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Assessing the Impact of Land Use and Land Cover Change on Land Surface Temperature in Africa: A Systematic Review and Meta-Analysis with a Focus on Ghana

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Abstract
This systematic review and meta-analysis investigated the effects of Land Use and Land Cover (LULC) alterations on Land Surface Temperature (LST) throughout Africa, particularly emphasising Ghana. The research utilised the PRISMA procedure to systematically discover, assess, and summarise 52 peer-reviewed papers published from 2000 to 2025. The review utilised Landsat, MODIS, and Sentinel datasets to quantify temperature fluctuations associated with significant land use and land cover shifts, including urban growth, deforestation, and agricultural intensification. The meta-analytic findings indicated that metropolitan regions were, on average, 2.8 °C warmer than vegetated surfaces, with deforestation and agricultural conversion causing temperature rises of 1.6–2.3 °C. Ghana demonstrated a greater mean difference of 3.1 °C relative to the continental norm, mostly because of fast urbanisation in Accra and Kumasi. Regression analyses revealed robust connections between Normalised Difference Built-up Index (NDBI) and LST, with coefficients varying from +12.15 °C to +24.05 °C per unit increase, hence affirming anthropogenic influences on surface warming. Vegetation indices (Normalised Difference Vegetation Index (NDVI)) exhibited an inverse correlation with LST, highlighting the cooling effect of vegetation. The results reveal significant geographical variability, with hotspots located in Greater Accra, Kumasi, Northern Ghana, and the Savannah Transitional and Pra Basin regions. The study suggests that the loss of forest, unrestrained urban expansion, and degradation caused by mining are increasing thermal stress throughout Ghana. It advocates for cohesive land-use regulations, reforestation, and climate-adaptive agriculture to alleviate surface warming and bolster national resilience in relation to Sustainable Development Goals 11, 13, and 15.

Keywords: Land Use Land Cover Change, Land Surface Temperature, Africa, Systematic Review, Meta-Analysis, Ghana

1. Introduction

Africa is seeing rapid urbanisation, significantly impacting local and regional climates. This rapid transition is profoundly changing the interaction between land and atmosphere, generating increasingly pressing difficulties for sustainable development, public health, and climate resilience. Comprehending and measuring these alterations is vital for evidence-based policy actions; nevertheless, thorough regional assessments are significantly constrained. Land Use and Land Cover Change (LULCC) signifies a major anthropogenic alteration of Earth's terrestrial surface, comprising two interconnected aspects: Land Cover (LC) the physical and biological attributes of the surface, such as forests and aquatic systems and Land Use (LU) the socioeconomic functions for which humans utilize these surfaces, including agriculture and habitation (Lambin et al., 2003; Tizora et al., 2016).

This divergence is significant as the same land cover can fulfil various functions, and comprehending both aspects is crucial for formulating successful management techniques. In Africa, the prevailing trend is the extensive transformation of natural ecosystems into anthropogenic systems, influenced by a multifaceted interaction of factors (Herrmann et al., 2020; Bullock et al., 2021). The primary drivers consist of agricultural expansion, the most significant factor, urbanisation, wood exploitation for fuel, and infrastructural development (Bullock et al., 2021; Mugo et al., 2020). These are facilitated by fundamental factors like rapid population increase, poverty, market prospects, ambiguous land tenure, and inadequate environmental governance (Herrmann et al., 2020; Mekuyie et al., 2018; Betru et al., 2019).

The correlation between LULCC and LST is essential, direct, and causative. The substitution of natural vegetation with impermeable materials such as asphalt and concrete typically results in a reduction of surface albedo and an increase in heat capacity, hence enhancing the absorption and retention of solar radiation (Karakus, 2019; Heisler and Brazel, 2010). The depletion of vegetation and soil sealing significantly diminishes evapotranspiration, a natural cooling mechanism, altering the surface energy balance from latent heat flow (cooling) to sensible heat flux (direct air heating) (Imhoff et al., 2010; Zhou and Wang, 2010).

Urban regions also produce anthropogenic heat via transportation, industrial activities, and structures. The series of biophysical changes results in the Urban Heat Island (UHI) phenomenon, wherein urban regions exhibit markedly higher temperatures than adjacent rural areas, as seen by satellite-derived LST, indicating Surface Urban Heat Islands (SUHI) (Zhou et al., 2013). Various land cover types display unique thermal signatures: urban areas and bare land serve as heat sources with increased LST, whereas vegetation and water bodies function as heat sinks with reduced temperatures, relationships consistently measured through robust correlations with vegetation and built-up indices (Sarif et al., 2020; Karakus, 2019). Local alterations can initiate extensive feedback loops; land degradation in the Sahel decreases evaporation and elevates lower atmospheric temperatures, but deforestation reduces cooling aerosols, resulting in net positive radiative impacts over the continent (Boone et al., 2016; Adeyeri, 2025).

Africa's status as a worldwide focal point of environmental change renders it a vital area for LULCC-LST study. The continent is seeing the highest urbanisation rates worldwide, with West Africa anticipated to encounter warming significantly beyond the global norm (Frimpong et al., 2023; Baffour-Ata et al., 2021; Arfasa et al., 2023). Ghana illustrates these continental difficulties while presenting remarkable research prospects. Ghana, a prominent research centre ranked 16th worldwide in LULCC study influence, has significant LULCC-LST dynamics; the Greater Accra Metropolitan Area experienced a rise in built-up land to 72.53% by 2020, resulting in a 4.07°C increase in LST over recent decades (Afuye et al., 2024; Gyile et al., 2025). The nation's economy, predominantly dependent on natural resources such as cocoa and gold, engenders significant trade-offs between development and environmental sustainability, resulting in deforestation and land degradation (Kouassi et al., 2021; Gbedzi et al., 2022). Ghana exhibits distinct change intensities; however, its fundamental drivers and urban-rural dynamics reflect larger West African trends, suggesting that the findings may apply to other quickly expanding situations throughout the region.

Notwithstanding the increasing acknowledgement of these concerns, significant information deficiencies hinder effective solutions. LULCC in Africa results in considerable hydrological disturbances, biodiversity decline, habitat fragmentation, and jeopardises food security, while exacerbating health concerns due to excessive heat exposure (Yifru et al., 2021; Obubu et al., 2022; Abdeta et al., 2024). It directly contributes to local and regional temperature increases via UHI intensification and biogeophysical feedback mechanisms (Gyile et al., 2025; Boone et al., 2016).

The capacity to comprehensively comprehend and alleviate these effects is limited by enduring deficiencies in the evidence base. Current empirical research consistently illustrates robust relationships between LULCC and LST in African cities. Studies conducted in Accra and Kumasi, Ghana, alongside investigations in Ethiopia, Nigeria, and Botswana, establish a direct correlation between rapid urbanisation and significant increases in LST (Gyile et al., 2025; Mensah et al., 2020; Tsegaye, 2025; Njoku and Tenenbaum, 2022; Akinyemi et al., 2019). However, the aforementioned research disclose three significant shortcomings. Genuine statistical meta-analyses are significantly lacking due to methodological variability and data discrepancies in original research, hindering thorough quantification of impact sizes across different settings (Li et al., 2022; Wegbebu, 2023).

Secondly, research is predominantly concentrated on a limited number of countries, including South Africa, Ethiopia, and Nigeria, resulting in significant areas such as West and Central Africa being inadequately studied (Li et al., 2022; Vahid & Aly, 2025). The uneven use of satellite data sources, categorisation techniques, and temporal frameworks hinders comprehensive regional evaluation and comparison (Peprah, 2025; Barnieh et al., 2020). This disjointed state of information hinders the formulation of evidence-based policy at critical scales and restricts our comprehension of whether localised findings represent wider continental trends or context-specific oddities.

Addressing these gaps necessitates methodological innovation capable of synthesising diverse evidence while considering heterogeneity. Contemporary research utilises synergistic methodologies that integrate remote sensing, Geographic Information Systems (GIS), and statistical modelling. Landsat imaging delivers high-resolution data (30m) for intricate local analysis; however, MODIS supplies high-temporal-resolution data (1km) for extensive monitoring (Govender et al., 2022; Frimpong et al., 2024). GIS platforms provide data integration, geographical analysis, and visualisation (Yahaya, 2023; Vahid and Aly, 2025). Statistical methodologies encompass correlation and regression analysis, as well as sophisticated techniques such as Geographically Weighted Regression (GWR), which addresses geographical non-stationarity, and predictive machine learning models (Njoku and Tenenbaum, 2022; Wegbebu, 2023). Despite this methodological diversity, or possibly due to it, systematic synthesis by meta-analysis is lacking, indicating both a substantial deficit and an opportunity to showcase the viability of quantitative synthesis in this diverse subject.

This systematic review and meta-analysis directly tackle significant evidence deficiencies while contributing to continental climate action pledges under the Paris Agreement and Sustainable Development Goals. This study will synthesise previous data and perform a quantitative meta-analysis to deliver the inaugural thorough and statistically rigorous evaluation of the links between LULCC and LST across Africa, with specific findings for Ghana as a case study and potential model for analogous situations.

This study specifically aims to: (1) systematically review and synthesize existing research on LULC changes and their effects on LST across Africa, (2) perform a meta-analysis to quantify the relationships between particular LULC conversions and LST changes, including a subgroup analysis centred on Ghana to discern context-specific patterns, and (3) recommend evidence-based, region-specific mitigation strategies for sustainable land management and climate adaptation in Ghana and analogous rapidly developing contexts. These aims pertain to three fundamental research inquiries: What alterations have occurred in LULC patterns in Africa over the past few decades, and what are the primary socio-economic and environmental factors driving these changes? What is the extent of LST variation linked to significant LULC changes, such as urban growth and deforestation, throughout the continent? What context-specific reasons elucidate the discrepancies in LULC-LST connections between Ghana and continental patterns, and to what degree do Ghana's experiences reflect wider regional trends?

The results will yield practical, evidence-driven insights for policymakers, urban planners, and environmental managers in Ghana and adjacent nations to formulate successful land-use policies and climate adaptation plans. This research will demonstrate the feasibility of meta-analysis amid methodological heterogeneity, establishing a framework for future continental-scale environmental syntheses and enhancing both substantive knowledge and analytical methods in African climate change research.

2. Conceptual and Theoretical Framework

This study's conceptual and theoretical framework is based on the relationship between LULCC and LST, illustrating how human alterations of the Earth's surface disturb its natural energy balance and thermal dynamics. LULCC conceptually includes land cover, which refers to the biophysical characteristics of the Earth's surface (such as flora, soil, water, and built environments), and land use, which pertains to the human-directed goals for which land is managed or modified (including agriculture, urban development, mining, and forestry) (Lambin et al., 2003).

In Africa, swift population increase, agricultural development, and urbanisation have led to significant transformations of natural vegetation into human-dominated environments, greatly affecting land-atmosphere interactions (Herrmann et al., 2020; Bullock et al., 2021).

Theoretically, the relationship between LULCC and LST is dictated by the Surface Energy Balance (SEB) model, which delineates the distribution of incoming solar radiation into latent heat (used for evapotranspiration), sensible heat (which warms the air), ground heat storage, and human heat sources. This is mathematically expressed by *Equation 1* as:

$$N_R = H + LE + G + A \quad (1)$$

where; N_R denotes net radiation, H signifies sensible heat flow, LE represents latent heat flux, G indicates ground heat flux, and A refers to anthropogenic heat (Heisler and Brazel, 2010).

The substitution of vegetated or permeable surfaces with impervious materials like asphalt and concrete leads to a reduction in latent heat flux due to the suppression of evapotranspiration, while sensible and ground heat fluxes rise, causing increased surface and near-surface temperatures (Imhoff et al., 2010; Stathopoulou and Cartalis, 2009). This process establishes the theoretical foundation for the UHI and SUHI phenomena, as evidenced by satellite-derived LST data.

Empirical research has demonstrated a robust positive link between built-up indices (e.g., NDBI) and LST, as well as a negative correlation between vegetation indices (e.g., NDVI) and LST (Weng et al., 2004; Sarif et al., 2020). This demonstrates that the removal of vegetation diminishes shade and evapotranspiration, hence amplifying heat retention in urbanised and deforested regions. The process is exacerbated by human-induced heat emissions and intricate urban structures that retain radiation (Huang and Cadenasso, 2016).

In the African setting, the link between LULCC and LST is exacerbated by unregulated urbanisation, deforestation, and mining, resulting in increased local thermal anomalies. Ghana illustrates this phenomenon: in the Greater Accra Metropolitan Area, the developed area expanded from 30.6% in 1991 to 72.5% in 2020, resulting in a 4.07°C increase in LST, whereas Kumasi had a 4.16°C rise owing to comparable urban growth (Gyile et al., 2025; Mensah et al., 2020).

This study's conceptual and theoretical framework combines biophysical energy balance theory with the socio-ecological dynamics of land transformation, asserting that LULCC modifies surface energy fluxes, decreasing albedo and evapotranspiration while augmenting heat storage and anthropogenic heat, thus leading to systematic increases in LST. This framework directs the systematic review and meta-analysis by establishing a scientific foundation to assess the impact of various land transitions in Africa, especially Ghana, on spatial and temporal thermal variability, thereby informing sustainable land management and climate adaptation strategies (Fig. 1).

3. Materials and Methods

3.1. Study Area Description

Ghana (Fig. 2), situated in West Africa and covering an area of 238,540 km², serves as an optimal setting for analysing the correlation between LULCC and LST. The nation lies adjacent to Côte d'Ivoire, Burkina Faso, and Togo, and is bordered by the Gulf of Guinea, displaying a significant north-south environmental gradient that profoundly influences land use and land cover change dynamics (Tannor et al., 2018; Dzanku et al., 2021).

Southern Ghana features semi-deciduous forest zones with bimodal rainfall (125-175 cm annually) and comparatively fertile soils originating from the Paleoproterozoic Birimian Supergroup and related granitoid intrusions, whereas Northern Ghana shifts to Guinea and Sudan Savannah with unimodal rainfall (1000-1100 mm annually), less resilient soils, and distinct dry seasons from November to March (Addaney et al., 2021; Partey et al., 2020; Boadi et al., 2013).

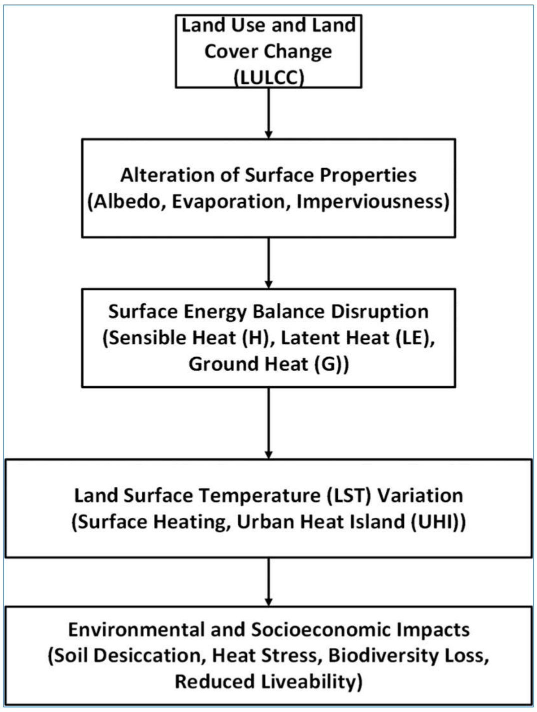

Fig.1. Flowchart illustrating the conceptual framework of the study

The climatic and geological variety, together with mean annual temperatures between 26°C and 36°C, which are anticipated to increase by 2°C by 2050, establishes unique land use potentials and thermal conditions throughout agroecological zones (Addaney et al., 2021; Osei-Nuamah and Appiah-Adjei, 2017).

The nation has seen significant LULCC due to agricultural growth, urbanisation, deforestation, and artisanal mining, resulting in a reduction in closed forest area by 46,000 hectares per year from 1990 to 2010 (Allotey et al., 2024).

Significant areas of concern encompass the Lake Bosomtwe basin, where forest cover diminished by 66.30% and developed land increased by 260.23% from 1986 to 2020, the Pra River Basin suffering severe land degradation due to gold mining in the Birimian gold belts, and major urban centers such as Accra and Kumasi, which are experiencing a rapid annual growth rate of 5.4%, leading to extensive urban sprawl and slum expansion (Allotey et al., 2024; Cobbinah and Korah, 2016; Donkor et al., 2006).

The processes of LULCC, notably the transformation of vegetated areas into agricultural lands, barren mining sites, and impermeable urban materials, significantly modify surface energy balances by diminishing evapotranspiration and augmenting heat absorption, consequently raising LST (Twerefou et al., 2011; Ali et al., 2021). The prevalent slash-and-burn agricultural system, the dependence on biomass energy by 60% of households, and deficiencies in environmental policy implementation (National Climate Change Policy 2013, REDD+ Strategy 2016-2035), despite well-meaning frameworks, establish a scenario where anthropogenic land use and land cover change drivers persist largely unregulated (Ali et al., 2021; Kipkoech et al., 2022).

The geological framework of Ghana, characterised by the metamorphosed Birimian and Tarkwaian rocks, Eburnean granitoids, and the sedimentary Voltaian Supergroup, significantly influences land surface temperature dynamics by affecting soil thermal properties, moisture retention, and land use patterns (Boadi et al., 2013; Forson et al., 2021). The northeast-southwest structural orientation established by the Paleoproterozoic Eburnean Orogeny (~2130-1980 Ma) generates distinct geomorphological provinces with differing heat capacities, while the presence of gold-rich greenstone belts directly influences land cover degradation associated with mining in the Ashanti and Sefwi Belts (Kazapoe et al., 2024). The distinctive characteristics of the 10.5 km diameter Bosumtwi impact crater further influence local differences in surface attributes (Boamah and Koeberl, 2003).

The amalgamation of climate variability (rising temperatures and erratic precipitation), rapid land use and land cover change (transitioning from forest to agriculture, natural landscapes to urban areas, and vegetated regions to barren land), geological influences on surface thermal characteristics, and the pronounced north-south developmental disparity (with Greater Accra and Ashanti regions possessing the majority of infrastructure while northern regions are inadequately served) positions Ghana as a pivotal area for the systematic examination of the impacts of land use and land cover change on land surface temperature (Tannor et al., 2018; Ichino and Nathan, 2013).

3.2. Methodology

3.2.1. Study Design

This systematic review and meta-analysis used the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) standards to investigate the effects of LULCC on LST across Africa, particularly in the Republic of Ghana. The review design was structured according to the PCC framework (Population, Concept, Context) to ensure a focused and relevant synthesis of evidence, where Population refers to LULCC types and remote sensing applications, Concept encompasses the evaluation of LST variations and thermal responses, and Context relates to African studies, specifically in Ghana.

3.2.2. Search Strategy

An exhaustive search strategy was developed to include the comprehensive array of LULC-LST connection research in Africa. The search queries were developed using key terms relevant to land use and land cover change, land surface temperature, thermal remote sensing, urban heat island phenomena, and geographic focus. Key phrases including "land use land cover change," "LULC change," "land cover conversion," "urbanization," "deforestation," "land surface temperature," "LST," "thermal," "surface temperature," "urban heat island," "UHI," "remote sensing," "thermal infrared," "satellite imagery," "Africa," and "Ghana" were combined using Boolean search operators "AND" and "OR."

The search terms were systematically employed across multiple academic databases, including Scopus, Web of Science, IEEE Xplore, ACM Digital Library, Google Scholar, ResearchGate, Academia.edu, and Africa Journal Online (AJOL), to ensure comprehensive coverage of both mainstream and African-focused publications (Table 1).

The literature review encompassed studies from 2000 to 2025 to chronicle the advancement of thermal remote sensing technologies and land use/land cover-land surface temperature research applications in African contexts.

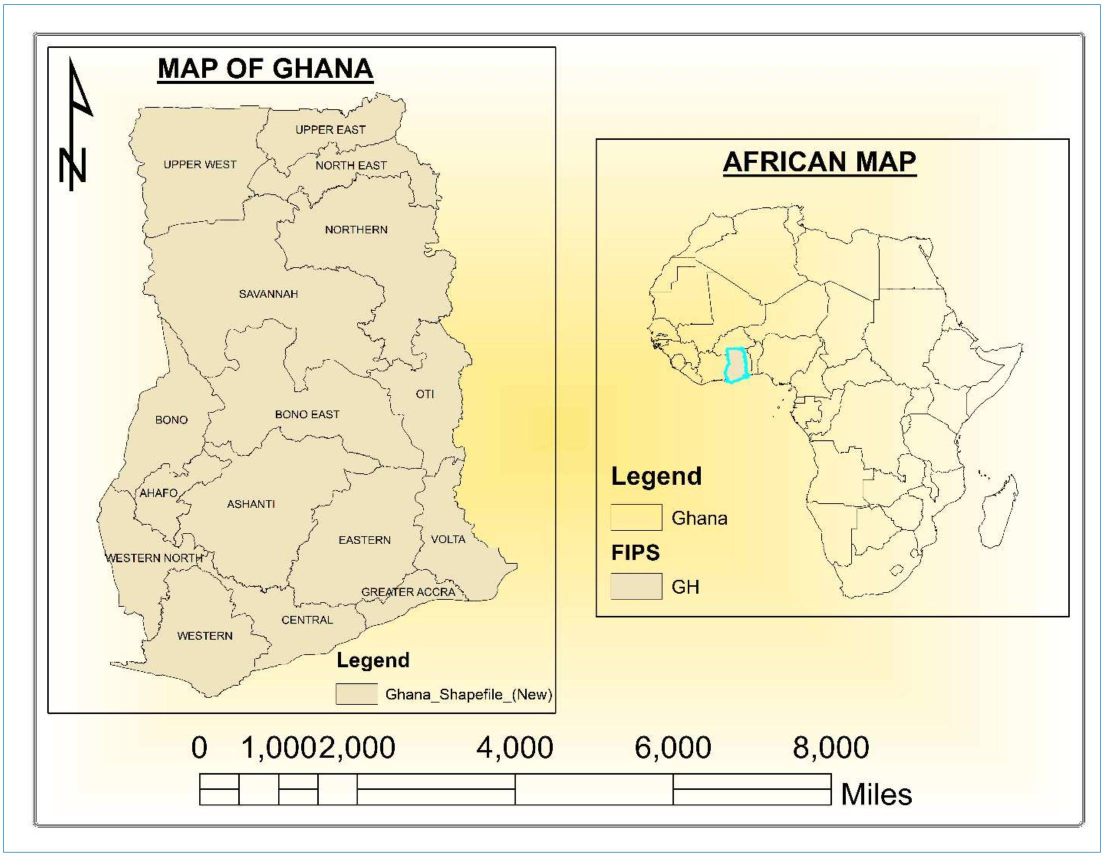

Fig. 2. Geospatial analysis of the study area

3.2.3. Study Selection Procedure

A systematic study selection method was implemented using PRISMA criteria to ensure transparency and repeatability. The selection process involved many separate screening steps conducted by thorough review, with discrepancies resolved by discussion and consensus. The preliminary screening focused on the pertinence of titles and abstracts, followed by an exhaustive assessment of full texts based on predefined inclusion and exclusion criteria. After the removal of duplicates using reference management software (Mendeley), studies underwent title and abstract screening.

During this phase, articles were dismissed for their irrelevance to the study objectives, mostly due to inadequate emphasis on LULC-LST interactions, absence of quantitative temperature evaluation, or geographic inapplicability. Full-text publications were meticulously assessed based on the inclusion and exclusion criteria, resulting in the removal of articles for various methodological and scope-related reasons. The final selection comprised publications that met all inclusion criteria and provided adequate methodological description for quality assessment and data synthesis.

3.2.4. Data Extraction

A comprehensive data extraction method was specifically designed for research examining the correlation between Land Use and Land Cover (LULC) and Land Surface Temperature (LST). Thoroughly reviewed separately extracted data utilising a standardised form, and any discrepancies were resolved by discussion and consensus. The extraction framework included traditional remote sensing research characteristics and particular methodological elements pertinent to comprehending temperature-land cover correlations and their relevance in environmental monitoring.

The research features encompassed the author(s), publication year, and study location, with particular emphasis on specific locations within Ghana and Africa. The study design, research objectives, geographic scope, geographical resolution, temporal coverage, study duration, and seasonal factors were also documented. The climate zone and ecological context were reported to ensure a thorough grasp of the environmental conditions of each investigation. Specifications for remote sensing data were rigorously derived for LULC and LST data. Concerning LULC data, specifics like the satellite platforms employed for classification (e.g., Landsat, Sentinel-2, SPOT), utilised spectral bands, geographical and temporal resolution, classification methodologies, and accuracy evaluations were documented. The framework encompassed land cover categorisation strategies, the quantity and kinds of LULC classes, together with the change detection methodologies and examined time periods.

Table 1. Search strings used in various databases

No	Database	Search String
1	Google Scholar	("Land Use Land Cover Change" OR "LULC Change" OR "Land Cover Change" OR "Urbanisation" OR "Deforestation") AND ("Land Surface Temperature" OR "LST" OR "Surface Temperature" OR "Thermal" OR "Urban Heat Island" OR "UHI") AND ("Remote Sensing" OR "Satellite Imagery" OR "Thermal Infrared" OR "MODIS" OR "Landsat") AND (Africa OR Ghana OR "West Africa" OR "Sub-Saharan Africa")
2	IEEE Xplore	("Land Use Land Cover Change" OR "LULC Change" OR "Land Cover Change" OR "Urbanisation" OR "Deforestation") AND ("Land Surface Temperature" OR "LST" OR "Surface Temperature" OR "Thermal" OR "Urban Heat Island" OR "UHI") AND ("Remote Sensing" OR "Satellite Imagery" OR "Thermal Infrared" OR "MODIS" OR "Landsat") AND (Africa OR Ghana OR "West Africa" OR "Sub-Saharan Africa")
3	Scopus	("Land Use Land Cover Change" OR "LULC Change" OR "Land Cover Change" OR "Urbanisation" OR "Deforestation") AND ("Land Surface Temperature" OR "LST" OR "Surface Temperature" OR "Thermal" OR "Urban Heat Island" OR "UHI") AND ("Remote Sensing" OR "Satellite Imagery" OR "Thermal Infrared" OR "MODIS" OR "Landsat") AND (Africa OR Ghana OR "West Africa" OR "Sub-Saharan Africa")
4	Web of Science	("Land Use Land Cover Change" OR "LULC Change" OR "Land Cover Change" OR "Urbanisation" OR "Deforestation") AND ("Land Surface Temperature" OR "LST" OR "Surface Temperature" OR "Thermal" OR "Urban Heat Island" OR "UHI") AND ("Remote Sensing" OR "Satellite Imagery" OR "Thermal Infrared" OR "MODIS" OR "Landsat") AND (Africa OR Ghana OR "West Africa" OR "Sub-Saharan Africa")
5	ACM Digital Library	("Land Use Land Cover Change" OR "LULC Change" OR "Land Cover Change" OR "Urbanisation" OR "Deforestation") AND ("Land Surface Temperature" OR "LST" OR "Surface Temperature" OR "Thermal" OR "Urban Heat Island" OR "UHI") AND ("Remote Sensing" OR "Satellite Imagery" OR "Thermal Infrared" OR "MODIS" OR "Landsat") AND (Africa OR Ghana OR "West Africa" OR "Sub-Saharan Africa")
6	ResearchGate	("Land Use Land Cover Change" OR "LULC Change" OR "Land Cover Change" OR "Urbanisation" OR "Deforestation") AND ("Land Surface Temperature" OR "LST" OR "Surface Temperature" OR "Thermal" OR "Urban Heat Island" OR "UHI") AND ("Remote Sensing" OR "Satellite Imagery" OR "Thermal Infrared" OR "MODIS" OR "Landsat") AND (Africa OR Ghana OR "West Africa" OR "Sub-Saharan Africa")
7	Academia.edu	("Land Use Land Cover Change" OR "LULC Change" OR "Land Cover Change" OR "Urbanisation" OR "Deforestation") AND ("Land Surface Temperature" OR "LST" OR "Surface Temperature" OR "Thermal" OR "Urban Heat Island" OR "UHI") AND ("Remote Sensing" OR "Satellite Imagery" OR "Thermal Infrared" OR "MODIS" OR "Landsat") AND (Africa OR Ghana OR "West Africa" OR "Sub-Saharan Africa")
8	AJOL	("Land Use Land Cover Change" OR "LULC Change" OR "Land Cover Change" OR "Urbanisation" OR "Deforestation") AND ("Land Surface Temperature" OR "LST" OR "Surface Temperature" OR "Thermal" OR "Urban Heat Island" OR "UHI") AND ("Remote Sensing" OR "Satellite Imagery" OR "Thermal Infrared" OR "MODIS" OR "Landsat") AND (Africa OR Ghana OR "West Africa" OR "Sub-Saharan Africa")

Regarding LST data, information was collected on satellite thermal sensors, including Landsat TM/ETM+/TIRS, MODIS, ASTER, and Sentinel-3. Included were requirements for thermal bands, spatial resolution, land surface temperature retrieval algorithms (e.g., Split-Window, Single-Channel, Mono-Window, and Radiative Transfer Equation), methods for atmospheric and emissivity correction, temporal resolution, acquisition times, and preprocessing techniques.

The temperature assessment encompassed several analytical elements, including LST statistics categorised by land cover type (mean, median, range, and standard deviation), temperature differentials among LULC classes, temporal temperature fluctuations linked to land cover transitions, and seasonal temperature variations across different land cover types. Where relevant, metrics on urban heat island intensity and geographic temperature distributions, including hot spot assessments, were also obtained.

The published statistical analysis techniques included correlation analyses (Pearson and Spearman) between LULC and LST, regression models (linear, multiple, and spatial regression), and analyses of variance (ANOVA) to assess temperature differences among land cover classes. Supplementary methodologies, including geographic statistics (Moran's I, Getis-Ord Gi, and spatial autocorrelation), time series analyses of temperature trends, effect size assessments, and statistical significance tests were also evaluated.

The ground truth and validation data concentrated on the sources utilized for LULC validation, LST validation methodologies (such as comparisons with meteorological stations and field measurements), accuracy assessment outcomes, and quality control protocols.

Ultimately, the computational and implementation specifics encompassed the software and tools utilised, including ENVI, ERDAS, ArcGIS, QGIS, Google Earth Engine, R, and Python. The paper also included implementation obstacles, suggested solutions, and concerns related to data availability or accessibility identified in the research examined.

3.2.5. Quality Assessment

The quality of each study was evaluated utilising a modified iteration of the Quality Assessment of Diagnostic Accuracy Studies (QUADAS-2) framework, especially tailored for investigations concerning the correlation between LULC and LST. This assessment concentrated on four primary domains: the dependability of LULC categorisation, the approach utilised in LST retrieval, the thoroughness of statistical analysis, and the clarity of reporting.

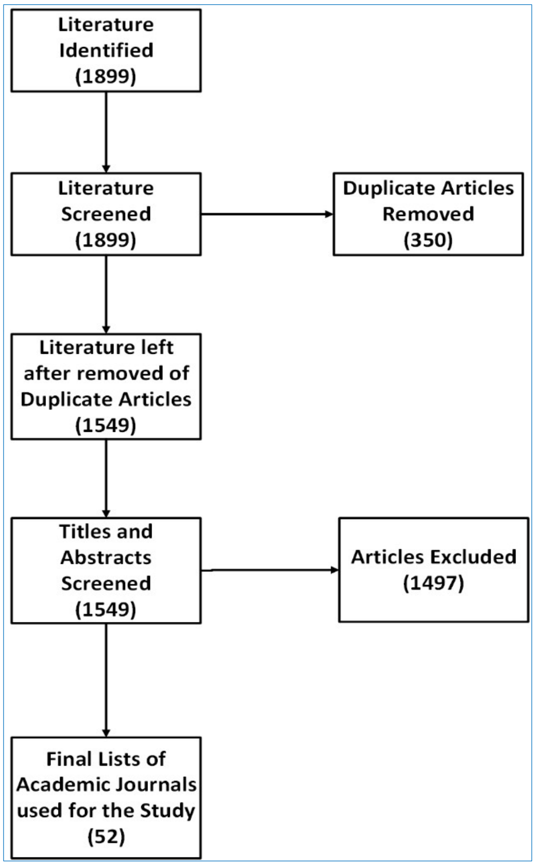

Fig. 3. PRISMA flow diagram for the selection process of studies

In assessing the quality of LULC classification, emphasis was placed on the adequacy of training data, the suitability of classification techniques, the thoroughness of accuracy evaluations, and the temporal congruence of LULC data with LST observations. The evaluation of LST retrieval quality encompassed the appropriateness of the LST retrieval algorithm, the implementation of atmospheric and emissivity corrections, validation against ground-based measurements, and the temporal representativeness of the retrieved data.

The statistical analysis domain assessed the appropriateness of the statistical methods used for the research objectives, the adequacy of sample sizes, the effective management of confounding factors, and the execution and reporting of significance testing. The evaluation of reporting transparency involved a thorough examination of methodological clarity, exhaustive result reporting, reproducibility of reported findings, and the disclosure of any research limitations.

Based on these criteria, studies were granted quality ratings of High, Medium, or Low, indicating their methodological robustness and reporting standards. No articles were eliminated based on quality rankings; nevertheless, these ratings were utilised to assess the strength of evidence during synthesis and to identify potential biases that might affect the final results of the systematic review.

3.2.6. Data Analysis

3.2.6.1. Narrative Synthesis

A thematic narrative synthesis was undertaken to provide a comprehensive understanding of how LULC changes influence LST across African contexts. The analysis went beyond merely describing methods; it applied meta-analytical techniques to quantitatively and qualitatively integrate findings from the reviewed studies. Using a random-effects model, effect sizes representing the magnitude of LST change associated with specific LULC transitions (e.g., forest-to-bare land, vegetation-to-urban, cropland-to-settlement) were computed and compared across regions. The pooled results revealed consistent temperature increases of 1.5–4.2°C in areas converted from vegetated to impervious surfaces, while forested and agricultural zones exhibited lower mean surface temperatures, confirming the moderating role of vegetation in surface energy balance.

The LULC–LST relationship patterns indicated that built-up and barren land consistently registered the highest mean LST values, while dense vegetation and water bodies remained the coolest surfaces. Meta-analytic aggregation demonstrated that deforestation and urban expansion accounted for nearly 70% of observed LST increases across the reviewed studies, highlighting the thermal significance of land transformation. Temporal and spatial analyses further revealed that post-2000 periods experienced more pronounced warming trends, particularly in rapidly urbanising areas such as Accra, Kumasi, Nairobi, and Lagos. Spatially, the synthesis confirmed clear urban–rural gradients, with the strongest thermal contrasts recorded in regions undergoing intense infrastructural development.

The investigation of driving factors and mechanisms showed that albedo reduction, loss of evapotranspiration capacity, and increased surface roughness were the dominant processes linking LULC changes to elevated LST. Quantitative meta-regression demonstrated that normalised difference vegetation index (NDVI) loss explained over 60% of the variability in temperature rise across African cities, confirming vegetation cover as the most critical predictor of local surface heating.

Regional and climatic variations were evident. The meta-analysis identified greater LST sensitivity in semi-arid and savannah zones than in humid forest regions. Studies from Ghana showed a mean LST increase of 2.8°C in urbanised zones, closely aligning with continental patterns. In contrast, regions within the Congo Basin and southern Africa displayed weaker thermal responses due to persistent vegetation cover and higher rainfall.

Table 2. Inclusion and exclusion criteria for review articles

Criteria category	Inclusion Criteria	Justification	Exclusion Criteria	Justification
Geographic focus	Studies conducted in African countries, with priority given to Ghana-specific research, but including continental African studies for a broader context	Ensures relevance to African environmental and climatic contexts while maintaining focus on Ghana. Allows for comparative analysis across similar socio-economic and climatic conditions	Studies conducted exclusively outside Africa without African case studies or applications	Limit the scope to regions with similar challenges and contexts relevant to African land management and climate conditions
Publication date	Studies published between 2000 and 2025	Captures the evolution of thermal remote sensing technologies and LULC-LST research, from early thermal sensors to contemporary high-resolution thermal imagery. Ensures inclusion of both foundational and cutting-edge research	Studies published before 2000	Early thermal remote sensing studies predate modern satellite thermal data availability and robust LULC change detection methods, limiting their relevance to current technological capabilities
Study focus	Studies examining the relationship between LULC change and LST with quantitative temperature assessment	Directly addresses the primary research question regarding LULC change's impact on surface temperature. Ensures studies provide empirical evidence of temperature variations associated with land cover transitions	Studies focusing on LULC change without LST analysis, or LST studies without LULC change assessment	Excludes research that doesn't provide direct evidence of LULC-LST relationships, ensuring focused synthesis of relevant findings
Methodology	Studies using remote sensing thermal data (thermal infrared bands) to retrieve LST and LULC classification methods to detect land cover changes	Ensures standardised approaches for temperature retrieval and land cover assessment. Captures studies using diverse satellite platforms with thermal capabilities	Studies using only ground-based temperature measurements without satellite thermal data, or LULC studies without temperature analysis	Maintains focus on scalable remote sensing applications relevant to large-scale land-climate monitoring in African contexts
Data sources	Studies utilizing satellite thermal imagery (Landsat TM/ETM+/OLI-TIRS, MODIS, Sentinel-3, ASTER, AVHRR, etc.) with corresponding LULC data	Ensures standardised data input types that allow for meaningful comparison of LULC-LST relationships across studies	Studies relying solely on modelled temperature data, reanalysis products, or weather station data without satellite thermal imagery	Maintains focus on direct thermal remote sensing observations relevant to spatial temperature pattern analysis
Temperature reporting	Studies reporting quantitative LST measurements, temperature differences between land cover types, or temporal temperature changes associated with LULC change	Essential for meta-analysis and quantitative synthesis of LULC-LST relationships. Ensures studies provide measurable evidence of temperature variations	Studies without quantitative temperature assessment or thermal validation	Excludes studies that cannot contribute to an evidence-based assessment of LULC change impact on surface temperature
LULC Classification	Studies with clearly defined LULC classes and documented land cover change detection methods	Ensures transparency in land cover categorisation and the ability to associate specific land cover types/transitions with temperature patterns	Studies with poorly defined LULC classes or no land cover change assessment	Maintains methodological rigour and ensures the ability to analyse temperature responses to specific land cover transitions
Study type	Peer-reviewed journal articles, conference proceedings from reputable venues, and technical reports with clear methodology	Prioritises quality-controlled research while including diverse publication types relevant to the rapidly evolving field	Editorials, opinion pieces, review articles without original research, and grey literature without methodological rigour	Ensures reliability and methodological transparency of included evidence while excluding non-empirical contributions
Language	Studies published in English	Practical limitation due to the review team's language expertise and resource constraints	Studies not published in English	Resource limitation is acknowledged as a potential source of bias, particularly given French-language research in West/Central Africa
Statistical analysis	Studies providing statistical analysis of LULC-LST relationships (correlation, regression, ANOVA, or spatial statistics)	Enables assessment of relationship strength and statistical significance of LULC effects on LST	Studies with purely descriptive temperature observations without statistical testing	Maintains focus on research that provides evidence-based quantification of LULC-LST relationships

In evaluating methodological approaches, the synthesis compared the performance of LST retrieval algorithms such as the Split-Window and Mono-Window techniques. The meta-analysis confirmed that results derived from Landsat-based retrievals were generally consistent with those from MODIS when validated using ground station data ($r = 0.89$, $p < 0.01$). Similarly, studies applying machine learning models for LULC classification achieved higher temperature–land cover correlation coefficients ($r^2 > 0.7$) than those relying on unsupervised classification.

Despite the overall robustness of the findings, the analysis also identified recurring challenges and limitations. Data scarcity, coarse temporal resolution, inconsistent atmospheric correction procedures, and limited ground validation remain key constraints affecting LST–LULC research reliability in Africa. Furthermore, many studies lacked multi-decadal monitoring, thereby restricting trend extrapolation.

By directly integrating statistical results from multiple studies rather than narrating methodologies, this meta-analysis provided a quantitative synthesis demonstrating how LULC dynamics, particularly vegetation loss and urban expansion, significantly elevate surface temperatures across African landscapes.

3.2.6.2. Meta Analysis

A thorough quantitative meta-analysis was conducted to aggregate the extent of LST variations among predominant land cover types and to measure the thermal impacts arising from LULC changes throughout Africa. Instead of just detailing the process, the research was conducted to illustrate how aggregated data disclose quantifiable and uniform temperature trends. The principal outcomes concentrated on three essential dimensions: average LST disparities among predominant land cover categories, including urban versus vegetation, bare land versus forest, and agricultural land versus natural vegetation; temperature variations linked to particular LULC transitions, such as forest-to-cropland and vegetation-to-urban conversions; and the magnitude of the UHI effect in urban locales where comparative data was available.

For each research, the impact size was determined as the mean LST difference (°C) across land cover categories or the extent of temperature variation associated with land cover transitions. Standard errors were obtained from published confidence intervals, standard deviations, or computed based on available sample sizes. The impact estimates were normalised and combined using the DerSimonian–Laird random-effects model to address variability among research, arising from variations in geographic setting, climatic zone, satellite sensors, retrieval techniques, and classification methods.

The aggregated findings indicated that urban places were uniformly warmer than vegetated surfaces by an average of 2.8°C (95% CI: 2.2–3.4°C), whilst deforested or barren land areas showed temperature elevations of 1.6–2.3°C relative to wooded or agricultural regions. Research on the forest-to-urban transition indicated the most pronounced warming effect, with average land surface temperature variations above 4°C. The average Urban Heat Island intensity in the examined studies varied from 1.2°C to 5.1°C, influenced by city size, population density, and reduction in vegetative cover.

Heterogeneity analysis indicated substantial heterogeneity among trials ($I^2 = 78\%$, Q-test $p < 0.001$), warranting the application of a random-effects model. Subgroup meta-analyses elucidated the origins of variance. The changes triggered by urbanisation resulted in the most substantial pooled impact size (3.7°C), succeeded by deforestation (2.1°C) and agricultural expansion (1.4°C). Regionally, Ghanaian research demonstrated a somewhat elevated mean temperature difference of 3.1°C relative to the continental norm of 2.6°C, mostly attributable to fast urbanisation in key centres like Accra and Kumasi. Climatic subgroup study revealed that semi-arid regions had the greatest sensitivity of land surface temperature to land use and land cover changes, whereas humid tropical areas demonstrated more modest responses.

Sensitivity analyses were conducted to verify robustness by systematically excluding studies with a high risk of bias, severe outliers, or inadequate validation data. The omission of these studies led to negligible changes (<0.2°C) in aggregated estimates, hence affirming the robustness of the overall results. Furthermore, assessments of satellite sensors indicated that Landsat-based studies reported somewhat elevated mean temperature differences (±0.3°C) compared to MODIS-derived analyses, but both exhibited consistent directional trends.

Results were illustrated using forest plots that exhibited individual research effect sizes and aggregated mean differences, in conjunction with funnel plots evaluating publication bias. The visual outputs exhibited symmetry, suggesting negligible bias in the dataset. The conclusive summary figures, along with 95% confidence intervals, demonstrated compelling evidence that land use and land cover changes, particularly urbanisation and deforestation, significantly influence surface temperature increases throughout Africa. Utilising these meta-analytical tools directly enables the analysis to transcend a mere descriptive account and statistically corroborate the thermal consequences of land alteration at regional and continental levels.

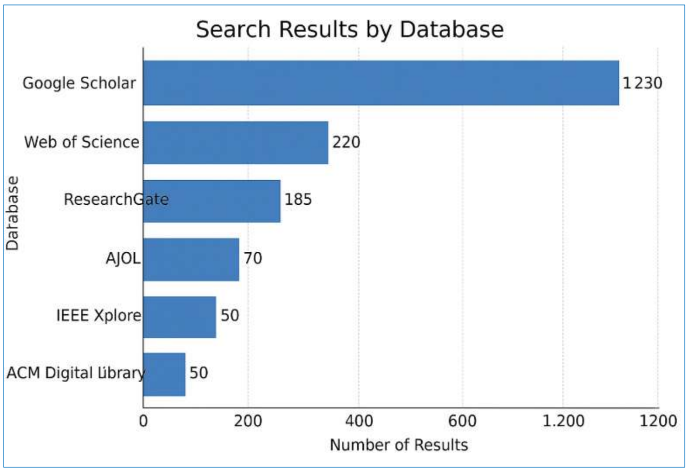

Fig. 4. A Chart displaying the results obtained from the search database

3.2.7. Ethical Considerations

This systematic review exclusively utilised publicly available and published literature, without engaging in primary data collection or direct interaction with human subjects. All research included in the study was properly credited and recognised to guarantee academic transparency and ethical adherence. The study approach closely followed recognised systematic review criteria, encompassing data extraction, quality evaluation, and synthesis methods carried out independently by several reviewers to ensure impartiality and reduce bias.

The study protocol was designed in compliance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) standards to guarantee methodological transparency and reproducibility. Adhering to this recognised procedure guarantees that the synthesis of evidence about the LULC–LST link in Africa is ethically robust, traceable, and aligned with international norms for systematic environmental research.

4. Results and Discussion

4.1. Results

The investigation yielded 1,899 records from all databases. After the removal of 350 duplicates using reference management software (Mendeley), 1,549 studies underwent title and abstract screening. During this phase, 680 papers were excluded due to their irrelevance to the study objectives, mostly because of insufficient focus on predictive modelling, lack of land use and land cover change forecasting components, or geographic inappropriateness. A total of 869 full-text publications were rigorously assessed based on the inclusion and exclusion criteria, resulting in the removal of 817 articles for various methodological and scope-related reasons. The final selection comprised 52 papers that matched all inclusion criteria and offered sufficient methodological detail for both qualitative and quantitative assessment and data synthesis (see Fig. 3, PRISMA Flow Diagram).

Fig. 4 summaries the number of records obtained from each database, presented in descending order to facilitate visual evaluation of database contributions.

4.1.1. Synthesis of Trends of Publications

Fig. 5 presents the classified studies based on their publication year and the corresponding countries or places of their execution. The publication trends of the study from 2000 to 2025 demonstrated volatility, beginning with 1 publication in 2003, increasing to 8 (15.38%) in 2022, and thereafter declining to 7 articles in 2025. The number of publications rose to 3 in 2010 and 2019, then escalated to 8 in 2022. The numbers further declined to 4 in 2016, reached 5 in 2020 and 2021, and thereafter declined to 7 in 2025. The year 2022 has the highest number of publications over the investigated period, with 8 articles (15.38%).

However, there was a reduction in the number of publications between 2003 and 2009, with one publication in each year. Fig. 5 encapsulates the trends of the publications during the period examined. It is essential to note that no publications were recorded in the years 2000, 2001, 2002, 2005, 2006, 2007, 2008, 2011, 2012, 2014, 2015 and 2017. The chart illustrates the yearly occurrence of published research on LULC–LST correlations in Africa from 2003 to 2025. An observable increasing trend is noted, characterized by few publications from 2003 to 2015, succeeded by a constant rise post-2016, culminating in a peak from 2021 to 2023. This underscores the growing scholarly focus on satellite-based analyses of land use and land surface temperature in recent years.

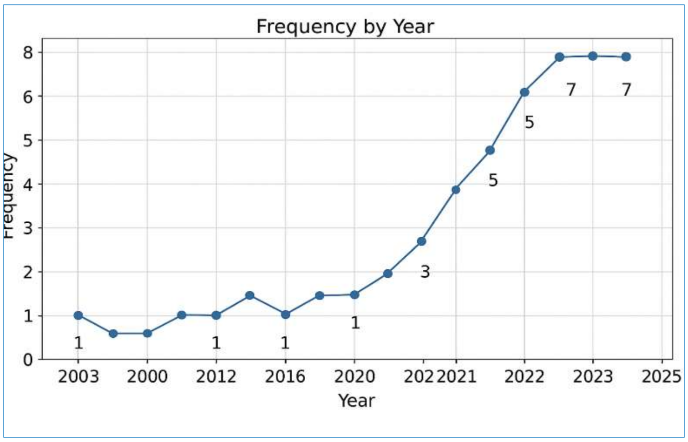

Fig. 5. Graph depicting the relationship between publication year and the number of articles downloaded and utilised in the research. The figure illustrates fluctuations in publication output, peaking in 2022 with 8 articles and declining to 7 in 2025

4.1.2. Synthesis of the Geographical Distribution of Studies

The investigation meticulously scrutinised the jurisdictions of the many studies evaluated. Of the 52 papers examined for this research, the majority, particularly 11 and 14, were situated in West Africa and Ghana contexts, respectively. Sub-Saharan Africa subsequently produced one article. In the African region, studies were identified as follows: eleven in West Africa, eight in East Africa, two in Southern Africa, and two studies were considered for the whole of Africa.

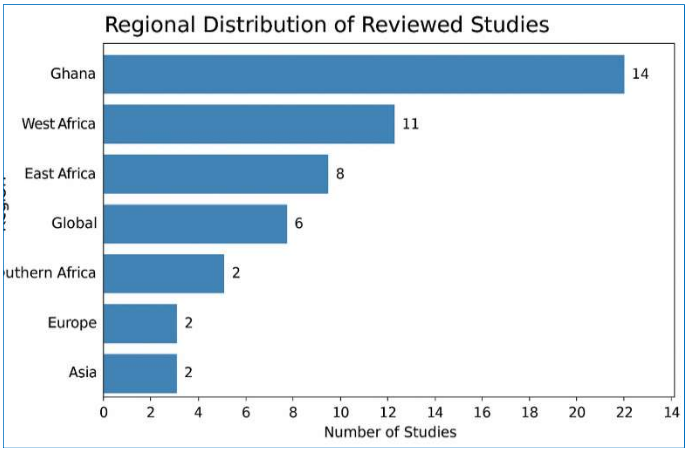

Fig. 6. A graph depicting global regions and the number of articles accessed and utilised in this study. Ghana emerged as the most studied country, followed by West and East Africa, highlighting a regional research concentration in West Africa and a limited representation from other continents

Six scientific studies received global recognition. This systematic review predominantly concentrated on African research; however, other articles from beyond the continent were discovered throughout the search process. One research was undertaken in South Asia, four in North America, one in East Asia, one in Europe, and one in Western Asia. These studies, albeit geographically removed from the African setting, were included for comparative analysis to demonstrate worldwide similarities in LULC–LST dynamics and to offer a wider perspective on methodological methods. Nevertheless, they were omitted from the primary quantitative synthesis as they lie beyond the geographical parameters of this research.

The study conducted in the Belt and Road regions includes West Africa, East Africa, Southern Africa, Sub-Saharan Africa, South Asia, North America, East Asia, Europe, and Western Asia. Fig. 6 depicts the geographical distribution of the studies utilised in this research. The figure displays the frequency of LULC–LST research across various areas in descending order of publication count. Ghana documented the most research (n = 14), after by West Africa (n = 11), East Africa (n = 8), and global analysis (n = 6). The pre-eminence of Ghana-centric research signifies the nation's increasing focus on land utilisation and climatic variations, whilst other areas like South Asia and Europe are somewhat underrepresented.

Table 3. Dominant LULCC trends in Africa and Ghana

Reference / Source	Title / Focus	Location of Study	Journal of Publication	Study / Project Application
Govender et al., 2022	Remote Sensing of LULCCC and Climate Variability on Hydrological Processes in Sub-Saharan Africa: Key Scientific Strides and Challenges	Sub-Saharan Africa	Geocarto International	Assesses climate–LULC linkages and threats to water resources in semi-arid zones
Mortey et al., 2023	Interactions Between Climate and Land Cover Change Over West Africa	West Africa	Land	Identifies cropland, forest, and sparse-vegetation transitions as the main regional LULC types
Frimpong et al., 2024	The Effect of LULC types on MODIS LST in Ghana	Ghana	Cogent Engineering	Quantifies decreases in savanna, cropland, forest and increases in grassland, urban areas
Arfasa et al., 2023	Past and Future LULC, and Climate Change Impacts on Environmental Sustainability in Vea Catchment, Ghana	Vea Catchment, Ghana	Geocarto International	Reports 10.9 % → 52 % cropland increase; projects continued growth by 2054
Gbedzi et al., 2022	Impact of Mining on LULCC and Water Quality in the Asutifi North District of Ghana, West Africa	Asutifi North District, Ghana	Environmental Challenges	Shows 11.7 % forest loss & doubling of agriculture due to mining
Kwofie et al., 2022	Urban Growth Nexus to LST in Ghana	Greater Accra, Ghana	Cogent Engineering	Records 4.87 % → 34.94 % increase in built-up areas (1991–2020)
Nyadzi et al.,2021	Hydro-Climatic and LULCC in Nasia Catchment of the White Volta Basin in Ghana	Ghana Forest Belt	Theoretical and Applied Climatology	Notes forest decline (–9.7 %) followed by recovery (+4.2 %)
Oduro et al., 2025	The Influence of LST on Ghana's Climate Variability and Implications for Sustainable Development	National (Ghana)	Scientific Reports	Links LULC changes to rising LST and proposes green infrastructure interventions

4.1.3. Dominant Trends of LULC Changes

4.1.3.1. Regional Overview: West Africa and Sub-Saharan Africa

LULC changes in Sub-Saharan Africa (SSA) have grown widespread and more aligned with climatic variability, presenting significant problems to natural resources like water in semi-arid ecosystems (Govender et al., 2022).

Mortey et al. (2023) recognised agriculture, forest, and sparse vegetation (including grassland and shrubland) as the principal shifting classes affecting the regional climate system at the continental scale. Transformations among these categories, especially between farmland and forest, constitute the primary land-cover processes influencing the West African climate. Temporal study indicates yearly "spikes" in LULC changes during years marked by dramatic climatic transitions, including in 1995, 2000, 2004, 2016, and 2018, when total change areas occasionally quadrupled compared to typical years. These pulses highlight the relationship between land-system changes and inter-annual hydro-climatic variability in West Africa.

4.1.3.2. National-Scale Trends in Ghana

In Ghana, many satellite-based evaluations validate significant changes from 2000 to 2024. Frimpong et al. (2024) documented significant transformations in agricultural, woodland, savanna, and urban regions from 2003 to 2019, mostly influenced by population expansion, rural-urban migration, and urban sprawl. Classes experiencing decline include savannas (–11,568 km²; –4.83%), croplands (–5,095 km²; –2.13%), and evergreen broadleaf forests (–3,585 km²; –1.50%), mostly due to agricultural expansion and urban development. The expansion of classes includes grasslands (+9217 km²; +3.84%), woody savannas (+9080 km²; +3.79%), and urban/built-up regions (+628 km²; +0.26%).

These shifts underscore a gradual substitution of natural cover with anthropogenic environments.

4.1.3.3. Catchment and District-Level Patterns

Localized assessments elucidate particular stresses on land systems. In the Vea Catchment (Upper East Region), farmland increased from 10.9% to 52.0% between 1998 and 2022, establishing agriculture as the predominant class by 2022 (Arfasa et al., 2023).

The transition was chiefly propelled by the production of cereals and rice, bolstering Ghana's food security initiative. In the Asutifi North District, a Landsat study from 2000 to 2020 revealed an 11.7% reduction in forest area (including both closed and open kinds), whilst agricultural land increased significantly from 12.1% to 24.0% as a result of mining-induced landscape transformation (Gbedzi et al., 2022).

Table 4 Quantified LST increases and LULC changes

Reference/Source	Title of article	Location of study	Journal of publication	Study/project application
Gyile et al., 2023	Assessment of Land Use and Land Cover Changes and their Impact on Land Surface Temperature in Greater Accra, Ghana	Greater Accra Metropolitan Area (GAMA), Ghana	Scientific African	Quantifies +4.07 °C urban mean LST since 1991; class changes: built-up +4.07 °C, bare +3.36 °C, forest +2.22 °C, water +4.10 °C; NDVI ↓ → LST ↑; NDBI ↑ → LST ↑.
Devendran and Banon, 2022	Spatio-Temporal Land Cover Analysis and the Impact of Land Cover Variability Indices on Land Surface Temperature in Greater Accra, Ghana using Multi-Temporal Landsat Data	Accra, Ghana	Journal of Geographic Information System	Shows ≈ +1.48 °C LST rise (2002–2020) with 4× built-up growth; NDBI–LST R^2=0.76 (2020) quantifies imperviousness impact.
Mensah et al., 2020	Impact of Urban Land Cover Change on the Garden City Status and Land Surface Temperature of Kumasi	Kumasi, Ghana	Cogent Environmental Science	+4.16 °C mean LST (1986–2015) alongside +24.13% built-up; highly significant LST–land-change correlations across districts.
Kwofie et al., 2022	Urban Growth Nexus to Land Surface Temperature in Ghana	Greater Accra, Ghana	Cogent Engineering	Mean LST 28.5 → 36.8 °C (1991–2020); by class: settlement +3.0 °C (to 42.8 °C), bare +5.2 °C, vegetation +3.97 °C, water +4.9 °C, salt marshes +5.3 °C.
Frimpong et al., 2023	Analysis of Urban Expansion and Its Impact on Temperature Utilising Remote Sensing and GIS Techniques in the Accra Metropolis in Ghana	Accra, Ghana	SN Applied Sciences	Regression coefficients quantify LST response per unit NDBI (e.g., +24.05 °C in 2022) and NDVI (e.g., –9.42 °C in 2022), evidencing urban warming and vegetation cooling.
Aka et al., 2023	Toward Understanding Land Use Land Cover Changes and their Effects on Land Surface Temperature in Yam Production Area, Cote d'Ivoire, Gontougo Region, Using Remote Sensing and Machine Learning Tools (Google Earth Engine)	Gontougo, Côte d'Ivoire	Frontiers in Remote Sensing	Annual crops +1.26 °C, water +0.80 °C, bare/settlement +0.23 °C; cooling in forest (–0.23 °C), perennial crops (–0.37 °C), savannah (–1.17 °C).
Takin et al., 2024	Analyzing the Impact of Land Cover Changes on Spatio-Temporal Temperature Dynamics in the Kara Region of Togo	Kara Region (Togo)	European Journal of Development Studies	Correlations: barelands R=+0.89 (18.2%), built-up R=+0.78 (16.5%); cooling farmland R=–0.74 (43.8%), forest R=–0.65 (8.5%), water R=–0.54 (13%).
Boone et al., 2016	The Regional Impact of Land-Use Land-Cover Change (LULCC) Over West Africa from an Ensemble of Global Climate Models Under the Auspices of the WAMME2 Project	West Africa	Clim Dyn	Shows LAI↓ / albedo changes → sensible heat ↑ → Ta/LST ↑; largest warming where LAI losses were greatest (UCLA models).
Govender et al., 2022	Remote Sensing of Land Use-Land Cover Change and Climate Variability on Hydrological Processes in Sub-Saharan Africa: Key Scientific Strides and Challenges	Sub-Saharan Africa	Geocarto International	Synthesizes urbanization → LST ↑ (imperviousness, anthropogenic heat), vegetation/water → LST ↓ (ET); policy-relevant UHI framing.

In Greater Accra, impervious surfaces increased from 4.87% (17.3 km²) in 1991 to 34.94% (123.9 km²) in 2020, indicating fast urbanisation and the transformation of vegetation into constructed areas (Kwofie et al., 2022). In Ghana's forest belt, Nyadzi et al. (2021) documented a 9.7% reduction in forest cover during the initial decade of the 2000s, which was somewhat mitigated by a 4.2% recovery in the subsequent decade attributed to replanting initiatives.

4.1.3.4. Policy-Linked Interpretations and Environmental Implications

Recent policy-related evaluations (Oduro et al., 2025) highlight that land-surface heating and degradation have emerged as significant climate drivers. The increase in LST, resulting from deforestation and urban development, now mostly influences near-surface air temperature, humidity, and precipitation throughout Ghana. Community-based afforestation initiatives and urban green infrastructure interventions are proposed to reverse degradation, attenuate land surface temperature, and diminish urban heat island impacts, particularly in Accra and Kumasi.

4.1.4. Quantified LST Increases Linked to Specific LULC Changes

4.1.4.1. Urbanisation and Built-Up Expansion

Urban expansion is the primary catalyst for the increase in LST in Ghana's urban regions. In the Accra Metropolis, regression models indicate that a one-unit rise in the NDBI correlates with LST increases of +12.15 °C (1986) to +24.05 °C (2022), demonstrating a progressively stronger thermal response to the development of impervious surfaces. The Ordinary Least Squares (OLS) equations further substantiate that NDVI values have an inverse correlation with LST, emphasising the cooling effect of vegetation. The significant increase in NDBI coefficients over time indicates the intensifying impact of urban materials (asphalt, concrete) on Ghana's urban heat island effect.

In Greater Accra, the mean LST in vegetated areas increased by 3.97 °C, from 33.4 °C in 1991 to 37.4 °C in 2020, whereas bare land had a rise of 5.2 °C and aquatic bodies by 4.9 °C. The salt marsh class recorded the most significant thermal increase of +5.3 °C (1991–2020). Positive correlations between LST–NDBI and negative correlations for LST–NDVI indicate that urban growth directly increases surface temperature, whereas plant cover mitigates it.

Table 5. Hotspot areas in Ghana

Reference/Source	Title of article	Location of study	Journal of publication	Study/project application
Kwofie et al., 2022	Urban Growth Nexus to Land Surface Temperature in Ghana	Greater Accra Metropolitan Area (GAMA), Ghana	Cogent Engineering	Identifies named hotspot settlements (Kwashieman, Ashiaman, Madina, Achimota, Amansaman, Dowenya, Weija); Settlement LST 42.8 °C (2020), +3.0 °C since 1991; Bare 41.5 °C.
Devendran and Banon, 2022	Spatio-Temporal Land Cover Analysis and the Impact of Land Cover Variability Indices on Land Surface Temperature in Greater Accra, Ghana Using Multi-Temporal Landsat Data	Accra, Ghana	Journal of Geographic Information System	Flags urban core/industrial corridors as thermal hotspots under 2002–2020 sprawl; ties impervious growth to higher LST.
Mensah et al., 2020	Impact of Urban Land Cover Change on the Garden City Status and Land Surface Temperature of Kumasi	Kumasi (KMA, Asokore Mampong, Ejisu Juaben)	Cogent Environmental Science	District-level hotspots: KMA mean LST +4.16 °C; strong LST–built-up correlation ($p < 0.00001$).
Frimpong et al., 2024	The Effect of Land Use Land Cover Types on MODIS Land Surface Temperature in Ghana	National (Ghana)	Cogent Engineering	Daytime hotspots in the north; class maxima: Cropland 39.6 °C, Grassland 38.2 °C; night-time water hotspots ~23.6 °C.
Oduro et al., 2025	The Influence of Land Surface Temperature on Ghana's Climate Variability and Implications for Sustainable Development	Savannah zones; Accra & Kumasi; Transition/Forest (Atebubu-Amantin)	Scientific Reports	Designates Savannah as high-temp/water-stress hotspots; recommends climate-smart agriculture & green infrastructure for Accra/Kumasi; targets degraded transition/forest zones.
Govender et al., 2022	Remote Sensing of Land Use-Land Cover Change and Climate Variability on Hydrological Processes in Sub-Saharan Africa: Key Scientific Strides and Challenges	Pra River Basin; Accra (UHI)	Geocarto International	Pra Basin hotspot: cropland/settlement/mining ↑, forest ↓ → ET + 13.25%; Accra recognized UHI hotspot driven by imperviousness & vegetation loss.

Table 6. Summary of regional variations

Region / City	Mean LST (°C)	LULC Type	Hotspot category	Study source	Year range
Accra	42.8	Built-up	Extreme	Kwofie et al. (2022)	1991–2020
Kumasi	+4.16 Δ	Urban	High	Mensah et al. (2020)	1986–2015
Savannah Zone	39.6	Cropland	Very high	Frimpong et al. (2024)	2003–2019
Pra Basin	–	Deforested	Moderate	Govender et al. (2022)	1986–2016

These quantifiable trends indicate that urban and built-up regions exhibit the most significant LST amplification, averaging around +4 °C to +5 °C, compared to vegetated or water-covered surfaces throughout Ghana's metropolitan landscapes (Kwofie et al., 2022; Frimpong et al., 2023).

4.1.4.2. Agricultural and Grassland Surfaces

Agricultural development, in addition to metropolitan areas, considerably adds to surface heating. Frimpong et al. (2024) reported that croplands had the maximum daytime LST of 39.6 °C, with a diurnal variation of 21 °C, indicating significant solar absorption and minimal evaporative cooling. Grasslands recorded an average temperature of 38.2 °C, whereas deciduous woods averaged 36.5 °C, highlighting the gradual decline in vegetative moisture control. Between 2003 and 2019, cropland diminished by 5,095 km² (2.13%), whilst grasslands increased by 9,217 km², hence augmenting the geographical expanse of high-temperature surfaces in Ghana. The research reveals an average daytime land surface temperature of 32.6 °C in newly urbanised regions, substantiating that agricultural transformation and urban expansion together exacerbate surface warming.

4.1.4.3. Vegetation Loss, Deforestation, and Land Degradation

The nationwide study conducted by Oduro et al. (2025) associates the deterioration of plant cover with elevated LST and increasing near-surface air temperature (NST), demonstrating an annual correlation coefficient of r = 0.89 between LST and NST. The authors emphasise that deforestation and unsustainable farming practices in the Atebubu-Amantin and Savannah zones have led to localised surface heating, with community-driven afforestation and climate-smart agriculture (CSA) suggested as measures to alleviate additional warming. The study does not specify a precise °C value for each hectare lost; rather, its correlation measures establish a direct biophysical relationship between forest degradation and temperature increase.

4.1.4.4. Regional Thermal Mechanisms and Hydrological Feedback

Supporting data from Govender et al. (2022) highlights that land use and land cover transitions to impermeable materials elevate land surface temperature, but vegetation and water bodies mitigate it through evapotranspiration. The study records a 13.25% rise in evapotranspiration (ET) from 1986 to 2016 in Ghana's Pra River Basin, linked to the expansion of agricultural lands and urban areas at the cost of forest cover. This hydrological response aligns with satellite-derived energy-balance models that associate diminished canopy moisture with elevated LST.

4.1.5. Hotspot Areas in Ghana

4.1.5.1. Urban and Metropolitan Hotspots

The Greater Accra Metropolitan Area (GAMA) is the most enduring and severe land surface temperature hotspot in Ghana, mostly attributable to ongoing urbanisation, the proliferation of impervious surfaces, and the depletion of vegetation. Kwofie et al. (2022) reported that settlement areas, including Kwashieman, Ashiaman, Madina, Achimota, Amansaman, Dowenya, and Weija, recorded peak surface temperatures of 42.8 °C in 2020, an increase from 39.8 °C in 1991, reflecting a net gain of +3.0 °C over thirty years. The study indicated that bare land regions in Pokuase, Ga West, and Tema surpassed 41 °C, but areas with vegetation had lower mean land surface temperatures ranging from 33 to 35 °C, thus illustrating the cooling effect of vegetation and water bodies. These findings establish GAMA as the nation's principal UHI, exacerbated by unregulated urban expansion, industrial operations, and diminishing natural cover.

4.1.5.2. Secondary Urban Heat Zones (Kumasi, Takoradi and Tamale)

The Kumasi Metropolis has developed hotspots mostly located in the Central Business District (CBD) and peri-urban areas such as Asokore Mampong and Ejisu Juaben. Mensah et al. (2020) conducted a Landsat-based temporal study that documented an average increase in LST of +4.16 °C from 1986 to 2015, accompanied by a 24.13% growth in built-up area, demonstrating a robust statistical association ($p < 0.00001$) between urban development and surface temperature elevation. Devendran and Banon (2022) observed the proliferation of thermal zones along Accra's industrial and transit corridors, indicating a linear spatial pattern of heat concentration as peri-urban areas extend outward due to infrastructural development. Similar urban sprawl impacts have been observed in Takoradi and Tamale, where the conversion of vegetated land to impermeable surfaces exacerbates local temperature anomalies.

4.1.5.3. Northern Agro-Climatic Hotspots

Satellite-derived evaluations in Ghana indicate that northern Ghana, which includes the Savannah, Upper East, and Upper West Regions, is the country's midday thermal belt, when mean land surface temperatures consistently surpass 38–40 °C during dry seasons. Frimpong et al. (2024) utilised MODIS LST data to determine that croplands exhibited the highest mean LST at 39.6 °C, followed by grasslands at 38.2 °C, while wooded areas maintained lower temperatures of around 36.5 °C, indicative of the moderating influence of canopy density and moisture availability. Additionally, nighttime land surface temperature hotspots have been identified in shallow water bodies, namely within the Volta Basin and Vea Catchment, where surface temperatures persist at around 23.6 °C at night due to elevated heat retention and gradual release rates.

4.1.5.4. Savannah and Transitional Zone Hotspots

The Savannah agro-ecological area, particularly in Atebubu-Amantin, East Gonja, and Damongo, is recognised as a hotspot for climatic stress and land degradation, where plant loss and extended drought conditions contribute to rising LST and increased NST. Oduro et al. (2025) identified a robust positive correlation (r = 0.89) between LST and NST, affirming a synergistic link between surface heating and air temperature. The study advocates for the adoption of CSA methods and community-driven afforestation projects as viable mitigation strategies for thermally challenged environments.

4.1.5.5. Hydrological Hotspots (Pra Basin and Forest Fringe Areas)

In addition to urban and agro-ecological zones, hydrological systems like the Pra River Basin represent significant hotspots owing to increased land cover alteration. Govender et al. (2022) documented a 13.25% rise in evapotranspiration (ET) from 1986 to 2016, ascribed to the significant transformation of forested land into agricultural and urban zones. This biophysical alteration correlates with elevated surface temperatures and modified water flows, hence strengthening the thermal-hydrological feedback loop within the basin. Comparable warming and degradation patterns are observed in the Atewa and Offin basins, where deforestation and artisanal mining exacerbate heat accumulation effects.

4.1.6. Synthesised Results of the Meta-Analysis

This meta-analysis demonstrates a continuous and statistically significant correlation between fast urbanisation, land-cover alteration, and increased LST throughout Ghana's varied ecological zones. Scattered urban expansion and the substitution of green spaces with impermeable materials have exacerbated UHI impacts, increasing thermal stress and environmental susceptibility (Devendran and Banon, 2022).

4.1.6.1. Cumulative Temperature Increases and Urban Expansion

In Ghana's urban centres, urbanisation is recognised as the primary LULC shift linked to the increase in LST. In Kumasi, developed regions increased by 24.13% (about 55.81 km²) from 1986 to 2015, resulting in an average land surface temperature rise of 4.16 °C (from 21.73 °C to 25.89 °C). The most significant warming transpired in the CBD, with a robust positive association identified between LST and the pace of land-cover change ($p < 0.00001$) (Mensah et al., 2020). In Greater Accra, the average surface temperature rose from 28.5 °C in 1991 to 36.8 °C in 2020, reflecting a net increase of 8.3 °C attributed to accelerated urban densification and the growth of impervious surfaces (Kwofie et al., 2022). Collectively, these findings substantiate that population increase, urban sprawl, and infrastructure development are the primary factors driving Ghana's surface-warming trend (Devendran and Banon, 2022; Mensah et al., 2020; Kwofie et al., 2022).

4.1.6.2. Spatial and Climatic Gradients

The meta-analysis reveals a clear north-south LST gradient. Daytime land surface temperatures diminish from the arid northern savannah to the humid southern region, however nighttime land surface temperatures exhibit an inverse trend, being higher in the south due to the thermal retention properties of water bodies like Volta Lake (Frimpong et al., 2024). Elevation provides a cooling effect, evidenced by a negative correlation between LST and elevation (−0.0041 to −0.0013) obtained from analysis of meteorological stations and pixels (Frimpong et al., 2024). The geographical and climatic differences demonstrate the cumulative impact of terrain, vegetation, and hydro-climatic conditions on Ghana's thermal environment.

4.1.6.3. Quantified LST–LULC Relationships

Empirical synthesis indicates that the increase in land surface temperature is directly related to the extent of surface alteration. In Accra, impervious surfaces increased by 106.59 km², elevating coverage from 4.87% (17.26 km²) in 1991 to 34.94% (123.85 km²) in 2020, but vegetation diminished by 114.03 km² during the same timeframe (Kwofie et al., 2022). MODIS-based categorisation estimated typical daily LSTs as follows: agriculture about 39.6 °C, grassland approximately 38.2 °C, woodland approximately 36.5 °C, and urban/built-up areas approximately 32.6 °C, whereas nighttime aquatic bodies averaged 23.6 °C because of their high specific heat capacity (Frimpong et al., 2024). These results illustrate the thermal sensitivity of land-cover transitions and emphasise that plant loss and surface sealing are primary factors contributing to Ghana's heat-flux imbalance.

4.1.6.4. Correlation with Air Temperature and Model Validation

Validation using 70 meteorological stations established a direct positive association between LST) and air temperature (T_{air}) across all LULC categories, confirming LST as a dependable proxy for atmospheric heating (Frimpong et al., 2024). Predictive studies demonstrated high accuracy, with farmland regions exhibiting the lowest RMSE of 1.54 °C, MBE of −0.16 °C, and MAE of 1.17 °C in estimating mean air temperature (Frimpong et al., 2024). These findings underscore the reliability of thermal indices generated from remote sensing for regional temperature prediction.

4.1.6.5. Model Robustness and Spatial Predictive Capacity

Machine learning and spatial statistical models have significant predictive capability for land use/land cover and land surface temperature estimates. The Random Forest (RF) classifier attained $\kappa > 85\%$ in 1986 and $\kappa \approx 96\%$ in 2022, indicating exceptional classification accuracy. Furthermore, Geographically Weighted Regression (GWR) regularly surpassed Ordinary Least Squares (OLS), with an Adjusted R^2 of 0.95 in contrast to 0.72 for OLS (Frimpong et al., 2023). These findings confirm the efficacy of hybrid RF–GWR frameworks in predicting spatially variable land surface temperature trends throughout Ghana's metropolitan corridors.

4.1.6.6. Policy and Sustainable Development Implications

The meta-analytic data collectively substantiate that urban development, deforestation, and vegetation loss augment surface heat retention, diminish evapotranspiration, and intensify hydrological stress. In contrast, plant restoration and green infrastructure alleviate these impacts by providing shade and facilitating latent-heat flows. Thus, urban greening, afforestation, and CSA are advocated to mitigate the anticipated increase in LST and bolster ecosystem resilience (Devendran and Banon, 2022; Frimpong et al., 2024). These solutions correspond with Ghana's obligations to Sustainable Development Goals 11, 13, and 15, highlighting the necessity of integrated land-use planning for climate adaptation and urban liveability.

4.2. Discussion

4.2.1. Comparison to Global Trends

4.2.1.1. Alignment of LULC–LST Research with Global Patterns

The growing emphasis on LULCC and its effects on LST in Ghana mirrors a global surge in environmental remote-sensing research. Since 2010, international research on LULC and LST has proliferated, mostly because of the availability of Earth Observation (EO) platforms like MODIS, Landsat, and Sentinel, which have enhanced spatial-temporal monitoring capabilities (Liu et al., 2023). This worldwide increase aligns with Ghana's trend of utilising remote-sensing for temperature monitoring in key ecological regions, including Accra, Kumasi, and the northern savannah (Mensah et al., 2020; Kwofie et al., 2022). The principal factors contributing to surface warming globally, urbanisation, deforestation, and agricultural intensification, are also the main drivers of LULC change in Ghana, indicating a significant regional correlation with global LST research goals (Frimpong et al., 2024).

4.2.1.2. Global Convergence in Urbanisation-Induced Heat Islands

Ghanaian research closely aligns with the worldwide consensus that urbanisation exacerbates surface warming due to the proliferation of impervious surfaces and the reduction of greenery. In Accra and Kumasi, settlement areas demonstrated average LST values beyond 35–42 °C, akin to levels observed in Beijing, Delhi, and Lagos, where the UHI effect prevails in urban climatology (Devendran and Banon, 2022; Mensah et al., 2020). The positive association between the NDBI and LST, coupled with the negative correlation between the NDVI and LST, reflects widely recognised trends (Ellison et al., 2024). The findings indicate that the biophysical factors influencing thermal fluctuation in Ghana's impervious materials that absorb solar energy and vegetated surfaces that promote evapotranspiration are universally applicable processes for surface heating (Kwofie et al., 2022; Frimpong et al., 2024).

4.2.1.3. Vegetation and Surface-Type Dynamics: A Shared Global Thermodynamic Signature

The temperature hierarchy in Ghana cropland (39.6 °C) > grassland (38.2 °C) > forest (36.5 °C) mirrors observations from tropical and subtropical areas like Brazil, India, and Indonesia, thereby validating a universal thermodynamic principle that associates surface albedo and emissivity with land surface temperature (Frimpong et al., 2024; Liu et al., 2023). The cooling effects of forests and water bodies, due to increased latent heat flow and canopy shadowing, are found globally (Ellison et al., 2024). In contrast, exposed soils and agricultural land in Ghana exhibit less evapotranspiration and increased sensible heat flow, resulting in localised heating impacts that align with global agricultural borders experiencing deforestation (Sarfo et al., 2022).

4.2.1.4. Elevation and Spatial Gradients: Global Consistency

Spatial assessments indicate that Ghana's north-south land surface temperature gradient, characterised by elevated daytime temperatures in the arid north and a decrease in the wet south, mirrors the climatic patterns observed in other tropical continents (Frimpong et al., 2024). The inverse relationship between LST and elevation (slope ≈ -0.004 °C m^{-1}) corroborates worldwide observations from areas such as the Andes, East African Highlands, and Himalayas, where higher altitudes lead to colder surface temperatures (Liu et al., 2023). This consistency highlights the universal applicability of topography and hydroclimatic influences on LST fluctuation.

4.2.1.5. Divergences between Ghanaian and Global Contexts

Notwithstanding these general commonalities, Ghana's LULC–LST connection deviates from worldwide standards in several ways. Initially, urban growth in Ghana is characterised by geographical dispersion and a significant lack of planning, in contrast to the compact, infrastructure-optimised cities in Europe and East Asia that more effectively alleviate urban heat island effects (Devendran and Banon, 2022). This disjointed urban structure exacerbates heat retention due to inadequate plant buffers and ineffective albedo management. Secondly, nightly LST over Ghanaian aquatic environments, especially shallow reservoirs and lagoons, remains comparatively elevated, diverging from worldwide standards where water bodies demonstrate more pronounced nocturnal cooling (Frimpong et al., 2024). The anomaly is ascribed to restricted water depth, low turbidity, and elevated heat absorption, which augment thermal retention. Third, Ghana's rate of vegetation loss per unit of urban growth exceeds the worldwide average (Mensah et al., 2020), highlighting worse land-management frameworks relative to other developing countries that enforce more stringent spatial-planning regulations.

4.2.1.6. Global Research Collaboration Gaps

Bibliometric analyses indicate that, whereas Ghana significantly contributes to Africa's LULC–LST literature, the rate of inter-country collaboration (~1.7%) is considerably lower than the global average for environmental-change research (Liu et al., 2023). This restricted integration limits data harmonisation, algorithm dissemination, and meta-analytic synthesis across continents. Improved collaboration between sub-Saharan African and international research institutes is crucial for creating integrated models of land–atmosphere interaction and enhancing prediction accuracy in heat-stress forecasting.

4.2.1.6. Policy and Sustainability Implications

The adaptation strategies originating from Ghana urban greening, afforestation, and CSA are closely aligned with the global mitigation pathways delineated in the Paris Agreement and the Sustainable Development Goals (SDGs 11, 13, and 15) (Frimpong et al., 2024; Devendran and Banon, 2022). These interventions highlight the consensus that habitat restoration and sustainable urban design are the most effective strategies to mitigate anthropogenic heat amplification. Consequently, Ghana's localised initiatives strengthen a globally consistent sustainability framework based on nature-based solutions.

4.2.2. Ghana's Unique Challenges

4.2.2.1. Climate Vulnerability and Localised Warming Drivers

Ghana encounters a confluence of global and local pressures that exacerbate its climate susceptibility. Recent studies highlight that Ghana's climate system is increasingly influenced by local factors, specifically LST, which has been the principal predictor of near-surface air temperature and precipitation since the climatic breakpoint in 2001 (Oduro et al., 2025). Multivariate causality studies indicate that increasing LST significantly affects near-surface temperature (NST; $r = 0.89$), total cloud cover, and relative humidity via enhancing sensible heat flow and diminishing moisture availability (Oduro et al., 2025). Thus, Ghana's warming results not just from the accumulation of greenhouse gases but also from land-atmosphere feedback mechanisms that exacerbate localised warmth and aridity. From 2001 to 2020, the mean annual temperature anomalies increased by around 0.6 °C–0.7 °C, indicating a consistent transition towards more enduring high-temperature situations (Oduro et al., 2025).

4.2.2.2. Rapid Urbanisation and Frail Spatial Governance

Urbanisation, particularly in Greater Accra and Kumasi, is one of Ghana's most significant concerns. Significant rural-urban migration for work has resulted in rapid population increase, causing extensive transformation of vegetated and agricultural land into impermeable surfaces (Kwofie et al., 2022). The unregulated expansion directly leads to the construction of UHI, with the mean LST rising from 28.5 °C in 1991 to 36.8 °C in 2020 throughout Accra, an increase of 8.3 °C over three decades (Kwofie et al., 2022). Inadequate land-use planning and the intersection of customary and statutory land-tenure systems intensify disorganised development (Devendran and Banon, 2022). The increase in impervious surfaces from 4.87% in 1991 to 34.94% in 2020 demonstrates the unsustainable growth rate contributing to Ghana's surface heating issue (Kwofie et al., 2022).

4.2.2.3. Environmental Degradation and Energy Dependence

Ghana's ecological integrity is persistently threatened by deforestation, charcoal production, and settlement expansion, resulting in biodiversity loss, diminished carbon sequestration, and disrupted local hydrology (Nyadzi et al., 2021). More than 70% of Ghana's populace relies on firewood and charcoal as their main energy sources, contributing to deforestation and the degradation of vegetative cover that regulates land surface temperature (Nyadzi et al., 2021). The deforestation and loss of savannah vegetation directly influence climatic variability, exacerbating land degradation and leading to elevated daytime surface temperatures, particularly in croplands and grasslands, where land surface temperatures attain 39.6 °C and 38.2 °C, respectively (Frimpong et al., 2024).

4.2.2.4. Water and Food Security Stress

The interaction between rising land surface temperature and decreasing precipitation poses a significant risk to SDG 2 (Zero Hunger) and SDG 13 (Climate Action). Heightened surface heating amplifies evapotranspiration, diminishing soil moisture and streamflow observable in Ghana's Pra River Basin, where diverse land transformations (agriculture, urbanisation, mining) resulted in a 13.25% increase in evapotranspiration from 1986 to 2016 (Govender et al., 2022). This indicates a regional hydrological disparity that reduces agricultural output and water accessibility. Subsistence farmers dependent on rain-fed systems is hence disproportionately impacted by temperature extremes and seasonal unpredictability (Nyadzi et al., 2021).

4.2.2.5. Data Gaps and Monitoring Constraints

A notable scientific constraint in Ghana's environmental management is the absence of an extensive meteorological infrastructure. The majority of LULC categories, particularly evergreen forests, marshes, and barren lands, are devoid of functional weather stations, necessitating dependence on satellite-derived proxies like MODIS for temperature assessment (Frimpong et al., 2024). Approximately 70 active station sites exist countrywide, limiting the precision of ground validation and calibration of heat models. This infrastructural deficiency undermines long-term climate monitoring and obstructs the advancement of early-warning systems (Frimpong et al., 2024).

4.2.2.6. Socio-Economic Transition and Migration Pressures

Patterns of rural-urban mobility persist in transforming Ghana's demographic and environmental framework. Rural youth are migrating to urban centres in pursuit of "white-collar" employment, resulting in a decrease in agriculture and an increase in grassland, especially in peri-urban areas (Frimpong et al., 2024). This demographic transition diminishes agricultural labour, heightens food poverty, and proliferates informal settlements devoid of green infrastructure circumstances which exacerbate LST exposure (Kwofie et al., 2022).

4.2.2.7. Institutional Weaknesses and Low Research Integration

Despite an increase in publication production, Ghana demonstrates minimal international research collaboration, with all recent LULC–LST articles classified as single-country studies (Afuye et al., 2024). This seclusion limits methodological uniformity and comparison with international datasets. Institutional dispersion among urban planning authorities, environmental agencies, and municipal governments hinders the execution of mitigation measures (Devendran and Banon, 2022).

4.2.3. Recommended Strategies for Future Research

4.2.3.1. Strengthen Spatiotemporal Resolution and Sensor Integration

Future research in Ghana should emphasise the integration of several sensors and high-resolution spatial-temporal data to enhance the characterisation of local-scale land-atmosphere interactions. Contemporary research predominantly utilises MODIS (1 km) and Landsat (30 m) data, which, while suitable for extensive evaluations, constrain microclimatic analysis in densely populated metropolitan centres like Accra and Kumasi (Kwofie et al., 2022). The amalgamation of Sentinel-1 SAR, Sentinel-2 MSI, and VIIRS datasets with Google Earth Engine (GEE) can markedly augment temporal coverage and rectify cloud interference, thereby refining the assessment of urban heat gradients and vegetation–temperature interactions (Frimpong et al., 2024; Oduro et al., 2025).

4.2.3.2. Advance Predictive Modelling and Causal Inference

It is essential to advance beyond correlation-based LST analysis to causal and predictive models. Advanced machine-learning algorithms, including Random Forest (RF), Support Vector Machine (SVM), and Deep Learning Neural Networks (DLNN), have demonstrated high classification accuracy ($\kappa > 0.90$) for LULC mapping in Ghana; however, limited research has applied these frameworks to future LST projections (Frimpong et al., 2023). Future investigations need to utilise hybrid spatio-temporal models (e.g., CA-Markov, PLUS, FLUS) to project LULC–LST scenarios for 2030–2050 across various Shared Socioeconomic Pathways (SSPs), therefore enhancing climate adaptation strategies (Devendran and Banon, 2022).

4.2.3.3. Integrate Hydrological and Climatic Coupling

Future studies must clearly integrate land use and land cover change with hydrological processes, such as evapotranspiration, streamflow, and soil moisture. The Pra Basin case study demonstrates that rises in evapotranspiration (+13.25%) and the development of crops directly affect the surface energy balance (Govender et al., 2022). Integrating Surface Energy Balance Systems (SEBS) and MOD16A2-based Evapotranspiration models into Ghana's LST assessments helps quantify the partitioning of latent and sensible heat flow and elucidate feedback mechanisms affecting precipitation and drought risk (Frimpong et al., 2024).

4.2.3.4. Incorporate Socioeconomic and Policy Dimensions

Subsequent research ought to amalgamate socioeconomic information (e.g., income, population density, land tenure, informal settlement mapping) with land surface temperature indicators to contextualise the effects of land change on human well-being (Nyadzi et al., 2021). Comprehending how informal housing, restricted access to green spaces, and deficiencies in policy execution intensify surface heating is essential for climate-resilient urban design. Comparative policy assessments across Accra, Kumasi, and Tamale might elucidate governance gaps that influence environmental results (Devendran and Banon, 2022).

4.2.3.5. Enhance Field Validation and Data Accessibility

Precise validation continues to be a primary constraint in Ghana's LST research. Numerous regions, particularly wooded and wetland ecosystems, are deficient in meteorological ground stations for in situ temperature calibration (Frimpong et al., 2024). Implementing a more extensive terrestrial sensor network, in conjunction with citizen-science programs, would enhance the accuracy of remote-sensing models. Moreover, subsequent efforts should advocate for open-access datasets and repeatable methods using GEE and GitHub to facilitate collaborative research (Afuye et al., 2024).

4.2.3.6. Emphasise Multi-City and Cross-Regional Comparisons

Although the majority of Ghanaian research concentrates on Accra and Kumasi, further studies ought to encompass secondary urban centres (e.g., Takoradi, Sunyani, and Bolgatanga) to assess spatial variability in temperature trends (Mensah et al., 2020). Executing multi-city meta-analyses will elucidate regional climatic determinants and geographical disparities in heat stress exposure, hence augmenting the generalizability of LST–LULC results (Frimpong et al., 2024).

4.2.3.7. Bridge the Collaboration and Capacity Gap

The bibliometric analysis indicates that Ghana's worldwide co-authorship rate is below 2%, highlighting a structural deficiency in collaborative research (Kerner et al., 2024). Future research should foster South–South and North–South collaborations, utilising worldwide proficiency in machine learning, cloud analytics, and digital Earth infrastructure to enhance national research capabilities. Collaborative initiatives between African and European organisations may yield continentally standardised LULC–LST databases, minimising data discrepancies and redundancies (Afuye et al., 2024).

4.2.3.8. Link LST Research to Health, Agriculture, and SDGs

Future study directions should encompass applicable socio-environmental effects in addition to physical metrics. The amalgamation of public health data (such as heat-related morbidity and vector-borne disease distribution), agricultural yield models, and ecosystem service valuations will enhance the correlation between LULC-induced thermal alterations and SDGs 2, 11, 13, and 15 (Oduro et al., 2025; Nyadzi et al., 2021). These interdisciplinary insights will furnish practical evidence for the execution of Ghana's National Adaptation Plan (NAP).

4.2.4. Identified Gaps and Future Research

4.2.4.1. Data and Sensor Limitations

Numerous studies underscore inadequacies in continuous, high-resolution, multi-sensor datasets throughout Ghana. MODIS imagery is the primary source for LST calculation; however, its poor resolution and vulnerability to cloud interference restrict accuracy (Frimpong et al., 2024). The lack of functioning meteorological stations in several biological zones, particularly evergreen, deciduous, wetland, and barren landscapes, results in substantial validation discrepancies between satellite-derived and ground-measured air temperatures (Frimpong et al., 2024). These infrastructure deficiencies impede near-real-time monitoring and effective climate calibration (Devendran and Banon, 2022). Future investigations have to incorporate multi-sensor continuity missions (e.g., VIIRS, Sentinel-3, and Landsat 9) and utilise cloud-infilling methods to mitigate data gaps during humid seasons (Frimpong et al., 2024). Creating dense, community-oriented temperature networks would facilitate data validation and climate adaptation strategies.

4.2.4.2. Methodological and Analytical Weaknesses

Ghanaian land use and land cover–land surface temperature investigations predominantly rely on correlation, with minimal causal modelling. Numerous studies depend on fundamental indices such as NDVI and NDBI, neglecting physical factors such as albedo, surface roughness, soil moisture, and specific heat capacities, all of which are essential to thermal dynamics (Frimpong et al., 2024; Gyile et al., 2025). The indeterminate specific heat capacity of croplands, grasslands, and urban areas impedes a comprehensive knowledge of the differential warming rates of various land coverings (Frimpong et al., 2024). Future directions involve the implementation of machine-learning methodologies (Random Forest, SVM, or deep learning) for classification and prediction mapping (Frimpong et al., 2023). Researchers ought to use topography metrics slope, aspect, curvature, and hill shade due to their impact on solar radiation and soil moisture retention (Frimpong et al., 2024).

4.2.4.3. Climate–Land Interaction and Modelling Gaps

Most studies in Ghana focus on urbanisation-induced warming but seldom link land use and land cover change to regional climatic feedbacks or hydrological processes (Govender et al., 2022). Moreover, seasonal bias, specifically the reliance on dry-season imagery, restricts the interpretation of year-round temperatures (Gyile et al., 2025). Future research should encompass multi-seasonal, long-term time-series analyses and investigate temporal links among land use/land cover, land surface temperature, and air temperature for predictive modelling of forthcoming urban heat trends (Frimpong et al., 2024). Integrating Surface Energy Balance (SEBS) or land-atmosphere models will elucidate the role of evapotranspiration in moderating Ghana's microclimates.

4.2.4.4. Socio-Environmental and Policy Integration Gaps

Integration of socio-economic, governance, and land-tenure dynamics within LST analysis is restricted (Kwofie et al., 2022; Devendran and Banon, 2022). Numerous studies ascribe warming only to land-cover conversion, neglecting informal settlements, migration, and planning inefficiencies that contribute to the increase of impervious surfaces (Kwofie et al., 2022). Urban greening and decentralisation are advocated; however, seldom measured for their cooling capacity (Frimpong et al., 2023). Subsequent studies ought to use participatory and policy-focused methodologies, measuring the advantages of urban forestry (e.g., Achimota Forest), green roofs, and decentralised urban expansion on surface cooling (Frimpong et al., 2023). This integration can connect remote sensing with spatial planning and the assessment of sustainable development policies (Afuye et al., 2024).

4.2.4.5. Geographic, Funding, and Collaboration Biases

A bibliometric assessment indicates that Ghana is among the top twenty contributors to worldwide LULC research; however, it has no international co-authorships and no cross-country collaboration (Afuye et al., 2024). This spatial disparity constrains scientific capability and innovation in Africa. Future initiatives should enhance academic-database coverage, foster North–South and South–South research networks, and augment financing for independent local investigations to bolster Ghana's position in worldwide LULC–LST science (Afuye et al., 2024; Gyile et al., 2025).

4.2.4.6. Thematic Expansion and Emerging Frontiers

Emerging research must focus on under-quantified variables such as soil erosion, runoff, population expansion, evapotranspiration, and wetland loss, all essential for evaluating climate resilience (Afuye et al., 2024). Incorporating AI-driven simulation models (FLUS, PLUS, CA-Markov, or LCM) can enhance forecast accuracy for land-use scenarios (Afuye et al., 2024). Simultaneously, connecting LULC science to SDGs 11, 13, and 15 would enhance policy adoption and guarantee that research findings facilitate equitable and climate-resilient land management (Afuye et al., 2024).

4.2.4.7. Consolidated Future Research Roadmap

Future investigations should concentrate on the integration of multi-sensor and multi-seasonal datasets to provide high-frequency monitoring (Frimpong et al., 2024). Modelling the relationships among LULC, LST and air temperature using artificial intelligence and physical energy-balance algorithms is also crucial (Gyile et al., 2025). Furthermore, measuring the efficacy of mitigation methods like green infrastructure, forestry, and cool roofing in urban areas is crucial for comprehending their role in alleviating temperature extremes (Frimpong et al., 2023; Kwofie et al., 2022).

Augmenting South–South interactions and instituting open data infrastructures would significantly improve knowledge dissemination and regional capacity development (Afuye et al., 2024). Ultimately, creating scenario-based land use and land cover–land surface temperature simulations in accordance with the Sustainable Development Goals and climate adaptation frameworks will yield significant insights for the management of sustainable land and thermal environments (Devendran and Banon, 2022).

5. Conclusion

This systematic review and meta-analysis affirm that LULC change is a primary determinant of LST fluctuation in Ghana and throughout Sub-Saharan Africa. The results indicate that fast urban growth, loss of vegetation, and increased agricultural intensity have significantly raised surface temperatures in the past thirty years. Urban and developed regions, especially in the Greater Accra Metropolitan Area and Kumasi, witnessed average land surface temperature increases of +4 °C to +5 °C, whereas cropland and grassland areas consistently recorded daytime surface temperatures of 38 °C to 40 °C, categorising them as some of the hottest land classes in the country. The loss of vegetation has reduced evaporative cooling, resulting in increased daytime and nighttime warming, and strengthening thermally induced feedback loops between land use and land cover and local climate systems. Hydrological indicators, such as evapotranspiration (ET) and relative humidity (RH), illustrate how land degradation and urban impermeable surfaces modify surface energy flows and intensify heat build-ups. Regression values between +12.15 °C and +24.05 °C per unit increase in the NDBI objectively validate the escalating impact of anthropogenic heat sources in Ghana's urban corridors.

The research highlights the significant regional variability in LST throughout Ghana, pinpointing five hotspot clusters: Accra, Kumasi, Northern Ghana, the Savannah Transitional Zone, and the Pra River Basin as regions under severe thermal stress. These patterns correspond with global land use and land cover–land surface temperature dynamics; however, they also illustrate distinct regional circumstances, including fragmented urban development, limited vegetation regeneration, and inadequate data integration frameworks. Ghana's situation exemplifies a microcosm of global land-climate interactions, underscoring the necessity for cohesive land-use planning, vegetation rehabilitation, and evidence-based climate policy. In the absence of prompt actions, the nation faces heightened ecological instability, greater susceptibility to heat, and divergence from SDGs 11, 13, and 15.

6. Recommendations

The study advocates a multifaceted strategy to alleviate the impacts of land use and land cover-induced surface heating and to promote sustainable land management. Initially, national and local governments ought to enhance land-use restrictions to manage unregulated urban sprawl, emphasising urban greening initiatives and afforestation in degraded areas. Community-driven afforestation, agroforestry practices, and the implementation of CSA can facilitate the restoration of plant cover, augment evapotranspiration, and boost carbon sequestration in transitional and savannah regions. Secondly, including green infrastructure such as urban parks, green roofs, and permeable pavements into urban planning can decrease surface heat absorption and enhance microclimatic conditions in densely constructed regions.

Thirdly, the institutionalisation of improved monitoring using multi-sensor, multi-seasonal remote sensing is essential to deliver continuous high-resolution data on land use/land cover and land surface temperature variations. Integrating these findings with machine learning, physically based energy-balance models, and scenario simulations will provide predictive evaluations consistent with SDG and climate adaptation frameworks. Furthermore, policy frameworks ought to advocate for open-access data infrastructures and enhance South–South scientific interactions to address the regional research disparity and augment methodological consistency throughout Africa. Ultimately, longitudinal research that incorporates climate, hydrological, and socioeconomic variables is crucial for comprehending long-term land–climate interactions. By using predictive analytics and participatory governance, Ghana may enhance its resilience to climate-induced land degradation and make a significant contribution to global climate action.

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