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Research Article

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Temporal Assessment of Land Use Land Cover (LULC), Land Surface Temperature, and Urban Heat Island Changes in Benin City, Edo State, Nigeria: A Case Study of 2017 and 2023

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ABSTRACT
Land use and land cover (LULC) define how land is shaped by human activities and natural processes. As cities grow, forests shrink, farmlands expand, and concrete landscapes replace green spaces. These changes disrupt environmental balance, influencing land surface temperature (LST) and intensifying the urban heat island (UHI) effect, where cities trap more heat than surrounding rural areas. Between 2017 and 2023, Benin City experienced rapid urban transformation. Tree cover dropped from 82.06% to 70.16%, an 11.9% decline, primarily due to urban expansion and land conversion. Built-up areas grew from 9.49% to 15.29%, while cropland and rangeland expanded by 2.15% and 4.19%, respectively. These shifts fueled rising temperatures, with high-temperature zones (>35°C) increasing by 1.52% and moderate-temperature areas (30-35°C) shrinking by 6.11%. The UHI effect worsened as cooler zones (<- 0.45) decreased by 26.48%, while urban heat accumulation intensified, with moderate and high UHI areas expanding by 14.56% and 11.92%. Unchecked urban growth threatens environmental stability. Reversing these trends requires afforestation programs to restore lost vegetation, stricter urban planning to control expansion, and heat mitigation strategies such as reflective roofing and urban greenery. Sustainable land management and continuous monitoring through remote sensing technologies will help build a more resilient and livable Benin City.

Keywords: Urban Heat, Land use, Land Surface Temperature, LULC, Environmental Health

Introduction Background of the Study

Land use and land cover (LULC) changes, land surface temperature (LST) variations, and urban heat island (UHI) effects have become major environmental concerns globally due to rapid urbanization, industrialization, and deforestation [1-3]. Studies indicate that over 55% of the world's population lives in urban areas, a figure projected to reach 68% by 2050, thereby increasing pressure on land resources and contributing to extensive land cover modifications [4-6]. The process of urbanization leads to the replacement of natural vegetation with impervious surfaces such as asphalt and concrete, which significantly alter local climatic conditions and contribute to the intensification of the UHI effect [7]. The UHI phenomenon results in urban areas experiencing significantly higher temperatures compared to their surrounding rural regions due to heat absorption by built surfaces and reduced evaporative cooling from vegetation loss [8-11].

In Africa, rapid urban expansion has led to significant LULC transformations, particularly in West African countries where urbanization rates are among the highest globally [12-15]. Nigeria, the most populous country in Africa, has undergone extensive land use changes, with cities like Lagos, Abuja, and Benin City experiencing widespread conversion of forests and agricultural land into built-up areas [16]. Studies have shown that urbanization in Nigeria contributes to increased land surface temperatures due to reduced vegetation and expanded impervious surfaces, exacerbating the effects of climate change at the local scale [17-19]. In Benin City, these transformations have been particularly pronounced, with significant losses in natural vegetation and increases in built-up areas leading to rising surface temperatures and intensified UHI effects [20].

Benin City, the capital of Edo State, is one of Nigeria's fastest-growing urban centers, with a population that has more than doubled over the past three decades Macrotrends, 2024. The city's expansion has led to large-scale LULC changes, with built-up areas increasing at the expense of forests, wetlands,

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and agricultural land [21,22]. A study analyzing LULC changes from 1987 to 2019 found that built-up areas expanded by 36%, while forest cover declined from 47% to 11% of the total land area, indicating rapid deforestation and urban encroachment [20]. Projections suggest that by 2050, built- up areas in Benin City will reach 542.32 km², further intensifying urban heat and environmental degradation [22].

The impact of these LULC changes extends beyond increased temperatures. Deforestation and loss of vegetation in Benin City contribute to reduced carbon sequestration, increased flood risks, and deteriorating air quality [23]. Studies have shown that the reduction of tree cover leads to lower air purification efficiency, while impervious surfaces increase surface runoff and reduce groundwater recharge, exacerbating urban flooding [24-26]. Additionally, the heat retention capacity of built-up areas contributes to increased energy demand for cooling, leading to higher electricity consumption and associated costs for residents [24]. The combination of these factors highlights the need for continuous monitoring of LULC changes and their environmental implications in Benin City.

Remote sensing and Geographic Information Systems (GIS) provide essential tools for analyzing LULC, LST, and UHI trends over time. Satellite imagery from Sentinel- 2 and Landsat 8 has proven to be highly effective in monitoring urban expansion and its impact on surface temperature dynamics [28]. Sentinel-2, with its high spatial resolution ranging from 10m to 60m, is particularly suitable for detailed LULC classification, allowing for precise mapping of vegetation, water bodies, and built-up areas (ESA, 2022). Landsat 8, equipped with the Thermal Infrared Sensor (TIRS), is widely recognized for its ability to capture LST variations, making it an ideal dataset for assessing UHI intensity and spatial distribution [29]. The integration of these datasets provides a comprehensive approach to understanding how urbanization influences temperature patterns and land cover dynamics over time.

A study by Fabolude and Aighewi examined LULC changes in Benin City from 1987 to 2019 using Landsat satellite imagery [20]. Their findings revealed that built- up areas increased from 151.44 km² in 1987 to 236.92 km² in 2019, with a corresponding decline in forest cover from 403.36 km² to 118.80 km². The study projected that by 2050, built-up areas would expand to 542.32 km², further reducing green spaces and exacerbating urban heat effects. The findings highlighted the role of population growth, economic development, and real estate expansion as key drivers of these changes. Another study by Olayiwola and Igbavboa analyzed the relationship between urbanization and UHI intensity in Benin City. The study found that temperature differences between urban and rural areas increased due to reduced vegetation cover and expanded built-up surfaces [22]. Their research indicated that unplanned urban expansion and inadequate green infrastructure contributed to rising land surface temperatures, leading to thermal discomfort and increased energy demands for cooling. In a related study, Odjugo et al. used the CA-Markov model to project future climate impacts of LULC changes in Edo State [23]. Their findings indicated that continued urban expansion would significantly reduce forest cover and increase surface temperatures in Benin City. The study recommended the implementation of urban greening initiatives and sustainable land use policies to mitigate the adverse effects of urbanization on local climate conditions.

These case studies emphasize the urgent need for systematic monitoring and management of LULC changes in Benin City. Understanding the spatial and temporal variations in land cover and temperature patterns can provide valuable insights for urban planners and policymakers to develop climate-resilient strategies that enhance environmental sustainability and mitigate the UHI effect.

Statement of the Problem

Urbanization in Benin City has led to extensive land use and land cover (LULC) changes, with significant implications for land surface temperature (LST) and urban heat island (UHI) effects. The rapid expansion of built-up areas, coupled with deforestation and the conversion of agricultural land, has altered the city's environmental and climatic conditions [20]. Studies indicate that between 1987 and 2019, built-up areas in Benin City increased from 151.44 km² to 236.92 km², while forest cover declined from 403.36 km² to 118.80 km² [20]. The loss of vegetation, which serves as a natural cooling mechanism, has intensified the UHI effect, leading to rising temperatures and increased thermal discomfort [21].

One of the major environmental challenges associated with urbanization in Benin City is the increase in land surface temperatures due to the dominance of impervious surfaces such as roads, rooftops, and concrete pavements [23]. The UHI effect, which results in urban areas being significantly warmer than their rural counterparts, has become more pronounced due to the expansion of built-up areas at the expense of vegetation [21]. This phenomenon contributes to increased energy consumption as residents rely on air conditioning to mitigate indoor heat stress, thereby raising electricity costs and exacerbating carbon emissions [27]. Additionally, higher temperatures in urban areas have been linked to increased health risks, including heat-related illnesses and cardiovascular complications, particularly among vulnerable populations such as the elderly and children [16].

Despite these significant environmental and health concerns, there is a lack of comprehensive studies that quantify the extent of LULC changes and their impact on LST and UHI in Benin City. Previous research has primarily focused on general urbanization trends without specifically examining the thermal implications of these transformations [21]. While some studies have assessed LULC changes using satellite imagery, many have relied on lower-resolution datasets, limiting the accuracy of spatial and temporal analyses [20]. Additionally, there is a gap in studies utilizing advanced remote sensing techniques such as Sentinel-2 for high-resolution LULC classification and Landsat 8 thermal infrared data for LST and UHI assessments.

Another critical issue is the absence of effective urban planning strategies to mitigate UHI effects and promote sustainable land management in Benin City. With projections indicating a further increase in built-up areas by 2050, it is crucial to implement policies that prioritize green infrastructure, urban afforestation, and climate-adaptive urban designs [23]. However, the lack of reliable data on UHI intensity and LST variations has hindered the development of evidence- based strategies for urban heat mitigation.

This study seeks to address these gaps by conducting a detailed spatio-temporal assessment of LULC, LST, and UHI dynamics in Benin City from 2017 to 2023 using Sentinel-2 and Landsat 8 data. By integrating high-resolution LULC classification and thermal infrared analysis, the research will provide a comprehensive understanding of how urban expansion influences surface temperatures and UHI effects. The findings will contribute to climate adaptation planning, sustainable urban development, and policy recommendations for mitigating urban heat stress in Benin City.

Aim

The primary aim of this study is to assess the temporal changes in land use and land cover (LULC), land surface temperature (LST), and urban heat island (UHI) intensity in Benin City, Edo State, Nigeria, between 2017 and 2023 using Sentinel-2 and Landsat 8 satellite data.

Objectives

- To classify and analyze LULC changes in Benin City between 2017 and 2023 using Sentinel-2 imagery.
- To evaluate variations in LST over the study period using Landsat 8 thermal infrared data.
- To assess the spatial extent and intensity of the UHI effect in Benin City between 2017 and 2023.
- To determine the relationship between LULC changes and LST variations.
- To identify key factors contributing to UHI formation and intensity in Benin City.

Justification of the Study

Urbanization is a major driver of environmental change, altering land use patterns, increasing impervious surfaces, and contributing to rising land surface temperatures. Benin City, like many rapidly expanding urban centers in Nigeria, has undergone significant LULC transformations in recent years. Despite these changes, there is limited research on how urban expansion has influenced temperature variations and the urban heat island (UHI) effect in the city. This study is necessary for several reasons.

First, it provides an empirical assessment of LULC changes using Sentinel-2 imagery, which offers high spatial resolution and frequent revisit times. Unlike older satellite datasets with lower resolution, Sentinel-2's capabilities allow for a more detailed classification of land cover types, improving accuracy in tracking urban expansion. Similarly, Landsat 8 thermal infrared data enable precise monitoring of land surface temperature (LST) variations, helping to establish clear trends in UHI intensity over time. The integration of these datasets enhances the reliability of the study's findings.

Second, the research addresses the environmental implications of increased urban temperatures. Elevated LST can negatively affect public health, increasing the risk of heat-related illnesses, cardiovascular diseases, and respiratory complications. It also influences energy consumption, as higher temperatures lead to greater reliance on cooling systems, thereby increasing electricity demand and costs for households and businesses. Identifying areas most affected by UHI can support the development of targeted interventions to mitigate these impacts.

Additionally, this study contributes to urban planning and policy-making. By analyzing spatial patterns of UHI, planners and policymakers can implement measures such as urban greening, reflective building materials, and improved ventilation corridors to reduce heat accumulation. Findings from this research can inform local government policies on sustainable land use, helping to balance urban expansion with environmental conservation efforts.

Finally, the study has broader significance for climate change adaptation. Urban heat islands exacerbate global warming effects by intensifying local temperature variations. Understanding how UHI trends have evolved in Benin City can provide insights into the broader climate resilience strategies needed for Nigerian cities facing similar challenges. This research offers a data-driven approach to addressing urban heat stress, contributing to both local and national efforts to build climate-resilient cities.

Scope of the Study

This study focuses on assessing land use and land cover (LULC) changes, land surface temperature (LST), and the urban heat island (UHI) effect in Benin City, Edo State, Nigeria, between 2017 and 2023. It employs remote sensing and GIS techniques, utilizing Sentinel-2 imagery for LULC classification and Landsat 8 thermal infrared data for LST and UHI analysis.

The study covers the entire metropolitan area of Benin City, capturing key urban districts and their surrounding environments. It examines changes in LULC categories such as built-up areas, vegetation, water bodies, and bare land to determine how urban expansion has influenced thermal variations. The temporal analysis focuses on 2017 and 2023 to assess recent trends in land cover transformation and temperature dynamics.

The research is limited to satellite-derived data and does not incorporate ground-based temperature measurements. The study also does not analyze indoor temperature variations or the effects of anthropogenic heat emissions from vehicles and industrial activities, as these factors fall outside the scope of remote sensing analysis.

While the primary focus is on Benin City, the findings may be applicable to other urban areas experiencing similar growth patterns and climatic conditions. The study aims to provide insights that can inform urban planning, environmental management, and climate adaptation strategies within Nigeria and beyond.

Methodology

Study Area Description (Benin City, Edo State)

Benin City, the capital of Edo State in southern Nigeria, is experiencing rapid urbanization, leading to significant land use and land cover (LULC) changes [21,30]. The city is geographically located between latitudes 6°19′N and 6°21′N and longitudes 5°36′E and 5°41′E, covering approximately 1,125 km² [30]. It has a tropical climate with distinct wet and dry seasons, annual rainfall between 1,500 mm and 2,000 mm, and temperatures ranging from 25°C to 29°C. The wet season is influenced by monsoon winds from the Atlantic Ocean, while the dry season is dominated by Harmattan winds from the Sahara Desert [21,30].

Urban expansion has led to extensive land conversion, with significant vegetation loss due to construction activities and deforestation. Between 1987 and 2019, built-up areas increased by 36 percent, while forest cover declined from 47 percent to 11 percent [20]. These land cover changes have contributed to rising land surface temperatures and the urban heat island (UHI) effect, where urbanized regions record higher temperatures than surrounding rural areas [20]. The reduction in green spaces has also increased flood risks, energy consumption for cooling, and air pollution levels [20].

Benin City is selected as the study area due to its rapid urban growth and associated environmental challenges [21,30]. As one of Nigeria's fastest-growing cities, it provides a relevant case for analyzing the impact of LULC changes on land surface temperature (LST) and UHI intensity.

Remote sensing and GIS techniques enable an in-depth assessment of urban climate dynamics, supporting evidence-based urban planning and environmental management strategies [20].

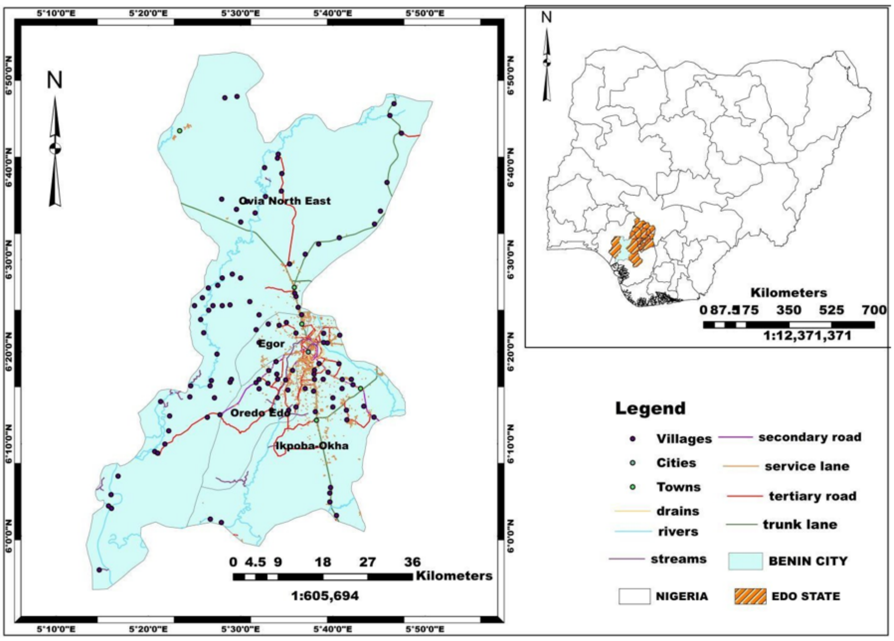

Figure 1: Map of Benin city, Edo state, Nigeria.

Research Design

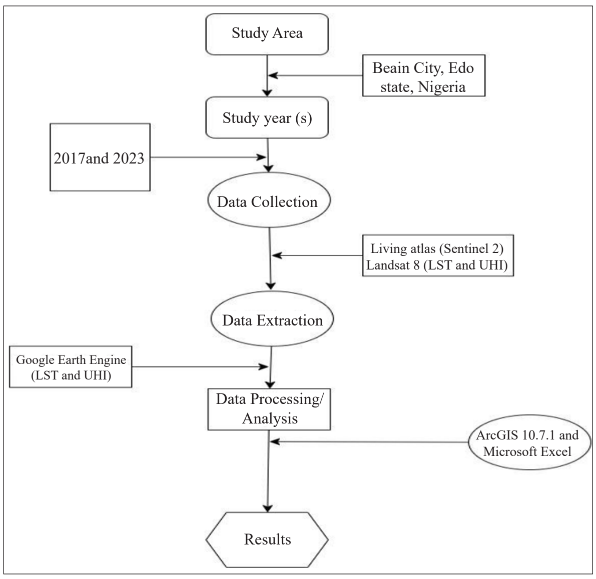

Figure 2: Research Design

This study follows a structured research design integrating remote sensing and GIS techniques to analyze LULC changes, LST variations, and UHI intensity in Benin City. The methodology ensures systematic data acquisition, processing, and analysis to derive reliable insights into environmental changes over time.

The study focuses on Benin City, a rapidly urbanizing region experiencing significant LULC changes. The analysis covers the years 2017 and 2023, selected to assess urban growth trends and their impact on temperature variations. These years provide a comparative basis for evaluating land cover transitions and heat intensity fluctuations.

Satellite data sources include Sentinel-2 imagery from ESRI for LULC classification and Landsat 8 thermal infrared data for LST and UHI assessment. Sentinel-2 provides 10-meter resolution multispectral imagery, making it ideal for differentiating built-up areas, vegetation, and water bodies. Landsat 8's Thermal Infrared Sensor (TIRS) captures surface radiation in Bands 10 and 11, which are essential for accurate land surface temperature retrieval using thermal infrared remote sensing techniques. The combination of these datasets offers a comprehensive approach to studying urban heat variations.

Google Earth Engine (GEE) is used for data extraction, providing a cloud-based environment for efficient processing of large remote sensing datasets. GEE facilitates image selection, atmospheric correction, and thermal band processing, ensuring accurate LST and UHI calculations. The cloud computing capabilities of GEE reduce processing time while enabling large-scale spatial analysis.

Data analysis is conducted using ArcMap 10.7.1 for LULC classification, spatial analysis, and urban heat mapping, while

Microsoft Excel is used for statistical analysis. Supervised classification is applied to Sentinel-2 imagery to accurately categorize land cover types. The processed LST and UHI datasets from GEE are imported into ArcMap for visualization, while Excel is used to compute percentage changes in land cover and analyze temperature trends.

This research design ensures a systematic and reproducible approach to assessing urban expansion, temperature variations, and UHI effects in Benin City. The integration of remote sensing, GIS, and statistical techniques enhances the accuracy of LULC classification and LST retrieval, providing meaningful interpretations of urban heat dynamics. The findings contribute to urban planning, climate adaptation strategies, and environmental sustainability policies aimed at mitigating the effects of rapid urbanization.

Data Type and Sources

This study relies on secondary data from remote sensing satellite imagery and meteorological records to evaluate LULC changes, LST variations, and UHI intensity in Benin City. The integration of high-resolution satellite imagery with climate data ensures accurate spatial and temporal analysis of environmental changes.

LULC classification is based on Sentinel-2 imagery, accessed from the Esri | Sentinel- 2 Land Cover Explorer. The dataset provides global land cover classifications derived from Sentinel-2 Level-2A imagery, processed at a 10-meter spatial resolution. The selection of Sentinel-2 is based on its high spatial resolution, frequent revisit time, and ability to differentiate built-up areas, vegetation, and water bodies. Sentinel-2 data is acquired in TIFF format, imported into ArcMap 10.7.1, and classified using supervised classification techniques.

LST and UHI assessments use Landsat 8 thermal infrared data, obtained from the United States Geological Survey (USGS) Earth Explorer. Landsat 8 features the Thermal Infrared Sensor (TIRS), which captures surface radiation in Bands 10 and 11, enabling temperature retrieval through the split-window algorithm. The dataset also includes the Operational Land Imager (OLI), which provides visible and near-infrared bands used for atmospheric corrections and land cover classification. The raw thermal data is converted into brightness temperature and further processed using emissivity adjustments to derive final land surface temperature values.

Data Collection and Preprocessing

The data collection and preprocessing phase ensures that acquired datasets are accurate and suitable for spatial analysis. The workflow for LULC classification begins with downloading Sentinel-2 imagery from Esri | Sentinel-2 Land Cover Explorer, importing the dataset into ArcMap 10.7.1, and applying radiometric and atmospheric corrections to enhance classification accuracy. Supervised classification is performed to categorize land cover types, and classification accuracy is validated using a confusion matrix.

LST retrieval is conducted using Landsat 8 thermal infrared data, processed in Google Earth Engine before further spatial analysis in ArcMap 10.7.1. The study area is defined in GEE, and Landsat 8 surface reflectance images are filtered by date range and cloud cover to ensure high-quality data. The thermal infrared bands are selected, brightness temperature is computed, and the split-window algorithm is applied to retrieve final land surface temperature values in degrees Celsius. The processed dataset is exported as a GeoTIFF file and imported into ArcMap for further analysis.

UHI analysis follows the same methodology as LST retrieval, as both rely on the same Landsat 8 thermal dataset. The processed thermal data is used to assess temperature variations across different land cover types. By overlaying LULC classification maps with temperature maps, the relationship between urbanization and rising land surface temperatures is analyzed. ArcMap is used to visualize the spatial distribution of urban heat intensity and identify areas most affected by temperature increases.

The integration of remote sensing and GIS-based methodologies ensures that the LULC, LST, and UHI datasets are accurate, reliable, and suitable for spatial interpretation. This structured workflow provides a robust foundation for evaluating the environmental impact of urban expansion in Benin City.

Software and Tools

The study utilizes multiple software tools for remote sensing analysis, GIS-based processing, and statistical evaluation. Google Earth Engine is the primary platform for retrieving and processing Landsat 8 thermal infrared imagery. It enables efficient large-scale data processing, including atmospheric corrections, brightness temperature conversion, and emissivity adjustments for accurate LST retrieval. The processed datasets are exported as GeoTIFF files for further analysis in ArcMap 10.7.1.

ArcMap 10.7.1 is used for land use classification, spatial analysis, and cartographic visualization. Sentinel-2 data is imported into ArcMap for supervised classification, while the processed land surface temperature dataset is analyzed to assess UHI intensity. The software's geospatial tools enable temperature extraction based on land cover type, allowing for a detailed examination of the relationship between urban expansion and rising temperatures.

Microsoft Excel is used for statistical analysis, including the computation of land cover change percentages and temperature variations. The combination of Google Earth Engine, ArcMap 10.7.1, and Microsoft Excel provides a structured and reliable framework for assessing land use changes, surface temperature dynamics, and UHI intensity in Benin City.

Results

Land Use/Land Cover Change in Benin City Between 2017 And 2023

Table 1: Table showing the land use/land cover change in Benin city between 2017 and 2023

LULC category	2017 (%)	2023 (%)	Change (%)
Water body	0.57	0.62	0.05
Trees	82.06	70.16	-11.9
Flooded vegetation	0.01	0.01	0
Crops	0.71	2.86	2.15
Built up area	9.49	15.29	5.8
Bare ground	0.20	0.01	-0.19
Rangeland	6.87	11.06	4.19

Table 1 provides an overview of land use and land cover (LULC) changes in Benin City between 2017 and 2023. The most notable change is the decline in tree cover, which dropped from 82.06% in 2017 to 70.16% in 2023, marking a significant 11.9% decrease. This reduction indicates widespread deforestation, primarily due to urban expansion and land conversion for agriculture. The decrease in tree cover is concerning as it contributes to environmental degradation, increased surface temperatures, and loss of biodiversity.

Trees play a crucial role in regulating local climates by providing shade and maintaining evapotranspiration, and their decline directly correlates with rising temperatures in urban areas [31-34].

Built-up areas expanded from 9.49% in 2017 to 15.29% in 2023, reflecting a 5.8% increase. This suggests rapid urbanization, where natural landscapes are being replaced by residential, commercial, and industrial developments. The increase in impervious surfaces such as concrete and asphalt contributes to the urban heat island (UHI) effect, as these materials absorb and retain more heat than vegetated areas [35,36]. The expansion of built-up areas also leads to increased surface runoff, reduced groundwater infiltration, and higher energy demands for cooling [35, 36].

Cropland increased from 0.71% in 2017 to 2.86% in 2023, a 2.15% rise. This suggests that more land has been converted for agricultural use, likely in response to population growth and food demand. However, this expansion often comes at the cost of deforestation, reducing the natural cooling effect provided by tree cover. Similarly, rangeland expanded from 6.87% to 11.06%, an increase of 4.19%, indicating further land conversion for livestock grazing or open fields. The impact of this change depends on land management practices—poorly managed rangeland can lead to soil erosion and desertification [37,38].

Water bodies increased slightly from 0.57% in 2017 to 0.62% in 2023, reflecting a 0.05% gain. This stability suggests that water bodies have not been significantly affected by urban expansion, although seasonal fluctuations and changes in hydrological systems could influence this in the future. Bare ground declined from 0.20% to 0.01%, a 0.19% reduction, suggesting that previously exposed land has either been developed into built-up areas or revegetated. Flooded vegetation remained unchanged at 0.01%, indicating stability in wetland areas.

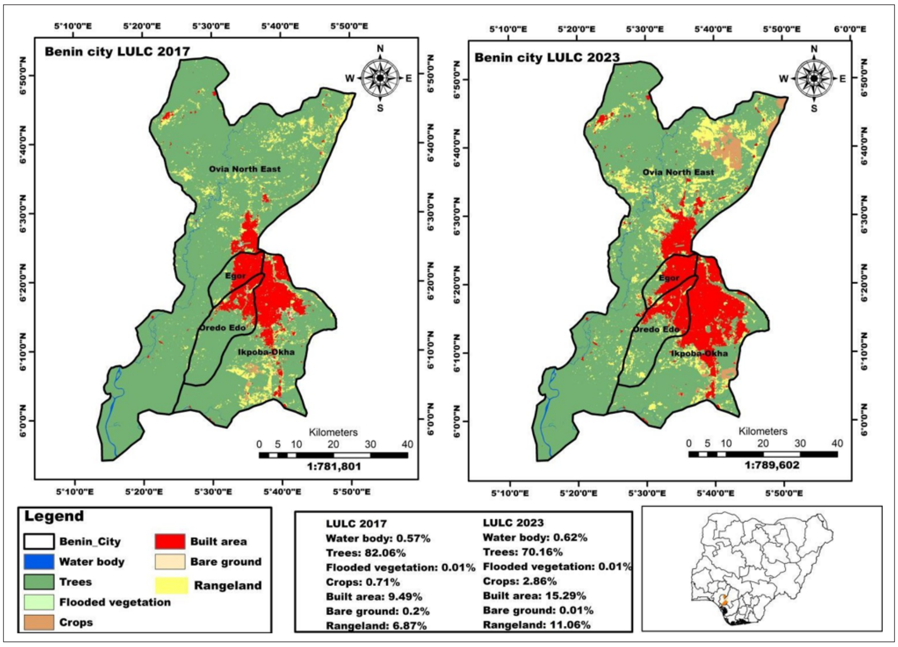

Figure 3: Map showing LULC of Benin city (2017 and 2023)

The map in Figure 3 provides a visual representation of these LULC changes. The spatial distribution highlights the expansion of built-up areas, the reduction in tree cover, and the increase in cropland and rangeland. Urban expansion is most evident in areas previously covered by vegetation, with significant land conversion in developing regions of the city.

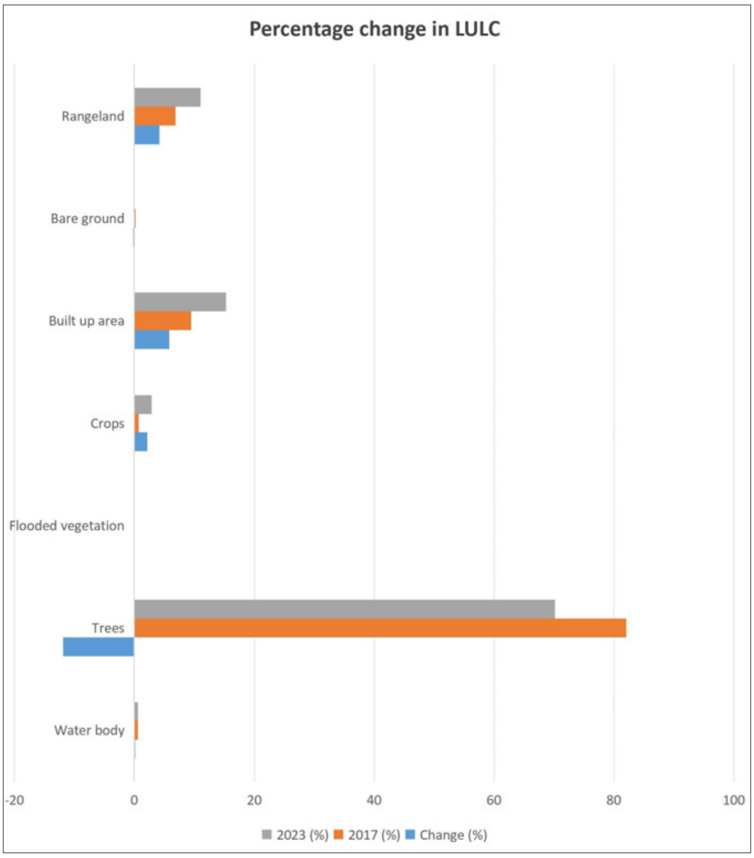

Figure 4: Bar chart showing the Percentage change in LULC in Benin city

Figure 4, a bar chart, illustrates the percentage change in LULC categories. The most significant changes are the decline in tree cover and the increase in built-up areas, emphasizing rapid urban growth and potential environmental implications, such as reduced carbon sequestration and increased surface runoff.

Land Surface Temperature Change Between 2017 And 2023

Table 2: Table showing the Land surface temperature change in Benin city between 2017 and 2023

LST Category (2017)	Area (sqkm)	Percentage (%)	LST Category (2023)	Area (sqkm)	Percentage (%)	Change (sqkm)	Change (%)
Low (<30)	1560.9400	30.65	Low (<30)	1794.66	35.24	233.78	4.59
Moderate (30 -35)			**Moderate (30 -35)**				
	2254.97	44.27		1942.47	38.16	311.2	-6.11
High (>35)	1277.09	25.08	**High (>35)**	1355.87	26.08	77.42	1.52

Table 2 outlines changes in land surface temperature (LST) across Benin City between 2017 and 2023. The low-temperature category (<30°C) increased from 1560.94 km² (30.65%) in 2017 to 1794.66 km² (35.24%) in 2023, representing a 233.78 km² (4.59%) increase. This suggests that some areas have retained cooling effects, likely due to vegetation cover or proximity to water bodies. The increase in low-temperature zones contrasts with the overall warming trend, indicating that afforestation efforts or natural vegetation regrowth may be influencing these areas.

Moderate-temperature zones (30-35°C) decreased from 2254.97 km² (44.27%) to 1942.47 km² (38.16%), reflecting a reduction of 311.2 km² (-6.11%). This decline suggests that previously moderate-temperature areas have either cooled due to vegetation retention or warmed into the high-temperature category due to urban expansion and deforestation.

High-temperature zones (>35°C) expanded from 1277.09 km² (25.08%) in 2017 to 1355.87 km² (26.08%) in 2023, marking an increase of 77.42 km² (1.52%). This confirms that extreme heat conditions have intensified, particularly in built-up areas where impervious surfaces absorb and retain more heat. The increase in high- temperature zones is directly linked to the rise in urban expansion and the reduction of vegetation.

The map in Figure 5 visually represents the distribution of temperature changes in Benin City between 2017 and 2023. Areas with increased built-up land show significant warming trends, while regions with retained vegetation or water bodies appear to have experienced slight cooling effects. The spatial pattern of LST changes highlights the influence of land cover modifications on temperature variations.

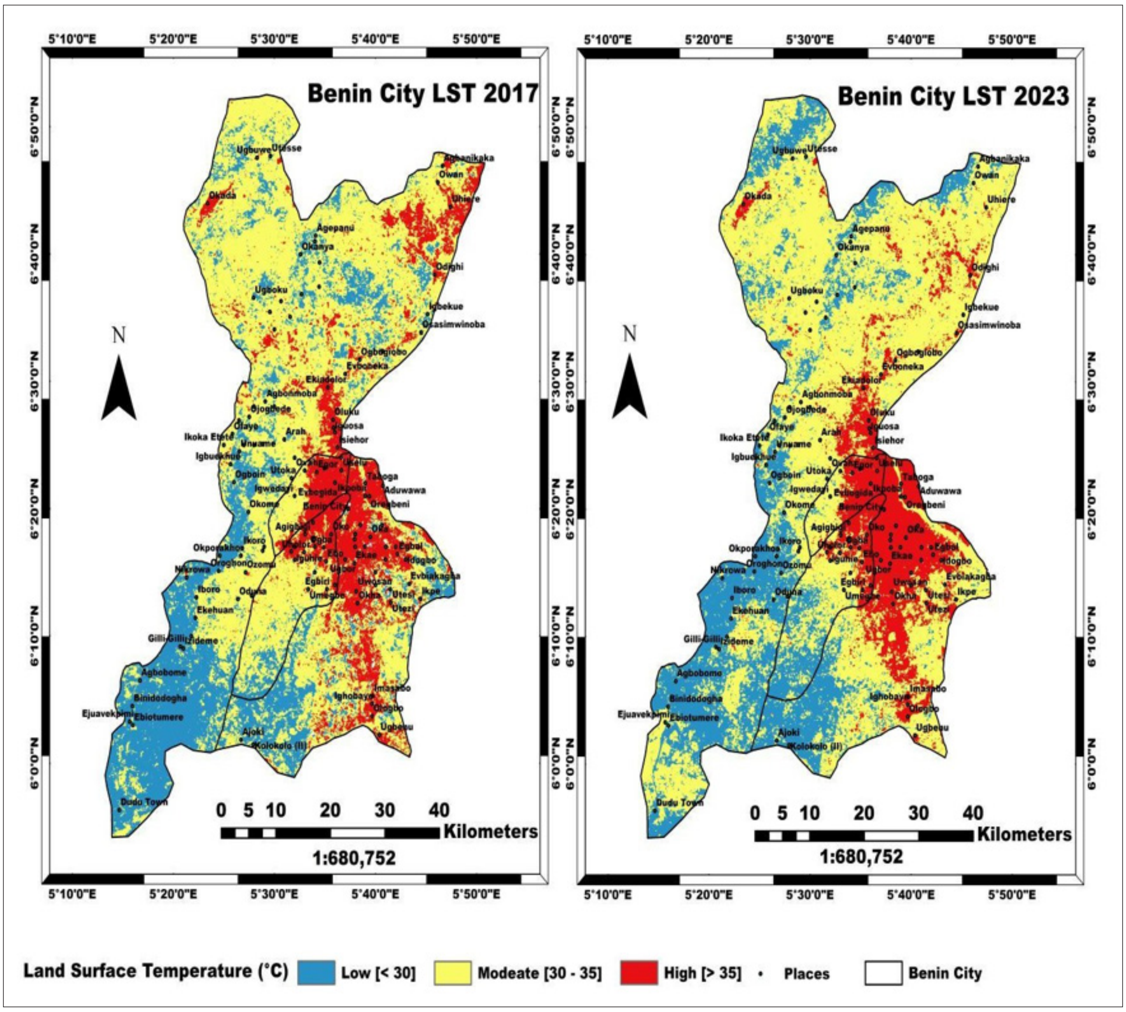

Figure 5: Map showing LST of Benin city (2017 and 2023)

Urban Heat Island Change Between 2017 And 2023

Table 3: Table showing the Urban heat island change in Benin city between 2017 and 2023

UHI Category (2017)	Area (sqkm)	Percentage (%)	UHI Category (2023)	Area (sqkm)	Percentage (%)	Change (sqkm)	Change (%)
Low (<- 0.45)	2473.53	48.54	Low (<- 0.45)	1123.65	22.06	1348.88	-26.48
Moderate (0.45 - 2.63)			**Moderate (0.45 - 2.63)**				
	1899.94	37.33		2643.06	51.89	741.67	14.56
High (>2.63)	719.53	14.12	**High (>2.63)**	1326.29	11.92	607.27	11.92

Table 3 presents changes in the urban heat island (UHI) effect in Benin City between 2017 and 2023. The low-UHI category (<-0.45) saw a significant reduction from 2473.53 km² (48.54%) in 2017 to 1123.65 km² (22.06%) in 2023, representing a 1348.88 km² (-26.48%) decrease. This decline suggests that many areas previously categorized as low-UHI zones have transitioned into moderate or high UHI zones due to urbanization. The loss of low-UHI areas highlights the diminishing presence of natural cooling mechanisms such as tree cover and open green spaces.

Moderate-UHI areas (0.45–2.63) expanded from 1899.94 km² (37.33%) to 2643.06 km² (51.89%), reflecting an increase of 741.67 km² (14.56%). This shift indicates that a significant portion of the city now experiences moderate heat accumulation, largely driven by urban expansion. The increase in moderate-UHI areas suggests that land use changes are influencing temperature distribution, affecting both residential and commercial zones.

High-UHI zones (>2.63) increased from 719.53 km² (14.12%) in 2017 to 1326.29 km² (11.92%) in 2023, representing a 607.27 km² (11.92%) rise. The spread of high-UHI zones confirms that extreme heat retention is becoming more pronounced in built-up regions. The presence of impervious surfaces, which absorb and store heat, is a key factor driving the expansion of high-UHI areas. This trend raises concerns about increased energy consumption for cooling, heat stress-related health risks, and the deterioration of air quality.

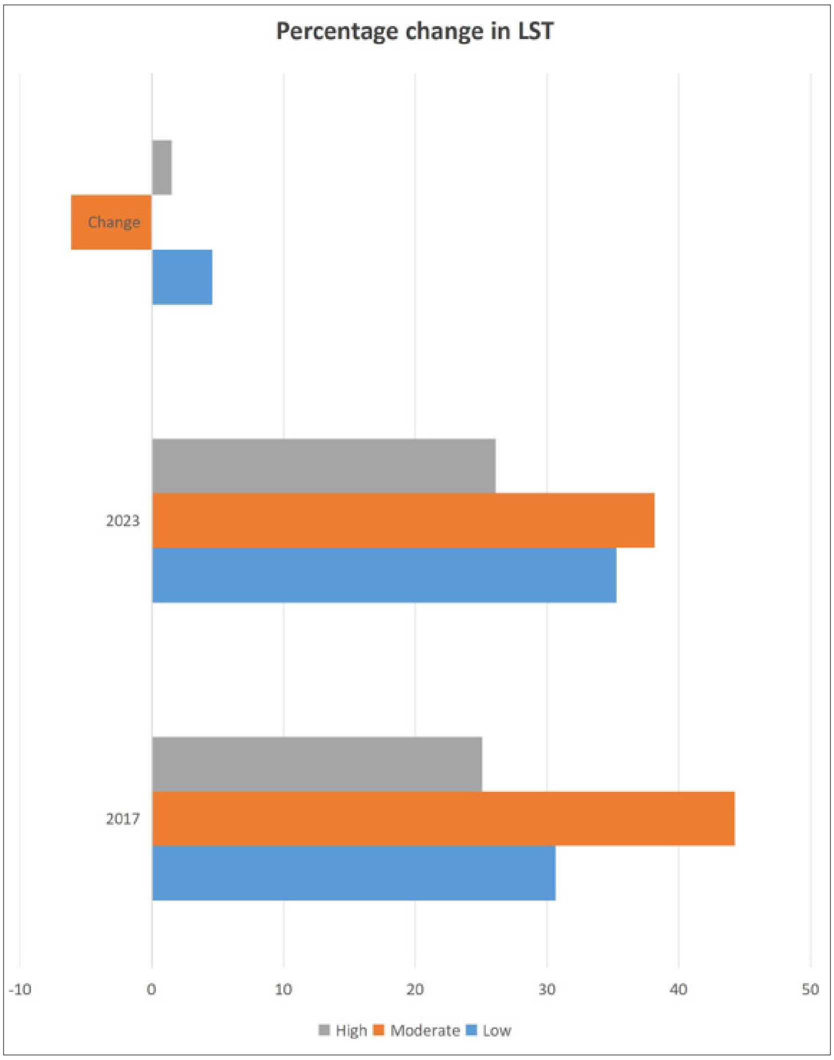

Figure 6: Bar chart showing the Percentage change in LST in Benin city

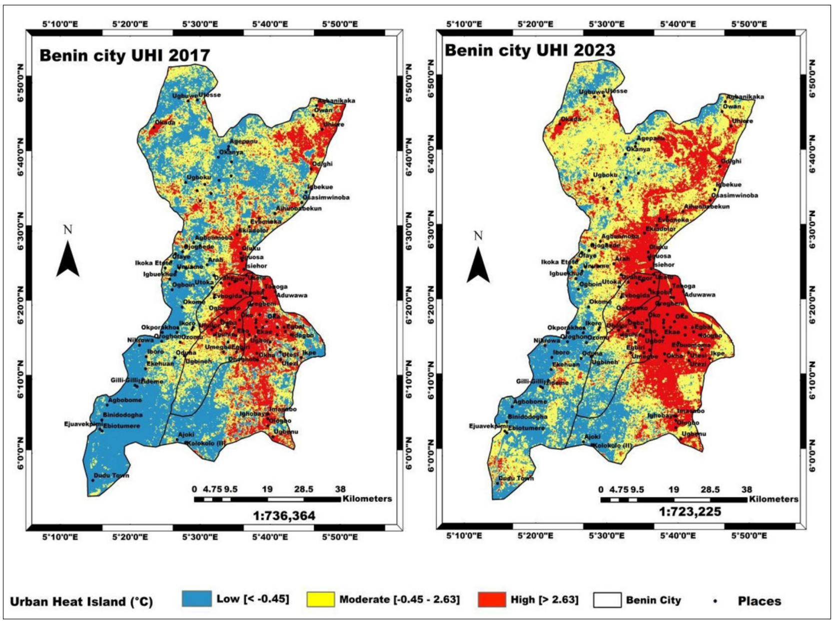

Figure 7: Map showing UHI of Benin city (2017 and 2023)

The map in Figure 7 provides a spatial representation of UHI intensity across Benin City. The map highlights the decline in low-UHI zones and the growth of moderate and high-UHI areas. Urban centers with high population density and infrastructure development correspond to areas experiencing the highest UHI intensities, confirming the link between land use changes and heat accumulation.

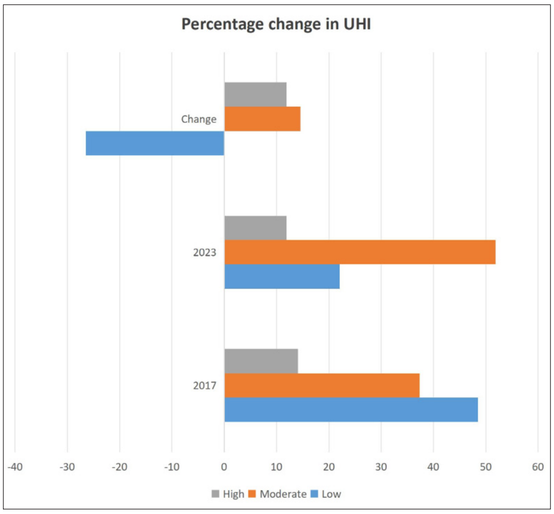

Figure 8: Bar chart showing the Percentage change in UHI in Benin city

Figure 8, a bar chart, summarizes the percentage change in UHI, showing the stark decline in cooler zones and the rise in moderate and high heat areas. This trend underscores the impact of urbanization on temperature increases, leading to potential environmental and health concerns.

Discussion

The findings of this study on land use and land cover (LULC) changes in Benin City between 2017 and 2023 reveal significant transformations in land categories, temperature variations, and urban heat island (UHI) intensity. These results align with broader trends of urban expansion, environmental degradation, and climate modification in southern Nigeria. The reduction in tree cover, expansion of built-up areas, changes in land surface temperature, and intensification of UHI effects provide insights into the ongoing environmental dynamics of Benin City. This chapter critically discusses the implications of these changes, contextualizing them within previous studies and providing a foundation for policy recommendations.

The reduction of tree cover by 11.9% between 2017 and 2023 signals increased deforestation in Benin City. This trend aligns with Fabolude and Aighewi (2022), who reported a 284.56 km² loss of forest cover in Benin City between 1987 and 2019, mainly due to urban expansion and land conversion for agriculture. The continuous decline in vegetation has significant ecological and climatic implications. Forests play a crucial role in carbon sequestration, mitigating the urban heat island effect, and sustaining biodiversity [39]. The decline in tree cover suggests that deforestation in Benin City is ongoing at an unsustainable rate, which could accelerate climate change impacts in the region. The study by Igben (2023) on LULC changes in southern Nigeria similarly observed a decline in forested areas due to logging, land clearing for settlements, and infrastructural development. In addition, Uchegbulam and Igben emphasized that deforestation in urban areas often leads to increased temperatures and land degradation, further exacerbating environmental vulnerabilities [40]. Urban expansion is evident in the increase in built-up areas from 9.49% in 2017 to 15.29% in 2023, representing a 5.8% rise. This result is consistent with previous research indicating that Benin City has experienced rapid urbanization over the past few decades [21]. The expansion of built-up areas can be attributed to population growth, economic activities, and infrastructure development. Fabolude and Aighewi projected that by 2050, built-up areas in Benin City could expand to 542.32 km² due to rapid urbanization, posing a challenge for sustainable land management [20]. The increase in urban development often results in the loss of green spaces, which exacerbates environmental issues such as flooding, reduced air quality, and heat stress [41]. The transformation of land from vegetated cover to built-up infrastructure also contributes to the intensification of the UHI effect, as impervious surfaces such as asphalt and concrete absorb and retain heat more than natural landscapes [42].

The increase in cropland from 0.71% in 2017 to 2.86% in 2023 suggests that more land is being converted for agricultural purposes. This trend aligns with findings by Igben, who observed a significant expansion of farmland in southern Nigeria due to rising food demand and economic incentives for agriculture [24]. While the increase in cropland may contribute to food security, it also raises concerns about deforestation, soil degradation, and biodiversity loss. Expanding agricultural land often involves clearing forests and grasslands, leading to habitat destruction and ecosystem disruption [43]. Studies by Dalil et al. and Patel et al. highlight that uncontrolled agricultural expansion can contribute to soil erosion, reduced water retention capacity, and increased greenhouse gas emissions [44,45]. The increase in rangeland from 6.87% in 2017 to 11.06% in 2023 further supports the argument that land is being increasingly converted for agricultural and grazing purposes.

Changes in land surface temperature (LST) between 2017 and 2023 indicate a notable increase in temperature extremes. The high-temperature category (>35°C) increased by 1.52%, while the moderate-temperature category (30–35°C) declined by 6.11%. These findings are consistent with Ogunjobi et al, who reported a strong correlation between urban expansion and rising temperatures in Nigerian cities [45]. The increase in high-temperature areas corresponds with the expansion of built-up surfaces, which absorb more solar radiation than vegetated areas. According to Fashae et al, urbanization in Nigeria has contributed to increased LST due to the replacement of natural surfaces with materials that have high thermal inertia [46]. This increase in surface temperature has several implications, including higher energy consumption for cooling, increased heat stress-related illnesses, and a decline in thermal comfort [47].

The urban heat island (UHI) effect analysis further supports the trend of rising temperatures in Benin City. The low UHI category (<-0.45) saw a significant reduction from 48.54% in 2017 to 22.06% in 2023, representing a 26.48% decrease in cooler areas. Conversely, the moderate UHI category (0.45–2.63) increased from 37.33% to 51.89%, while the high UHI category (>2.63) increased by 11.92%. These findings align with studies by Koko et al. and Olayiwola and Igbavboa, which demonstrated that urbanization in Benin City has led to increased heat retention, reducing the extent of cooler areas [48,21]. The intensification of the UHI effect has several consequences, including increased nighttime temperatures, greater energy demand for cooling, and higher incidences of heat-related mortality [49]. Additionally, elevated temperatures can contribute to the deterioration of urban air quality by increasing the formation of ground-level ozone and other pollutants [50].

The slight increase in water bodies by 0.05% and the reduction in bare ground from 0.20% to 0.01% suggest localized environmental changes. The minor expansion of water bodies may be due to increased rainfall, dredging activities, or flood-induced expansions, as observed by Igben in his study on the Niger Delta [24]. The decline in bare ground may indicate land stabilization through vegetation regrowth or conversion into built-up areas. This contrasts with Uchegbulam and Igben, who found that in some areas of southern Nigeria, bare land has increased due to erosion and sand mining [51-54].

Recommendations

Based on these findings, it is clear that Benin City is undergoing rapid urbanization, with significant environmental implications. The expansion of built-up areas, rising temperatures, and intensification of UHI effects highlight the need for sustainable urban planning and environmental management strategies. Addressing these challenges requires a multi-faceted approach that incorporates afforestation programs, improved land use planning, heat mitigation strategies, water management initiatives, sustainable agricultural practices, and public awareness campaigns.

Afforestation and reforestation programs should be implemented to mitigate the effects of deforestation. Large-scale tree-planting initiatives can help restore lost vegetation and improve urban cooling by increasing tree canopy coverage. Integrating green spaces into urban planning can enhance biodiversity, reduce heat retention, and improve air quality. Sustainable urban planning should include stricter zoning regulations to control uncontrolled urban expansion. Urban designs should prioritize green infrastructure, including parks, rooftop gardens, and urban forests, to counteract the loss of vegetation.

Heat mitigation strategies such as the promotion of cool roofing materials, reflective pavements, and increased use of vegetative shading should be adopted to reduce LST and UHI intensity. Investing in climate-resilient infrastructure can help cities adapt to rising temperatures. Water management and flood control measures should be strengthened to address the challenges posed by changing water bodies. Improving drainage systems and regulating dredging activities can prevent flooding and environmental degradation.

Sustainable agricultural land management practices should be promoted to balance food production with environmental conservation. Techniques such as agroforestry and conservation agriculture can help minimize land degradation while ensuring food security. Public awareness campaigns and policy enforcement should be enhanced to educate communities about sustainable land use practices and the importance of environmental conservation. Enforcing laws against illegal deforestation, land degradation, and environmental pollution is crucial for sustainable development.

Continuous research and monitoring of LULC, LST, and UHI dynamics using remote sensing and GIS technologies should be prioritized to track environmental changes and inform policy decisions. Future studies should focus on long-term projections of urban expansion and climate change impacts to develop more effective mitigation strategies.

Conclusion

Urban expansion in Benin City between 2017 and 2023 has reshaped its landscape, increased built-up areas while reduced vegetation. Rising land surface temperatures and worsening urban heat island effects highlight the environmental cost of rapid development. If these trends continue unchecked, the city will face higher heat stress, increased energy demand, and worsening air quality. Reclaiming green spaces, enforcing better urban planning, and integrating cooling strategies like tree planting and reflective surfaces will help counteract these effects. Long-term sustainability depends on proactive land management and continuous monitoring to ensure urban growth does not come at the cost of environmental health.

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