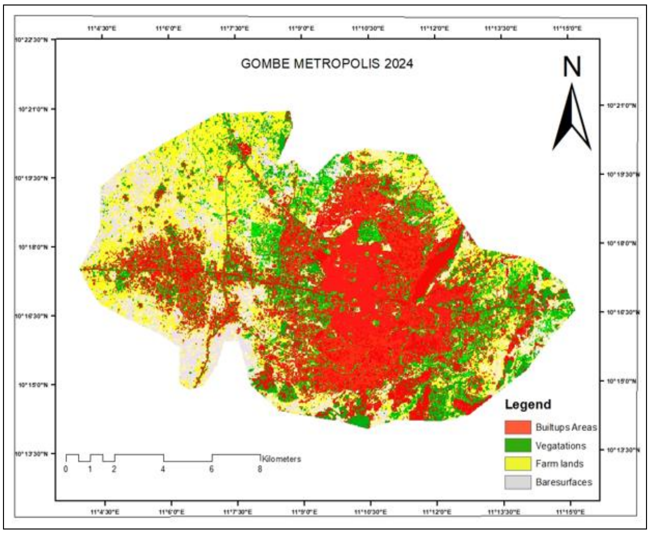

Fig 5: LULC Map of Gombe Metropolis in 2024

Table 3: LULC Distribution Summary from 1994 to 2024

LULC Class	1994 (ha)	%	2004 (ha)	%	2014 (ha)	%	2024 (ha)	%
Bare Surfaces	3,653	2.0%	22,897	12.5%	26,244	14.4%	31,226	17.1%
Built-up Areas	19,665	10.8%	22,621	12.4%	40,815	22.4%	72,512	39.7%
Farmlands	69,153	37.9%	61,482	33.7%	74,095	40.6%	41,119	22.5%
Vegetation	90,086	49.3%	75,557	41.4%	41,403	22.7%	37,700	20.6%

3.2 Spatial Thermal Patterns and Distribution

Temperature data obtained from MERRA-2 satellite observations for Gombe Metropolis between 1994 and 2024 shows a consistent upward trend in surface temperatures, largely driven by anthropogenic activities and rapid Urban Expansion. From 1994 to 2024, the mean annual temperature increased from 25.71°C to 26.91°C, marking a net rise of 1.2°C. The temperature trend line suggests a steady warming pattern, particularly from 2004 onwards, which coincides with significant land use transitions as seen in the LULC analysis. Fig 6 shows the Annual Mean Temperature Trend (1994–2024).

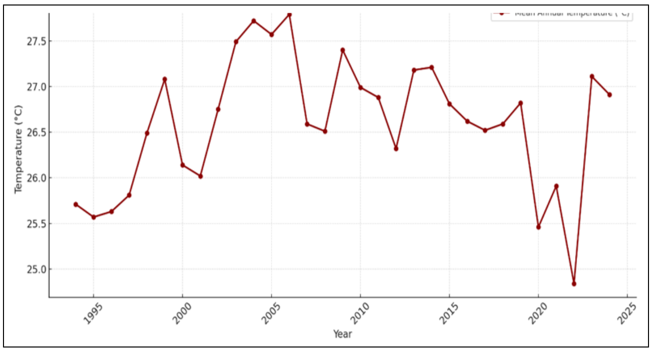

Fig 6: Annual Mean Temperature Trend (1994–2024)

The NDVI result for 1994 shows that Gombe metropolis was characterized by predominantly dense and continuous vegetation cover, especially in the northern and eastern sections where natural vegetation and water bodies were abundant. Most areas exhibited moderate to high vegetation density, reflecting minimal urban expansion and limited human disturbance. The landscape had strong natural vegetation, contributing to thermal regulation and environmental health. Fig 7 shows the 1994 NDVI Map for Gombe Metropolis.

The NDVI result for 2004 indicates that Gombe metropolis experienced a reduction and fragmentation of vegetation cover due to emerging urban development's and infrastructure expansion. Vegetated areas became more scattered, and patches of non-vegetated surfaces increased. This reflects the impact of early urban expansion and human activities on natural vegetation, underscoring the need for proactive vegetation management and conservation. Fig 8 shows the NDVI Map for Gombe Metropolis in 2004.

The NDVI result for 2014 reveals accelerated vegetation decline with dense vegetation areas shrinking further and becoming more isolated primarily at the urban periphery. Built-up zones, commercial centers, and bare surfaces dominated large parts of the metropolis, causing significant vegetation loss. This highlights the growing influence of urban heat islands and human activities, emphasizing the importance of urban greening, reforestation, and sustainable land-use planning as shown in Fig 9.

The NDVI result for 2024 shows that Gombe metropolis is dominated by sparsely vegetated and non-vegetated surfaces, with only limited areas of dense vegetation remaining. This reflects the cumulative impact of decades of urban expansion, intensive human activities, and seasonal dryness on natural vegetation. The findings stress the critical need for urban greening initiatives, reforestation, and sustainable land management to restore environmental resilience and thermal regulation in the metropolis.

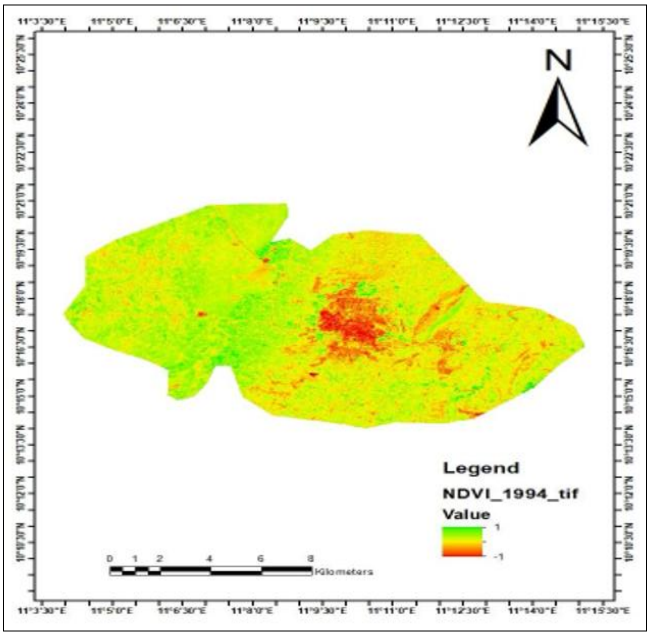

Fig 7: NDVI Map for Gombe Metropolis 1994

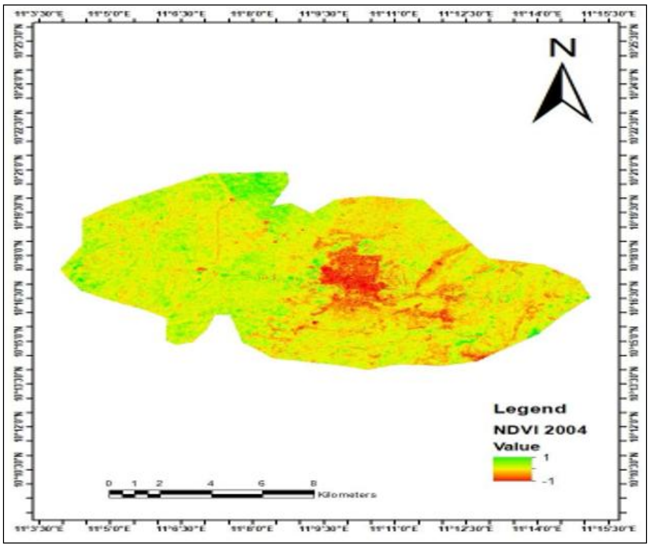

Fig 8: NDVI Map for Gombe Metropolis 2004

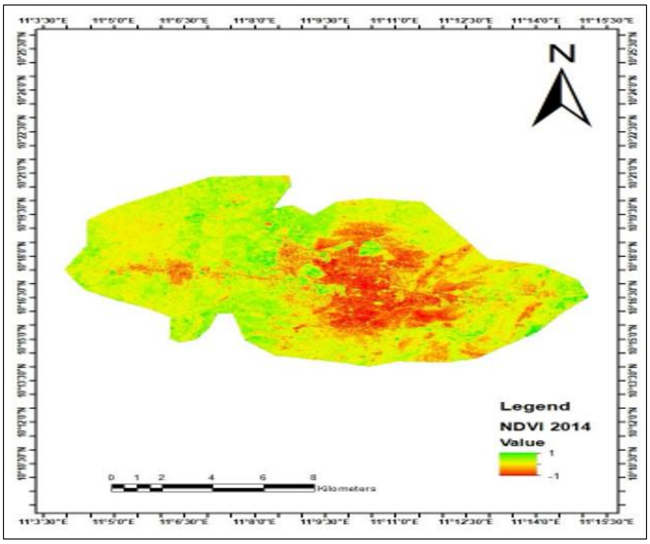

Fig 9: NDVI Map for Gombe Metropolis 2014

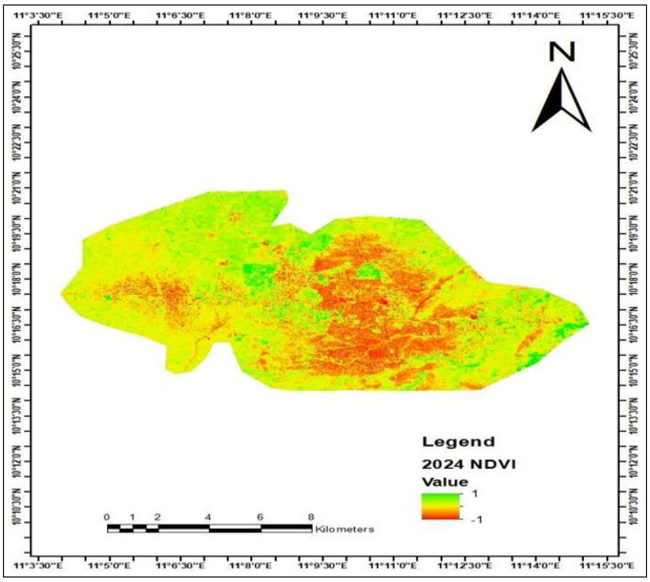

Fig 10: NDVI Map for Gombe Metropolis 2024

3.3 The Decadal Temperature Statistics

To better observe changes over time, the temperature data were grouped into decades and statistically analyzed as shown in table 4. The decade 2004–2013 recorded the highest decadal mean (26.81°C), while 2024 alone recorded the highest single-year variability (SD = 3.53°C). The extreme heat in 2024 (32.93°C in April) and extreme cold in December 1994 (19.63°C) reflect both natural variability and urban-induced climate shifts. Overall Warming: The mean temperature rose by 1.2°C over 30 years. Warming Rate: A linear regression analysis shows an average increase of 0.04°C/year, which is higher than global rural averages. Thermal Shocks: 2004, 2010, and 2024 recorded exceptional spikes, aligning with periods of aggressive land transformation.

Table 4: Decadal Temperature Summary for Gombe Metropolis

Period	Mean Temp (°C)	Min (°C)	Max (°C)	Standard Deviation (°C)
1994–2003	25.94	24.02	27.49	0.89
2004–2013	26.81	26.02	27.79	0.52
2014–2023	26.39	24.84	27.21	0.75
2024	26.91	20.84	32.93	3.53

3.4 Seasonal Temperature Patterns

The average monthly temperatures were analysed to identify seasonal variations and trends across decades and it was observed that the Hot Season (March–May): April experienced the most pronounced warming — from 30.42°C in the 1990s to above 32°C post-2020. Rainy Season (June – September):

Temperatures rose moderately, with less extreme variability. Cool Season (November–February): Recorded the highest fluctuations — with December 1994 at 19.63°C and February 2024 at 20.84°C, suggesting possible weakening of night time cooling. The patterns observed clearly support a correlation between land use change and local temperature rise, Loss of vegetation reduces natural cooling, expansion of built-up and bare surfaces increases surface heat retention and the urban heat island effect is evident, particularly in the hot and cool seasons.

These findings strongly support Objective Two, confirming that Gombe's Urban Expansion has directly influenced thermal characteristics over the last 30 years.

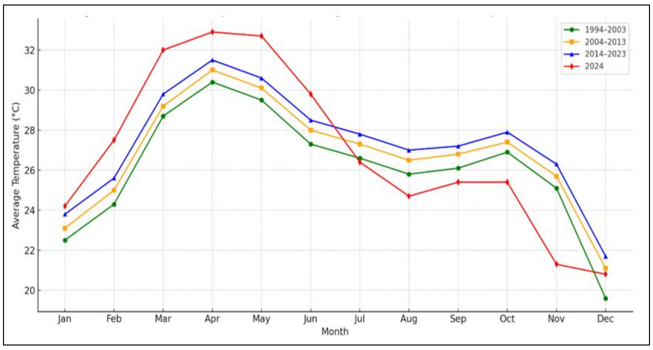

Fig 11: Seasonal Temperature Patterns by Decade

3.5 Relationship between Land Use Change and Temperature Dynamics

Statistical analysis was conducted to determine the relationship between LULC changes and temperature variations. Pearson correlation coefficients were calculated between the percentage of each land cover type and annual mean temperature for corresponding years. Multiple linear regression analysis was performed to develop a predictive model for temperature based on LULC composition:

LST = 23.45 + 0.089(Built-up %) + 0.056(Bare %) - 0.067(Vegetation %) - 0.023(Farm %). Model Statistics:

- $R^2 = 0.782$
- Adjusted $R^2 = 0.748$
- F-statistic = 23.4 ($p < 0.001$)
- Standard Error = 0.47°C

This model explains 78.2% of the temperature variation, indicating a strong relationship between land use composition and thermal conditions.

The Urban Heat Island Intensity (UHII) was calculated for each study period by comparing temperatures between built-up areas and surrounding vegetation/agricultural areas:

Table 5: Correlation between LULC Classes and Temperature

LULC Class	Correlation Coefficient (r)	Significance Level	Relationship
Built-up Areas	+0.847	$p < 0.001$	Strong Positive
Bare Surfaces	+0.792	$p < 0.001$	Strong Positive
Vegetation	-0.823	$p < 0.001$	Strong Negative
Farm Lands	-0.234	$p < 0.05$	Weak Negative

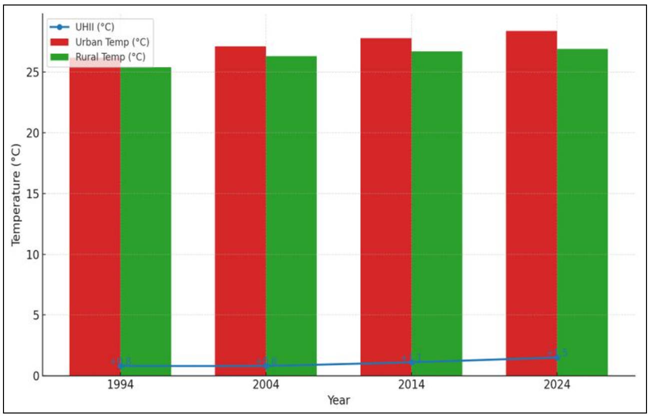

Fig 12: Temperature Difference Maps between Urban and Rural Areas

This temporal change map illustrates the spatial pattern of temperature variations during the first decade of study. The analysis reveals:

1. **Moderate warming (1-2°C)** in areas undergoing initial urban development.
2. **Cooling effects (-1 to 0°C)** in some agricultural areas due to improved irrigation or seasonal variations.
3. **Hotspot emergence** with temperature increases of 3 - 4°C in specific zones of rapid construction.
4. **Spatial correlation** between areas of LULC conversion and temperature rise, with 78% of warming areas corresponding to vegetation-to-built-up transitions.

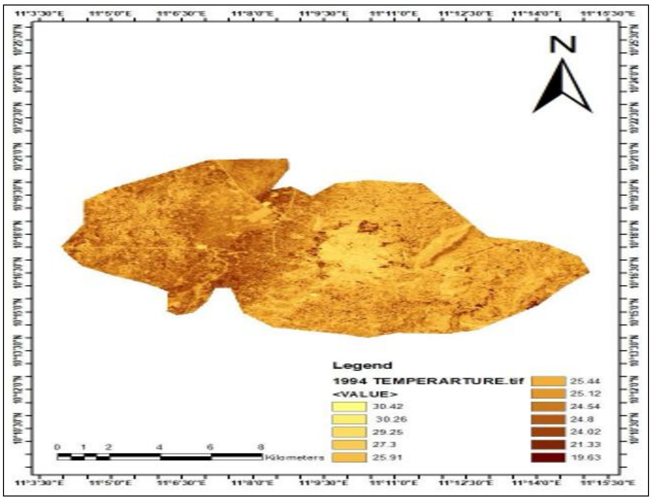

Fig 13: Temperature Change Analysis in 1994 to 2004

The second decade shows accelerated thermal changes with more pronounced spatial patterns, in which the Intensive warming (3-6°C) concentrated in areas of rapid urban expansion, particularly in the southeastern and western corridors. Widespread moderate warming (1-3°C) across transitional zones where agricultural land was converted to mixed-use development. Localized cooling (-1 to 0°C) limited to areas where green infrastructure was implemented or seasonal water bodies expanded. Heat island intensification with temperature increases exceeding 5°C in the urban core, demonstrating the cumulative effect of urban expansion.

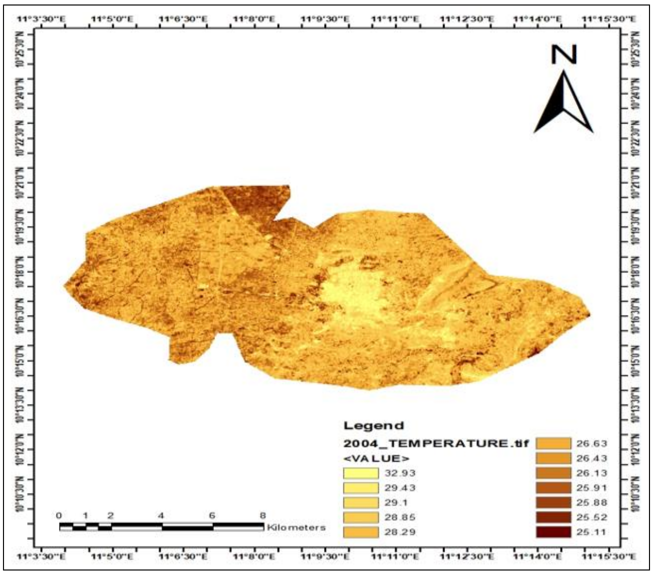

Fig 14: Temperature Change Analysis (2004-2014)

The most recent decade exhibits the most dramatic thermal transformation, Extreme warming (4-8°C) in newly developed areas, particularly in the northern and southern expansion zones. Urban heat island maturation with core areas showing sustained high temperatures and reduced thermal variability. Peripheral warming extending beyond the immediate urban boundary which indicating the regional thermal impact of urbanization. Limited cooling zones now restricted to planned green spaces and protected vegetation areas, emphasizing the critical role of deliberate conservation efforts.

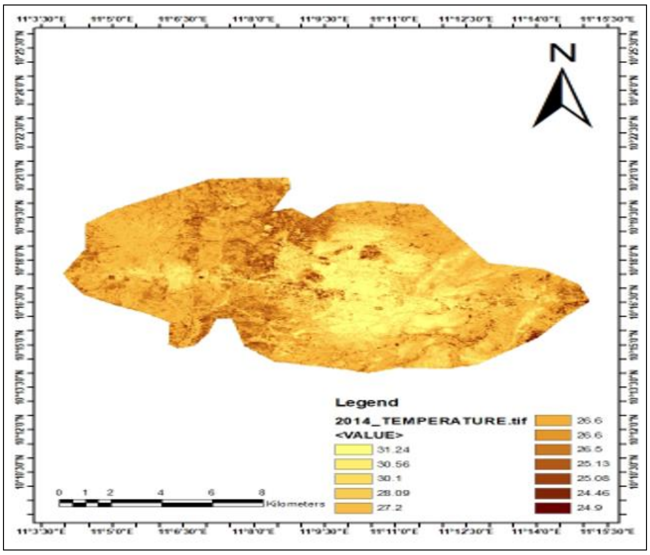

Fig 15: Temperature Change Analysis (2014-2024)

This comprehensive 30-year change analysis synthesizes the complete thermal transformation of Gombe Metropolis in which the overall warming trend affecting 85% of the study area, with average temperature increases of 1.2°C. Maximum warming zones (6-10°C) concentrated in areas that underwent complete land cover conversion from natural vegetation to dense urban development. Thermal amplification in the urban core areas where cumulative effects of multiple development phases created extreme heat conditions. Spatial heterogeneity reflecting the complex interaction between land use change, topography, and urban planning decisions. Regional impact extending beyond administrative boundaries, indicating the metropolitan-scale influence of urban thermal modification.

This cumulative analysis validates the strong statistical relationships identified in the correlation analysis ($r = 0.847$ for built-up areas, $r = -0.823$ for vegetation) and supports the regression model's predictive capacity ($R^2 = 0.782$). The analysis reveals an intensifying urban heat island effect, with the temperature difference between urban and rural areas increasing from 0.8°C in 1994 to 1.5°C in 2024.

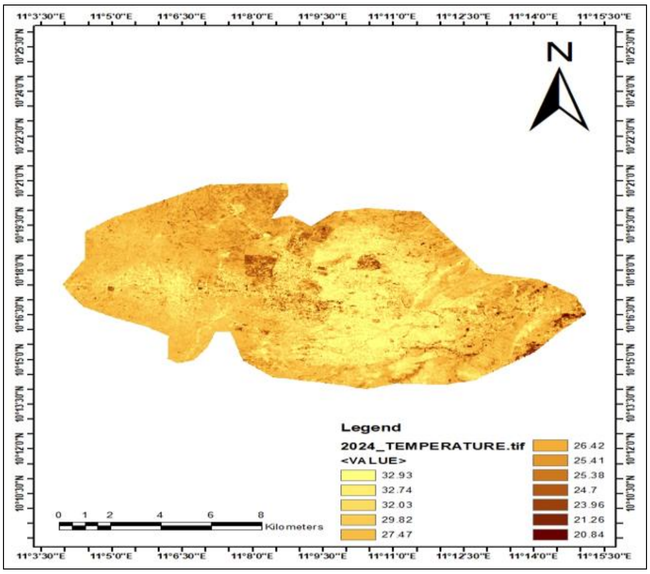

Fig 16: Cumulative Temperature Change Analysis (1994-2024)

Table 6: Urban Heat Island Intensity over Time

Year	Urban Mean Temp (°C)	Rural Mean Temp (°C)	UHII (°C)
1994	26.2	25.4	+0.8
2004	27.1	26.3	+0.8
2014	27.8	26.7	+1.1
2024	28.4	26.9	+1.5

3.6 Spatial Analysis of Temperature - LULC Relationships

To assess the spatial variation in surface temperature relative to land use and land cover (LULC), temperature zones were delineated concentrically from the urban core of Gombe Metropolis in 2024. Each zone reflects a dominant LULC class and demonstrates how proximity to urban areas influences thermal patterns.

The highest temperature (28.9°C) was recorded within the 0–2 km zone, where the land is predominantly covered by built-up infrastructure (85%). This aligns with the Urban Heat Island (UHI) effect, where dense development results in elevated surface temperatures. As the distance from the city centre increases, the mean temperature decreases gradually, reaching 26.2°C in the outermost zone (>8 km), which is largely dominated by natural vegetation (70%). The temperature gradient of –2.7°C between the urban core and rural vegetated outskirts highlights the cooling role of green cover and agricultural land, in contrast to the heat-retaining nature of built environments. This zonal temperature pattern provides clear evidence of the spatial manifestation of UHI effects in Gombe Metropolis. It emphasizes the importance of land cover in regulating urban thermal conditions and the need for sustainable spatial planning that incorporates green buffers, tree cover, and farmland protection as part of climate adaptation strategies.

Table 7: Temperature Variation by Distance from Urban Core (2024)

Distance Zone	Mean Temperature (°C)	Dominant LULC	Temperature Gradient
0-2 km	28.9	Built-up (85%)	Baseline
2-4 km	28.1	Built-up (65%)	-0.8°C
4-6 km	27.4	Mixed (45%)	-1.5°C
6-8 km	26.8	Agriculture (60%)	-2.1°C
>8 km	26.2	Vegetation (70%)	-2.7°C

The findings of this study reveal that Gombe Metropolis has undergone a profound transformation in land use over the past 30 years, with built-up areas expanding from 11% in 1994 to approximately 40% in 2024. This expansion, occurring at a remarkable annual rate of 8.96%, exceeds the urbanization rates reported in many other sub-Saharan African cities. According to Seto, Güneralp, and Hutyra (2012), urban land expansion in developing countries typically ranges between 2% and 5% annually, indicating that Gombe's rate is significantly above average. This rapid urban growth is driven primarily by population increase, economic development, and infrastructural expansion. As the administrative capital of Gombe State, the city has attracted substantial rural-urban migration, contributing to increased demand for housing and public services. Similar findings were reported by Oloukoi *et al*. (2014) in their study of urban expansion in Akure, Nigeria, where administrative relevance and state investments were key urban growth drivers. Additionally, infrastructural projects such as road construction and the siting of government institutions have opened previously undeveloped areas, encouraging further expansion. Flexible land allocation practices and limited enforcement of planning regulations have also contributed to horizontal sprawl, consistent with the patterns observed in cities like Ibadan (Abiodun *et al*., 2017).

The environmental implications of Gombe's urban expansion are stark. Vegetation cover declined by over 58% between 1994 and 2024, a trend that has serious ecological consequences. The conversion of green spaces into impervious surfaces significantly affects biodiversity, carbon sequestration, and hydrological processes. As reported by Zhou *et al*. (2014), urban vegetation loss in fast-growing cities leads to reduced evapotranspiration, increased runoff, and diminished groundwater recharge.

Loss of vegetation also contributes to declining air quality and elevated surface temperatures. Vegetation acts as a natural coolant and pollutant filter. Its removal amplifies the urban heat island (UHI) effect, exacerbating environmental stress. This observation supports the conclusions drawn by Oke (1982) and later confirmed by Emmanuel and Krüger (2012), who emphasized the importance of vegetation in mitigating urban thermal discomfort in African cities. The temperature analysis shows a clear warming trend, with mean annual temperatures rising from 25.71°C in 1994 to 26.91°C in 2024. The calculated warming rate of 0.04°C per year is more than double the global average of approximately 0.018°C per year (IPCC, 2021), suggesting that local factors—particularly Urban Expansion—are exacerbating regional climate change.

Urban heat island intensity (UHII) increased from 0.8°C in 1994 to 1.5°C in 2024. This is consistent with findings from similar studies in African urban centres such as Lagos, Abuja, and Kumasi, where UHII ranges between 0.5°C and 2.0°C (Adegun, 2017; Owusu *et al*., 2019). The increasing UHII in Gombe highlights the need for urban cooling interventions and improved urban planning. Most alarming is the seasonal intensification of warming. The dry season (March to May) experienced the greatest temperature rise, pushing daytime temperatures beyond 32°C in April post-2020. This trend increases the risk of heat-related health problems, particularly for vulnerable populations.

The correlation analysis reveals strong positive relationships between built-up and bare surfaces with temperature ($r = 0.847$ and $r = 0.792$, respectively), and a strong negative relationship with vegetation ($r = -0.823$). These results reinforce the hypothesis that urban land use transformation significantly influences local temperatures. The multiple regression model, explaining 78.2% of the temperature variability ($R^2 = 0.782$), indicates robust predictive power. These results align with Li *et al*. (2017), who demonstrated that urban LULC is a primary driver of land surface temperature variations in fast-growing cities in Asia and Africa.

Model coefficients show that for every 1% increase in built-up areas, temperature increases by approximately 0.089°C, while a 1% increase in vegetation reduces temperature by 0.067°C. Bare land, while less impactful than built-up areas, still contributes 0.056°C per 1% increase. These findings highlight the significant role of land management in climate resilience planning. Spatial temperature gradients show a clear decline from the urban core (28.9°C) to vegetated peripheries (>8 km from core: 26.2°C). This 2.7°C difference underscores the role of LULC in shaping microclimatic conditions. Comparable zonal studies by Voogt and Oke (2003) have demonstrated similar gradients in North American and African cities, linking urban core temperature elevation to the density of impervious surfaces. These spatial patterns support the need for green belts and decentralized development strategies to limit heat concentration in city centres.

Given the identified links between urban form and thermal conditions, urban planners and decision-makers must prioritize sustainable practices. These should include the Integrating green infrastructure into new and existing developments to buffer urban heat. Revising zoning laws to include mandatory vegetation thresholds in residential and commercial plots. Investing in urban cooling technologies such as reflective surfaces and passive ventilation. Furthermore, environmental impact assessments should become a mandatory component of urban expansion approvals, ensuring that growth does not outpace ecosystem capacity.

In summary, this study provides empirical evidence that urban expansion in Gombe Metropolis has significantly altered its thermal regime. The built environment, while necessary for growth, has intensified heat conditions through vegetation loss and surface sealing. These trends mirror patterns seen in other rapidly urbanizing regions but are particularly acute in Gombe due to the pace and scale of land cover transformation. These findings confirm the rejection of the null hypothesis and reinforce that there is a statistically significant relationship between land use/land cover changes and temperature variations in Gombe. Urban Expansion has emerged as a dominant force modifying local climate, with profound implications for sustainability, health and resilience.

4. Conclusion

This study investigated the impact of urban expansion on the thermal characteristics of Gombe Metropolis, Nigeria, over a 30-year period from 1994 to 2024. Using multi-temporal Landsat satellite data combined with Geographic Information System (GIS) techniques, the research examined land use and land cover (LULC) changes and their relationship with land surface temperature (LST) dynamics, providing a detailed spatial and temporal analysis of urban growth and its environmental consequences. Key findings include the Land Use and Land Cover Changes in which the built-up areas in Gombe expanded dramatically by over 268%, growing from 10.8% (19,665 ha) of the land area in 1994 to 39.7% (72,512 ha) in 2024. Conversely, vegetation cover declined by 58.2%, from 49.3% (90,086 ha) to 20.6% (37,700 ha) over the same period. Farmlands fluctuated, initially increasing before sharply decreasing to 22.5% in 2024, while bare surfaces increased nearly eightfold. These changes illustrate extensive transformation of natural and agricultural lands into urban and impervious surfaces, reflecting intense human-driven landscape alteration.

In temperature trends and patterns, the mean annual land surface temperature rose by 1.2°C during the study period, from 25.71°C in 1994 to 26.91°C in 2024, with an average warming rate of 0.04°C per year - over twice the global rural average. Urban heat island intensity intensified from 0.8°C to 1.5°C, with hotspots concentrated in the built-up city core, reaching temperatures as high as 35°C in 2024. Seasonal analysis revealed that the hottest months (March-May) experienced the most pronounced warming, particularly in April, exacerbating heat stress risks.

Lastly, the relationship between LULC and Temperature shows that the statistical analyses demonstrated strong positive correlations between built-up area percentage ($r = +0.847$) and bare surfaces ($r = +0.792$) with temperature increases, while vegetation had a strong negative correlation ($r = -0.823$). Multiple linear regressions explained 78.2% of temperature variability based on LULC composition, confirming the significant influence of land cover transformation on thermal conditions.

These findings emphasize that rapid, unplanned urban expansion in Gombe has significantly altered local microclimates by reducing vegetation and increasing impervious surfaces, resulting in heightened surface temperatures and intensified urban heat island effects. The study conclusively shows that urban expansion has been a dominant driver of changing thermal characteristics in Gombe Metropolis. The direct conversion of natural and agricultural lands into built-up areas has led to increased land surface temperatures and a pronounced urban heat island effect, with significant implications for environmental sustainability, public health, and urban resilience. The strong statistical relationship between LULC changes and rising surface temperatures supports the rejection of the null hypothesis, confirming a significant influence of land use pattern dynamics on local thermal regimes. These outcomes highlight the critical need for incorporating environmental considerations into urban planning to mitigate adverse heat effects in rapidly growing cities in semi-arid regions.

5. Recommendations

Each recommendation directly corresponds to one of the study's specific objectives, aiming to address the identified challenges and guide future sustainable urban development.

1. Local authorities should control excessive built-up expansion by promoting urban greening through tree planting, creation of green belts, and preservation of natural and agricultural lands. This will restore ecological balance and improve livability.
2. Government and planners should set up a continuous monitoring system to track land surface temperature. New urban projects should undergo thermal impact assessments, with designs that include reflective surfaces, permeable pavements, and more tree cover to reduce heat.
3. Planners should use predictive models to guide land use decisions and zoning regulations. Emphasis should be on retaining vegetation and limiting impervious surfaces to ensure better thermal comfort and sustainable development.

6. References

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