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Land Surface Temperature Variability in Africa: A Systematic Review and Meta-Analysis with a Focus on Ghana

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Abstract
Land Surface Temperature has become an essential variable for comprehending climatic variability, urban heat islands, and ecological resilience, especially in Africa, where growing urbanization and deforestation exacerbate thermal stress. This study conducts the inaugural systematic review and meta-analysis of land surface temperature variability throughout Africa, concentrating specifically on Ghana. Following PRISMA guidelines, 67 peer-reviewed and grey literature sources published from 2000 to 2025 were synthesized to evaluate spatio-temporal land surface temperature changes, analytical methods, and policy implications. Results reveal a continent-wide warming trend characterized by significant diurnal asymmetry, highlighted by ongoing nighttime warming. Urban areas like Accra and Kumasi exhibit considerable heat island effects, primarily due to the reduction of greenery and the proliferation of impermeable surfaces. Vegetation and aquatic environments constantly exhibit cooling effects, whereas barren land and developed regions record the highest land surface temperature readings. Landsat imagery predominates in Ghanaian research for its geographical resolution, while MODIS products are appreciated for their temporal consistency; nonetheless, the integration of multi-sensor methodologies is still constrained. The distinctive vulnerabilities of Ghana's deforestation, uncontrolled urban development, and coastal susceptibility highlight the necessity for climate-sensitive design. This study identifies significant research deficiencies, such as the inadequate representation of coastal dynamics, health implications, and equity factors in urban heat reduction efforts. The findings establish a foundation for adaptive land-use planning, climate-smart agriculture, and urban resilience methods, delivering crucial insights for Ghana and Africa's overarching climate adaptation initiatives.

Keywords: Land Surface Temperature, Climate Variability, Sub-Saharan Africa, Systematic Review, Meta-Analysis

1. Introduction

Land Surface Temperature (LST) is a critical geophysical measure characterized as the radiometric skin temperature of the Earth's surface, indicating the thermodynamic temperature at the land-atmosphere boundary (Li et al., 2023; Yu et al., 2017). Designated as a Critical Climate Variable by the Global Climate Observing System, LST is pivotal in Earth's energy equilibrium and functions as the principal metric for quantifying Urban Heat Island effects, monitoring ecosystem stress, and evaluating climate change repercussions (Li et al., 2023; Imhoff et al., 2010). In contrast to air temperature recorded by meteorological stations, LST is obtained via satellite thermal infrared sensors and reacts more swiftly to surface heating and cooling dynamics, rendering it particularly sensitive to alterations in land use and environmental disturbances (Weng, 2009).

LST variability in Africa is influenced by a complex interaction of human-induced land use changes, climate fluctuations, and biophysical surface characteristics. Human-induced factors, including deforestation and urbanization, have significant influences at local and regional levels. Deforestation for agricultural purposes induces considerable biophysical warming (about 1.3 K in East Africa) via diminishing evapotranspiration and surface roughness (Reiners et al., 2023; Abera et al., 2018).

Urbanization supplants natural vegetation with heat-retaining impermeable surfaces, resulting in pronounced urban heat islands, with research indicating that over 61% of warming in cities such as Lagos is attributable to urbanization (Guo et al., 2022; Li et al., 2022). Anthropogenic alterations interact with natural climatic factors, such as rainfall-vegetation dynamics, ENSO-induced drought variability, and greenhouse gas-induced warming, notably reflected in persistent nighttime temperature increases across the continent (Abera et al., 2020; NourEldeen et al., 2020). Biophysical parameters such as plant resilience, soil moisture, albedo, and topography influence these responses and dictate the extent of LST variations across diverse landscapes (Abera et al., 2018).

Notwithstanding the crucial significance of LST, its precise monitoring encounters considerable technological obstacles that notably impact research in Africa. Cloud cover generates extensive data deficiencies and clear-sky bias, while atmospheric interference necessitates intricate adjustments that introduce significant uncertainty (Li et al., 2022; Zhou et al., 2019). Retrieval accuracy is significantly influenced by the exact calculation of Land Surface Emissivity, as a 1% inaccuracy can result in inaccuracies beyond 1K (Yoo et al., 2020). A basic constraint is present in the spatio-temporal trade-off, wherein high-resolution sensors like Landsat (30m) possess 16-day revisit intervals, whilst frequent sensors like MODIS (twice daily) function at a coarse 1 km resolution, which is inadequate for diverse landscapes (Miao et al., 2021). Crucially for African research, there exists a significant deficiency of representative ground observations necessary for the validation of satellite products, exacerbated by data accessibility challenges and the intrinsic disparity between point-scale in-situ measurements and pixel-scale satellite data (Grieco et al., 2019; Mo et al., 2021).

Studies at the continental level validate a prevailing warming trend throughout Africa, marked by significant diurnal asymmetry, with nighttime warming being nearly ubiquitous and more stable than daytime variations, a critical indicator of anthropogenic impact (Abera et al., 2020; NourEldeen et al., 2020). The most significant warming is observed in North and West Africa, the East African coast, highland regions, and nearly all examined metropolitan areas (Li et al., 2022).

LST sharpening approaches are utilised to address spatio-temporal gaps; nonetheless, they result in uncertainty (RMSE ~1.1-1.5°C) and decreased dynamic range, especially in diverse environments (Huryna et al., 2019; Bartkowiak et al., 2024).

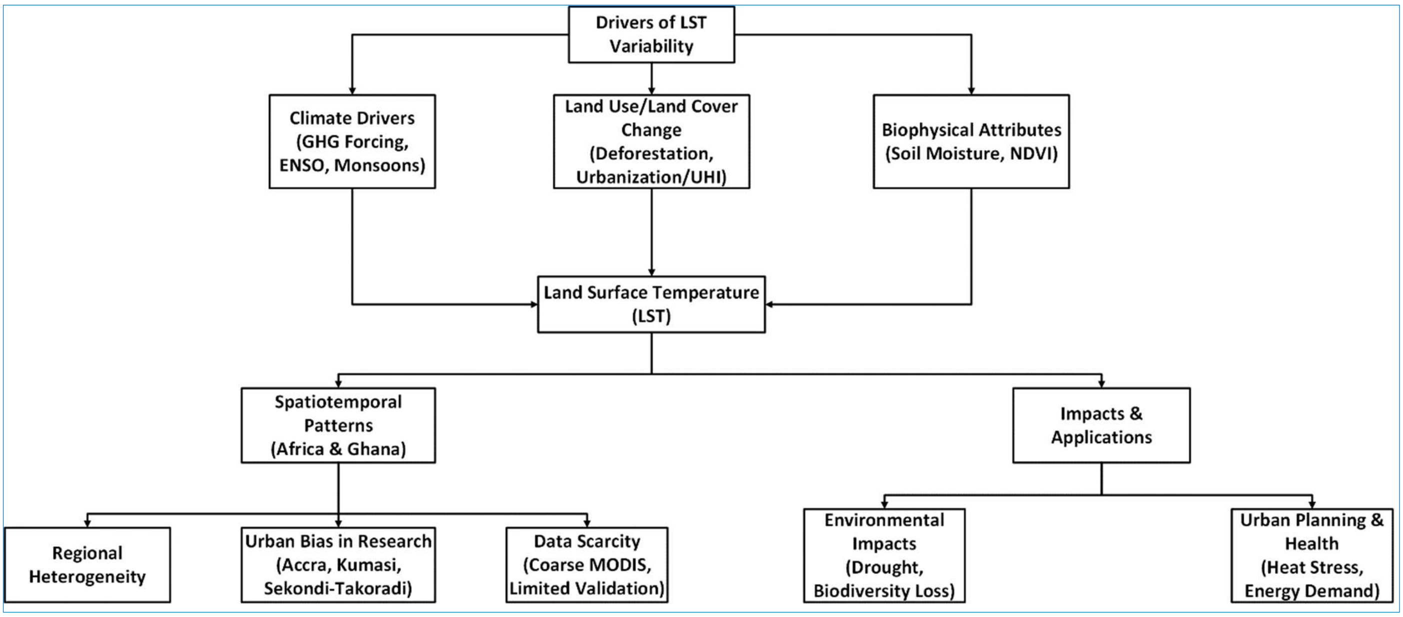

Fig. 1. Flowchart depicting the conceptual framework of the study

Nonetheless, LST research in Africa is hindered by significant systemic deficiencies that greatly restrict our comprehension of continental-scale patterns and local-scale effects. Research output demonstrates significant geographical bias, predominantly centred in a limited number of countries (South Africa, Nigeria), whereas extensive areas of West and Central Africa remain largely unexamined (Enu et al., 2023; Afuye et al., 2024). A notable lack of comprehensive meta-analyses synthesising LST trends throughout Africa's many ecological zones exist, with the current literature remaining disjointed due to differing techniques, sensors, and temporal frameworks (Peprah et al., 2025a; Peprah et al., 2025b; Peprah et al., 2025c; Tetteh et al., 2025). Moreover, LST research frequently neglects to include wider socio-ecological frameworks, exhibiting a deficiency in studies that connect LST to health outcomes and an inadequate examination of equity considerations in heat island mitigation techniques (Jael, 2023; Tetteh et al., 2025).

Ghana illustrates these research deficiencies while exhibiting distinct vulnerabilities that require immediate focus. The nation has severe environmental challenges due to the loss of almost 80% of its high forest cover since the 20th century, which directly contributes to localised warming and the degradation of ecosystem services (Awuni et al., 2023; Gyile et al., 2025). Prominent cities such as Accra have significant urban heat islands with temperature increases of 4-6 °C, clearly associated with accelerated urbanisation and the depletion of plant cover (Wemegah et al., 2020). Ghana's large coastline confronts compounded climate threats from rising sea levels, altered precipitation patterns, and thermal stress; nonetheless, research focusing on coastal LST changes is conspicuously lacking in the literature (Aduko et al., 2025; Afuye et al., 2024). This study gap is particularly alarming considering Ghana's coastal susceptibility to climate change effects, such as saltwater intrusion, coastal erosion, and ecosystem degradation, all of which are influenced by thermal dynamics. In Ghana, research predominantly concentrates on Accra and Kumasi, neglecting other metropolitan centres and rural coastal regions, which are critically underexamined despite their substantial populations and ecological significance.

A systematic review and meta-analysis offer a crucial methodological framework to rectify these knowledge deficiencies by statistically integrating varied LST findings across Africa, quantifying geographical and thematic biases in current research, assessing the efficacy of diverse remote sensing methodologies in African contexts, and furnishing a unified evidence base to inform climate adaptation policies in under-researched areas such as Ghana.

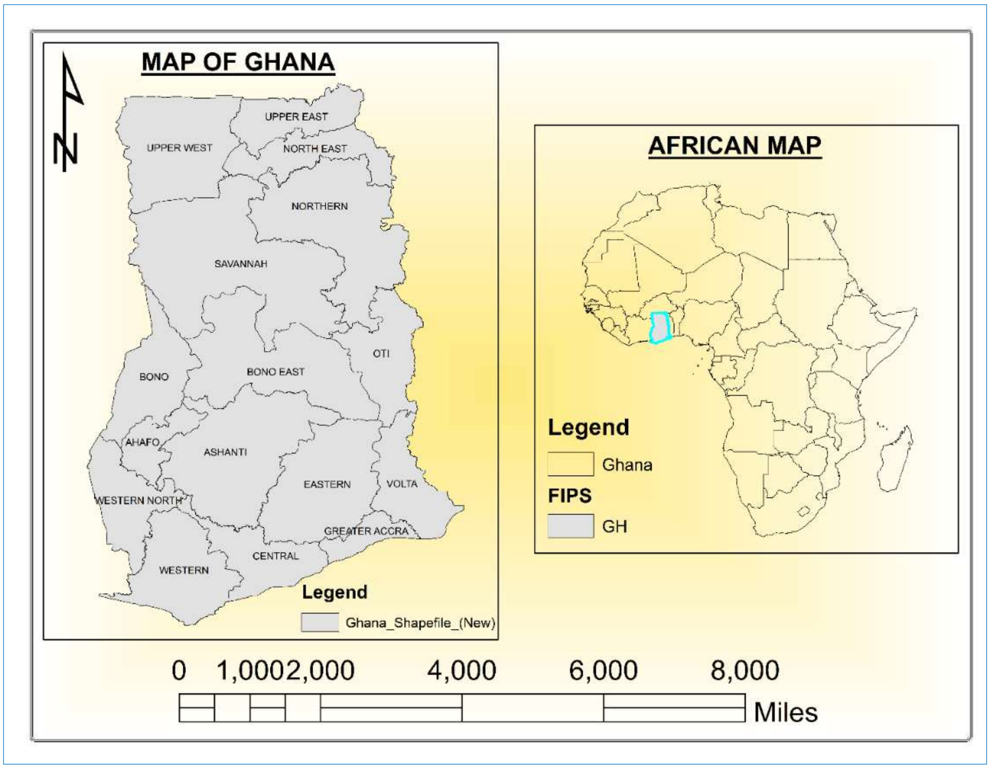

Fig. 2. Geographical overview of the research area

This study aims to: (1) analyse and synthesise spatial and temporal trends in LST variability across Africa, with a particular emphasis on Ghana; (2) evaluate the efficacy and constraints of remote sensing instruments employed for LST monitoring in various African terrains; and (3) assess Ghana-specific LST patterns, their determinants, and implications for climate adaptation policy. The study examines three fundamental inquiries: What are the primary regional and temporal patterns of LST in Africa, particularly in Ghana? To what extent do prevalent remote sensing instruments accurately measure LST fluctuation throughout Africa's varied terrains? What are the principal policy implications for climate adaptation, urban development, and public health measures in Ghana derived from pooled continental evidence?

This research will deliver the inaugural comprehensive meta-analysis of LST variability throughout Africa, with a specific emphasis on Ghana, thereby directly informing national and local climate adaptation policies, sustainable urban planning strategies to alleviate heat island effects, and public health interventions to address thermal stress. This study will systematically identify essential research gaps related to coastal vulnerabilities and health impacts, thereby directing future research investments and capacity building in Earth observation science throughout West Africa, ultimately enhancing climate resilience strategies in one of the world's most climate-vulnerable regions.

2. Conceptual Framework

LST is the radiometric skin temperature of the Earth's surface, reflecting the thermal energy emitted by terrestrial surfaces, as recorded by satellite-based thermal infrared (TIR) sensors, including MODIS, Landsat, and Sentinel-3 (Li et al., 2023; Weng, 2009). LST, as a Critical Climate Variable (CCV), is essential for comprehending the Earth's energy equilibrium, surface-atmosphere dynamics, and spatiotemporal temperature fluctuations (Li et al., 2023; Imhoff et al., 2010). This study employs a systematic review paradigm, considering LST variability as the resultant effect of climatic, anthropogenic, and biophysical interactions (Abera et al., 2018; Peprah et al., 2025c). These interconnected variables collectively affect the geographical and temporal patterns of LST, particularly in climatically varied and quickly urbanising nations like Ghana (Enu et al., 2023; Gyile et al., 2025).

The fluctuations in LST are predominantly influenced by meteorological forces, land use and land cover change (LULCC), and inherent biophysical variables. Climatic factors, such as greenhouse gas buildup, augmented longwave radiation, and interannual variability from the El Niño–Southern Oscillation (ENSO), elevate LST by obstructing nighttime surface cooling (Urdiales-Flores et al., 2023; NourEldeen et al., 2020). Human-induced land alterations, including deforestation, agriculture, and urbanisation, markedly diminish evapotranspiration and increase sensible heat flow, hence raising surface temperatures, especially in tropical areas (Abera et al., 2018; Reiners et al., 2023). Biophysical parameters such as NDVI, soil moisture, elevation, and proximity to water bodies affect surface thermal dynamics by controlling heat absorption and dissipation (Li et al., 2022; Orimoloye et al., 2018).

Throughout Africa, these factors exhibit variability, resulting in unique regional LST patterns. In Ghana, temperature elevation is more pronounced during arid seasons and in urban areas undergoing vegetation depletion and heightened impervious surface coverage (Gyile et al., 2025; Wemegah et al., 2020). Cities like Accra and Kumasi demonstrate significant Urban Heat Island (UHI) effects, with LST variations of 4–6°C between urban centres and surrounding areas largely attributable to swift urban development, reduction of green spaces, and insufficient land-use governance (Gyasi-Addo and Bennadji, 2020a; Olawoyin and Acheampong, 2023). The absence of high-resolution thermal datasets and insufficient ground-based validation infrastructure in Ghana and much of sub-Saharan Africa impedes the precision and reliability of LST estimates (Peprah et al., 2025c; Grieco et al., 2019).

The ramifications of LST variations reach well beyond thermal mapping. Increased LST expedites soil moisture reduction, vegetation distress, drought intensity, and wildfire susceptibility (Li et al., 2023; Watson et al., 2018). In urban environments, it intensifies thermal discomfort, elevates cooling energy requirements, and amplifies susceptibility to heat-related ailments, especially in informal, low-income populations (Das and Das, 2020; Whitmee et al., 2015). These results compromise public health, ecological resilience, and urban sustainability. However, the majority of research disproportionately focuses on urban areas and transient patterns, frequently overlooking socio-ecological intricacies, longitudinal studies, and empirical verification (Peprah et al., 2025b; Enu et al., 2024).

This paradigm facilitates systematic review and meta-analysis that contextualises LST within an intricate system of climate, land, and social interactions. This facilitates the examination of urban-rural LST gradients in Ghana, the impact of land use changes on localised warming, methodological rigour, and the incorporation of health and ecological aspects in LST research. The technique seeks to generate evidence-based insights to inform sustainable land governance, urban climate adaptation, and environmental policy throughout the African continent (Tetteh et al., 2025; Afuye et al., 2024). Fig. 1 is the flowchart depicting the conceptual framework of the study.

3. Materials and Methods

3.1. Study Area Description

Ghana (Fig. 2), situated in West Africa between around 4.5°N and 11.5°N latitude, has a significant north-south climatic gradient that profoundly affects LST trends. The nation's tropical monsoon climate is regulated by the Intertropical Convergence Zone (ITCZ), resulting in various agro-climatic zones ranging from the wet coastline and forest areas in the south to the drier Sudan and Guinea savannah regions in the north. The gradient is evident in temperature ranges from roughly 25.5°C in the wooded southern region to almost 30°C in the northern savannah, with recorded warming trends of about 1.0°C each decade since 1960 (De Pinto et al., 2012; Yamba et al., 2023). Precipitation diminishes significantly from over 2000mm yearly in the southwest to about 1100mm in the north, with the southern region exhibiting a bi-modal distribution and the northern region characterized by a singular, strong rainy season (Asante and Amuakwa-Mensah, 2015).

The nation's physical geography is primarily characterised by the Palaeoproterozoic Birimian Supergroup, encompassing approximately 75% of the area. This formation is integral to the West African Craton and establishes a northeast-southwest structural alignment of ridges and valleys that affects local microclimates and topographic influences on LST (Yao and Robb, 2000; Chudasama et al., 2015). The remaining 25% comprises coastal sedimentary basins with diverse thermal characteristics. This geological substrate underpins many ecosystems, from tropical rainforests exhibiting elevated evapotranspiration rates that regulate LST, to sparse savannah flora characterized by increased sensible heat flow.

The pronounced north-south disparity transcends natural elements to encompass human geography, as colonial and post-independence advancements are concentrated in southern urban centers such as Accra and Kumasi, resulting in significant Urban Heat Island effects, whereas northern regions predominantly engage in agriculture, with potential for both rain-fed and irrigated farming systems that variably influence surface energy balance (Abdulai et al., 2018).

Environmental pressures from rapid urbanization, deforestation, mining operations (notably gold extraction), and agricultural development have profoundly altered land cover patterns throughout Ghana, directly affecting LST fluctuations. The farm sector constitutes 69% of environmental degradation expenses, whereas mining and urban growth have significantly impacted thermal characteristics due to plant loss and surface alteration (Adomako and Ampadu, 2015; Mensah et al., 2015). The effects of climate change are seen in the southward proliferation of dry regions, a heightened occurrence of extreme weather phenomena, and recorded drops in NDVI in metropolitan locales such as Accra. The interplay of physical, climatic, and anthropogenic variables generates a complex mosaic of surface conditions that influences geographic and temporal variability in LST throughout Ghana's varied terrain (Cobbinah et al., 2017; Yamba et al., 2023).

Table 1. Inclusion and exclusion criteria

Criteria	Inclusion	Exclusion
Geographic focus	Studies in Africa (priority: Ghana)	Studies outside Africa without relevance
Publication date	2000–2025	Before 2000
Study focus	LST variability, trends, drivers (urbanisation, land cover change, climate)	Non-LST temperature studies (e.g., air temperature only)
Methodology	Remote sensing–based LST retrieval and analysis	Purely model-based or ground-only studies without remote sensing inputs
Data sources	MODIS, Landsat, Sentinel, ASTER, VIIRS, etc.	Non-remote sensing or local-only thermometers
Accuracy metrics	Quantitative reporting of LST (°C, anomalies, statistical models, or validation with ground data)	Studies without measurable LST values
Study type	Peer-reviewed journals, reputable conference papers, and technical reports	Editorials, commentaries, opinion pieces
Language	English	Non-English publications (due to resource limitations)

3.2. Methodology

3.2.1. Study Design

This systematic review and meta-analysis followed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) standards to guarantee transparency, reproducibility, and scientific rigour. The review was structured according to the PCC framework (Population, Concept, Context), wherein the population encompassed remote sensing datasets and models utilised for estimating or analysing LST. The concept concentrated on the variability, trends, and determinants of LST within African ecosystems, particularly in Ghana. The context pertained to studies conducted throughout Africa, emphasising Ghana-specific research while also incorporating continental and sub-regional comparisons for comprehensive insights. This architecture is for a systematic synthesis of knowledge about the trends, drivers, and methodological methods in LST monitoring throughout Africa.

3.2.2. Search Strategy

A thorough literature review was performed to encompass all pertinent research on LST variability in Africa. Searches included terms about LST, variability, climate change, urban heat islands, remote sensing platforms such as Landsat, MODIS, Sentinel, and ASTER, along with geographic limits encompassing Africa, Ghana, and West Africa. Boolean operators ("AND" and "OR") were employed for refining. The search terms encompassed combinations of “Land Surface Temperature,” “LST,” or “Surface Thermal Variability,” alongside “Remote Sensing,” “Satellite Imagery,” “MODIS,” “Landsat,” or “Sentinel,” in conjunction with “Climate Change,” “Urban Heat Island,” or “Temperature Trends,” and geographic identifiers such as “Africa,” “Ghana,” or “West Africa.” The subsequent databases were methodically examined: Scopus, Web of Science, IEEE Xplore, Google Scholar, ResearchGate, Academia.edu, and Africa Journals Online (AJOL). Literature was confined to the timeframe from 2000 to 2025, documenting the progression of LST research from the first MODIS-based investigations to advanced high-resolution Sentinel and machine learning-assisted methodologies.

3.2.3. Study Selection Procedure

The selection process was done according to PRISMA's multi-phase protocol. During the identification phase, all search results were consolidated into Mendeley reference manager. During the screening phase, duplicates were removed, and the remaining titles and abstracts were evaluated against the inclusion criteria (Table 1). The subsequent phase involved evaluating whole texts for methodological appropriateness. Ultimately, in the inclusion phase, the papers that satisfied all criteria were selected for analysis. The entire selection workflow, including identification, screening, eligibility, and inclusion stages, is illustrated in Fig. 3. The preliminary search produced 985 publications from the searched databases, from which 385 duplicates were eliminated. A total of 600 full-text papers were evaluated, and 67 investigations were finally incorporated into the review.

3.2.4. Data Extraction

A uniform data extraction template was created, and all papers were meticulously examined with data separately extracted by thorough reviewing, while any discrepancies were handled by consensus. The retrieved attributes encompassed study characteristics, including author names, publication year, geographic location (country, region, urban or rural environment), and research aims. Specifications for remote sensing were documented, encompassing the sensor or platform utilized, spatial and temporal resolution, as well as processing techniques like atmospheric correction and cloud masking. Documented analytical methodologies included statistical and machine learning techniques, time-series analysis, anomaly identification, and regression modelling. Significant effects were discerned, specifically emphasizing LST variable patterns, seasonal and yearly trends, urban-rural disparities, and the impact of climate and land use determinants. Validation processes were documented, encompassing ground measurements, meteorological data, and statistical accuracy metrics.

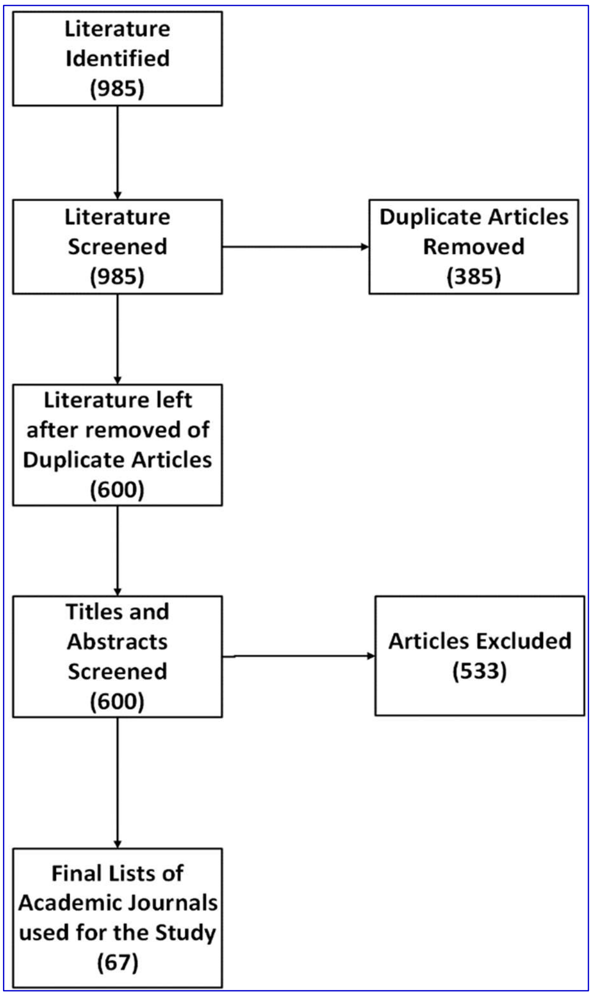

Fig. 3. PRISMA flow diagram for the study selection process

3.2.5. Quality Assessment

The quality of the study was evaluated utilizing a modified QUADAS-2 framework specifically adapted for LST research. The evaluation concentrated on critical areas, including the dependability of LST retrieval techniques, encompassing sensor calibration and preprocessing stages, the suitability of validation methods such as ground truthing and cross-comparisons, the clarity of methodology and overall reproducibility, and the pertinence of the research to African or Ghanaian environmental contexts.

According to these criteria, studies were classified as High, Medium, or Low quality. No studies were omitted simply due to quality; nonetheless, the ratings were included as weighing factors in the synthesis of findings.

3.2.6. Data Analysis

3.2.6.1. Narrative Synthesis

A thematic synthesis was performed to categorize the findings into principal areas of emphasis. Temporal variability of LST was analyzed concerning seasonal and yearly fluctuations, in addition to long-term warming tendencies. Spatial patterns were evaluated, emphasizing disparities between rural and urban areas, including urban heat islands, as well as ecosystem-specific variability noted in the savanna, woodland, and Sahel regions. The review examined the factors influencing LST fluctuation, including land use and land cover alterations, urban growth, deforestation, and overarching climatic variability. Ultimately, methodological patterns were examined, focusing on variations in sensor utilization, including MODIS and Sentinel, the implementation of time-series techniques, and the amalgamation of climate and land use information.

3.2.6.2. Meta-Analysis

While sufficient comparable quantitative data were available, a random-effects meta-analysis was done. The effect size was quantified as mean changes or normalized effect sizes in LST (°C) over various time periods, land cover types, or geographic regions. Subgroup analyses were conducted to yield more profound insights. This analysis juxtaposed Ghana with the broader African context, scrutinized variability across ecosystems including forests, savannas, urban areas, and arid regions, evaluated discrepancies among data sources such as MODIS, Landsat, and Sentinel, and assessed temporal changes, particularly between the periods of 2000–2010 and 2011–2025.

4. Results and Discussion

4.1. Results

4.1.1. Synthesis of Trends of Publications

This section categorises the studies according to their publication year and the respective nations or locations of their implementation. This facilitated an evaluation of the geographical dispersion of research on the subject, together with historical publishing trends. The study disclosed significant information regarding the publication statistics of the selected research publications. The publishing tendencies of the study from 2000 to 2025 exhibited volatility, commencing with 1 publication in 2009, escalating to 11 (16.42%) in 2023, and then diminishing to 7 publications in 2025. The number of publications increased to 2 in 2015, then surged to 3 in 2017 and 2018, increased to 8 in 2019 and 2021, reached 9 in 2020, and thereafter fell to 7 in 2024 and 2025. In 2023, the peak number of publications recorded throughout the analysed period was 11 articles (16.42%). Nonetheless, there was a decline in the number of releases from 2009 to 2015, with only one or two releases per year. Fig. 4 summarizes the publishing patterns for the analyzed period. It is essential to observe that no publications were documented in the years 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2011, 2013, 2014, and 2016 (Fig. 4).

4.1.2. Synthesis of the Geographical Distribution of Studies

The examination rigorously examined the jurisdictions of several research studies assessed. Among the 67 publications examined for this research, the majority, specifically 19 and 22, were identified in Ghana and Global studies, respectively.

The examination of Africa subsequently yielded six papers. The research undertaken in the African area includes three studies in West Africa, three in East Africa, four in Southern

Africa, one in North-East Africa, one in North Africa, and three in Sub-Saharan Africa. A research investigation was undertaken in North America, East Asia, South Asia, and Europe. Twenty-two scientific research publications garnered international acclaim. The research undertaken in the Belt and Road areas includes North Africa, North-East Africa, West Africa, East Africa, Southern Africa, North America, South Asia, East Asia, North America, Europe, and Sub-Saharan Africa. Fig. 5 illustrates the geographical distribution of the studies employed in this research.

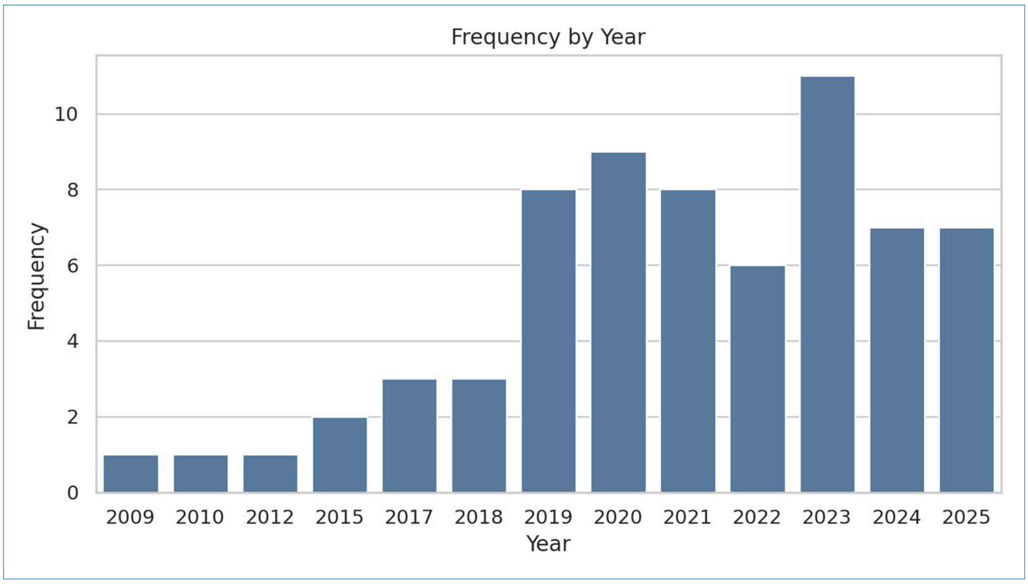

Fig. 4. A graph depicting the relationship between publication year and the number of papers downloaded and utilized in the research

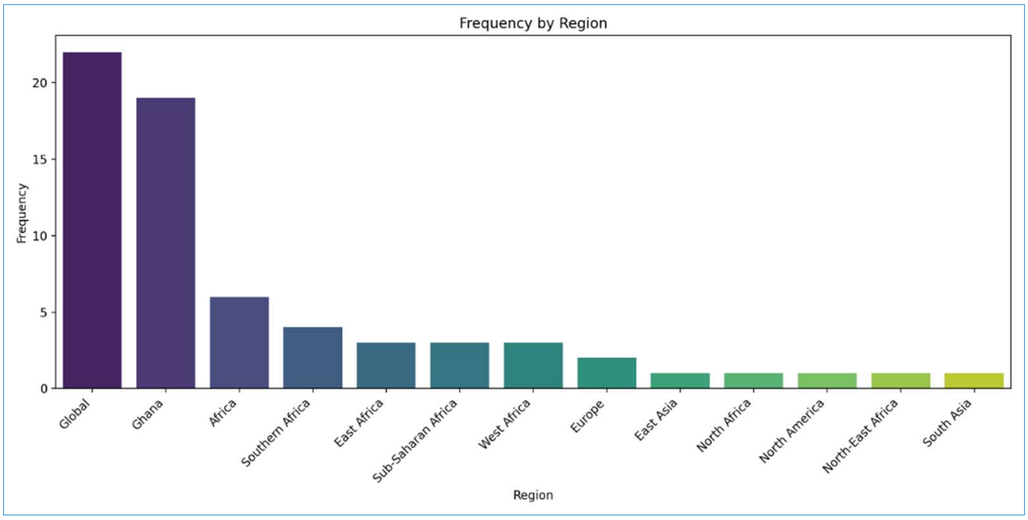

Fig. 5. A graph depicting geographical regions and the number of papers accessed and utilized in this study

4.1.3. Spatial-Temporal Patterns of LST in Africa

In Africa's swiftly urbanising environments, LST displays strong spatial disparities: urban centres are warmer than adjacent rural and vegetated areas, and several cities have escalating surface urban heated islands (SUHI). Recent syntheses indicate a geographic study bias favouring nations like South Africa, Ethiopia, and Nigeria; however, they nevertheless reveal distinct warming signals and increasing urban heat exposure.

Accra, Ghana, is one of the places where the Urban Heat Island (UHI) effect has been shown to intensify, with forecasts indicating that the number of urban person-days subjected to high heat may escalate by a factor of 20 to 52 by the 2090s (Li et al., 2022).

Regionally, East Africa (2003–2018) displays a pronounced day–night disparity: daytime LST trends are spatially heterogeneous, featuring areas of both warming and cooling that largely offset each other at the regional level, while nighttime LST reveals extensive and statistically significant net warming of approximately 0.003 K annually. This divergence has diminished the diurnal surface temperature range over most of the area, with decreasing DSTR prevailing in both annual and seasonal cycles (Abera et al., 2020).

Evidence from Ethiopian cities (1990–2020) indicates that LST trends strongly correlate with urban growth. High-temperature zones expanded significantly, approximately 50% in Addis Ababa and 86% in Adama, gradually encroaching from urban centers into peri-urban regions. The LST ranges differed by city, with Addis Ababa documenting temperatures between 26.07 and 29.01 °C, while Adama recorded temperatures from 28.24 to 32.88 °C.

Table 2. Summary of studies of spatiotemporal patterns of LST trends in Africa

Reference/source	Title of article	Location of study	Journal of publication	Study/project application
Li et al., 2022	The Impacts of Urbanisation and Climate Change on the Urban Thermal Environment in Africa	Multi-city review (incl. Accra, Addis Ababa, Dar es Salaam, etc.)	Climate	Continental review of SUHI/LST trends, exposure projections, and research gaps.
Abera et al., 2020	Land Surface Temperature Trend and Its Drivers in East Africa	East Africa (regional, 2003–2018)	Journal of Geophysical Research: Atmospheres	Regional LST trend attribution: nighttime warming and declining diurnal LST range.
Akinyemi et al., 2019	Land cover change effects on land surface temperature trends in an African urbanizing dryland region	Gaborone, Botswana	City and Environment Interactions	Class-wise day/night LST trends; drought/low reservoir levels amplifying daytime LST over water.
Degefu et al., 2023	Dynamics of green spaces – Land surface temperature intensity nexus in cities of Ethiopia	Addis Ababa, Hawassa, Adama, Bahir Dar (1990–2020)	Heliyon	City-scale LST evolution; NDBI↑ raises LST; NDVI/MNDWI provide cooling; LST ranges by city.
Measho et al., 2023	Characterizing Cropland Patterns Across North-East Africa Using Time Series Vegetation Indices	North-East Africa croplands	JGR: Biogeosciences	Links LST/NDVI to phenology; identifies high-impact sub-regions and average cropland LST (~34.4 °C).
Nega and Balew, 2022	The relationship between land use land cover and land surface temperature using remote sensing: systematic reviews of studies globally over the past 5 years	Global review with African evidence	Environmental Science and Pollution Research	Synthesizes LULC–LST gradients (built-up & bare hottest; vegetation & water coolest).

Table 3. Key studies on LST changes in Ghana

Reference/Source	Title of article	Location of study	Journal of publication	Study/project application
Wemegah et al., 2020	Assessment of Urban Heat Island Warming in the Greater Accra Region	Greater Accra (Accra and Tema)	Scientific African	Quantified UHI magnitude & spatial extent using Landsat (1991, 2002, 2017) + station temps (1980–2017); assessed LST thresholds & nocturnal UHI.
Buo et al., 2021	Estimating the expansion of urban areas and urban heat islands (UHI) in Ghana: a case study	Accra and Kumasi	Natural Hazards	Mapped urban sprawl (2002–2017) and estimated SUHII/SUHIM with Landsat; examined bare soil/vegetation controls on LST.
Kwofie et al., 2022	Urban growth nexus to land surface temperature in Ghana	Greater Accra Region	Cogent Engineering	Linked LULC/NDVI to LST (1991–2020); quantified vegetation cooling (−3 to −5 °C) and warming of salt marshes/barelands (+5.3/+5.2 °C).
Olawoyin and Acheampong, 2023	The Dynamics of Land-Use/Land-Cover and Land Surface Temperature Changes in the Greater Accra Metropolitan Area, Ghana 1986–2020	Greater Accra Metropolitan Area (GAMA)	IOSR Journal of Humanities and Social Science	Mapped LULC–LST; showed 31.06% (>40 °C) by 2020; identified coastal 'dissected plateau' hot pattern; linked heat to urbanization/deforestation.
Gyile et al., 2025	Assessment of Land Use and Land Cover Changes and Their Impact on Land Surface Temperature in Greater Accra, Ghana	Greater Accra (GAMA)	Scientific African	Assessed LULCC–LST with Landsat (1991, 2002, 2015, 2020); mean LST ↑ ~4.0 °C; built-up ↑ ~4.07 °C; inverse LST–NDVI relationship.
Gyasi-Addo, 2021	Evaluation of the effect of urbanization on urban thermal behaviour using UHI indicators: the case of the CBD of Accra	Accra (Central Business District)	PhD Thesis, Robert Gordon University	Measured canopy-layer UHI (≈0.5–3 °C); stronger nocturnal UHI; linked intensity to LCZ morphology & vegetation.
Johnson, 2024	Assessing the Impacts of Climate Change of Coastal Winneba-Ghana	Winneba (Coastal Savannah)	Unpublished report/thesis	Found a stronger rise in minimum temperatures ($R^2 \approx 0.73$) than maxima; discussed coastal nocturnal UHI influence and RCP projections.

Blue and green infrastructure significantly lowered surface temperatures; for example, big water bodies like Lake Tana and Lake Hawassa decreased urban heat island intensity by around 50% on average. In contrast, increased built-up intensity indicated by the Normalized Difference Built-up Index (NDBI) raised LST, but diminishing vegetation cover, as seen by lower NDVI, reduced cooling capacity (Degefu et al., 2023).

Arid urban areas exemplify supplementary factors and vulnerabilities. In semi-arid Gaborone, Botswana (2000–2018), both diurnal and nocturnal LSTs exhibited a general rise; however, land cover and hydrology significantly influenced the observed trends. The Gaborone Dam had the most significant daytime temperature increase, ranging from +2.6 to +5.7 K, while experiencing nocturnal cooling of up to −1.2 K, with patterns strongly associated with drought-related fluctuations in water levels. Settlement expansion zones exhibited significant increases, with daytime LST rising by around +4.5 K and nighttime by about +2.2 K (Akinyemi et al., 2019).

Agricultural systems in North-East Africa exhibit spatially unequal LST pressures outside urban areas. The mean LST of farmland averaged around 34.4 °C from 2001 to 2020, with the most pronounced impacts on crop phenology noted in southern Sudan and northeastern Tanzania. These regions exhibited warming correlated with plant browning and detrimental seasonal alterations (Measho et al., 2023).

At the continental level, analyses of LULC and LST correlations elucidate a distinct geographical hierarchy of thermal intensity. Developed and exposed terrains regularly have the greatest LSTs, whilst aquatic environments and dense flora display the lowest values. Mean LSTs reported in African studies range from 19–21 °C for water, 24–27 °C for forest, 27–28 °C for savanna, 31–32 °C for cropland, 30–31 °C for shrubland, 33–34 °C for bare land, and 29–30 °C for built-up areas, underscoring the cooling benefits of blue–green infrastructure and the thermal drawbacks of impervious development (Nega and Balew, 2022).

Table 4. Key summary of studies

Reference/source	Title of article/thesis	Location of study	Journal of publication/venue	Study/project application
Wemegah et al., 2020	Assessment of Urban Heat Island Warming in the Greater Accra Region	Greater Accra (GAMA), Ghana	Scientific African	Landsat TM/ETM+/OLI-TIRS LST retrieval (1991, 2002, 2017); NDVI/LULC links to UHI.
Gyile et al., 2025	Assessment of Land Use and Land Cover Changes and their Impact on Land Surface Temperature in Greater Accra, Ghana	Greater Accra (GAMA), Ghana	Scientific African	Landsat LST mapping; Landsat 8 Band 10 preferred over Band 11 due to lower noise.
Aduko et al., 2025	Assessing the Environmental Impacts of Urban Sprawl on Vegetation Cover and Ecosystem Integrity in Wa Municipality	Wa Municipality, Ghana	World Development Sustainability	Landsat-based LULC change analysis (1986–2018) with implications for LST/urban heat.
Olawoyin and Acheampong, 2023	The Dynamics of Land-Use/Land-Cover and Land Surface Temperature Changes in the Greater Accra Metropolitan Area, Ghana 1986–2020	Greater Accra (GAMA), Ghana	IOSR Journal of Humanities and Social Science (IOSR-JHSS)	Multi-epoch Landsat for LULC–LST change; long-term urban heat patterns.
Buo, 2019	Urban Sprawl Dynamics and Urban Heat Islands (UHI) in Ghana	Ghana	Dissertation	Notes Landsat single-channel LST, MODIS daily products and atmospheric inputs; complementary use.
Li et al., 2022	The Impacts of Urbanisation and Climate Change on the Urban Thermal Environment in Africa	African cities	Climate	Compares typical **resolutions** and **revisit**: Landsat (fine spatial, 16-day) vs MODIS (1 km, twice-daily); both used for SUHI.
Gyasi-Addo and Bennadji, 2020a	Investigating the Major Causes of Morphological Transformations in the CBD of Accra and the Impact on Urban Heat Intensity	Accra, Ghana	Proceedings of the 36th Annual ARCOM Conference	LCZ classification supported by Landsat/aerial imagery; urban morphology vs heat (not MODIS LST).
Johnson, 2024	Assessing the Impacts of Climate Change of Coastal Winneba-Ghana	Winneba, Ghana	Dissertation	Climate projections/temperature context (GCMs); satellite used for shoreline digitizing, not LST.
Kwofie et al., 2022	Urban Growth/Nexus to Land Surface Temperature in Ghana	Accra, Ghana	Cogent Engineering	Urban growth & LST with Landsat; intra-city hot spots linked to impervious expansion.
Mushore et al., 2022	Determining the Influence of Long-Term Urban Growth on Surface Urban Heat Islands using Local Climate zones and Intensity Analysis Techniques	Bulawayo, Zimbabwe	Remote Sensing	Landsat-derived LST aggregated by LCZ; example of fine-scale urban thermal structure outside Ghana.

4.1.4. Highlight of LST Changes in Cities or Ecological Zones in Ghana

Research examining LST fluctuations in Ghana's urban areas and ecological regions demonstrates consistent evidence of increasing thermal trends associated with alterations in land use and land cover. Wemegah et al. (2020) evaluated UHI warming in the Greater Accra Metropolitan Area (GAMA) and identified significant warming trends by combining Landsat imagery (1991, 2002, 2017) with station-based temperature data (1980–2017), particularly emphasizing nocturnal UHI effects in Accra and Tema. Buo et al. (2021) advanced this research by quantifying the extension of urban areas and UHIs in Accra and Kumasi, revealing that urban sprawl from 2002 to 2017 exacerbated surface UHI intensities, with bare soil and scarce vegetation having the most significant impact on LST.

Kwofie et al. (2022) demonstrated that between 1991 and

2020, vegetation consistently reduced surface temperatures by 3–5 °C, while salt marshes and barelands contributed to warming by 5.3 °C and 5.2 °C, respectively. This indicates that the expansion of settlements (from approximately 17 km² to 124 km²) resulted in an average LST increase from approximately 28.5 °C to 36.8 °C.

Olawoyin and Acheampong (2023) analysed the dynamics of LULC and LST in the Greater Accra Metropolitan Area (GAMA) from 1986 to 2020. They discovered that by 2020, more than 31% of the region had exceptional LSTs above 40 °C, with coastal dissected plateaus regularly identified as hot zones due to significant urbanization and vegetation depletion. Recent research by Gyile et al. (2025) corroborated these trends, indicating that the mean LST rose by almost 4 °C over three decades in Greater Accra, with urbanized regions seeing a notable increase (+4.07 °C) and vegetation exerting a distinct cooling influence via a negative LST–NDVI correlation.

Gyasi-Addo (2021) assessed UHI dynamics in Accra's Central Business District, revealing canopy-layer UHI intensities ranging from 0.5 to 3 °C, with heightened intensities observed at night, and attributed these variations to the topology of local climatic zones.

In the coastal savannah town of Winneba, Johnson (2024) indicated that from 1980 to 2019, minimum temperatures increased more significantly ($R^2 \approx 0.73$) than maximum temperatures, consistent with coastal nocturnal urban heat island effects, while predictions under RCP scenarios suggested more warming by mid-century

National climatic assessments indicate that coastal Ghana experienced a temperature increase of 0.9 °C from 1960 to 2001, with forecasts suggesting a rise of 1.1–1.3 °C by 2030 and up to 2.1 °C by 2050. In contrast, northern Ghana is warming at an accelerated pace, anticipated to reach 2.5 °C by 2050 (Wemegah et al., 2020; Buo et al., 2021; Kwofie et al., 2022; Olawoyin and Acheampong, 2023; Gyile et al., 2025; Gyasi-Addo, 2021; Johnson, 2024). These studies together highlight the influence of urban growth, deforestation, and ecological gradients on LST dynamics, with vegetation and water consistently acting as cooling agents compared to built-up and bare areas.

4.1.5. Comparison of MODIS Versus Landsat in Capturing LST Variability

Comprehensive literature reviews indicate that the majority of empirical LST retrievals for Ghanabright utilize Landsat thermal data, employing workflows that convert Digital Numbers (DN) to radiance, then to brightness temperature, and ultimately to LST, with emissivity derived from land cover classifications (e.g., Greater Accra/GAMA case studies from 1991, 2002, and 2017; selection of Landsat 8 Band 10 due to its reduced noise compared to Band 11).

These studies associate increasing LST with urban sprawl and vegetation depletion, revealing significant negative correlations between NDVI and LST in Accra/Sunyani, thereby illustrating the efficacy of Landsat for detailed urban heat mapping and the relationship between land cover and temperature (Wemegah et al., 2020; Gyile et al., 2025; Aduko et al., 2025).

In contrast, direct assessments of MODIS-based LST are rarely done. MODIS is characterized by a relatively coarse spatial resolution (~1 km) but offers high temporal frequency (twice-daily from Terra/Aqua) and standardized LST products that are beneficial for analysing regional or seasonal variability. Numerous reviews indicate that MODIS products, along with water vapor estimates, can enhance Landsat LST derivations or facilitate broader assessments of urban heat islands in Africa (Buo, 2019; Li et al., 2022). In summary, MODIS demonstrates superior temporal coverage and regional scale, whereas Landsat offers enhanced spatial detail for intra-urban heterogeneity, a trade-off consistently evident in the Ghanaian cases you assembled (e.g., intricate intra-city patterning in GAMA compared to the regional, frequent monitoring capabilities of MODIS).

Importantly, the review sources fail to offer a rigorous, direct accuracy comparison of MODIS and Landsat LST for identical locations and dates in Ghana. They demonstrate the application of Landsat for decadal urban evolution and LST mapping (e.g., GAMA 1986–2020; studies in Wa, Sunyani, and Accra) while recognizing MODIS for high-frequency monitoring at broader scales. Numerous entries emphasize prevalent caveats cloud interference, emissivity assumptions, and the necessity to synchronize spatial and temporal scales when analysing LST versus near-surface air temperature further highlighting why many Ghana-centric LST/UHI applications in your corpus favour Landsat's spatial resolution and subsequently advocate for sensor integration when practicable (e.g., MODIS for continuous time series; Landsat for micro-scale mapping).

4.1.6. Synthesized Results from the Meta-Analysis

The synthesis findings from the meta-analysis reveal that LSTs have been escalating across Africa, including Ghana, with a heightened intensity of UHI in several locations. Accra has notably undergone an increase in surface urban heat intensity due to the dual stresses of increasing urbanization and climate change. This tendency reflects findings from several African cities, including Addis Ababa, Akure, Dar es Salaam, Kampala, Khartoum, and Nairobi, with Cairo being the sole exception where a decline was seen. The results indicate that the majority of research uniformly documents rising temperatures, suggesting that Africa's expanding urban populace would encounter more heat stress in the future (Li et al., 2022; Fotso-Nguemo et al., 2023; Rohat et al., 2019).

The meta-analysis identified LULC change as the principal cause of increases in LST and UHI effects. The proliferation of constructed surfaces and the depletion of vegetation or aquatic environments diminish natural cooling mechanisms, thereby increasing LST. Harare witnessed a 92% augmentation in high-density built-up areas, a 75.5% diminution in open spaces, and a concomitant temperature increase of 1–2 °C (Mushore et al., 2017). Additional contributing elements encompass urban morphology, construction materials such as asphalt and corrugated metal, and diminished ventilation, while local circumstances like altitude, coastal effects, and air quality further alter heat intensities (Mohajerani et al., 2017; Imran, 2021). Methodologically, the majority of investigations utilize satellite remote sensing, with MODIS delivering high temporal resolution (bi-daily, about 1 km) and Landsat supplying precise spatial information (approximately 30 m, 16-day return interval). Both are frequently integrated with ground data to enhance dependability (Wu et al., 2012; Hazaymeh and Hassan, 2015).

Evidence from Accra, Ghana, demonstrates the extent of land use and land cover shifts that underpin these findings. From 1991 to 2015, forest cover decreased from 34.2% to 6.0%, grasslands diminished, and urban areas nearly quadrupled, resulting in elevated LST and exacerbated surface urban heat islands (SUHI) (Eshun et al., 2021; Mante, 2020). Research indicates that, even within identical local climatic zones (LCZ), the presence of substantial shade trees or other vegetation has quantifiable cooling effects, hence underscoring the function of urban greenery as a mitigation strategy (Wong et al., 2021). Notwithstanding these insights, the review underscores that West Africa is inadequately represented in UHI and LST studies relative to Asia and North America, resulting in considerable knowledge deficiencies in spatial and temporal coverage, as well as in comprehending the vulnerabilities of informal settlements (Li et al., 2024; Benaomar and Outzourhit, 2024).

The combined data ultimately associate increasing LST and UHI effects with significant human hazards, such as heat-related ailments, diminished productivity, and pressure on water and energy infrastructures. Future forecasts indicate that by 2100, hundreds of millions of urban people in Africa may face extended high heat episodes, a situation exacerbated by the urban heat island effect (Huang et al., 2019; Rohat et al., 2019). In rapidly urbanizing environments like Ghana, our findings underscore the critical necessity to incorporate climate-sensitive urban design, enhance green infrastructure, and rectify data deficiencies through localized and socio-economically inclusive research.

4.2. Discussion

4.2.1. Linking LST Trends to Urbanization, Land Use Changes, and Climate Resilience

Urban sprawl, the substitution of flora with impermeable surfaces, and the exacerbation of SUHI have been extensively recorded. Analyses of African cities, including Accra, Addis Ababa, Dar es Salaam, and various South African urban centers, indicate that urban cores exhibit higher temperatures than their peripheries, as dense built environments enhance heat retention, whereas green and blue spaces offer cooling advantages (Li et al., 2022; Nega and Balew, 2022). Data from Gaborone, Botswana, demonstrates that regions of settlement growth exhibit significant increases in both daytime and overnight LST, whereas major water bodies undergo daytime warming during drought conditions but suffer evening cooling (Akinyemi et al., 2019).

LULCC significantly influences LST variability, as bare land and urban regions constantly exhibit the highest temperatures, whereas vegetated and wetland areas maintain milder temperatures owing to evapotranspiration (Nega and Balew, 2022). Vegetation indices, such as NDVI, have a negative correlation with LST, but built-up indices, such as NDBI, demonstrate a positive correlation (Nega and Balew, 2022). Irrigated agricultural areas mitigate daytime LST, but deforestation, loss of vegetation, and the proliferation of impermeable surfaces intensify warming (Piao et al., 2019; Akinyemi et al., 2019).

Extensive teleconnections, such as ENSO, influence LST. Occurrences such as the 2015 El Niño and the 2007 La Niña corresponded with inflection points in LST changes in Botswana (Akinyemi et al., 2019). Droughts exacerbate rises in LST, particularly over water bodies experiencing reduced levels, as evidenced by the Gaborone Dam (Akinyemi et al., 2019). Mineral dust in the Sahel alters radiative fluxes and reduces diurnal LST ranges, hence facilitating warming (Nicholson, 2001). Forecasts indicate that East African cities are expected to encounter heightened heat risks, although cities in West and Central Africa are among the most vulnerable to intense heat (Li et al., 2022).

Accra, Ghana, has a growing urban heat island effect, along with national warming anomalies observed during the early 2000s. Accelerated urban growth, reduction of vegetation, and climatic fluctuations all exacerbate elevated surface temperatures and increasing urban heat loads (Li et al., 2022; Nega and Balew, 2022).

4.2.2. Contrast of African/Ghanaian Trends with Other Regions

Africa, exemplified by Ghana, is experiencing rapid urbanization, resulting in more pronounced and widespread warming signals compared to those often observed in mid-latitude, well-controlled cities. Globally, nearly 90% of anticipated urban expansion will occur in Asia and Africa, with African cities experiencing rapid and frequently unplanned growth. Coastal metropolitan areas in West Africa, such as Accra, are particularly vulnerable to storm surges and rain-induced flooding, as well as extreme heat risks projected to exceed historical levels significantly (e.g., 20–52 times greater exposure by the 2090s across major African cities). Less than 5% of published urban climate studies concentrate on African cities, despite the increasing surface urban heat island effect in Ghana, indicating a discrepancy between risk and study attention (Li et al., 2022; Aduko et al., 2025).

In Accra, Ghana's largest metropolitan area, the intensity and geographical configuration of urban warming diverge from the patterns often observed in several temperate cities. The Surface Urban Heat Island Magnitude (SUHIM) in Accra and Kumasi was found to surpass that of a European comparison group, even during the 2016 heat wave in Europe. Conversely, Berlin's air-based Surface Urban Heat Island Intensity (SUHII) may exceed the values observed in Ghana. The authors attribute these discrepancies to climatic zones and urban configurations, highlighting the capacity of tropical cities to experience significant surface heat loads despite variations in air-UHI comparisons (Buo, 2019). Geographically, Accra’s LST distribution resembles a "dissected plateau" characterized by dispersed hot areas associated with urban populations, in contrast to the domeshaped, centrally peaked UHI often seen in mid-latitude cold-temperate cities (Olawoyin and Acheampong, 2023).

Over a span of 29 years, the Greater Accra Metropolitan Area (GAMA) experienced a temperature increase of approximately +4.07 °C in developed regions, which is comparable to Islamabad's ~+3.8 °C and aligns with trends observed in Delhi. However, GAMA's rate of warming surpasses the widely referenced average rate of ~0.32 °C per decade, likely due to urban expansion outpacing population growth and the substitution of vegetation with impermeable surfaces.

The rankings of LST by land-cover type (built-up > water > bare > forest) correspond to worldwide cities, and the established cooling relationship between vegetation (NDVI) and LST persists. Two distinct nuances pertinent to Ghana are evident: even fragmented urban green spaces provide significant cooling effects, in contrast to the elevated coverage thresholds observed in Beijing, and water bodies within the GAMA experienced a temperature increase of approximately +4.1 °C, likely attributable to pollution, shallowness, proximity to heat-absorbing structures, diminished flow/area, and rising sea temperatures mitigating the conventional urban-cooling function of aquatic environments (Gyile et al., 2025).

Land-cover alterations and governance capabilities elucidate why Ghana's surface warming indicators frequently exhibit more intensity than those in several North American or European cities. In Accra, developed land increased from 55.1% to 83.79% between 1991 and 2018, while green space decreased from 41% to 15%; Kumasi had an even more rapid decline in urban green space throughout the late 2000s. These changes diminish carbon sequestration and ecosystem services while exacerbating land surface temperatures, whereas urban areas in places with ongoing reforestation or robust green infrastructure policies can maintain or mitigate surface temperatures (Aduko et al., 2025; Aka et al., 2023).

The disparities in institutions and data exacerbate the divide. Ghanaian and other African planning institutions are characterized by inadequate resources and poor coordination, undermining enforcement of regulations concerning urban sprawl, setbacks, and green-space preservation, contrasting with the more integrated planning controls and climate adaptation strategies found in many European and North American contexts. Africa's limited observational networks and model inadequacies, such as those concerning the West African monsoon, increase uncertainty and hinder localized heat-risk management compared to regions with extensive, long-term meteorological data (Aduko et al., 2025; Haltermann and Tischler, 2020; Aka et al., 2023).

Wider land-use pressures also differ. Africa's deforestation rate is approximately twice that of the global average (≈4 million ha yr^{-1}), exacerbating regional surface-energy and hydroclimatic responses; conversely, certain regions in North America and Europe have reversed this trend through forest recovery and conservation, which contribute to cooler surfaces and heat mitigation efforts (Baffour, 2024).

Ultimately, the findings from the Accra region on the determinants of heat align with world physics dense urban structures and extensive impervious surfaces elevate LST and urban heat island effects, yet the social exposure presents a distinct profile: In tropical West African cities, air-conditioning is often unattainable for many individuals and can exacerbate street-level heat when utilized, disproportionately impacting lower-income residents; this issue of equity is typically less pronounced in higher-income, temperate-zone cities (Buo, 2019; Wemegah et al., 2020).

4.2.3. Recommendation Strategies for Urban Planning, Agriculture and Climate Resiliency

4.2.3.1. Urban planning

Prioritize the enforcement of green and blue infrastructure while integrating LST data into development choices. Enhance collaboration among planning authorities, implement zoning regulations to prevent unregulated sprawl, and incorporate parks, green roofs, and urban trees in both new and renovated neighbourhoods to alleviate urban heat island effects and enhance thermal comfort (Gyasi-Addo and Bennadji, 2020a; Gyasi-Addo and Bennadji, 2020b; Oduro et al., 2025).

Augment this with "sustainable and economical" housing, enhanced land-use regulations in heat-prone areas, and intentional incorporation of water bodies and green corridors, acknowledging that dense urban forms can exacerbate urban heat islands without specific cooling interventions (Wemegah et al., 2020). Establish the regular use of LST estimates and forecasts (e.g., ANN/MARS outputs) to locate heat-sensitive facilities, inform material selections, and schedule interventions; these models enhance heat-risk prediction for planners (Peprah et al., 2025a).

Integrate physical initiatives with public awareness, climate-adaptive urban design (such as shaded pathways, reflecting materials, and natural ventilation), enhanced drainage and water-harvesting systems, and cross-sector collaborations to ensure sustained implementation (Gyasi-Addo and Bennadji, 2020a).

4.2.3.2. Agriculture

Safeguard arable land, integrate climate-smart agriculture (CSA), and manage water resources with more intention. Incorporate LST measures into seasonal determinations (crop selection, irrigation scheduling, pest risk assessment) and agricultural practices (Peprah et al., 2025a). Implement Climate-Smart Agriculture practices mulching, low tillage, legume intercropping, drought-resistant cultivars (particularly in savannah regions), with agroforestry and soil conservation structures to mitigate heat and rainfall variability (Oduro et al., 2025).

Invest in localized rainwater gathering and community reservoirs to mitigate dry periods and sustain crops, in accordance with the existing "one-district, one-dam" initiative (Oduro et al., 2025). Cease the conversion of agricultural and forest areas through comprehensive land-management strategies; previous unsustainable practices have resulted in macroeconomic losses, highlighting the consequences of inactivity (Frimpong et al., 2022).

4.2.3.3. Climate resilience

Concentrate on urban heat island abatement, integrated land-water management, specific health interventions, and community-driven execution. Mitigating urban heat through green and blue infrastructure, together with more stringent land-use regulations, diminishes extremes, risks, energy consumption, and pollution (Wemegah et al., 2020). Implement a comprehensive resilience program that prioritizes LST management, integrating land and vegetation stewardship with water security measures (such as rainwater harvesting and reservoir storage) and community involvement (Oduro et al., 2025). Enhance public health readiness: convey heat-related dangers, equip healthcare professionals for heat stress and respiratory challenges, mitigate vector-borne threats (e.g., malaria), and protect drinking and irrigation water supplies as rising temperatures strain water resources (Frimpong et al., 2022). Implement collaborative delivery among local government, NGOs, and communities, ensuring the protection of coastal livelihoods (marine safety) and cultural assets in the context of climate-induced displacement (Baffour, 2024).

4.2.3.4. Ghana's context

The recommendations are based on evidence from UHI studies in Accra and Kumasi, as well as national climate analyses. They integrate immediate cooling strategies (such as trees, water, and albedo), structural reforms (including enforcement, zoning, and drainage), risk intelligence (LST-driven planning and CSA), and collaborative efforts with communities and health systems. These solutions directly address the factors you identified: urban growth, vegetation degradation, and heat intensification, while promoting the Sustainable Development Goals related to urban areas, climate, and land use. (Gyasi-Addo and Bennadji, 2020a; Wemegah et al., 2020; Oduro et al., 2025; Frimpong et al., 2022; Peprah et al., 2025a)

4.2.4. Addressing Gaps and Future Research

4.2.4.1. Continental and regional gaps that shape the Ghana Agenda

Recent evaluations indicate a pronounced geographic bias, characterized by a scarcity of research in West and East Africa, a lack of multi-city and multi-climate-zone comparisons, and an excessive dependence on surface urban heat island (SUHI) data obtained from remote sensing rather than air-temperature urban heat island metrics. Research on the influence of urban morphology, blue-green infrastructure, and socio-economic sensitivity on heat is relatively limited, particularly with low-income populations (Li et al., 2022).

4.2.4.2. Ghana/Accra-Specific blind spots

The literature in Greater Accra emphasizes the necessity for micro-scale urban climate investigations, particularly concerning station siting impacts between Tema and Accra airport, and advocates for thorough assessments of mitigation strategies, including green infrastructure, affordable and sustainable housing, and stricter land-use regulations, rather than merely endorsing them (Wemegah et al., 2020). In GAMA, current analyses frequently emphasize the dry season and a limited range of indicators, so they constrain their capacity to encompass seasonal and diurnal oscillations, along with other biophysical influences. Subsequent investigations ought to incorporate multi-seasonal data, evaluate a wider array of indices, link socio-economic factors to LST, and examine anomalous phenomena such as the thermal increase of urban water bodies attributed to pollution, shallow depth, or proximity to heat-absorbing infrastructures (Gyile et al., 2025).

4.2.4.3. Methods and data gaps

A forward path entails employing high-resolution, high-cadence sensing technologies such as Sentinel-2 for LULC and Sentinel-3 or MODIS for LST. This approach integrates LST with atmospheric measurements from stationary or mobile transects to differentiate between surface and air UHI, while incorporating predictive modelling via urban climate and GIS simulations to evaluate cooling strategies before implementation. There is a necessity for vulnerability mapping that incorporates LST with demographic and health data, in addition to analyses of governance limitations that hinder implementation (Olawoyin and Acheampong, 2023). At the meta-scale, bibliometric analyses reveal the limitations of database scope and the underrepresentation of themes like evapotranspiration, urban sprawl, and runoff, while advocating for the implementation of sophisticated models such as FLUS, LCM, CA-Markov, and PLUS, alongside AI and ML methodologies on Google Earth Engine. Funding and South–South coordination are essential to rectify regional under-representation (Afuye et al., 2024).

4.2.4.4. Modelling gaps for Ghana case studies

Case studies in Ghana frequently employ a restricted set of climate drivers, such as monthly averages of temperature, wind speed, relative humidity, and precipitation, seldom investigating diurnal or short-term variability, and typically compare machine learning architectures without incorporating broader baselines like NWP, SVM, LSSVM, CART, DT, or ARIMA. The subsequent steps should entail hybrid modelling that integrates machine learning with statistical or physics-based methodologies, broadening predictor sets to encompass variables such as solar radiation and wind direction, and performing cross-regional validation across Ghana's ecological zones (Peprah et al., 2025a).

4.2.4.5. Future research priorities for Ghana

The forthcoming research agenda for Ghana must emphasize multi-scale and multi-source heat monitoring by integrating Sentinel-2/3 and Landsat with in-situ air temperature networks and mobile transects to accurately capture diurnal and seasonal variations, while distinctly differentiating surface from air urban heat islands to enhance the correlation between satellite signals and human exposure (Olawoyin and Acheampong, 2023; Li et al., 2022). A further priority is the integration of coupled land use/land cover (LULC) and socio-economic modeling, which incorporates urban growth models like FLUS, LCM, CA-MC, and PLUS alongside demographic, mobility, building stock, tenure, and poverty data to quantify determinants and evaluate planning alternatives that mitigate LST while enhancing equity (Afuye et al., 2024). Furthermore, research must transition from theoretical advocacy to empirically validated performance evaluations of trees, parks, riparian buffers, wetlands, cool roofs, pavements, and urban agriculture across various local climate zones, documenting their temperature effects and ancillary benefits regarding flood mitigation, air quality enhancement, and biodiversity (Li et al., 2022; Wemegah et al., 2020).

A crucial objective is to delineate heat-health risks and energy or cooling costs to pinpoint areas of thermal injustice, as well as to quantify economic losses in productivity and energy consumption to bolster the rationale for interventions (Olawoyin and Acheampong, 2023; Li et al., 2022). Urban water bodies represent an inadequately researched phenomenon, necessitating an examination of the reasons behind the increased LST in urban lagoons and rivers, as well as the potential of nature-based cooling solutions, such as restoration and shade, to alleviate these impacts (Gyile et al., 2025).

Ultimately, coordinated comparative studies among Accra, Kumasi, Tamale, and Tema, as well as with peer cities in West Africa, should be established to mitigate regional bias and formulate transferable design principles for tropical cities (Li et al., 2022). These should implement hybrid machine learning–physics methodologies, evaluate more comprehensive predictor sets encompassing radiation and wind direction, document model generalization across various zones and seasons, and guarantee transparency via pre-registration and open access to data and code to facilitate replication and synthesis (Peprah et al., 2025; Afuye et al., 2024).

5. Conclusion

This analysis affirms that Africa, namely Ghana, is undergoing rapid warming, with urban regions exhibiting significant intensification of LST attributed to deforestation, urban expansion, and alterations in land use. Remote sensing instruments like Landsat and MODIS have demonstrated their utility in monitoring these processes, albeit each entails compromises in spatial and temporal resolution. The results highlight the immediate necessity for tailored climate adaptation measures in Ghana, particularly in rapidly developing urban and coastal areas. Evidence repeatedly demonstrates that plant and aquatic environments function as essential mitigators of warming, whereas developed and barren regions intensify heat stress. Integrating remote sensing with socio-economic and ecological data is essential for improving resilience measures, addressing data deficiencies, and effectively connecting scientific knowledge to policy implementation.

6. Recommendation

To alleviate LST-related hazards, urban planning in Ghana must emphasize green and blue infrastructure, enforce land-use restrictions, and incorporate LST data into zoning and development choices. Agricultural plans must use climate-smart methods, like agroforestry, mulching, and drought-resistant crops, while protecting existing arable land from unsustainable conversion. Interventions for climate resilience should prioritize community-based adaptation, augmented health readiness for heat stress, and better water resource management. Research must extend to under-explored regions, namely Ghana's coastal and northern ecological zones, employing integrated multi-sensor monitoring and hybrid modelling methodologies. Policymakers must connect land system transition dynamics to health equality and economic productivity to enhance the justification for sustainable land management and climate adaptation.

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Conflict of Interest

The author asserts the absence of any conflicts of interest regarding the content of this research.

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