

**ASSESSMENT OF LAND SURFACE TEMPERATURE
AND URBAN HEAT ISLAND CHANGES IN BENIN CITY
USING GEOSPATIAL TECHNIQUES**

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SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE
AWARD OF A BACHELOR OF SCIENCES {BSCGEM - B.SC. GEOMATICS}
DEGREE, IN THE FACULTY OF ENVIRONMENTAL SCIENCES,
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NOVEMBER, 2025

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CERTIFICATION

This is to certify that this project was carried out by **OKORO, CHRIS IKPONWONSA** with Matriculation Number: **ENV2002791** of the Department of Geomatics, Faculty of Environmental Sciences, University of Benin, Edo State, Nigeria.

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Date

EXTERNAL EXAMINER

Date

DEDICATION

This work is dedicated to Almighty God, whose grace, wisdom, and guidance made this achievement possible. I also lovingly dedicate it to my parents, Mr and Mrs Godwin Okoro for their endless support, prayers, and encouragement throughout my academic journey.

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To my sibling Favour, Joyce, Raymond and Dominion thank you for your constant encouragement and support towards me.

Above all, I return all glory and honour to God for His unending mercy and faithfulness during my time at the University.

ABSTRACT

Rapid urbanization and land-use modification have intensified surface temperatures in many developing cities, including Benin City, Nigeria. This study assessed the spatio-temporal variations in Land Surface Temperature (LST) and Urban Heat Island (UHI) intensity in Benin City from 2014 to 2024, and examined the relationship between land-cover changes and surface thermal patterns using Remote Sensing and Geographic Information System (GIS) techniques. Landsat satellite imagery was processed to derive LST, Normalized Difference Vegetation Index (NDVI), and Land-Use/Land-Cover (LULC) maps. Change detection analysis, raster differencing, and statistical evaluation were used to quantify temperature variations, land-cover transitions, and UHI development.

Results showed a noticeable increase in surface temperature over the study period, particularly within built-up areas where expansion and conversion of vegetated land were observed. Vegetation loss weakened natural cooling functions, while the growth of impervious surfaces contributed to higher thermal retention. Correlation analysis further confirmed a strong negative relationship between NDVI and LST, indicating that areas with dense vegetation experienced significantly lower temperatures. UHI hotspots intensified within densely urbanized zones, reflecting the impact of urban growth on thermal conditions.

The study concludes that urbanization in Benin City is a major driver of increasing surface temperature and strengthening UHI effects. It emphasizes the need for sustainable urban planning strategies, including urban greening, heat-responsive development, and environmental regulation, to enhance thermal comfort and climate resilience. Findings provide valuable geospatial insight for policymakers, urban planners, and environmental stakeholders in promoting climate-adaptive development within the city.

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ACRONYMS

LULC	Land Use Land Cover
LST	Land Surface Temperature
UHI	Urban Heat Island
NDVI	Normalized Difference Vegetation Index
NDBI	Normalized Difference Built-Up Index
NDWI	Normalized Difference Water Index

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Surface temperature is a key environmental parameter that reflects the heat retained and emitted by the Earth's surface. One prominent phenomenon associated with rising surface temperatures in urban areas is the Urban Heat Island (UHI) effect, where urban zones exhibit significantly higher temperatures than surrounding rural regions (Oke, 1982; Voogt & Oke, 2003). This thermal disparity is primarily driven by anthropogenic activities and the replacement of natural landscapes with heat-absorbing surfaces such as concrete, asphalt, and dense urban infrastructure (Grimmond, 2007).

Urbanization and land surface transformation are major contributors to elevated Land Surface Temperature (LST). In recent decades, cities like Benin City in Edo State, Nigeria, have experienced rapid urban expansion, resulting in significant land-use/land-cover (LULC) changes (Aderoju *et al.*, 2020). These transformations increase LST and intensify UHI effects by reducing vegetation and natural cooling processes such as evapotranspiration and shading (Zhang *et al.*, 2022). The expansion of impervious surfaces also disrupts hydrological systems, increases runoff, and limits groundwater recharge, further altering the urban microclimate (Akbari *et al.*, 2001).

These environmental changes have broad implications for climate regulation, public health, energy demand, and ecological sustainability (Santamouris, 2015). Benin City has experienced rapid urbanization over the past five decades, characterized by substantial population growth and infrastructural development (Akhigbe *et al.*, 2023). Such development intensifies heat retention, leading to thermal discomfort, increased electricity consumption, and heightened health risks, particularly for vulnerable populations living in heat-sensitive environments (Nwajei & Idowu, 2024).

The application of geospatial technologies particularly Remote Sensing and Geographic Information Systems (GIS) has become essential for analyzing UHI dynamics and LST variations over time (Weng, 2009). Satellite data allow for spatiotemporal assessment of temperature distribution, enabling the identification of LST hotspots and evaluating the impact of LULC change (Zhou *et al.*, 2018). GIS techniques further enhance understanding by enabling spatial modeling, mapping, and trend analysis, thereby supporting climate-responsive urban planning (Yue *et al.*, 2023).

Technological advances in remote sensing have significantly improved the precision of urban climate studies, facilitating evidence-based planning and adaptive environmental management (Estoque *et al.*, 2017). Rising LST and UHI effects also pose socio-economic challenges, increasing household cooling costs and greenhouse gas emissions, while disproportionately affecting low-income communities (Mishra & Ghosh, 2021). This raises concerns about climate equity and sustainable urban development.

Benin City's experience underscores the pressing challenges faced by rapidly urbanizing regions in Sub-Saharan Africa, where planning systems often struggle to match development pace (Ede *et al.*, 2022). As the city continues to expand, continuous monitoring of climatic changes and integration of climate-smart strategies into urban planning becomes critical.

This study aims to investigate temporal trends in Land Surface Temperature (LST) and Urban Heat Island (UHI) dynamics in Benin City from 2014 to 2024 using satellite-based analysis. It specifically examines how land cover transitions influence surface temperatures and identifies UHI hotspots. The findings are expected to guide policymakers and urban planners in adopting climate-resilient strategies to mitigate UHI impacts and enhance thermal comfort for urban residents.

1.1 Statement of the Problem

Urbanization in Benin City has accelerated over the past few decades, resulting in significant alterations to land use and land cover (LULC). This rapid growth has led to an increase in impervious surfaces, such as roads, buildings, and other infrastructure, replacing natural vegetation and altering the city's thermal environment. Consequently, the city is experiencing rising land surface temperatures (LST) and the intensification of Urban Heat Island (UHI) effects conditions that contribute to thermal discomfort, increased energy demand, and health-related risks among urban residents.

Despite these growing environmental concerns, there is a critical lack of localized, empirical research that specifically examines the spatiotemporal dynamics of LST and UHI in Benin City. Most existing studies on climate variability in the region either focus on broader meteorological patterns or overlook the direct impact of urbanization on urban thermal conditions. As a result, planners and decision-makers are often left without the detailed, data-driven insights necessary to implement effective climate adaptation and mitigation strategies.

Furthermore, the absence of current and comprehensive assessments using modern geospatial techniques limits the ability to monitor and model thermal changes accurately over time. Without such insights, it is difficult to identify UHI hotspots, evaluate the impact of land cover change, or plan for resilient and sustainable urban development. Therefore, there is an urgent need to assess the trends in LST and UHI in Benin City using geospatial technologies in order to inform urban planning, improve environmental quality, and enhance public health and climate resilience.

1.2 Aim and Objectives

The aim of this research was to assess the spatial and temporal changes in Land Surface Temperature (LST) and Urban Heat Island (UHI) effects in Benin City from 2014 to 2024.

This aim was pursued through the following objectives:

- i. the acquisition of Landsat 8 imagery of Benin City from 2014-2024;
- ii. processing the acquired data;
- iii. Analysis of the processed data; and
- iv. change detection analysis.

1.3 Scope of the Study

The scope of this study covered:

- i. the study area, Benin City, covers an area of 1,204 square kilometers;
- ii. the study spanned a period of ten years, from 2014 to 2024;
- iii. acquisition of Landsat imagery from USGS EarthExplorer;
- iv. data analysis using Raster calculator and Microsoft Excel;
- v. change detection analysis.
- vi. Give recommendation for urban planning.

1.5 Justification of the Study

Benin City, similar to many rapidly growing urban centers in Sub-Saharan Africa, has undergone considerable land use and land cover (LULC) transformations in recent decades, driven by rising population and expanding infrastructure. These transformations have resulted in an increase in impervious surfaces such as roads and buildings and a significant decline in vegetated areas. Consequently, the city has become more susceptible to the negative impacts of elevated land surface temperatures (LST) and the Urban Heat Island (UHI) effect.

Despite the increasing severity of these environmental issues, there is a noticeable lack of localized, empirical research that explores the spatial and temporal patterns of LST and UHI in Benin City. Much of the existing literature on climate variability in Nigeria focuses on

broader climatic trends or targets larger cities, often overlooking the urbanization challenges faced by mid-sized cities like Benin.

In addition, urban planners and environmental stakeholders in Benin City currently lack access to comprehensive geospatial data and thermal assessments necessary for developing effective heat mitigation, land management, and climate adaptation strategies. This information gap poses a major obstacle to building urban resilience in the face of ongoing climate change and intensifying heat-related risks.

This study is therefore essential to address this gap by utilizing geospatial technologies-such as remote sensing and GIS-to examine LST and UHI trends in Benin City from 2014 to 2024. The research will generate valuable insights into the thermal impacts of urbanization and provide a scientific foundation for informed urban planning, environmental policy, and climate-resilient development in the city.

CHAPTER 2

LITERATURE REVIEW

2.1 Remote Sensing and Geospatial Theory

Benin City, like many expanding urban centers, is experiencing rapid land cover transformation, leading to intensification of urban heat island (UHI) effects. Between 2017 and 2023, remote sensing data indicates that the city saw a decline of approximately 12% in tree cover, with a concurrent rise in built-up areas. This has resulted in an expansion of high-temperature zones (exceeding 35 °C) and a reduction in naturally cooler spaces. The theoretical framework that aligns this study is the Remote Sensing and Geospatial Theory. Remote Sensing and Geospatial Theory collectively offer the scientific and methodological foundations necessary for observing, measuring, analyzing, and interpreting Earth's surface and related phenomena across spatial and temporal dimensions. These theories establish the principles required to capture, process, and analyze data gathered from sensors mounted on satellites, aircraft, drones, or terrestrial platforms, transforming raw spectral measurements into usable geographic information. They underpin numerous applications, including environmental monitoring, resource management, urban and regional planning, and disaster assessment.

The investigation of land surface temperature (LST) and urban heat island (UHI) changes in Benin City using geospatial techniques is fundamentally grounded in Remote Sensing and Geospatial Theory, as it depends on extracting precise, spatially explicit temperature data from satellite imagery to assess patterns and temporal trends in urban microclimates. Without the conceptual and methodological support offered by these theories, the observation, measurement, or analysis of LST variations at appropriate spatial and temporal resolutions would not be feasible.

Central to Remote Sensing Theory is the understanding of electromagnetic energy interactions with surface materials, which dictates how various surfaces reflect, absorb, and emit energy across different wavelengths. This principle is critical for estimating LST because thermal infrared bands on satellite sensors record emitted radiation that directly corresponds to the physical temperature of the land surface. Applying radiative transfer equations core elements of Remote Sensing Theory enables the conversion of satellite digital numbers into continuous LST datasets, which are necessary for accurately assessing temperature distributions.

Remote Sensing Theory also underscores the significance of spectral, spatial, radiometric, and temporal resolution, which collectively determine a sensor's capacity to detect specific features and monitor changes over time. The use of sensors such as the Landsat Thermal Infrared Sensor (TIRS) or MODIS provides LST data with resolutions suitable for capturing variations within urban microclimates. According to these theoretical principles, fine spatial resolution is essential to observe localized LST differences, while frequent temporal resolution is vital for tracking the progression of UHI phenomena over time.

A fundamental aspect of Remote Sensing Theory involves preprocessing and correcting raw satellite data processes including radiometric calibration, atmospheric correction, and geometric rectification which remove noise and distortions that obscure true surface characteristics. Accurate application of these concepts ensures that derived LST maps faithfully represent real ground conditions. For instance, correcting for atmospheric water vapor attenuation is necessary for reliable LST retrieval, highlighting the indispensability of atmospheric correction algorithms based on Remote Sensing Theory.

Furthermore, Remote Sensing Theory provides methodologies for image classification and change detection, which are crucial for evaluating UHI dynamics. The use of supervised or unsupervised classification techniques on multispectral imagery allows differentiation among land cover types such as vegetation, built-up areas, and water bodies that significantly

influence LST. Change detection algorithms quantify transitions in land use, such as vegetation decline or urban expansion, that alter thermal characteristics and intensify UHI effects. Employing these methods demonstrates the theory's assertion that temporal analysis of satellite data is essential for revealing environmental changes.

Geospatial Theory, meanwhile, serves as the framework for managing, processing, analyzing, modeling, and visualizing spatial data within Geographic Information Systems (GIS). It introduces key concepts including coordinate systems, map projections, spatial relationships (e.g., adjacency and connectivity), topology, and spatial autocorrelation, which are necessary for accurately depicting and analyzing spatial patterns. These principles guide procedures such as georeferencing LST raster datasets, integrating them with land use or administrative layers, and conducting spatial analyses to locate UHI hotspots.

One of the fundamental concepts in Geospatial Theory is the integration of diverse spatial datasets to enable comprehensive, multi-layered analyses of complex environmental phenomena. By combining LST maps with layers representing land cover, population density, or transportation networks, it becomes possible to correlate socio-economic factors with thermal patterns, thereby enriching the overall analysis in alignment with the theory's emphasis on holistic spatial understanding.

Geospatial Theory also establishes the mathematical and computational foundations of spatial statistics, which can be applied to quantify relationships between landscape patterns and LST distributions. Techniques such as Moran's I or Getis-Ord G_i^* facilitate the identification of statistically significant clusters of high or low temperatures, thus revealing spatial patterns of UHI intensity and enabling a shift from descriptive to inferential analysis of spatial processes.

Moreover, concepts of scale and spatial hierarchy within Geospatial Theory are crucial for examining how phenomena detected at one level, such as neighborhood-scale LST variations,

may display different patterns or significance at broader levels, like citywide trends. Analyzing data across multiple scales from individual blocks to the full urban area adheres to the theory's guidance that scale-sensitive analysis is essential for comprehending both the drivers and impacts of UHI.

An additional concept rooted in Geospatial Theory is spatial interpolation, which estimates values at unsampled locations based on observations from nearby points. Gaps in satellite LST data, often caused by cloud cover, can be addressed through interpolation techniques such as kriging or inverse distance weighting, producing continuous, comprehensive LST surfaces essential for robust UHI assessments.

Both Remote Sensing and Geospatial Theory emphasize temporal dynamics, recognizing that processes shaping the Earth's surface evolve over time and require longitudinal analyses. Comparing LST datasets from different years enables the quantification of shifts in UHI patterns, reflecting the theories' insistence on temporal analysis for understanding the progression of landscape and climate changes.

These theories also highlight the importance of effective visualization and communication of spatial data, noting that clear and interpretable maps and graphics facilitate understanding of complex spatial patterns by stakeholders. Creating well-designed maps depicting LST and UHI changes translates theoretical concepts into practical decision-support tools for planners, policymakers, and public health officials, embodying the commitment of these theories to actionable, real-world applications.

Additionally, Remote Sensing and Geospatial Theory support data fusion techniques, which integrate information from multiple sensors or data sources to enhance both spatial and thematic accuracy. Combining optical data with thermal imagery, or merging satellite-derived

LST with ground-based measurements, increases the reliability of results, showcasing the theories' advocacy for multi-source data integration.

These theories also encourage the use of spatial modeling to simulate future processes, such as predicting UHI intensity under different urban growth scenarios. By coupling empirical LST measurements with urban expansion models in a GIS environment, it becomes possible to anticipate potential changes and design proactive interventions, following the theories' emphasis on using models to inform future planning.

Another key aspect of Remote Sensing and Geospatial Theory is their promotion of standardized and reproducible methodologies, enabling consistent application over time and across locations for reliable comparisons and long-term monitoring. Employing standardized LST retrieval algorithms and widely accepted GIS procedures ensures methodological rigor and enhances replicability, reflecting core theoretical values.

Furthermore, these theories stress the cost-effectiveness and scalability of spatial technologies, making them highly suitable for research in regions with limited data availability or financial resources. By leveraging freely accessible satellite imagery and open-source GIS software, the practical value of these theories is demonstrated through democratized access to advanced environmental monitoring tools.

Finally, Remote Sensing and Geospatial Theory underscore the interdisciplinary potential of spatial technologies, which enable integration of insights from fields such as climatology, urban planning, public health, and ecology. Research that connects physical measurements of LST with urban land use patterns and socio-economic variables embodies this interdisciplinary perspective, contributing to a more comprehensive understanding of UHI dynamics in urban environments like Benin City.

In conclusion, the assessment of land surface temperature and urban heat island changes in Benin City using geospatial techniques aligns deeply with Remote Sensing and Geospatial Theory. By applying principles related to electromagnetic energy interactions, spatial data management, spatial analysis, visualization, modeling, and multi-scale integration, this research exemplifies how these theories support rigorous, spatially explicit investigation of urban thermal environments. Through such work, theoretical concepts are translated into practical tools for monitoring, interpreting, and addressing UHI challenges, advancing both scientific understanding and urban sustainability efforts.

2.2 Review of Literature

Urban climate studies have become increasingly vital in promoting sustainable urban development, especially in light of the growing temperature extremes and environmental stress caused by rapid urban expansion. Two critical indicators that highlight urban thermal characteristics are Land Surface Temperature (LST) and the Urban Heat Island (UHI) effect. These elements reflect the influence of land use, vegetation distribution, and urban density on city-level climate patterns.

To analyze these thermal changes effectively, Geographic Information Systems (GIS) and remote sensing technologies have proven to be powerful tools. These technologies support spatial analysis and visualization, enabling researchers to assess temperature distributions and heat patterns across urban regions with high precision. This review examines the main ideas, research approaches, and practical uses of LST and UHI assessments, with a focus on how GIS enhances this process.

The discussion begins by defining LST and UHI, explaining the physical and environmental processes that drive them. It also considers the broader consequences of urban heat build-up, such as increased demand for cooling energy, public health challenges, and decreased quality of life, especially in tropical climates.

Following this, the review explores the use of GIS and satellite imagery (e.g., Landsat, MODIS) in mapping and analyzing thermal conditions. Several studies conducted in various cities both globally and in Nigeria demonstrate how spatial data can be used to identify heat-prone areas, observe changes in land cover, and develop responsive planning strategies. For example, research by Weng *et al.* (2014) and Oguntunde *et al.* (2019) illustrates how GIS-based analysis can support evidence-driven environmental planning.

The literature also addresses the Nigerian context, where uncoordinated urban growth frequently leads to intensified UHI effects. Cities such as Lagos, Abuja, and Ibadan have been extensively studied, revealing a direct link between rising LST values and increased built-up development. In contrast, mid-sized urban centers like Benin City have received limited scholarly attention despite facing comparable or even greater climate-related planning challenges.

Furthermore, the review outlines how GIS can guide the formulation of heat mitigation strategies, including the identification of priority zones for green infrastructure, improved land use design, and climate-conscious urban layouts. The integration of spatial tools with planning theories such as systems theory, urban ecology, and smart growth has proven effective in fostering resilient urban environments.

A critical evaluation of the existing body of work shows that, although the use of GIS and remote sensing in urban heat analysis is expanding, significant research gaps remain, especially in less documented urban regions. Moreover, few studies apply a multi-theoretical approach to evaluate LST and UHI in the Nigerian urban setting.

2.2.1 The Concept Of Urban Heat Island

The Urban Heat Island (UHI) is a form of climate modification that occurs unintentionally as a result of human activities, particularly within urban and suburban environments. It is

characterized by higher air and surface temperatures in cities compared to their surrounding rural areas (Oke, 2020; Enete, Awuh & Ikekpeazu, 2014). Oke (2020) provided a foundational framework for understanding the UHI phenomenon by analyzing the urban energy balance. He explained that daytime UHI is mainly driven by reduced vegetation cover, low surface reflectivity (albedo), and the high heat storage capacity of urban materials, whereas nighttime UHI results from the gradual release of heat stored in built-up surfaces. This framework remains highly relevant for explaining the differing responses of urban and rural surfaces to solar radiation.

Similarly, Enete, Awuh, and Ikekpeazu (2014) examined spatial and seasonal variations of UHI in Douala, Cameroon, using temperature measurements across different land-use types. Their study identified pronounced nighttime UHI effects during both dry and rainy seasons, while daytime thermal patterns were more variable and, in some cases, revealed cooler urban zones during the rainy season. These findings highlight the significant role of vegetation, moisture, and land cover in influencing land surface temperature (LST). Bayan, Alhawiti, and Diana (2016) further investigated the relationship between land use and LST using Landsat 8 satellite imagery over a thirty-year period. Their results showed that land-use changes strongly affect surface temperature, with built-up areas consistently recording higher LST values, thereby demonstrating the usefulness of remote sensing for monitoring urban growth and its thermal impacts.

Historically, Luke Howard, a British meteorologist, was the first to document an “excess of heat” in 1818 by comparing temperatures within the city of London to those of the surrounding countryside (Oke, 2020). Although he did not use the term “heat island,” the concept was later formalized by meteorologists who observed similarities between urban isotherm patterns and the topography of an island. Within cities, UHI zones are often characterized by steep thermal gradients resembling cliffs surrounded by cooler areas. As one

moves toward the city center, these gradients typically flatten into thermal plateaus, with localized hotspots occasionally forming where temperatures rise again peaks‘ (2000; Oke, 2004; American Meteorological Society, 2015).

This has been summarized in Figure 1.0.

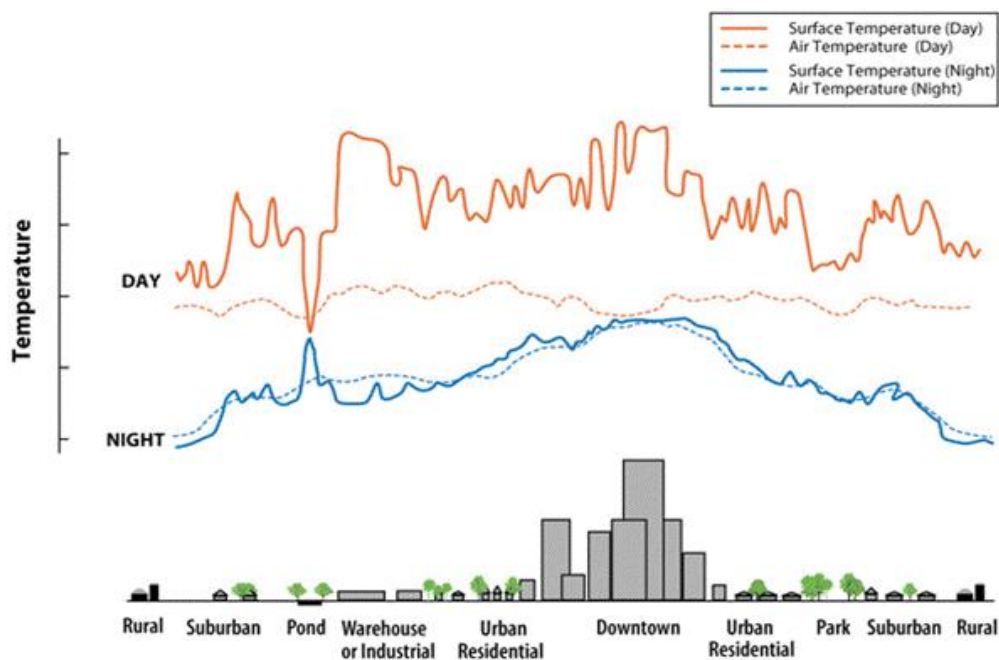


Figure 2.1: An idealized cross profile of urban heat island Source: EPA, (2009).

2.2.2 Geographic Information System: An Overview

Geographic Information Systems (GIS) have evolved as an important tool in environmental analysis, notably for studying Land Surface Temperature (LST) and Urban Heat Island (UHI) phenomena. GIS is a computer-based system for collecting, storing, analyzing, and visualizing spatial data. It enables the integration of several datasets to better comprehend complicated environmental linkages, making it critical for assessing surface temperature fluctuations in metropolitan area.

Weng *et al.* (2014) demonstrated that urban areas with reduced vegetation tend to exhibit higher LST values, highlighting a strong negative relationship between vegetation cover and

surface temperature. Their study, based on Landsat data, provided a model for estimating LST using vegetation abundance, contributing to improved mapping and analysis of UHI patterns..

Urban Heat Island (UHI) is a climatic situation in which urban areas have greater temperatures than their surrounding Rural areas are characterized by dense infrastructure, minimal vegetation, and high energy use (Oke, 2024). These temperature discrepancies between urban and rural areas have ramifications for human health, energy consumption, and urban sustainability.

In an effort to improve the understanding of urban thermal environments, Voogt and Oke (2013) reviewed the application of thermal remote sensing in urban climate research. They emphasized that while satellite data are valuable for mapping surface temperature, accurate interpretation requires attention to factors like surface emissivity, sensor resolution, and urban geometry. Their work supports the growing use of high-resolution thermal imagery in urban studies, especially for detecting hotspots and surface heat patterns.

Ogashawara and Bastos (2012) conducted a comprehensive study aimed at examining the influence of land cover changes on the Urban Heat Island phenomenon using multi-temporal thermal imagery from Landsat TM for the years 1986, 2001, and 2010 in São José dos Campos, Brazil. They applied a hybrid supervised classification method to categorize land cover into urban areas, vegetation, bare soil, and water bodies. To better understand the spatial variation in LST, they utilized spectral indices such as the Normalized Difference Vegetation Index (NDVI), Normalized Difference Built-up Index (NDBI), and Normalized Difference Water Index (NDWI).

Their findings demonstrated a strong positive correlation between LST and areas covered by built-up and bare surfaces, while regions with high vegetation and water content exhibited lower surface temperatures. Specifically, NDBI had the highest positive correlation with LST, indicating that built-up areas significantly contributed to the urban heat effect. In contrast,

NDVI and NDWI were inversely correlated with temperature, reinforcing the cooling influence of vegetation and water.

They further employed a Monte Carlo simulation to assess the statistical significance of changes in land cover and LST over time. The study concluded that urban expansion and vegetation loss were key drivers of the increasing intensity of UHI in the study area. The authors also emphasized the need to improve classification techniques to more accurately distinguish between bare soil and built environments when analyzing LST dynamics.

Gago *et al.* (2013) examined various strategies for mitigating UHI effects in cities. Their review underlined the importance of remote sensing in identifying heat-prone areas and evaluating the impact of interventions such as increased green cover, reflective surfaces, and better urban planning. They concluded that integrating thermal data with urban design can help reduce surface temperatures and improve livability in dense urban settings.

Akinbode *et al.* (2016) carried out an empirical analysis of UHI in Ibadan, Nigeria, using Landsat 8 satellite imagery. Their findings revealed that urban built-up areas recorded significantly higher LST values compared to vegetated zones. The study confirmed that impervious surfaces such as roads and buildings are major contributors to elevated urban temperatures, reinforcing the importance of green infrastructure in urban planning.

In conclusion, GIS offers a solid foundation for studying and visualizing LST and UHI events. Its use of both spatial and non-spatial data allows urban planners and environmental scientists to examine the effects of land cover changes, create cooling methods, and make informed decisions for sustainable urban development. As urbanization accelerates, GIS will remain a critical tool for solving the thermal concerns of modern cities.

2.2.3 Applications of GIS in LST and UHI

Geographic Information System (GIS) applications in Land Surface Temperature (LST) and Urban Heat Island (UHI) study are wide-ranging, including environmental monitoring, urban planning, disaster management, and public health. GIS not only helps to identify areas of thermal stress, but it also gives tools for simulating future situations and assisting decision-making processes.

One significant application is the spatial distribution mapping of LST. GIS can extract and visualize surface temperature fluctuations across metropolitan areas by employing thermal bands from satellite images, such as Landsat's Band 10

Weng (2020) used satellite imagery to investigate how rapid urban development in the Zhujiang Delta of China contributed to surface temperature changes. His study confirmed that increased built-up land directly led to higher LST values, establishing a strong connection between urban growth and UHI effects. This early application of remote sensing in UHI research demonstrated the potential of satellite thermal data in detecting spatial heat variations across urban landscapes.

Mallick *et al.* (2018) developed an advanced approach for estimating LST using a combination of Landsat and MODIS satellite data, integrated within a GIS environment. Their method improved the accuracy of LST retrieval and enabled better monitoring of urban thermal patterns, particularly in tropical cities. The study supports the value of multi-source datasets in assessing surface temperature and understanding spatial UHI distribution.

Adeniyi and Oriye (2013) conducted a study in Lagos, Nigeria, using Landsat imagery to assess seasonal UHI variations. Their results showed a clear pattern: built-up urban zones consistently exhibited higher LST values than surrounding vegetated or water-covered areas. The study highlighted the importance of integrating land cover classification with thermal data to measure urban heat effects in a Nigerian context.

Yuan and Bauer (2017) compared two major indicators of UHI impervious surface area and vegetation cover using Landsat data. They found that areas with higher percentages of impervious surfaces (like roads and buildings) were more strongly associated with increased LST than areas with sparse vegetation. Their findings suggest that surface sealing from urban development is a key driver of urban heating, making impervious surface area a reliable predictor for assessing UHI intensity. These studies have supported the use of green infrastructure in urban heat reduction by confirming that temperatures in vegetated regions are consistently lower than those in built-up zones.

Moreover, multi-criteria decision analysis (MCDA) and risk assessment both use GIS. GIS assists in identifying locations that are susceptible to high levels of heat stress by combining LST with layers like population density, road networks, and health infrastructure.

Wong *et al.* (2016) evaluated how green infrastructure on a tropical university campus influenced outdoor thermal comfort. By using thermal remote sensing alongside field temperature measurements, they found that areas with greater vegetation coverage were significantly cooler than paved or built-up areas. This demonstrated the cooling effect of urban greenery and supported green planning strategies as effective UHI mitigation measures.

Chen *et al.* (2016) focused on land cover classification using Landsat data and decision tree methods. Although the study's primary aim was to map land cover types, it also revealed that surface temperature differed significantly across land cover categories. This work contributed to a better understanding of how vegetation, urban infrastructure, and water bodies influence LST patterns and UHI development. Thus, GIS improves the precision and usefulness of climate simulations by serving as a tool for both data processing and display.

Gill *et al.* (2017) also emphasized the importance of green infrastructure in adapting cities to the impacts of climate change. Though their study focused more on policy and urban planning, it underlined how increased vegetation and open green spaces can reduce LST, particularly in

dense urban environments. Their work provides a strong justification for incorporating thermal data into urban design and environmental management.

Finally, GIS has a wide range of applications in LST and UHI. From temperature mapping to policy planning, GIS acts as a vital link between data and action. Its capacity to examine spatial-temporal trends and combine varied datasets makes it an indispensable tool for tackling the difficulties of urban thermal environments and developing climate-resilient communities.

2.2.4 Urban Heat Island Studies in Nigeria

In Nigeria, early documented research on urban climate dates back to the work of Oguntoyinbo (1970), who investigated the albedo and reflective characteristics of urban and rural surfaces in Ibadan. His findings revealed mean albedo values of approximately 12% for urban surfaces and 6% for rural areas. Building on this pioneering effort, Oguntoyinbo (2016) further examined the influence of urbanization on Ibadan's climate using thermo-hygrographs and a whirling hygrometer to measure temperature and relative humidity across the city. Following these foundational studies, several empirical investigations into the urban heat island (UHI) phenomenon were conducted using ground-based instruments, including those by Ojo (1981), Adebayo (1985), and Omogbai (1985).

Subsequent studies expanded the scope of urban climate research in Nigeria. Adegoke (2012) analyzed variations in carbon monoxide levels in relation to thermal comfort in Ibadan, while Efe (2012) examined how the urban landscape affects precipitation patterns and rainwater quality in Warri. Nduka and Abdulhameed (2018) conducted similar investigations in different cities, with Nduka focusing on Kano and Abdulhameed on Onitsha metropolis. Both studies assessed the spatio-temporal variation of the urban canopy heat island using digital temperature loggers (i-buttons) and established significant spatial and temporal variability in UHI intensity within their respective study areas.

Ademiluyi, Okude, and Akanni (2018) reviewed notable Nigerian studies in land use and urban climate research, including the NIRAD Project (1976/79), Areola (1977), FORMECU (1996), and Omojola (1997). While the NIRAD Project, Areola's work, and FORMECU primarily focused on land use classification, Omojola extended the analysis to include land use change detection. Similarly, Ekpenyong (2018) employed GIS techniques to model land use and land cover changes in Akwa Ibom State between 1984 and 2003, revealing extensive urban expansion into farmlands and secondary forests, alongside a 50% reduction in mangrove forests. These changes were identified as threats to food security and local climate stability.

Further investigations into land use dynamics include the work of Bisong (2017), who analyzed land use conversion in southeastern Nigeria between 1972 and 2001 and found that deforestation rates were higher on publicly controlled lands than on communal lands. Agricultural land use characteristics were shown to correlate strongly with deforestation rates. In a similar vein, Idoko, Bisong, and Okon (2018) assessed land use changes in the Federal Capital Territory, Abuja, using satellite imagery from 1987 and 2004. Their analysis revealed a substantial reduction in vegetation cover by over 85%, alongside increases in built-up and farmland areas, highlighting rapid urban expansion.

Enete (2019) evaluated the microclimate of Enugu using paired measurement programs and Landsat/ETM satellite imagery. The findings indicated marked differences between daytime and nighttime urban climate modification, with a pronounced downtown-centered heat island observed at night during both dry and rainy seasons. Daytime temperature variations were strongly linked to sky-view factors and the thermal properties of urban surfaces. Thermal comfort analysis revealed temperature ranges between 25.4°C and 27°C, conditions under which more than half of the population experiences discomfort. Umar and Satish (2016) similarly examined UHI patterns in Kano metropolis using Landsat imagery from 1986, 2000,

and 2014. Their results showed multiple heat islands concentrated in densely built-up areas and along major road networks, with UHI intensity negatively correlated with vegetation (NDVI) and positively correlated with built-up density.

Remote sensing-based studies have also been widely applied in Abuja and other Nigerian cities. Lays (2013) analyzed land cover dynamics in Abuja using Landsat imagery from 1986 to 2011 and found a 207% increase in built-up areas, alongside a decline in vegetation cover. The study concluded that vegetation helps mitigate UHI effects, while built-up areas intensify them. Bernard and Raymond (2015) investigated the relationship between land use/land cover change and surface temperature in Makurdi using multi-temporal Landsat data. Their findings showed a consistent decline in vegetation and wetland areas, with surface temperature exhibiting negative correlations with vegetation and wetness indices but positive correlations with built-up indices, emphasizing urbanization as the main driver of temperature increase.

Additional studies include Julius and Oyewole (2016), who examined urban land use changes in Akure using aerial imagery overlays and identified unguided urban expansion and encroachment into green areas. Adeoluwa (2015) assessed the impact of land use change on land surface temperature in Onitsha using Landsat imagery from 1989, 2002, and 2014. The results showed a significant loss of natural land cover to built-up areas, accompanied by increasing land surface temperatures and the emergence of surface urban heat islands. Nduka (2015) and Abdulhameed (2016) further confirmed significant spatial and temporal variations in urban canopy heat islands in Onitsha and Kano using temperature data loggers.

Finally, Abegunde and Adedeji (2015) investigated the impact of long-term land use change on surface temperature over a 42-year period using Landsat imagery. Their analysis revealed a substantial increase in settlement areas and a corresponding decline in vegetation cover, with built-up areas exhibiting the highest temperature emissions. Overall, these studies collectively

demonstrate that rapid urbanization and land use transformation are key drivers of urban heat island development and land surface temperature variation across Nigerian cities.

2.2.5 Land Surface Temperature (LST) and Urban Heat Island (UHI) in Benin City

Land Surface Temperature (LST) is defined as the measure of the Earth's surface temperature derived from satellite thermal infrared data. Unlike air temperature, which is measured about 2 meters above ground, LST directly reflects the temperature of the land surface such as soil, vegetation, buildings, and paved surfaces. The Urban Heat Island (UHI) effect refers to the observed phenomenon whereby urban areas exhibit significantly higher temperatures than their surrounding rural environments. This occurs primarily due to human-induced land modifications, dense construction materials, and reduced vegetation.

Benin City, located in the tropical rainforest belt of southern Nigeria, has experienced rapid urbanization over the past three decades. This transformation has significantly altered its land cover characteristics, which in turn has contributed to rising LST and a pronounced UHI effect.

In an effort to understand the thermal characteristics of urban environments in Nigeria, Efe and Eyefia (2014) conducted a detailed study on urban warming in Benin City. Their research combined meteorological data with mobile temperature surveys to assess the variation in surface temperatures across different land use zones within the city. The findings revealed a consistent urban heat island effect, with temperature differences of up to 4.4 °C recorded between dense urban areas and surrounding rural zones. The study also observed that weekdays, associated with increased human and vehicular activity, experienced higher temperature levels than weekends. These results suggest that anthropogenic activities significantly contribute to localized warming. The authors emphasized the need for climate-responsive urban planning, including the integration of vegetation and green infrastructure

such as green roofs, to mitigate the intensifying effects of urban heat. Their findings revealed that densely built-up zones like Akpakpava and the Government Reserved Area (G.R.A.) had LST values as high as 31.7°C, while greener and less developed zones maintained lower temperatures around 26.2°C.

The primary drivers of UHI in Benin City include the extensive conversion of natural vegetation to impervious surfaces, high building density, industrial activity, and vehicular emissions.

Okoye *et al.* (2024) conducted a temporal analysis using Landsat imagery from 2017 and 2023, showing a significant decline in vegetative cover from 82.1% to 70.2%, while built-up areas increased from 9.5% to 15.3%. Correspondingly, areas with high surface temperatures (>35°C) increased, while those with moderate temperatures (30–35°C) decreased. This shift highlights the impact of rapid land cover changes on thermal behavior in urban environments.

Moreover, Efe and Eyefia (2014) observed daily and weekly variations in surface temperature, with higher readings recorded during weekdays, attributed to increased human and vehicular activities. Their study also showed an average urban-rural temperature difference of about 0.5°C and intra-urban variation reaching up to 4.4°C, emphasizing the complexity and localized nature of the UHI phenomenon.

The implications of elevated LST and UHI in Benin City are multifaceted. Environmentally, higher temperatures can exacerbate air pollution, alter local rainfall patterns, and increase the frequency of heatwaves. From a health perspective, urban residents are at greater risk of heat-related illnesses, particularly among vulnerable groups such as the elderly, children, and outdoor workers. Energy consumption for cooling also tends to rise in response to elevated temperatures, leading to increased carbon emissions and economic burden.

To mitigate the adverse impacts of UHI, scholars recommend the incorporation of green infrastructure into urban planning. Strategies include the development of green roofs, urban parks, tree-lined streets, and the adoption of reflective building materials.

Okoye *et al.* (2024) emphasize the need for afforestation and sustainable land use policies to restore ecological balance and reduce urban temperatures.

Efe and Eyefia (2014) also advocate for policy interventions that integrate urban climate considerations into land use and infrastructure planning.

2.2.6 Factors Affecting the Intensity of UHI

Urban heat island intensity is influenced by several factors, including population size, urban morphology, and the spatial extent of the city. The temperature difference between the maximum temperature within an urban area and that of the surrounding suburban or rural environment is referred to as Urban Heat Island Intensity (UHII) (Ferrari, 2020; Oke, 2015). Rapid urbanization characterized by increased population density, extensive use of automobiles, and the expansion of impervious surfaces has contributed significantly to rising urban temperatures. Temperature elevation is typically most pronounced in city centers during nighttime, indicating that the UHI phenomenon is predominantly nocturnal.

Givoni (2023) described UHI as a condition in which urban temperatures exceed those of adjacent rural areas, occurring during both daytime and nighttime periods. He noted that the greatest temperature contrasts, often ranging between 3°C and 10°C, occur during clear and calm nights. Similarly, Bonan (2012) observed that high-density, mixed-use urban areas can be 5–7°C warmer than surrounding low-density, single-use districts, while city centers are generally about 2°C warmer than suburban areas.

The intensity of urban heat islands is controlled by a combination of meteorological and urban structural factors. Meteorological parameters such as wind speed, cloud cover, and humidity

play a key role in moderating urban temperatures. In addition, urban characteristics including city size, building density, building height-to-street width ratios, population concentration, anthropogenic heat release, and urban canyon geometry strongly influence the magnitude of UHI. Other contributing factors include the extent of vegetation cover, presence of water bodies, topography, patterns of water drainage, and prevailing meteorological conditions, all of which can either amplify or reduce urban heat island intensity.

2.2.6.1 Location of the City

Climatic elements such as topography, wind speed and direction, temperature, humidity, fog occurrence, precipitation, and temperature inversions vary from one location to another within a given region. These variations are largely influenced by factors including the distance between a city and the sea, elevation above sea level, slope orientation, and the overall setting and terrain of the urban area.

Wang et al. (2018) investigated the influence of long-term urban development on thermal conditions in Hangzhou using Landsat satellite imagery spanning a 20-year period. Object-based image analysis was employed to delineate impervious surfaces, while correction techniques were applied to improve the accuracy of land surface temperature (LST) estimates. Urban Heat Island intensity was assessed by comparing surface temperatures between densely built-up urban cores and adjacent transitional zones. The findings showed that the built-up area expanded at a rate exceeding 30 km² per year, leading to notable changes in the city's thermal characteristics. Urban expansion toward the southeastern part of the city was identified as the primary contributor to rising temperatures, highlighting the importance of urban form and growth direction in shaping UHI intensity. The study demonstrates the effectiveness of remote sensing in monitoring LST dynamics and relating them to urban structural changes.

Li et al. (2023) explored the global distribution of cooling benefits provided by urban green spaces across 500 cities. Their results indicated that economically disadvantaged populations generally have reduced access to vegetated areas, which exposes these communities to higher surface temperatures. The study underscores the environmental justice implications of UHI and LST, emphasizing that sustainable urban planning and heat mitigation strategies must integrate both ecological considerations and social equity to ensure balanced thermal comfort across urban populations.

2.2.6.2 The Size of the City and Population

Urbanization is driven by the physical expansion of cities and the large-scale movement of people from suburban and rural areas into urban centers. Improvements in living standards such as increased vehicular traffic, widespread use of air conditioning during hot periods, intensive consumption of electrical energy for heating in colder seasons, and growing industrial activities combined with high population density and city size, are major contributors to the development of the urban heat island (UHI) phenomenon.

Ford et al. (2024) developed hierarchical modeling frameworks that integrated remote sensing data with meteorological observations to analyze spatial variations in UHI across multiple cities. Their models incorporated both characteristics of the built environment and climatic factors, demonstrating that land cover types, urban form, and regional weather conditions collectively influence land surface temperature (LST) patterns. The study emphasized the need to consider multiple spatial scales when assessing urban thermal environments and highlighted the value of combining remote sensing techniques with statistical modeling for improved UHI analysis.

Similarly, Zhou et al. (2017) examined UHI characteristics in 419 cities worldwide using remote sensing data. Their results indicated that UHI intensity is closely associated with urban size, vegetation availability, and land use structure. In many cases, city centers were

substantially warmer than surrounding peripheral areas, particularly during the summer. The study underscored that the scale and configuration of urban development play a critical role in shaping urban thermal behavior, while also emphasizing the importance of green spaces and regulated urban growth in mitigating heat accumulation.

2.2.6.3 Density of Built-Up Area

Local climatic conditions within individual urban areas play a significant role in influencing the concentration and arrangement of built-up surfaces. Peng et al. (2022) investigated the impact of urban green patches on land surface temperature in tropical megacities using high-resolution satellite imagery and landscape metrics. Their findings revealed that even relatively small green spaces can produce measurable cooling effects, particularly during hot afternoon periods. However, the magnitude of this cooling was found to depend on the size, shape, and spatial distribution of vegetation, highlighting the critical role of well-planned green infrastructure in reducing LST and mitigating urban heat island effects in densely populated tropical cities.

Che-Ani et al. (2010) reviewed a range of strategies aimed at reducing the Urban Heat Island (UHI) effect, with emphasis on sustainable urban environmental practices. The study identified human activities such as high building density, limited green spaces, and the use of heat-absorbing construction materials as major contributors to elevated land surface temperatures. The authors recommended urban design solutions including green roofs, high-albedo and reflective materials, and extensive urban greening as effective mitigation measures. Their work further highlights the value of geospatial analysis in identifying heat-vulnerable areas and supporting sustainable urban planning, particularly in rapidly growing cities such as Benin City.

2.2.6.4 Urban Morphology

Zhu et al. (2019) employed machine-learning approaches to examine the influence of urban form on land surface temperature (LST) in high-density, subtropical cities. Their results showed that elements such as building height, street width, and surface cover type have a strong impact on surface temperature patterns. Vegetated areas consistently recorded lower temperatures, whereas compact, densely built environments exhibited higher LST values. The study demonstrates that urban morphology is a key determinant of UHI intensity and that thoughtful urban design and spatial planning can help reduce urban heat stress.

2.2.6.5 Thermal Properties of Fabric

Voogt and Oke (2015) investigated how different surface materials contribute to the formation of the Urban Heat Island using remote sensing techniques. Their findings revealed that impervious materials such as concrete and asphalt absorb and store significantly more heat than natural or vegetated surfaces. This variation in thermal behavior leads to elevated LST in built-up areas, emphasizing that surface material composition plays a critical role in shaping UHI intensity.

2.2.6.6 Surface Waterproofing

The expansion of non-porous and water-resistant urban surfaces contributes to increased UHI intensity by limiting surface permeability and reducing evaporation. The lack of vegetated and moisture-retaining surfaces further suppresses evaporative cooling within cities. Saha et al. (2024) examined land-use evolution and LST trends in three rapidly growing global cities using Landsat imagery and spatial metrics. Their study showed that the growth of impervious surfaces, particularly in city centers and expanding outskirts, significantly increased surface temperatures. Areas with dense infrastructure and minimal vegetation were found to retain more heat, reinforcing the UHI effect and highlighting the importance of long-term geospatial monitoring for effective urban thermal management.

2.2.6.7 Anthropogenic Heat

Tsou et al. (2012) assessed the contribution of anthropogenic heat released from buildings, vehicles, and human activities to nighttime UHI intensity in Taipei. Their findings indicated that these internal heat sources can raise nighttime urban temperatures by about 1 °C, confirming that human-generated energy emissions play a substantial role in urban thermal dynamics. Chapman (2016) further emphasized that urbanization and human-induced land-use changes, particularly increased impervious surfaces and reduced vegetation, significantly elevate LST and intensify UHI effects. Using geospatial methods, the study highlighted anthropogenic activity as a central driver of altered urban thermal patterns, especially in rapidly expanding cities.

2.2.6.8 Air Pollution

Urban areas generate diverse forms of air pollution, primarily from vehicular emissions, industrial activities, and air-conditioning systems. The contribution of industrial pollution varies among cities depending on the type and concentration of industrial facilities. Different land-use types influence UHI intensity differently, with industrial and commercial zones often producing higher temperatures due to inappropriate spatial allocation and intense human activity. High-density residential and commercial areas are therefore major contributors to urban heat. Huang et al. (2019) analyzed spatial variations in UHI intensity across major cities using remote sensing data and found that land-cover characteristics, urban morphology, and anthropogenic heat emissions are key drivers of elevated LST. Their work demonstrates the effectiveness of geospatial techniques in identifying thermal patterns and understanding human–environment interactions, supporting their application in fast-growing cities such as Benin City.

2.2.6.9 Wind Speed

Urban Heat Island intensity is often amplified by reduced wind movement caused by dense building arrangements and low-albedo surfaces, which trap warm air within urban canyons. Limited evaporation further restricts airflow and cooling efficiency in cities. Consequently, UHI characteristics are influenced by both intrinsic urban features such as city size, population density, building configuration, and land use and external factors including climate, weather conditions, and seasonal variability. Chen et al. (2015) examined how biophysical surface properties such as vegetation cover, albedo, and soil moisture affect LST in urban environments. Their findings identified vegetation as a dominant cooling factor and underscored the importance of incorporating land-surface characteristics into urban heat studies, reinforcing the usefulness of geospatial tools for assessing LST and UHI in diverse contexts, including African cities like Benin City.

2.2.7 Effects of Urban Heat Island

Urban environmental conditions can negatively affect the livability and attractiveness of built-up and central urban areas, reducing their desirability for residential, commercial, or recreational activities. As a result, people often change their location preferences and migrate away from overheated city centers, leading to outward urban expansion. This population movement contributes to prolonged stability or stagnation in some inner-city areas while accelerating growth at the urban periphery.

In many developing countries, Urban Heat Island (UHI) events have diverse impacts on the environment and human populations, particularly through the deterioration of air quality. Rising urban temperatures increase the demand for energy, especially for air-conditioning systems. During summer periods, this heightened energy demand leads to increased emissions from power generation, thereby intensifying air pollution levels.

Akbari (2017) noted that the conversion of natural land cover into buildings and paved surfaces significantly elevates surface and air temperatures in urban areas. This temperature increase associated with the UHI effect drives higher electricity consumption for cooling and exacerbates air pollution. The study recommended mitigation measures such as the adoption of cool roofing materials and enhanced urban greening to reduce urban temperatures and energy demand.

Nichol (2015) applied remote sensing techniques to assess UHI effects during both daytime and nighttime periods. The findings showed that urban areas consistently record much higher surface temperatures than surrounding rural regions, particularly during the day. These temperature differences were strongly influenced by land cover composition and the presence of vegetation, emphasizing the cooling role of green spaces.

Duncan et al. (2018) investigated UHI characteristics in Belém, Brazil, using satellite imagery and found that central urban zones experienced the greatest increases in land surface temperature over time as a result of urban expansion. Dense built-up areas were identified as especially susceptible to heat accumulation, particularly during the dry season. Similarly, Zhou et al. (2018) analyzed the Yangtze River Delta in China and observed pronounced UHI effects within urban clusters, with summer temperatures significantly higher than winter values. Their study confirmed that urban development elevates both daytime and nighttime land surface temperatures, with UHI intensity closely associated with population density and the extent of built-up surfaces.

2.3 Evaluation of Reviewed Literature

The reviewed literature has provided a comprehensive understanding of the Urban Heat Island (UHI) phenomenon and the significance of Land Surface Temperature (LST) analysis using geospatial techniques. Several scholars have explored the underlying mechanisms, causes, and impacts of UHI across different urban contexts, employing a range of remote sensing and GIS

methodologies to assess urban thermal patterns. These studies collectively emphasize the strong influence of anthropogenic activities, land cover changes, and urban morphology on LST and UHI intensity.

Early foundational work, such as that by Oke (1982) and Landsberg (1981), emphasized that the transformation of natural land surfaces into urban environments with materials like asphalt and concrete intensifies heat absorption and retention. These materials contribute to elevated temperatures, especially in urban centers, by reducing surface reflectivity and limiting cooling through evapotranspiration.

Further studies, such as Akbari (2015), supported these findings by illustrating how surface modifications in urban areas heighten energy consumption for cooling, particularly during warmer periods. Similarly, Voogt and Oke (2015) highlighted that impermeable urban materials significantly contribute to higher LST, and that the heat stored during the day is slowly released at night, sustaining UHI effects even after sunset.

Vegetation emerges as a key mitigating factor in many studies. Research by Chen *et al.* (2015), Goward *et al.* (2015), and Ahmed *et al.* (2019) found that increased vegetation cover correlates with lower surface temperatures. These studies demonstrated that green spaces help reduce LST due to processes like shading and evapotranspiration. Peng *et al.* (2022) also reported that even small patches of greenery can offer measurable cooling benefits, especially in compact tropical cities. These findings underscore the necessity of incorporating vegetation into urban development plans to counteract the UHI effect.

Numerous investigations into urban growth patterns, including Duncan *et al.* (2018) and Zhou *et al.* (2018), revealed that urban expansion is a significant contributor to rising temperatures. Their research showed that newly developed and densely built-up areas consistently record higher LST values. These observations are consistent with Weng (2015), who linked the

increase in built-up surfaces directly to surface heat concentration. In the Nigerian context, studies like those by Akinbode *et al.* (2016), Umar and Satish (2016), and the more recent work in Lafia (2025) confirm that urbanization, combined with vegetation loss, leads to intensified UHI effects in rapidly developing cities.

The reviewed works also demonstrate the utility of remote sensing and Geographic Information Systems (GIS) in analyzing urban heat dynamics. Weng *et al.* (2024) and Mallick *et al.* (2018) effectively used satellite data to monitor LST distribution and detect hotspots. Their methods incorporated indices such as NDVI and NDBI to differentiate between vegetation, built-up areas, and water bodies, making it easier to identify high-risk zones. These tools are especially valuable in regions undergoing rapid land use changes, where timely data are essential for planning interventions.

Beyond physical surface changes, other influencing factors have also been explored. Studies by Ford *et al.* (2024) and Zhou *et al.* (2017) revealed that urban size, morphology, and population density significantly impact LST and UHI intensity. Additional research, such as that by Tsou *et al.* (2012) and Chapman (2016), emphasized the role of human activity like energy consumption and vehicle emissions as a source of anthropogenic heat, particularly during nighttime hours. Moreover, Li *et al.* (2023) introduced an important social dimension by demonstrating that disadvantaged communities often have less access to cooling infrastructure and green spaces, thereby experiencing higher urban temperatures.

In conclusion, the reviewed literature collectively identifies urban expansion, surface sealing, lack of vegetation, and anthropogenic heat emissions as the primary drivers of the UHI phenomenon. While most studies agree on the roles these factors play, they also highlight the usefulness of geospatial technologies for quantifying and managing UHI impacts. Although global in scope, there remains a need for localized studies in West Africa and Nigeria in particular. Given Benin City's rapid development and changing land use, this research aims to

build on the current knowledge base by applying geospatial techniques to evaluate the spatial and temporal dynamics of LST and UHI in the city. The goal is to generate useful data for sustainable urban planning and environmental management.

2.4 Gaps in Literature

The reviewed literature reveals several research gaps that this study aims to address. First, there is a lack of localized studies on LST and UHI in Benin City. While much of the existing research has focused on large Nigerian cities like Lagos, Ibadan, and Kano, mid-sized urban centers such as Benin City remain underexplored despite experiencing rapid urban growth. Additionally, many studies have not considered the role of socioeconomic factors in shaping urban heat exposure. . Another limitation is the inadequate attention to seasonal variations in LST and UHI, particularly in tropical climates where the contrast between dry and rainy seasons can greatly affect surface temperatures.

Moreover, most research relies on single-source satellite imagery, such as Landsat, without integrating higher-resolution or multi-sensor datasets like MODIS or Sentinel, which could enhance spatial accuracy and temporal coverage. There is also limited application of advanced geospatial and statistical techniques. While basic remote sensing methods are commonly used, more sophisticated tools such as machine learning models, landscape metrics, and urban thermal simulations are rarely employed to understand the complex interactions between land cover and surface temperature. Finally, although some studies discuss green infrastructure as a mitigation strategy, there is a weak connection between geospatial findings and practical urban planning solutions. Few studies provide location-specific recommendations for climate-responsive development, particularly in the context of West African cities.

CHAPTER THREE

METHODOLOGY

3.1 Description of the Study Area

The study Area-Benin City, the capital of Edo State, is located between latitudes $6^{\circ}17'N$ and $6^{\circ}26'N$, and longitudes $5^{\circ}35'E$ and $5^{\circ}45'E$. It spans an area of roughly 1,204 square kilometers and had a population of approximately 1.015 million according to the 2006 census, with an estimated annual growth rate of 3.73%. The city's topography is predominantly flat with gentle undulations, and its elevation ranges between 50 and 150 meters above sea level. Several rivers and streams, most notably the Ogba and Ikpoba rivers, provide effective drainage and significantly influence the city's hydrological and vegetation characteristics. Benin City falls within the tropical rainforest climatic zone and experiences two major seasons: the rainy season from April to October and the dry season from November to March. Annual rainfall typically ranges from 1,500 mm to 2,000 mm, while average temperatures remain consistently high, around $27^{\circ}C$. Humidity levels are generally elevated, especially during the rainy season, contributing to the city's warm, lush environment.

Benin City, the political, cultural, and economic hub of Edo State, holds deep historical significance as the seat of the ancient Benin Kingdom. It is bordered to the north and east by Uhunmwonde Local Government Area, to the west by Ovia North-East, and to the south by Orhionmwon Local Government Area. The city comprises three major local government areas Oredo, Egor, and Ikpoba-Okha which host a diverse mix of residential, industrial, institutional, and commercial land uses. In recent decades, Benin City has experienced rapid urban growth driven by population increase, infrastructural development, and expanding commercial activities. This expansion has led to complex land use patterns, accelerated spatial development, and a range of environmental challenges, including elevated land surface temperatures, loss of green spaces, and occasional urban flooding. Considering its climatic

characteristics, accelerated urban growth, and evolving land use patterns, the area was used as case study for exploring environmental dynamics such as land surface temperature (LST), urban heat island (UHI) effects, and other urban climate phenomena using geospatial and remote sensing techniques.,

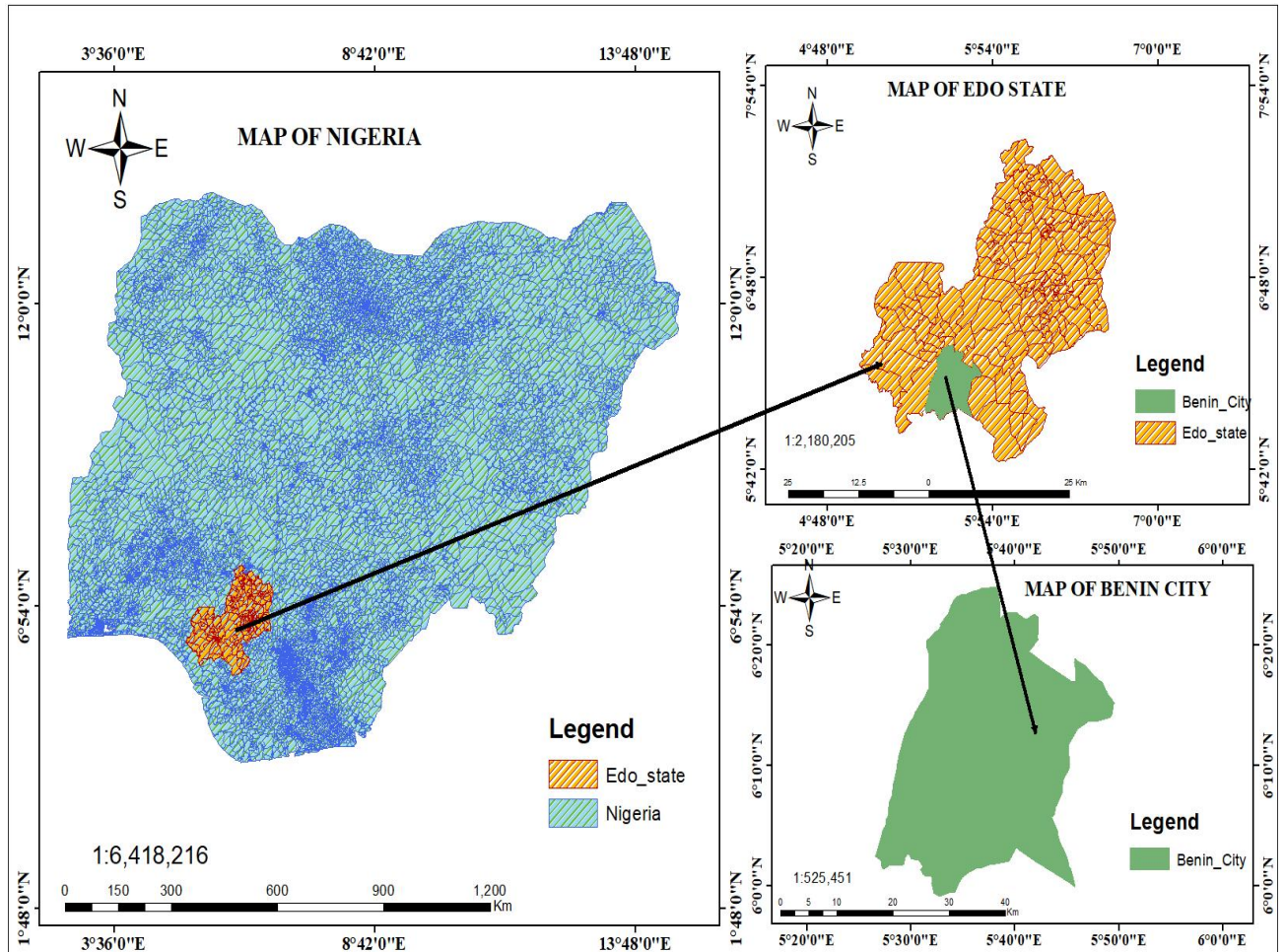


Figure 3.1: The Study Area

Source: <https://open.africa/dataset/?tags=Nigeria+LGA+Boundaries>

3.1.0 METHODOLOGY FOR THE ASSESMENT OF LAND SURFACE TEMPERATURE AND URBAN HEAT ISLAND USING GEOSPATIAL TECHNIQUES

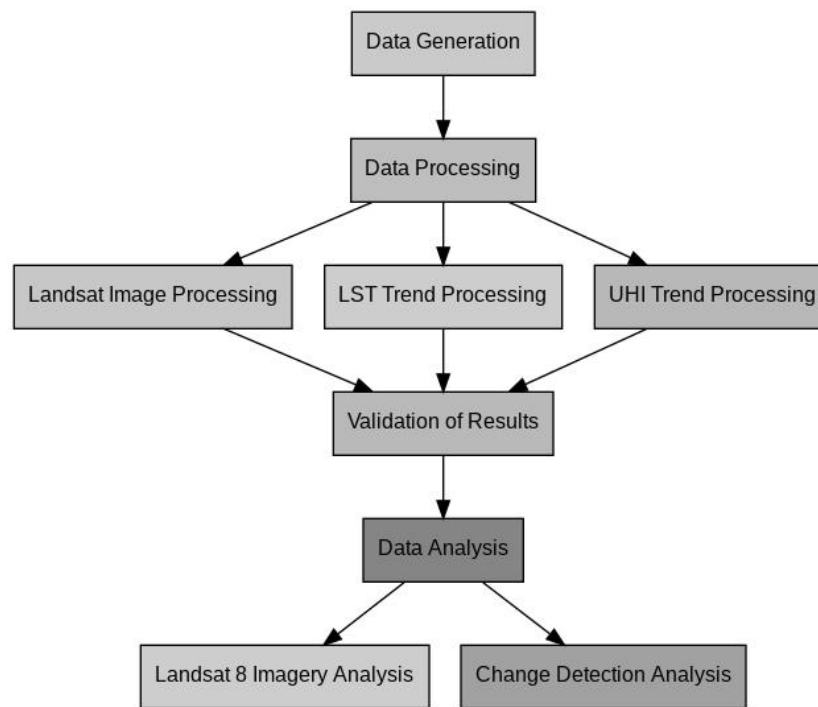


Figure 3.2: Flow Chart for the The Assessment Of Land Surface Temperature And Urban Heat Island

The classified maps were generated through supervised classification in ArcGIS 10.x, using the Maximum Likelihood Algorithm. Each map was standardized to the same projection and spatial resolution to ensure accurate comparison. Once classification was completed, the individual maps were overlaid and processed using change detection tools within ArcGIS, such as the Raster Calculator, Reclassify, and Combine functions.

3.1.1 Land Use/Land Cover (LULC) Map Generation

Landsat 8 OLI/TIRS imagery for the years 2014 and 2024 were downloaded from the USGS Earth Explorer portal <https://earthexplorer.usgs.gov/>. The images were selected during the dry season (typically between December and March) to minimize cloud cover and enhance spectral clarity for classification.

Multi-temporal Landsat satellite imageries were downloaded to analyze the land use and how urban growth has influenced heat patterns over a 4 year period. The images were sourced

from the United States Geological Survey (USGS) Earth Explorer platform. <https://earthexplorer.usgs.gov/>. Two images were downloaded; Landsat 8 & 9 for 2014 and Landsat 8 & 9 for 2024. The images were projected using the WGS 84 datum and UTM Zone 31N coordinate system.

To download Landsat imagery from the USGS EarthExplorer platform, I converted the Benin city shapefile into a km file using google Earth. Then open Usgs under the search criteria upload the kmz file, under data set choose landsat, under landsat choose landsat collection 2 level-2, choose landsat 8-9 Oli/Tirs c2l2, cloud cover 10-15%, data range: 01/01/2014-31/12/2024, additional criteria: satellite 8 or 9, click on result then pick a footprint that covers your region of choice then click download > level 2 surface reflectance band>add all files to bulk and click cancel

Click item basket>start order>landsat2l2b>submit product selection>start downloading>launch bulk download>save to a folder>start downloading.



Figure 3.3: Landsat Imagery

Pre-processing steps included layer stacking, sub-setting the study area boundary, and atmospheric correction using the FLAASH tool in ArcGIS. The LULC classification was done through Supervised Classification using the Maximum Likelihood Algorithm (MLA).

Training samples were digitized for four major classes: built-up areas, vegetation, bare land, and water bodies.

3.2 DATA PROCESSING

FLOW CHART FOR THE PROCESSING OF LANDSAT 8 OLI/TIRS IMAGERY DATA FROM 2014-2024

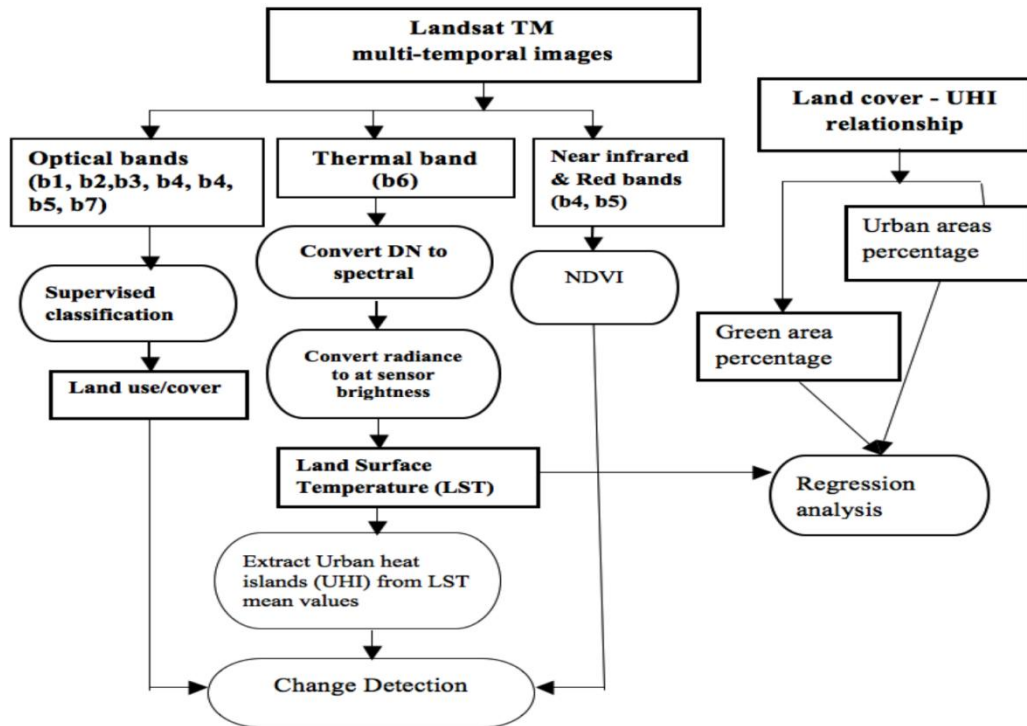


Figure 3.4: Flow Chart for the Processing Landsat 8 OLI/TIRS Imagery Data from 2014-2024

3.2.1 Processing the Landsat 8 Imagery data

The Landsat satellite images for the years 2014 and 2024 were processed using ArcGIS 10.x and standard remote sensing techniques to prepare them for spatial analysis. The processing steps are as follows:

1. Band Stacking – Merged the individual spectral bands of each satellite image to produce a multispectral composite.

2. Clipping to Study Area – Cut the multispectral image to fit the exact boundary of Benin City using the study area shapefile.

3. Image Corrections – Applied atmospheric and radiometric corrections to enhance data accuracy by reducing the effects of atmospheric interference and sensor errors.

4. LULC Map Production

- i. Selected key spectral bands, particularly those in the visible and near-infrared range.
- ii. Conducted supervised classification using the Maximum Likelihood algorithm.
- iii. Used training samples collected from identifiable land cover features within the study area.

5. Land Surface Temperature Computation

- I. Extracted the thermal infrared band (Band 10).
- II. Converted Digital Numbers (DN) to Top of Atmosphere (TOA) radiance.
- III. Derived brightness temperature from the radiance values.
- IV. Calculated Land Surface Temperature (LST) by incorporating surface emissivity values obtained from NDVI.

6. UHI Analysis – Measured the temperature variation between urban (built-up) and rural (vegetated) zones to determine Urban Heat Island intensity.

7. Data Output and Storage – Saved all processed data as raster layers and thematic maps for further spatial analysis and interpretation.

3.2.2 Land Surface Temperature (LST) Estimation

LST was derived from the Thermal Infrared Sensor (TIRS) Band 10 of the Landsat 8 imagery using the following step-by-step procedure:

Step 1: Conversion of Digital Number (DN) to Top of Atmosphere (TOA) Radiance

$$L_{\lambda} = M_L \times Q_{cal} + A_L \quad (3.1)$$

Where:

L_{λ} = TOA spectral radiance (Watts/m²·sr·μm)

M_L = Radiance multiplicative scaling factor (from Landsat imagery data)

A_L = Radiance additive scaling factor (from Landsat imagery data)

Q_{cal} = Quantized calibrated pixel value (DN)

Step 2: Conversion of TOA Radiance to Brightness Temperature (BT)

$$B_T = \left(\frac{K_2}{\ln\left(\frac{K_1}{L_{\lambda} + 1}\right)} \right) - 273 \quad (3.2)$$

Where:

B_T = Brightness temperature in Kelvin (K)

K_1 = Thermal constant 1 for Band 10 (from metadata)

K_2 = Thermal constant 2 for Band 10 (from metadata)

L_{λ} = TOA spectral radiance (from Step 1)

Step 3: Normalized Difference Vegetation Index (NDVI)

$$\frac{NIR - RED}{NIR + RED} \quad (3.3)$$

Where:

NIR = Band 5 (Near Infrared)

RED = Band 4 (Red)

Step 4: Proportion of Vegetation (PV)

$$PV = \left(\frac{NDVI - NDVI_{\min}}{NDVI_{\max} - NDVI_{\min}} \right)^2 \quad (3.4)$$

Where:

NDVI_{min} and NDVI_{max} = minimum and maximum NDVI values in the image

PV = Fractional vegetation cover

Step 5: Land Surface Emissivity (LSE)

$$\varepsilon = 0.004 \times PV + 0.986 \quad (3.5)$$

Where:

ε = Surface Emissivity

PV = Proportion of vegetation (from Step 4)

Step 6: Final Land Surface Temperature (LST) Calculation

$$LST = \left(\frac{B_T}{1 + \left(\frac{\lambda \times B_T}{\rho} \right) \ln \varepsilon} \right) \quad (3.6)$$

Where:

LST = Land Surface Temperature in Kelvin

B_T = Brightness temperature (from Step 2)

ϵ = Land surface Emissivity (from Step 5)

λ = Wavelength of emitted radiance (approximately 10.895 μm for Band 10)

$\rho = h \times c / \sigma = 14388 \text{ m}\cdot\text{K}$

h = Planck's constant ($6.626 \times 10^{-34} \text{ Js}$)

c = Speed of light ($2.998 \times 10^8 \text{ m/s}$)

σ = Boltzmann constant ($1.38 \times 10^{-23} \text{ J/K}$)

3.2.3 Urban Heat Island (UHI) Quantification

The Urban Heat Island (UHI) effect was quantified by calculating the difference in LST between densely built-up (urban) areas and surrounding non-urban (vegetated) zones. The UHI intensity was computed using the following formula:

$$\text{UHIintensity(index)} = \frac{\text{LST} - \text{LST}_m}{\text{LST}_{sd}} \quad (3.7)$$

LST_m = LST mean

LST_{sd} = LST standard deviation

Urban and rural zones were identified from the LULC maps. Spatial overlays were used to extract LST values from the respective land cover classes.

3.3 VALIDATION OF RESULTS THROUGH NDVI–LST CORRELATION

ANALYSIS

To verify the accuracy of the spatial analysis, a correlation assessment was carried out between the Normalized Difference Vegetation Index (NDVI) and Land Surface Temperature

(LST). First, a fishnet grid was created across the study area to generate evenly spaced sampling points. The centroid of each grid cell was used as the reference point for data extraction.

Using the Extract Multi Values to Points tool in ArcGIS, NDVI and LST values were extracted at each fishnet centroid. The resulting dataset was then exported to Microsoft Excel for statistical analysis. In Excel, a scatter plot was produced, with NDVI as the independent variable (x-axis) and LST as the dependent variable (y-axis). A trendline was added to the plot, and the correlation coefficient (R) and coefficient of determination (R^2) were computed.

3.4 ANALYSIS OF RESULTS

3.4.1 Analysis of the Landsat Imagery

The processed data were analyzed using ArcGIS 10, supported by statistical and spatial tools such as:

- i. Spatial Analyst Tools – for raster operations: reclassification, raster calculator, overlay, surface analysis, and zonal statistics.
- ii. Extraction Tools – to clip or extract raster/vector data for the study area
- iii. Spatial Statistics Tools – for pattern analysis: hot spot analysis (Getis-Ord G_i^*), Moran's I, cluster/outlier analysis, mean center, and standard deviational ellipse.
- iv. Data Management/Statistical Tools – for summary statistics, frequency counts, and descriptive analysis.

3.4.2 Change Detection Analysis

Change detection was conducted by comparing the LULC and LST maps across the years (2014-2024). This allowed the identification of spatial and temporal variations in surface temperature associated with land use transitions. The UHI trends were analyzed using zonal

statistics and visualized through thematic maps, graphs, and line plots showing temperature rise patterns over time. Change detection analysis was employed to assess the temporal variations in land use/land cover (LULC) over a specified period, with the aim of identifying transitions between different land cover classes. This analysis was conducted using a post-classification comparison approach, which involved independently classifying satellite images for the years 2014 and 2024, followed by a pixel-by-pixel comparison of the classified outputs.

Change Detection Steps:

A. LULC Change Detection (2014–2024)

- i. Satellite images for 2014 and 2024 were pre-processed through radiometric and atmospheric correction, including cloud masking.
- ii. The images were classified into Land Use/Land Cover categories using supervised classification.
- iii. The classified maps were clipped to the Benin City boundary for consistency.
- iv. A post-classification comparison was carried out by overlaying the 2014 and 2024 LULC maps.
- v. The percentage increase or decrease for each LULC category was calculated.
- vi. The results were visualized using thematic maps to illustrate spatial patterns of change.

B. LST Change Detection (2014–2024)

- I. LST maps for 2014 and 2024 were extracted from Landsat thermal bands.
- II. The derived LST maps were validated for accuracy.
- III. Both LST maps were clipped to the study boundary.
- IV. Raster differencing ($LST_{2024} - LST_{2014}$) was performed using the Raster Calculator.
- V. The resulting difference map was categorized into classes (increase, decrease, no change).

- VI. Descriptive statistics, including mean, minimum, maximum, and standard deviation, were computed to quantify LST changes.
- VII. Spatial maps were produced to highlight areas of temperature increase and decrease.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Land Use/Land Cover (LULC) Classification Results

The supervised classification of Landsat imagery for 2014 and 2024 produced four primary land-use classes: built-up areas, vegetation, bare land, and water bodies. The classification revealed significant spatial changes over the study period which is shown in Figure 4.1 and Figure 4.2

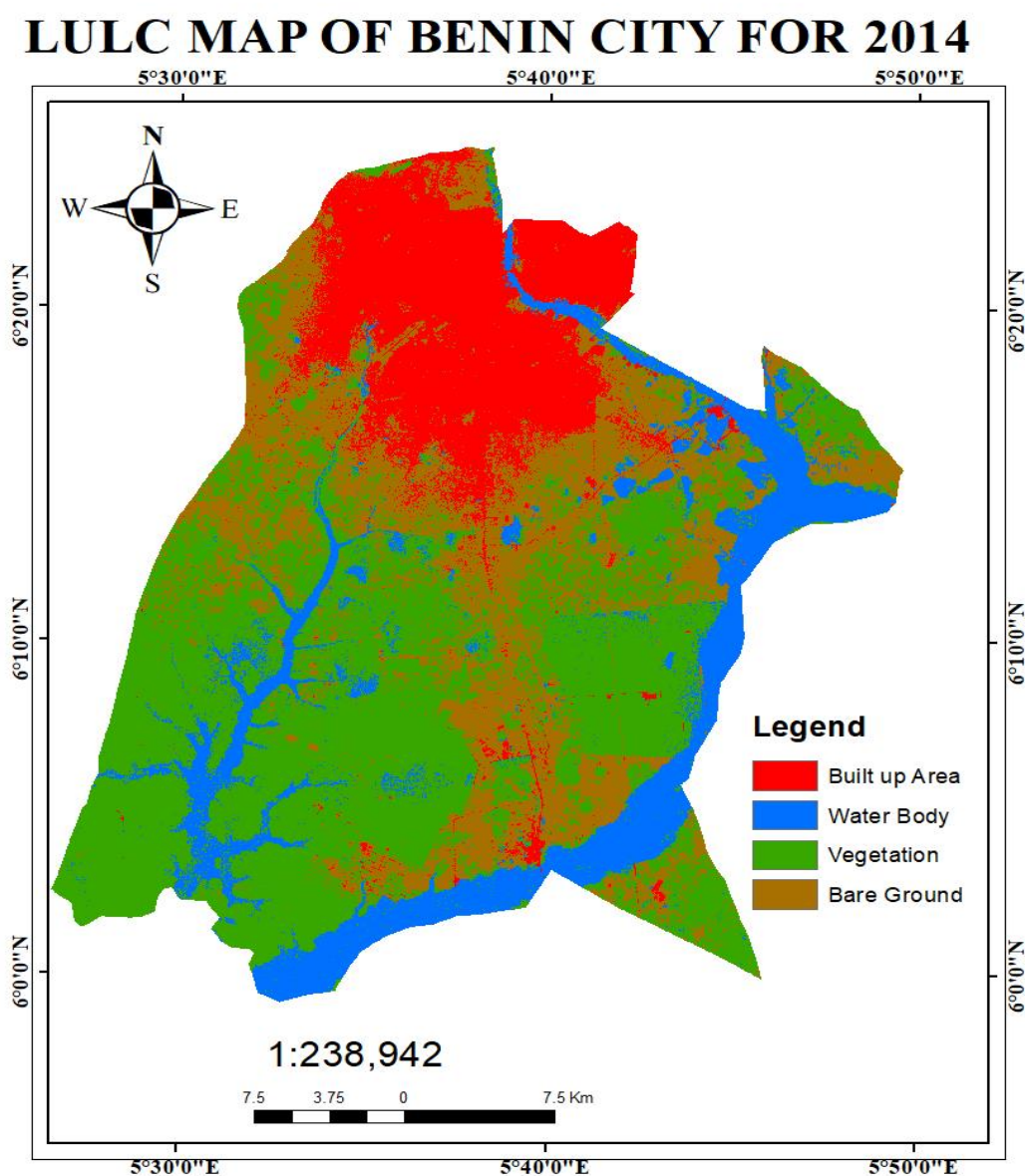


Figure 4.1:LULC Map for 2014

Figure 4.1 shows dominance of vegetation cover across most parts of Benin City, particularly in peri-urban fringes, while built-up areas were concentrated around the urban core (Oredo, Egor, and Ikpoba-Okha LGAs).

LULC MAP OF BENIN CITY FOR 2024

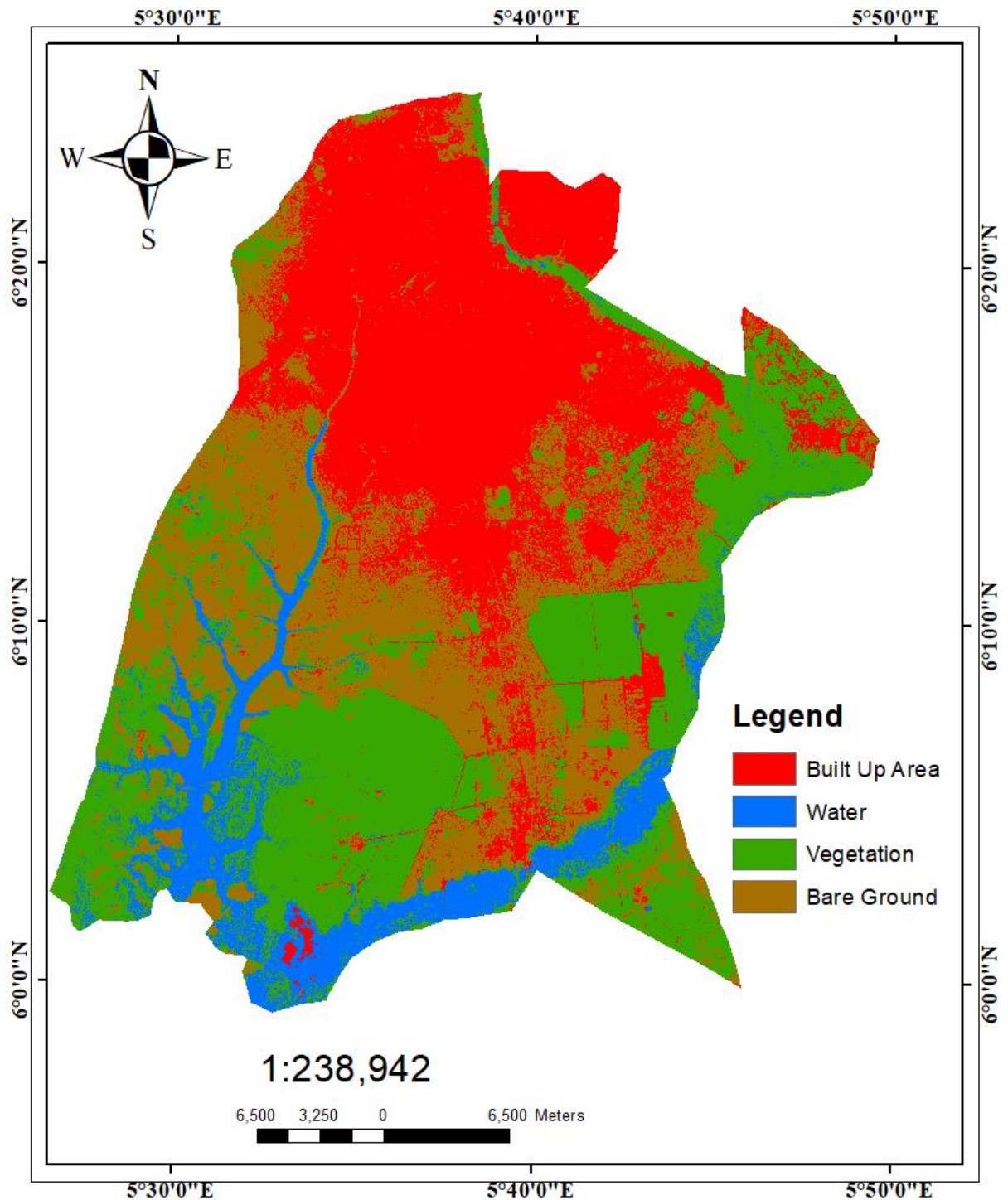


Figure 4.2: LULC Map for 2024

In Figure 4.2 an observable expansion of built-up areas occurred, particularly along major road corridors, commercial zones, and newly developing suburbs. Vegetation cover experienced noticeable reduction, indicating continued urban expansion and conversion of green spaces to built environment.

4.2. Land Surface Temperature (LST) Distribution

Figure 4.3 and Figure 4.4 showing LST change maps between the year 2014 and 2024

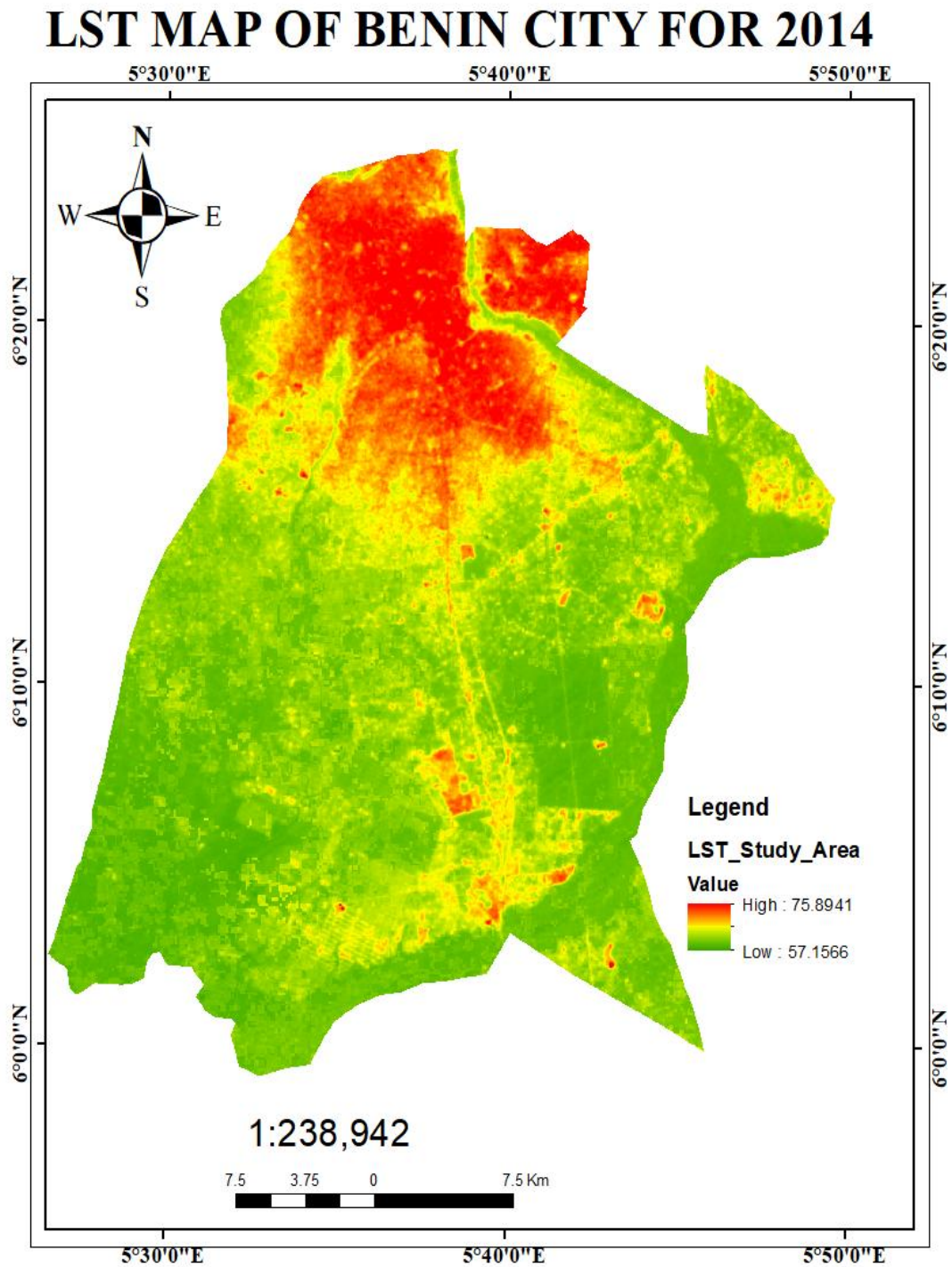


Figure 4.3: LST map for 2014

LST MAP OF BENIN CITY FOR 2024

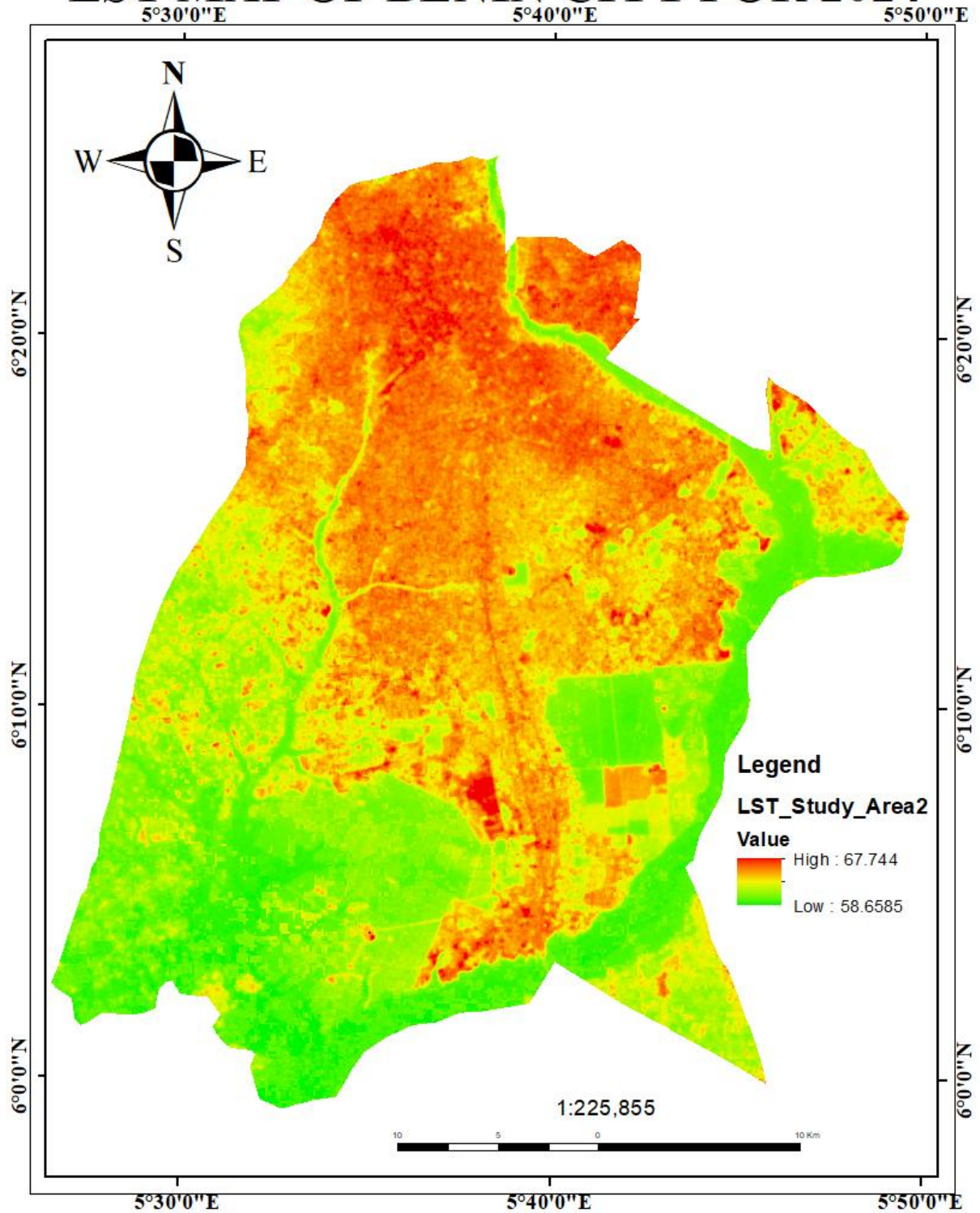


Figure 4.4: LST map for 2024

Figure 4.3 and Figure 4.4 illustrates the spatial and temporal variation in Land Surface Temperature (LST) within the study area for the years 2014 and 2024, providing a clear basis for detecting changes in surface thermal conditions over a ten-year period. By placing the two

LST maps side by side, the pattern and extent of temperature variation across the study area can be visually compared.

In 2014, land surface temperature values ranged from approximately 57.16 °C to 75.89 °C. Lower temperature values, represented by green tones, were dominant across large portions of the study area, particularly toward the southern and peripheral zones. These areas are likely associated with vegetated surfaces, water bodies, or less developed land. Higher temperature values, shown in yellow to red colours, were mainly concentrated in the northern and central parts of the area, indicating zones of intense human activity, exposed soil, or built-up surfaces. The spatial distribution suggests that high-temperature areas were relatively localized, reflecting a more balanced thermal environment at that time.

By 2024, the LST values ranged from about 58.66 °C to 67.74 °C. Although the maximum temperature value appears lower than that recorded in 2014, the spatial extent of moderate to high temperature zones increased significantly. Warmer surface conditions became more widespread, especially across the central and northern parts of the study area. Areas that previously exhibited lower temperatures show a noticeable transition toward higher LST classes, indicating a reduction in cooler surfaces. This pattern suggests increased surface heating linked to changes in land use, such as urban expansion, vegetation removal, and growth in impervious surfaces.

4.3 URBAN HEAT ISLAND(UHI) DISTRIBUTION

UHI MAP OF BENIN CITY FOR 2014

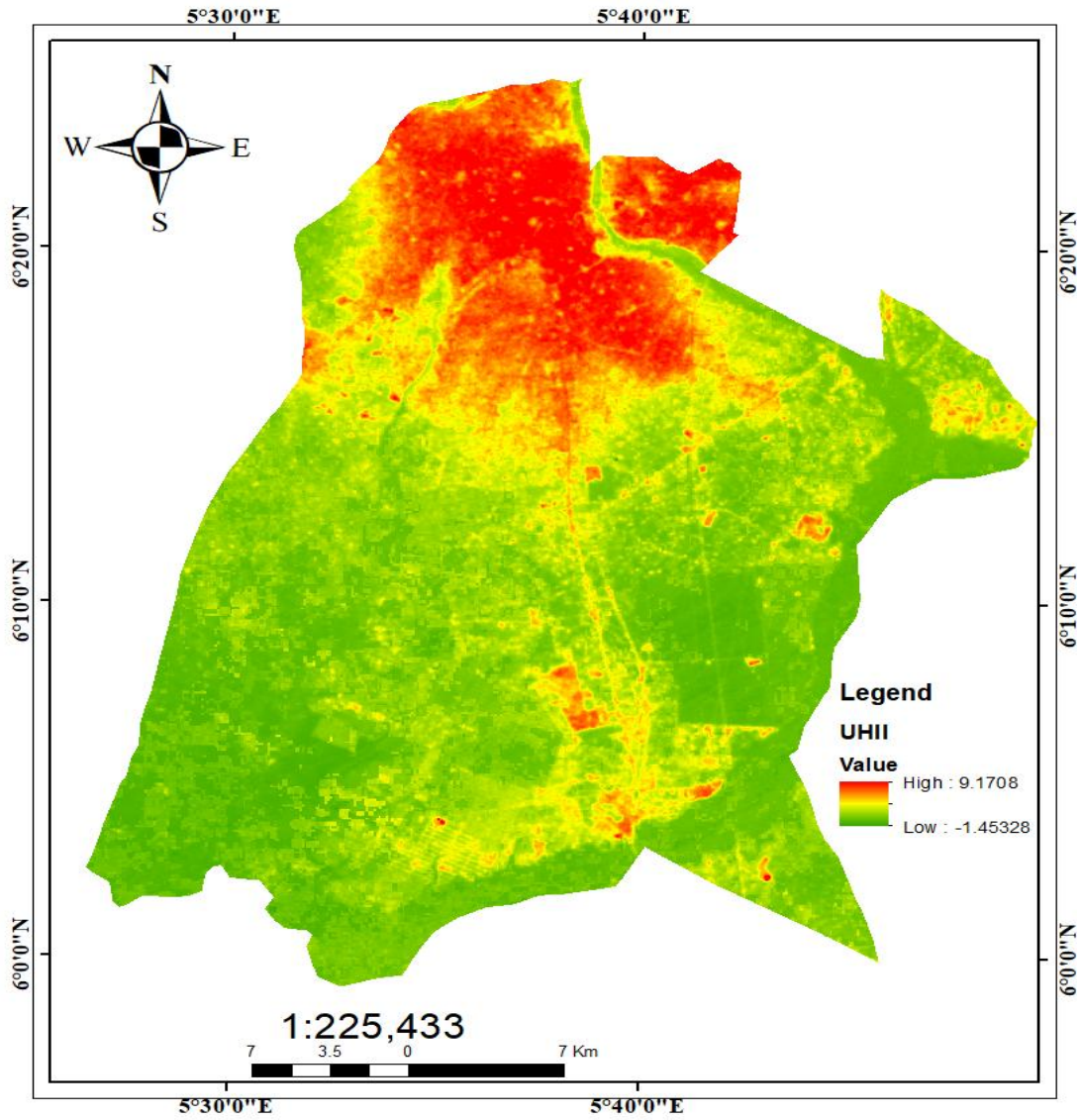


Figure 4.5: UHI map for 2014

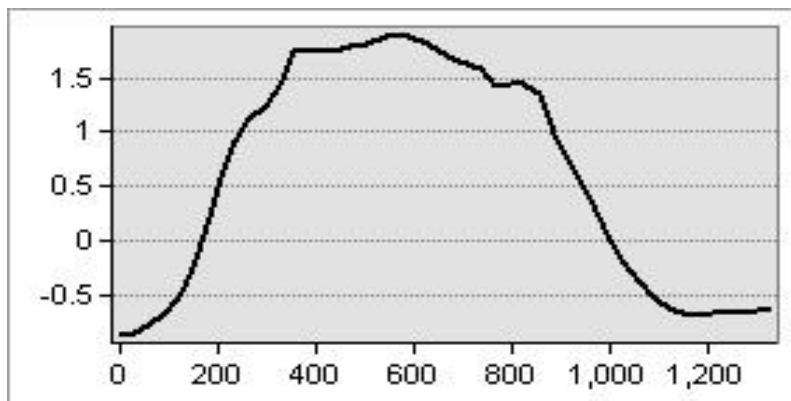


Figure 4.6: UHI Heat Index Graph for 2014

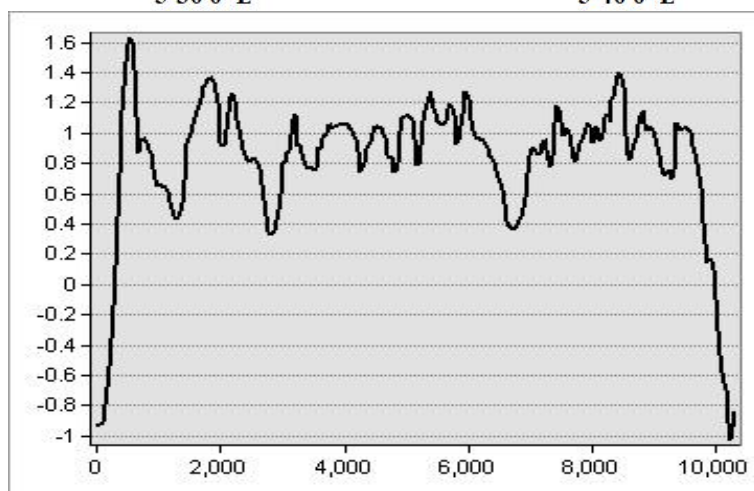
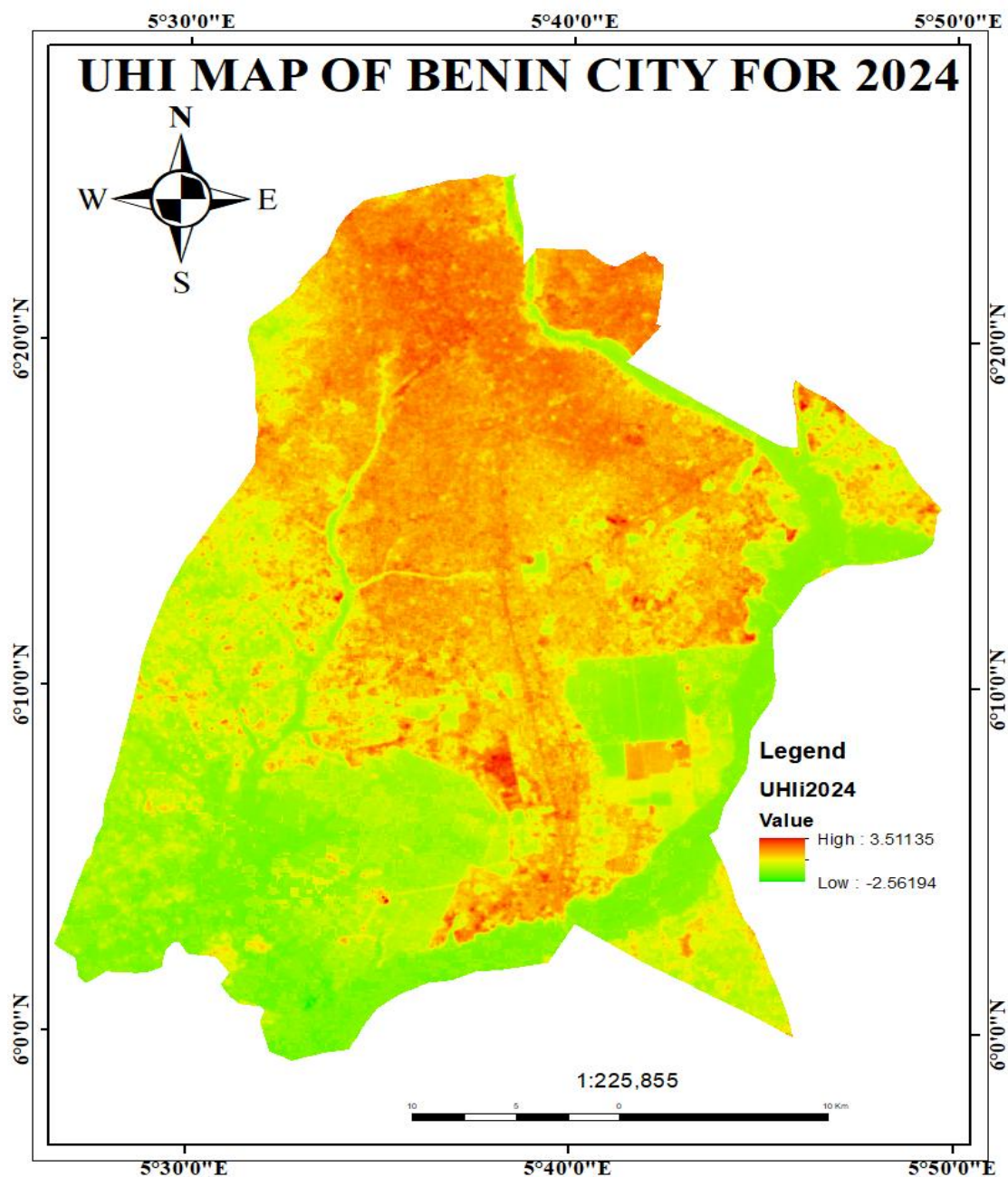


Figure 4.7: UHI Heat Index Map and Graph for 2024

Figure 4.5 -Figure 4.7 illustrate the spatial distribution and intensity of surface temperature anomalies relative to surrounding cooler areas, thereby revealing how urban-induced heating has evolved over a ten-year period. The maps use a colour gradient in which green represents low or negative UHI values, indicating cooler or less heat-intensive areas, while yellow to red colours represent higher UHI values, corresponding to zones of stronger urban heat island effects.

In 2014, UHI values ranged from approximately -1.45 to 9.17 . Areas with high UHI intensity were mainly concentrated in the northern and central parts of Benin City. These zones are characterized by extensive built-up development, dense road networks, and limited vegetation cover, all of which contribute to increased heat absorption and retention. The southern and peripheral parts of the city were dominated by lower UHI values, suggesting the presence of more vegetation, open spaces, or less urbanized land uses that promote cooling through evapotranspiration. Although distinct hotspots were present in 2014, they appeared relatively localized, indicating that strong urban heat effects were confined to specific sections of the city.

By 2024, UHI values ranged from about -2.56 to 3.51 . While the maximum UHI value is numerically lower than that observed in 2014, the spatial extent of moderate UHI conditions increased noticeably across the city. Warm zones expanded from the core urban areas into surrounding regions, especially across the central corridor and northern sections of Benin City. Several areas that previously exhibited lower UHI intensity in 2014 transitioned into moderate or high UHI classes in 2024, reflecting increased surface heating. This widespread distribution suggests intensified urban development, reduction in vegetation cover, and increased impervious surfaces such as roads, rooftops, and paved areas.

4.4 Change Detection Analysis

4.4.1 LULC Change Detection

Table 4.1: 2014 LULC Percentage change

Name	Sum of Area	%
Bare Ground	293.6991382	25%
Built Up Area	200.4396446	17%
Vegetation	494.5871805	43%
Water Body	164.5614758	14%
Grand Total	1153.287439	100%

Table 4.2: 2024 LULC Percentage Change

Name	Sum of Area	%
Bare Ground	309.8423236	27%
Built Up Area	392.7925394	34%
Vegetation	345.6025869	30%
Water	105.0404795	9%
Grand Total	1153.277929	100%

Table 4.1 and Table 4.2 confirm large-scale conversion of vegetation to built-up land between 2014 and 2024. The spatial pattern indicates peri-urban sprawl driven by population growth, housing demand, and infrastructure expansion.

4.4.2 LST Change Detection

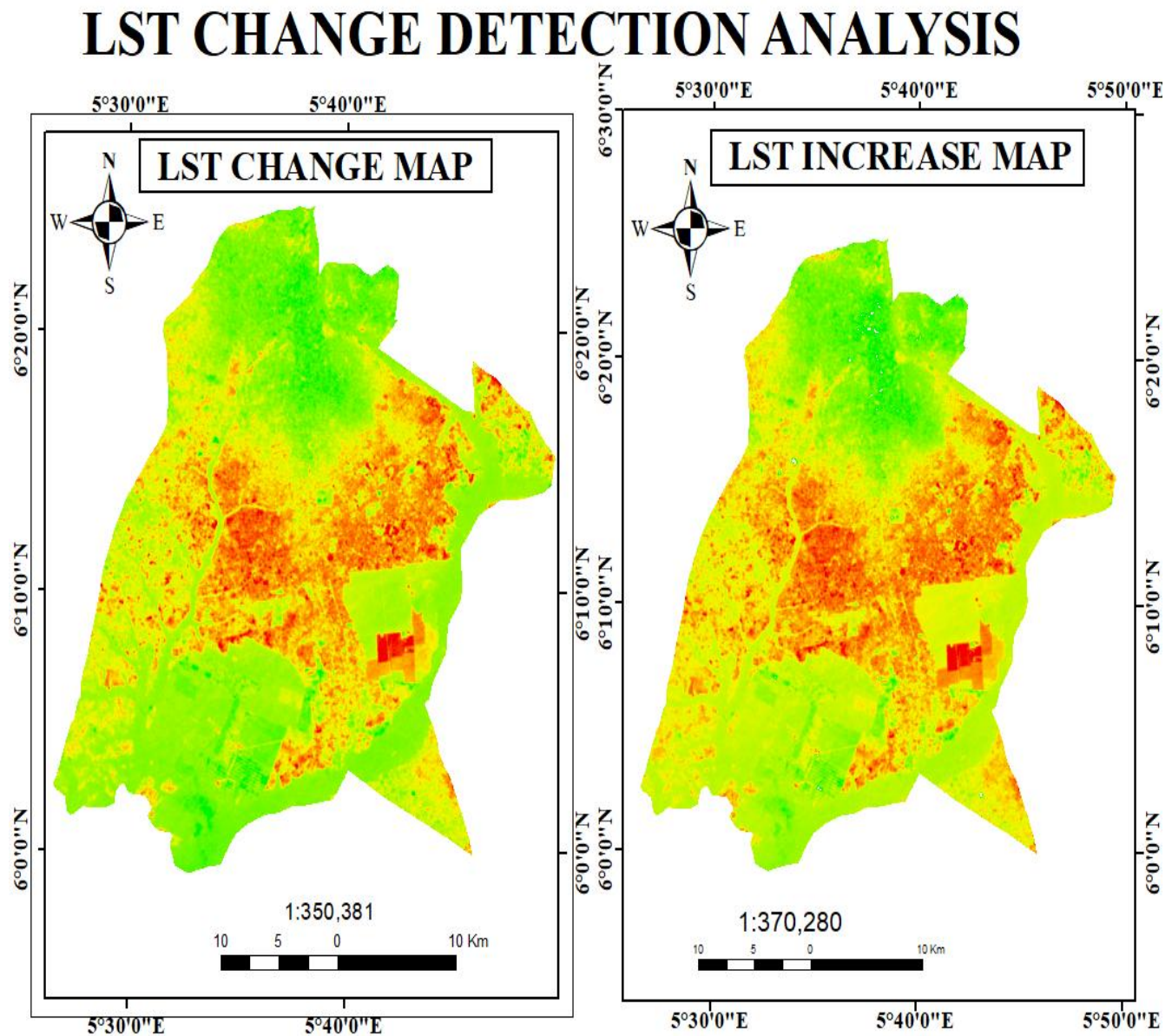


Figure 4.8: LST change detection analysis

Raster differencing revealed an increase in average surface temperature over the Ten-year period. Hotspots expanded into new urban growth areas, while previously developed areas intensified in heat accumulation.

4.5 VALIDATION OF RESULTS

4.5.1 NDVI–LST Correlation Analysis

To validate surface temperature results, NDVI and LST values were extracted at evenly spaced locations generated using a fishnet grid. NDVI and LST values were then plotted and the correlation coefficient computed.

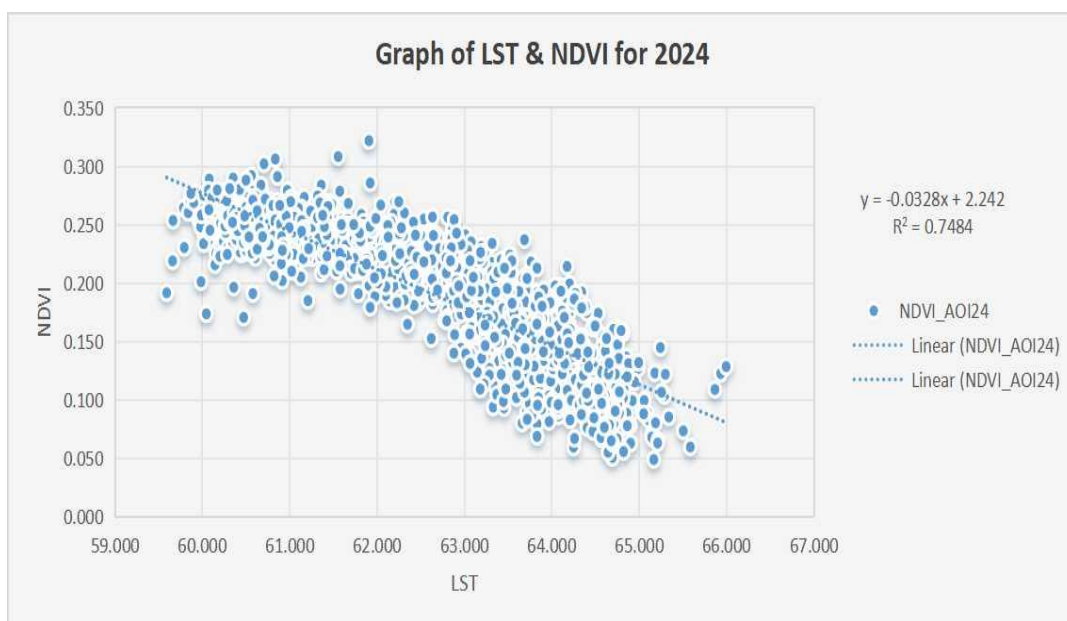
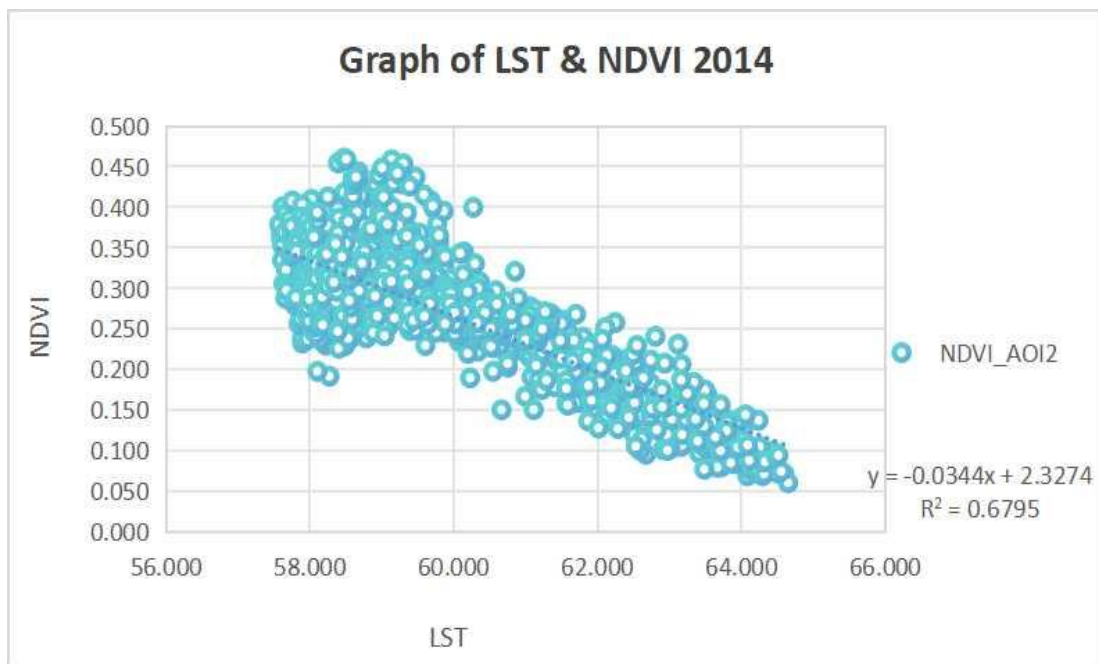


Figure 4.9: Graph showing correlation between NDVI & LST for 2014 and 2024

Figure 4.9 showed both negative correlation, confirming that: Higher NDVI values correspond to lower LST and Lower NDVI values correspond to higher LST.

This inverse relationship emphasizes the cooling effect of vegetation through shading and evapotranspiration and supports the hypothesis that vegetation loss intensifies surface heat.

4.6 Discussion of Findings

This study successfully assessed land surface temperature (LST), vegetation cover (NDVI), and urban heat island (UHI) patterns in Benin City using GIS and remote sensing techniques. The results revealed a clear relationship between land-use changes and surface temperature distribution. Built-up and densely developed areas recorded higher temperatures, confirming strong UHI effects, while vegetated and undeveloped areas showed lower temperatures due to cooling effects from shading and evapotranspiration.

The negative correlation obtained between NDVI and LST indicates that areas with more vegetation experience reduced surface temperatures. This finding aligns with previous studies and demonstrates the vital role of green spaces in regulating urban microclimate. The spatial patterns also reflect urban growth trends, where expansion of built-up surfaces contributes to rising temperature levels.

Overall, the study achieved its aim and objectives by successfully mapping LST, analyzing NDVI, detecting changes over time, and identifying UHI hotspots. The results highlight the importance of integrating vegetation and climate-responsive planning strategies to enhance environmental sustainability and urban livability in Benin City.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSION

This study examined Land Surface Temperature (LST), land-use dynamics, and Urban Heat Island (UHI) patterns in Benin City using GIS and remote-sensing techniques. The results revealed a noticeable increase in surface temperature between 2014 and 2024, particularly in densely built-up areas. Expansion of impervious surfaces and reduction of vegetation cover contributed significantly to this rise, reinforcing the strong negative relationship between NDVI and LST.

The study demonstrates that rapid urbanization in Benin City is intensifying heat stress and altering the local microclimate. These findings underscore the importance of sustainable land-use planning and climate-responsive development to improve environmental quality and urban resilience.

5.2 RECOMMENDATIONS

1. **Urban Greening Initiatives:** Increase urban vegetation through tree planting, green corridors, and public parks to reduce surface heating and enhance cooling.
2. **Climate-Smart Urban Planning:** Integrate heat-mitigation measures in development plans, including controlled expansion of built-up areas and preservation of natural vegetation.
3. **Use of Cool Roofing & Permeable Surfaces:** Encourage reflective roofing materials and permeable pavements to minimize heat absorption and improve storm water infiltration.
4. **Policy and Enforcement:** Strengthen environmental regulations to limit indiscriminate land clearing and enforce green-space requirements in new developments.
5. **Public Awareness:** Promote community awareness programs on the role of vegetation and climate-friendly practices in reducing urban heat.

6. Further Studies: Future research should explore seasonal variations, incorporate ground-based temperature data, and consider socio-economic heat vulnerability analysis.

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