# URBAN HEAT ISLAND IN ACCRA,GHANA


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**ABSTRACT**

This report presents the final project undertaken during my internship at the Geomatic Unit of the Ghana National Petroleum Corporation (GNPC). The project focused on analyzing the Urban Heat Island (UHI) effect in Accra, Ghana. The study used remote sensing techniques and GIS tools to investigate land surface temperature (LST) variations and vegetation cover in relation to urbanization patterns. Using Landsat 8 satellite imagery, I calculated Normalized Difference Vegetation Index (NDVI) and derived LST to detect spatial UHI patterns. The outcome revealed significant temperature disparities between highly urbanized and vegetated zones. The project serves as a decision-support resource for urban planners, highlighting zones with potential heat stress and recommending green infrastructure strategies.

The Greater Accra region is the most urbanized region in Ghana. Over the last decade, the region has undergone rapid population shift and urban sprawl. This has modified the natural environment of the area and led to the formation and warming of Urban Heat Island (UHI). Previous studies have not established enough evidence on the existence of UHI phenomenon in the region. For this reason, this study examined the existence, magnitude, and spatial extent of UHI warming as well as its effect on temperature extremes in the region. The study used Landsat satellite imagery captured in 1991, 2002 and 2017, and in-situ daily minimum and maximum temperature data spanning the period 1980 to 2017. The satellite images were processed and analyzed using an integrated Geographic Information System (GIS) and remote sensing technique while extreme temperature indices were assessed with the ClimPACT2 software. The study found that UHI existed in the region with an increasing spatial coverage and a magnitude of about 4.07°C, 5.79°C, and 4.86°C in 1991, 2002, and 2017 respectively. The built-up and bare land areas experienced the strongest effect of UHI warming. In addition, enhanced UHI warming effect caused an increase in the frequency and intensity of warm temperature extremes in the region. A faster increase in night time temperatures than day time resulted in a decrease in diurnal temperature range of the region. Considering the high rate of warming amidst rapid urban expansion, more warming is expected in the region. This is expected to exacerbate climate extreme events and weather-related health issues. It is also expected to increase energy consumption, air pollution and human discomfort.

## INTRODUCTION AND BACKGROUND

The Urban Heat Island (UHI) effect is a well-documented environmental phenomenon in which urban areas record significantly higher surface and air temperatures than their surrounding rural regions. This is primarily due to anthropogenic activities, dense infrastructure, and minimal vegetation. Urban heat intensification affects thermal comfort, energy demand, air quality, and public health. In Ghana, particularly in Accra, the UHI effect has been exacerbated by rapid population growth and unplanned urban sprawl.

Over the past years, many areas in Ghana have undergone population shifts from rural to urban. Between 1931 and 2010 for instance, the population of urban areas has grown from 9.4% to about 50.9%. The urban growth is accompanied by uncontrolled Land Use and Land Cover Change (LULCC) for developmental activities such as industrialization, construction of roads and buildings with high thermal capacity materials creating impervious surfaces. These activities modify the natural environment which in turn alters the Surface Energy Budget (SEB) and gives way to the formation of Urban Heat Island (UHI). The UHI phenomenon is where an urban area is significantly warmer than its surrounding peri-urban and rural areas. The existence of UHI can elevate both air and land surface temperatures (LST) and adversely impact the micro-climate and energy consumption of urban areas. It can also intensify the concentration of air pollutants and greenhouse gases in urban areas, as well as affect human health and comfortability.

Greater Accra is the most urbanized region in Ghana. Urbanization in the area has increased from 72.6% in 1960 to 90.5% in 2010. According to the Ghana Statistical Service, construction materials used in Greater Accra as at 2010 for outer walls were mostly made of 83.6% of cement and concrete, while wood contributed about 10.5%. About 80.3% of floors were made up of cement and concrete. Metal sheets for roofing accounted for about 48.6%, while slate and asbestos contributed 43.5%. These materials are impervious and have high heat capacity, which affects the region’s local climate and natural environment. For instance, Wemegah analyzed the diurnal temperature variations in urban and peri-urban areas in the coastal zone of Ghana and found that the urban areas (Accra and Tema) were significantly warmer than peri-urban areas (Akatsi and Saltpond) at night time. Thus, the increase in impervious materials in the urban areas elevates UHI warming and influences climate extreme events such as enhanced convective rainfall and heatwaves in the region. This can result in the intensification of life-threatening weather-related risks such as heat-droughts, flash floods, and lightning and thunderstorms in the area.

Previous studies characterizing the existence, magnitude, and spatial extent of UHI warming in the Greater Accra region are limited. Mensah examined land cover, land surface temperature, and Urban Heat Island effects in the city of Accra but the work covered a short period of 12 years (2005–2017) and lacked details on the magnitude, intensity, and spatial extent of UHI in the city. Manu et al. also explored whether the rise in temperature over Accra was as a result of global warming or urbanization. However, this study did not include land use or land cover classification and was silent on UHI magnitude and spatial coverage. In other parts of Ghana, earlier studies have reported on the UHI phenomenon but did not establish enough evidence on the existence, magnitudes, and spatial coverage of UHI.

In this study, a comprehensive assessment of UHI warming in the Greater Accra region is carried out. The study classified land cover changes and determined urban growth. It then mapped out UHI zones and determined their intensity and spatial extent. Using the Urban Thermal Field Variance Index (UTFVI), the impact of UHI on urban life was examined. The study also analyzed how temperature extremes and urbanization influenced UHI warming in the region. The outcome of this study will provide information to support policy development in the region. It will also improve our understanding of UHI's effect on human life and comfort, and offer ways to mitigate its warming effects.

## Brief Literature Review

Wemegah et al. (2020) demonstrated that land surface temperature in the Greater Accra region has increased in parallel with urbanization, where some built-up areas experience surface temperatures up to 4.86°C higher than neighbouring vegetated regions. Other studies support the correlation between vegetation loss and increased LST, emphasizing the importance of urban green infrastructure to reduce UHI intensity. Remote sensing and GIS techniques are widely adopted tools in urban climate studies, offering reliable insights for UHI detection and mitigation.

## Aims and Objectives

- To examine the spatial distribution of UHI in Accra using satellite-derived temperature data.
- To compute NDVI and LST from Landsat 8 imagery to analyze urban surface conditions.
- To identify and map temperature hotspots across the city.
- To recommend strategies for UHI mitigation through urban greening and zoning.
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## Relevance of the Project

As climate-related heat stress becomes more prevalent, understanding spatial heat distribution in urban centers is vital for sustainable development. This project provides geospatial evidence to support climate-adaptive urban planning in Accra and similar cities in sub-Saharan Africa.

## METHODS AND MATERIALS

### Project Area Description

This study was performed over the Greater Accra region of Ghana, with focus on the city of Accra and Tema. The region was chosen mainly because it is the most populated, industrialized, and commercial region in Ghana. The Greater Accra region is located within the geographical boundaries of latitudes 5.5500° to 5.9167°N and longitude 0.2500° to 0.4167°W in the coastal zone of Ghana. It is bounded by the Gulf of Guinea and the Atlantic Ocean to the South and irregular hills of about 20 m above sea level to the North. The landscape slopes towards the Atlantic Ocean and the entire drainage system flows into the sea in the South. The study area has a tropical monsoonal climate with rainfall mainly associated with mesoscale convective systems and controlled by advection of moisture from the Gulf of Guinea. The seasonal rainfall pattern in the area is bi-modal with a major wet season from March to July and a minor wet season from September to November and a mean annual rainfall of the coastal zone varying between 740 mm and 890 mm. February and March are the hottest months with average temperature range of about 24°C – 33°C while June to September is the coolest with an average temperature range of about 22°C – 29°C.

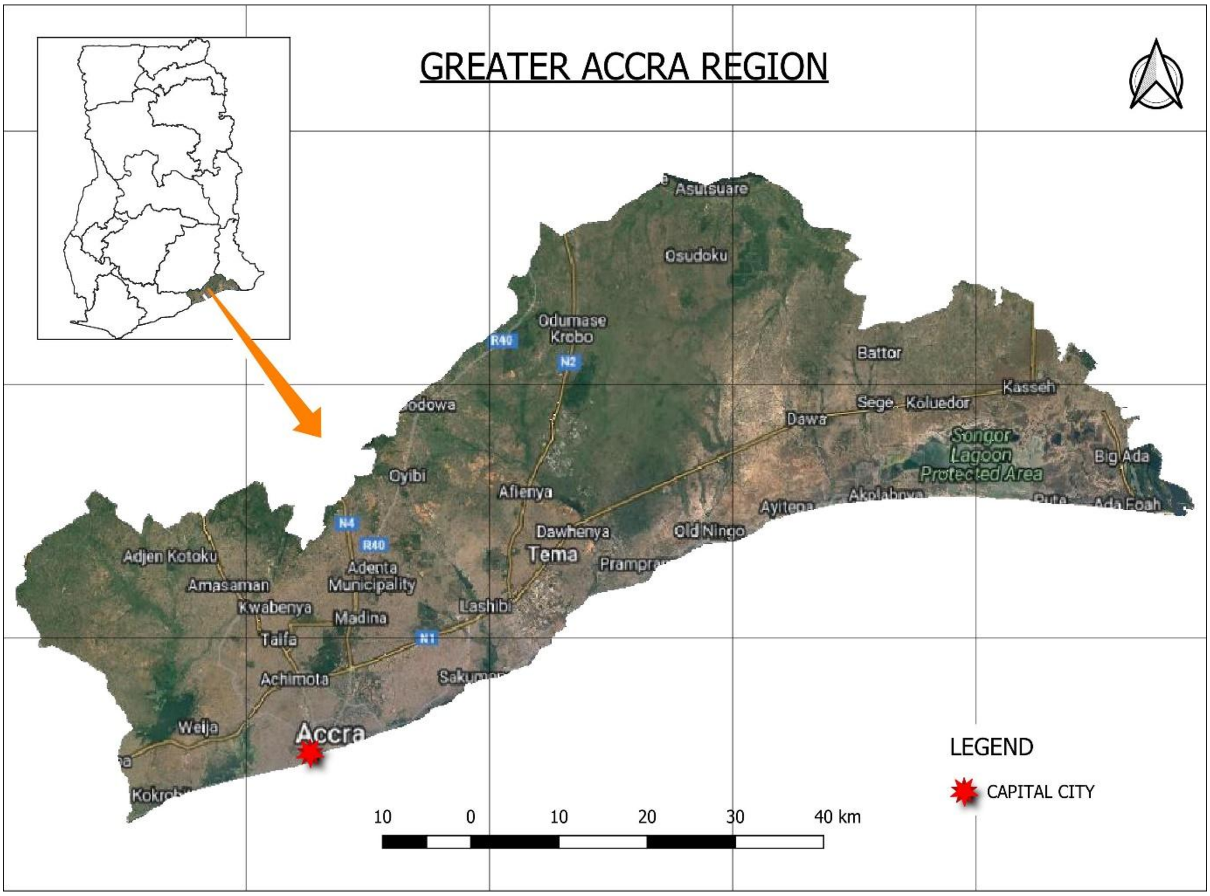


*Fig 1: A picture showing the study area( Greater Accra )*

**Data Used and Sources**

| DATA TYPE | DESCRIPTION | SOURCE |
|---|---|---|
| Landsat 8 OLI/TIRS | Multispectral and Thermal Bands (Bands 4,5,10) | USGS EarthExplorer |
| Administrative Boundaries | Accra municipal shapefile | DIVA-GIS |
| Land Use Land Cover Maps | Raster classifications for validation | Copernicus Global Land Service |
| Population Density (Optional) | Human exposure reference data | WorldPop Project |

**Methodology Overview**

1. **Data Acquisition and Preprocessing:** Landsat 8 data was downloaded for a cloud-free period. The satellite imagery was clipped to the Accra administrative boundary. Radiometric and atmospheric corrections were applied. Cloud masking was performed using the quality assessment band.

2. **NDVI Calculation:** The Normalized Difference Vegetation Index (NDVI) was computed using Bands 5 (NIR) and 4 (Red): NDVI = $\frac{\mathrm{NIR-Red}}{NIR+Red}$ This index provided a measure of vegetation cover across the study area.

3. **Land Surface Temperature (LST) Estimation** :LST was derived from Band 10 (thermal infrared) using the following steps:
    - Conversion of Digital Number (DN) to TOA Radiance.
    - Conversion of TOA Radiance to Brightness Temperature.
    - Estimation of Land Surface Emissivity (LSE) using NDVI thresholds.
    - Final LST calculation using the radiative transfer equation.

4. **Classification and Mapping** :The LST raster was classified into five thermal zones to identify UHI hotspots. NDVI was also classified into vegetation density categories. Overlay analysis was done to compare vegetation and temperature patterns.

5. **Urban Thermal Field Variance Index (UTFVI)** UTFVI was calculated to assess the ecological impact of UHI. The index integrates both temperature and vegetation data to evaluate thermal comfort levels in the urban environment.

6. **Visualization and Interpretation** :All maps were produced in ArcGIS Pro. Legends, scale bars, and metadata were added to all outputs. Results were interpreted based on spatial correlations and urban patterns.

## RESULTS

### Land Cover Change and Urban Growth

The results of the land cover classification showed extensive urban growth and decline in vegetation cover in the Greater Accra region from 1991 to 2017. The land cover map clearly illustrates the transformation that has occurred over this period, with vegetation and open land being replaced by urban developments and infrastructure. Built-up areas expanded considerably, especially in the urban cores of Accra and Tema, where rapid population growth and industrial development are concentrated.

In 1991, vegetation accounted for approximately 59.0% of the region's surface. This reduced to 54% by 2002, representing a 4.19% decline in green cover. Concurrently, built-up areas increased from 13.6% to 19.4%, reflecting a 5.80% rise in urban development. Bare soils showed a slight reduction from 6.3% to 4.8%. By 2017, the changes were more dramatic: built-up areas had expanded to 31.6%, while vegetation had declined to 24.2%, indicating a loss of over 30% of the region's vegetated land cover. These results are visually represented in the land cover change map.

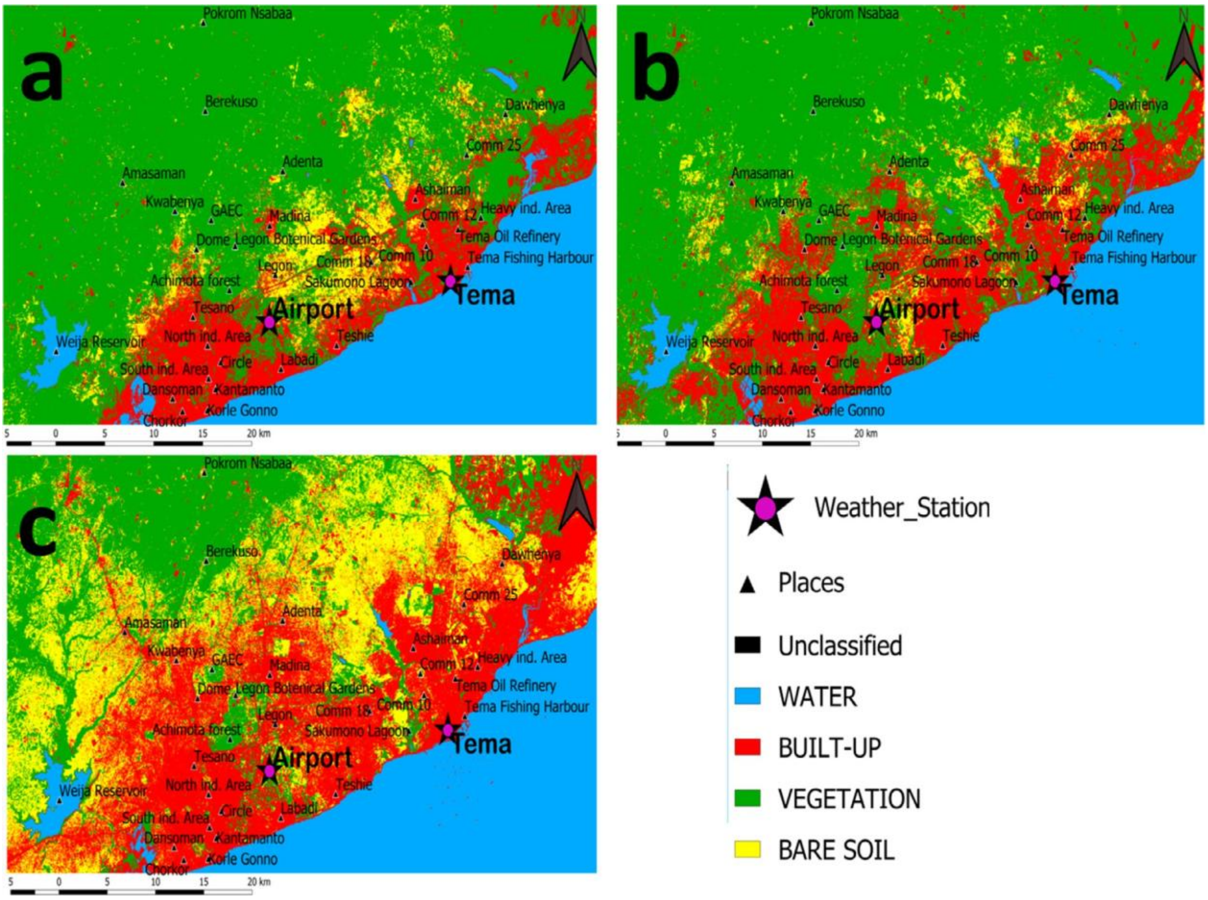


*Figure 1: Land cover classification map of Greater Accra showing spatial changes in vegetation, built-up, and bare soil areas between 1991 and 2017.*

## Land Surface Temperature (LST) and Urban Heat Island (UHI)

The spatial distribution of Land Surface Temperature (LST) for the years 1991, 2002, and 2017 reveals significant increases in surface temperature over time. The LST maps demonstrate that areas with extensive urban development—particularly those with concrete, asphalt, and other impervious surfaces—consistently exhibited higher temperatures compared to vegetated or water-covered zones.

The average LST was generally higher in 2002 than in 1991 or 2017. Built-up and bare soil areas recorded the highest LST values, confirming the strong influence of urbanization on heat concentration. Conversely, LST over water bodies remained largely unchanged during the study period. These observations clearly indicate the intensification of the Urban Heat Island (UHI) effect, where urban zones become significantly warmer than their rural surroundings.

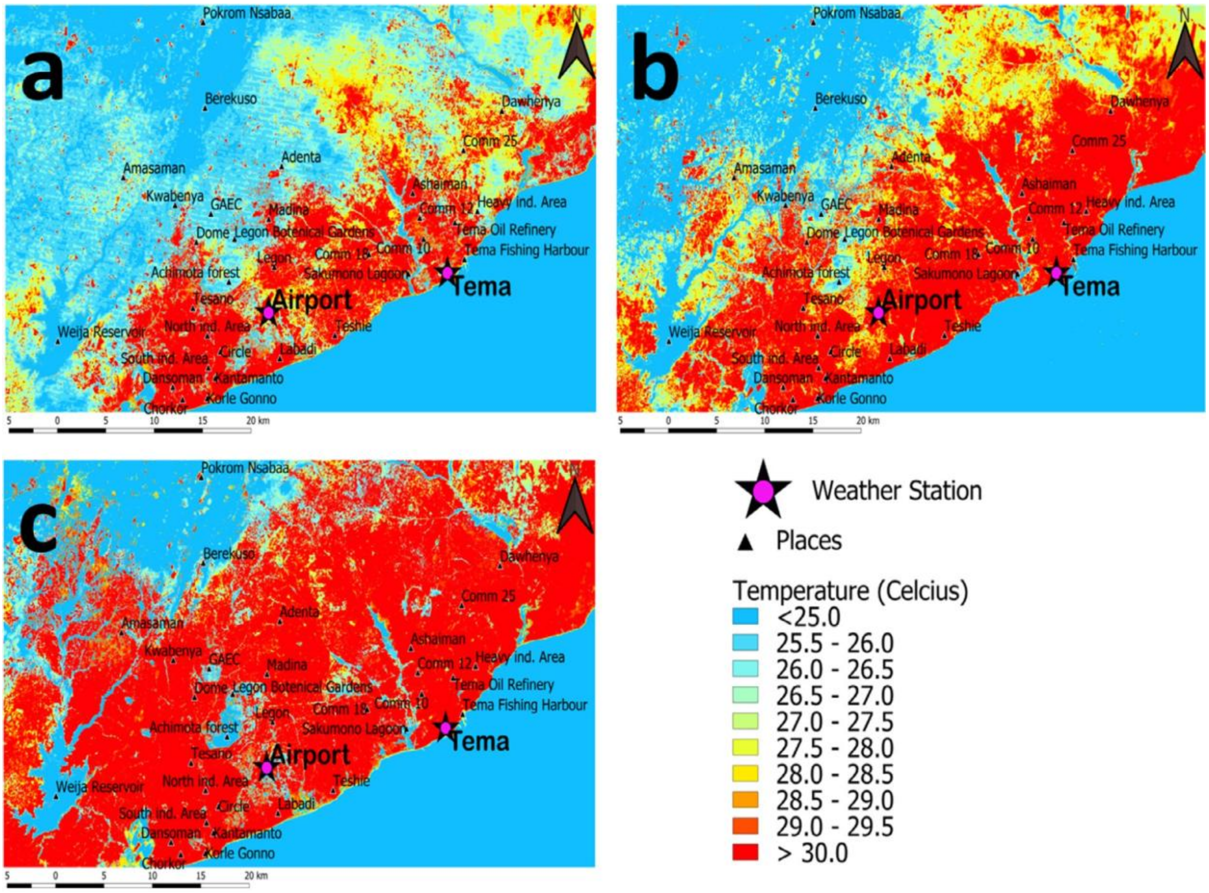


*Figure 2: Land Surface Temperature (LST) map showing spatial variation and UHI intensity across Greater Accra for the years 1991, 2002, and 2017.*

**Urban Thermal Field Variance Index (UTFVI)**

The UTFVI map provided additional insight into the environmental impact of increased surface temperatures across Greater Accra. Areas identified as having high UTFVI values corresponded with regions of high LST and low vegetation index, mainly within the urbanized parts of the region. These areas are characterized by ecological stress and thermal discomfort, making them hotspots of potential health and environmental risks.

The UTFVI results also support the observed land cover transitions, emphasizing the loss of ecological quality in rapidly urbanizing zones. These findings underscore the urgent need for climate-resilient urban planning strategies that prioritize vegetation preservation and green infrastructure development.

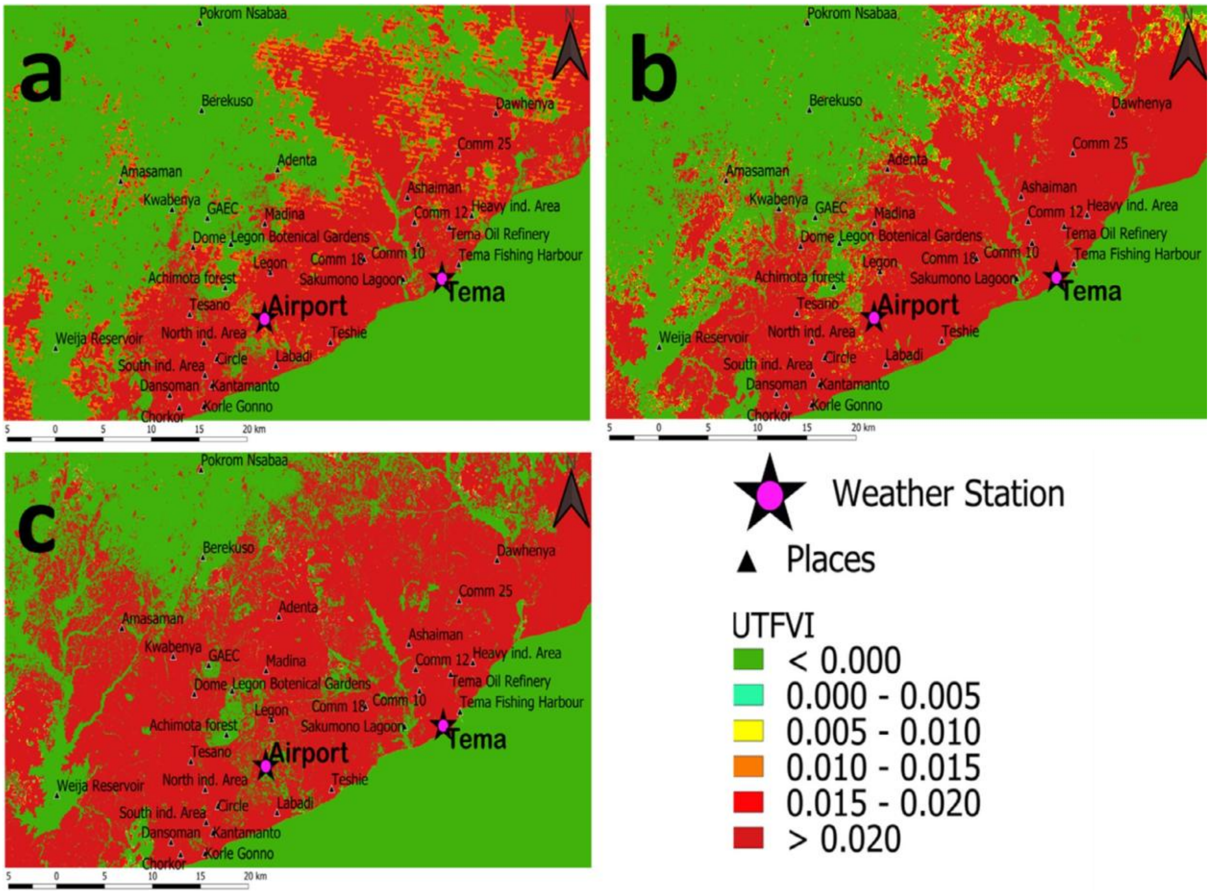


*Figure 3: Urban Thermal Field Variance Index (UTFVI) map indicating ecological stress zones and levels of thermal discomfort in Greater Accra.*

## DISCUSSION

The comprehensive assessment of the Urban Heat Island (UHI) phenomenon in the Greater Accra region revealed a strong relationship between urbanization, land cover changes, and surface temperature dynamics. The integration of meteorological data and remote sensing techniques provided a multi-dimensional understanding of how rapid urban development has influenced regional microclimates.

Using Landsat satellite imagery from the U.S. Geological Survey (USGS) and observed temperature data from the Ghana Meteorological Agency (GMet), the study analyzed land surface temperatures (LST), vegetation indices, and temperature extremes across the Greater Accra region. These datasets were processed using GIS-based spatial analysis and the ClimPACT2 software to investigate the spatial and temporal evolution of UHI intensity, its ecological impact, and implications for human health and urban planning.

Between 1991 and 2017, built-up areas increased significantly while vegetative cover declined across the region. In 1991, urban development was mostly concentrated around central business districts such as North and South Industrial Areas, Kantamanto, Kaneshie, Tema Port, Tema Heavy Industrial Area, and the Fishing Harbour. By 2017, these urban centers had expanded significantly, and formerly vegetated lands had been transformed into impervious surfaces like roads, buildings, and bare soil.

The LST analysis confirmed that temperatures were consistently higher over built-up and bare soil areas than over vegetated regions and water bodies. The cooling effects from vegetation—through shading, evaporation, and evapotranspiration—helped to reduce localized temperatures. In contrast, impervious surfaces contributed to the absorption and re-radiation of heat, intensifying the UHI effect.

A notable observation is that in 2002, urbanization was more compact and concentrated in the southern sector of the region due to urban conurbation. However, by 2017, urban growth exhibited characteristics of urban agglomeration, leading to a more spread-out development pattern. This shift in urban morphology had direct implications on the intensity and spatial coverage of UHI. More compact urban zones had higher UHI intensity due to greater heat accumulation and reduced airflow, while dispersed developments allowed for more natural cooling and reduced heat build-up.

The study also employed the Urban Thermal Field Variance Index (UTFVI) to assess ecological stress due to elevated temperatures. The UTFVI maps indicated that built-up and bare land areas exhibited the worst thermal comfort and highest ecological stress levels. This aligns with previous studies that have demonstrated similar patterns in rapidly urbanizing regions.

Warming trends in minimum and maximum daily temperatures were evident in both Accra and Tema. The increase in temperature extremes, particularly nighttime warming, was more pronounced in Accra than Tema. This pattern is indicative of intensified nocturnal UHI effects in Accra, largely due to the city's faster urban expansion and reduced vegetative cover. Interestingly, although Accra warmed faster overall, nighttime temperatures in Tema were slightly higher, likely due to the location of the synoptic station in a densely built-up area. Daytime temperatures were generally higher in Accra, possibly due to limited sea breeze and reduced surface evaporation.

The study found that the diurnal temperature range (DTR) had declined in both cities, reflecting a greater rise in nighttime temperatures compared to daytime. This trend suggests the increasing dominance of anthropogenic heat sources and the inability of the urban environment to cool down effectively at night. The observed trends in temperature extremes support global research findings and highlight the impact of land use changes and urban morphology on urban climate dynamics.

An evaluation of the urbanization effect (UE) on climate indices showed that indices related to minimum temperatures (e.g., TNm, TNx) were more strongly influenced in Accra, pointing to intensified nocturnal heat stress. Conversely, indices related to maximum temperatures (e.g., TX10p) showed a stronger influence in Tema, suggesting more severe daytime heat stress.

The findings underscore the importance of urban planning strategies that integrate climate adaptation and mitigation. With UHI intensity reaching approximately 4.86°C and spatial coverage nearing 50%, the ecological and public health implications of this warming trend are significant. Policy actions should prioritize the expansion of green spaces, enforce zoning regulations, and promote building designs that reduce heat absorption.

**Limitations of the Study:**

- Satellite data are subject to atmospheric disturbances and may introduce errors in surface temperature estimation.
- The temporal resolution of Landsat imagery limited the frequency of analysis; more granular temporal data could enhance trend detection.
- Emissivity estimates were based on generalized NDVI thresholds, which may not fully capture local surface material variations.

Despite these constraints, the methodologies employed are scientifically robust and suitable for long-term urban heat monitoring and planning.

## CONCLUSION AND RECOMMENDATIONS

This study conducted a multi-temporal analysis of Urban Heat Island (UHI) warming in the Greater Accra region using meteorological data and remote sensing techniques. Landsat satellite imagery from 1991, 2002, and 2017 combined with daily temperature data from GMet provided comprehensive insight into the dynamics of land cover change, LST variations, UHI intensity, UTFVI, and extreme temperature trends. The results confirmed a significant increase in built-up areas accompanied by a sharp decline in vegetative cover, leading to enhanced UHI effects.

The analysis affirms that UHI currently has an intensity of approximately 4.86°C and affects over 50% of the region. Ecological stress is highest in impervious surface zones, while vegetation and water bodies continue to serve as thermal buffers. UHI warming has led to more frequent and intense warm temperature extremes, a faster rise in nighttime temperatures compared to daytime, and a reduced diurnal temperature range. These conditions are likely to worsen with continued urban expansion, contributing to elevated greenhouse gas emissions, increased air pollution, energy consumption, and adverse public health outcomes.

In addition to reaffirming the presence and escalation of UHI in Accra and Tema, the study showed that compact urban growth led to higher UHI intensity, while urban agglomeration resulted in wider but less intense warming. These insights are critical for shaping sustainable urban development strategies.

**Recommendations:**

- Promote urban greening through the development of parks, green belts, and vegetative roofs.
- Adopt green, reflective, and permeable construction materials to reduce heat retention.
- Strengthen land use regulations to limit unplanned settlements and preserve natural landscapes.
- Relocate or modify the placement of meteorological stations for more accurate climate readings.
- Educate the public and policymakers on UHI mitigation techniques and sustainable practices.
- Expand research into the socio-economic impacts of UHI and incorporate them into climate adaptation plans.

Continued monitoring and evaluation are essential to managing the urban heat risks and supporting climate-resilient city planning in Ghana’s most urbanized region.

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