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Review article: Climate hazards and risk in African cities – knowledge gaps and research needs

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Abstract. This study presents a semi-systematic synthesis of scientific literature published between 2015 and 2025 on climate risk in African cities. From an initial set of 1,832 records identified through broad climate- and urban-related keywords, 273 articles were selected through title and abstract screening. Using a mixed-methods approach, the study combines quantitative mapping of geographic coverage, climate hazards, methodologies, and keyword networks with expert review and AI-assisted synthesis of research gaps. Results reveal a rapidly growing but uneven knowledge base. Research is concentrated in a limited number of regions and large cities, while Central Africa and secondary cities remain underrepresented. Studies focus mainly on a restricted set of hazards, with few adopting multi-hazard risk perspectives. Earth Observation is widely used but remains underexploited, while high-resolution urban climate modelling and integrated assessments of social vulnerability, governance, and health impacts are still limited. Most studies are retrospective and rarely combine future climate scenarios with projected urban growth, highlighting a gap between scientific knowledge and urban planning needs.

1 Introduction

Although the African continent has played only a modest role in driving global warming, it remains among the regions most exposed and vulnerable to climate change impacts (Ayompe et al., 2020). This imbalance raises fundamental issues of climate justice, as populations that have contributed least to the problem face some of its most severe consequences. Under continued global warming, climate-related hazards are projected to intensify markedly across the continent (IPCC, 2023).

Cities are at the centre of this challenge. Urban areas concentrate people and assets, while local characteristics such as impervious surfaces and anthropogenic materials aggravate heat and flood risks. Rising temperatures also interact with health issues, for example by expanding the habitat of malaria-carrying mosquitoes (Sinka et al., 2020). At the same time, floods and storms continue to expose the fragility of urban infrastructure, particularly in informal settlements, where homes may easily overheat, collapse in storms, or be swept away in floods (UN-Habitat, 2022). More than half of Africa's urban residents, around 230 million people, live in such settlements, and their number is rising.

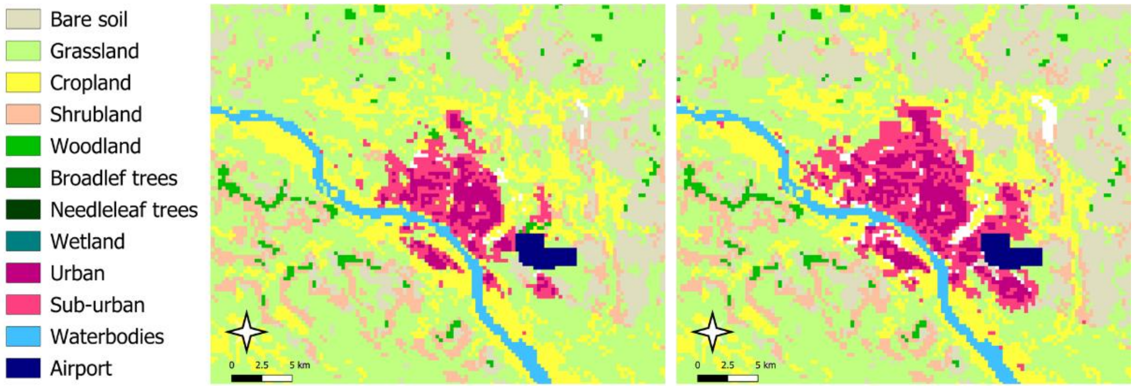

Figure 1. Land-use maps of Niamey, Niger, for 2005 (left) and 2020 (right) at 300 m resolution, generated by integrating ESA CCI Land Cover, Global Human Settlement Layer built-up fractions, ESA WorldCover, and OpenStreetMap data. The comparison illustrates the urban growth of Niamey over just 15 years, which is exemplary of the rapid expansion seen in many African cities.

The speed of urbanisation adds another layer of urgency, as can be seen from Figure 1. Africa is projected to host some of the world's largest megacities by the end of this century (Hoornweg and Pope, 2017). Much of this growth is informal and unplanned, which increases exposure to hazards and limits adaptive capacity (Mukim and Roberts, 2023). This creates a triple risk: (1) the concentration of resources and people in cities, (2) structural vulnerability and limited adaptation options, and (3) urban features that amplify climate impacts. Despite these realities, fast-growing secondary cities in Africa remain substantially underrepresented in urban climate studies (Montfort et al., 2025).

Climate research in Africa has traditionally focused more on rural concerns, such as agriculture and water resources, than on urban challenges (Carr et al., 2020). Funding flows are also skewed, with most climate research funds directed to institutions outside Africa, leaving African researchers with limited resources to generate locally relevant knowledge (Overland et al., 2022). As a result, decision-relevant climate information at the city scale remains scarce, undermining efforts to support adaptation and limiting access to international climate finance.

Model-based climate information at the urban scale also remains limited. Global and regional climate models typically operate at spatial resolutions too coarse to capture city-level processes, creating a mismatch between research outputs and local adaptation needs (Hamdi et al., 2020; Graça et al., 2022).

Earth Observation (EO) provides an important complementary source of climate-relevant information, particularly in regions where ground-based monitoring networks are sparse, as in much of Africa. Satellite observations offer spatially consistent measurements of environmental conditions over large areas and multi-decadal time periods, enabling the analysis of land-cover change, urban expansion and surface temperature patterns at spatial resolutions of tens of metres (Li et al., 2022a; Wulder et al., 2019). In recent years, the European Space Agency (ESA) and the Copernicus programme have substantially expanded the availability of such datasets through missions such as Sentinel and initiatives including the Climate Change Initiative (CCI) and the Global Human Settlement Layer (GHSL), which provide harmonised global information on land cover and urbanisation (Buchhorn et al., 2020; Melchiorri, 2022).

While these advances have improved the availability of climate-relevant data, important knowledge gaps remain regarding climate risks in African cities. African cities are growing rapidly while facing intensifying climate risks, but the knowledge base needed to support adaptation planning remains underdeveloped.

This study synthesises what is currently known and unknown about climate risks in African cities. This is addressed through both quantitative and qualitative analyses of a sample of scientific publications on urban climate in Africa. The assessment follows a semi-systematic approach, combining automated procedures with expert evaluation of the literature. In the remainder of this paper, an overview of the data and methods is provided, including the method used to establish the sample of scientific articles. Subsequently, results are presented stemming from quantitative and qualitative assessments, which are followed by the conclusions.

2 Data and methods

2.1 Selection of articles

The initial step of the study consisted of selecting scientific articles from the Web of Science (WoS) archive using the set of keywords provided in Table 1. A final search update was conducted in January 2026, focusing on the period 2015–2025, meaning that a limited number of articles formally assigned to publication year 2025 may not yet have been indexed at the time of the search.

The search strategy was intentionally designed to prioritise sensitivity over specificity in order to minimise the risk of excluding potentially relevant studies at the search stage. In this context, the search restrictions were deliberately kept limited. Nevertheless, in order to maintain a sufficient focus on the urban context, variants of the term “urban” were required to appear in the article title. The only topical keyword imposed was “climat*”, thereby encompassing terms such as “climate”, “climatic”, and “climatological”. No explicit hazard-related terms (e.g. heat, flooding, drought) or methodological terms (e.g. modelling, remote sensing) were prescribed in advance, since preliminary tests indicated that such restrictions excluded several studies already known to be relevant to the topic under investigation. The intention was therefore to avoid introducing a thematic bias at the search stage.

The geographical focus was specified as comprehensively as possible, both at the continental level (“Africa*”) and at the national level by including the names of all 54 African countries, following the United Nations Department for General Assembly and Conference Management classification of the African Group and its Member States.

Table 1. Keywords used for the selection of articles in the Web of Science records. The asterisk ('*') denotes a wildcard. The 'Topic' category contains the Title, Abstract, and Keywords.

	Keyword	**In**
	urban* OR city OR cities OR metropol*	Title
AND	climat*	Topic
AND	Africa* OR Algeria* OR Angola* OR Benin* OR Botswana* OR "Burkina Faso" OR Burkinabé OR Burundi* OR "Cabo Verde" OR "Cape Verdean" OR Cameroon* OR "Central Africa*" OR Chad* OR Comoros OR Comorian* OR Congo* OR DRC OR Djibouti* OR Egypt* OR "Equatorial Guinea" OR Eritrea* OR Eswatini OR Swazi* OR Ethiopia* OR Gabon* OR Gambia* OR Ghana* OR Guinea* OR "Guinea-Bissau" OR "Ivory Coast" OR Ivorian OR Kenya* OR Lesotho OR Basotho OR Liberia* OR Libya* OR Madagascar OR Malagasy OR Malawi* OR Mali* OR Mauritania* OR Mauritius OR Mauritian* OR Morocc* OR Mozambique* OR Namibia* OR Niger* OR Nigeria* OR Rwanda* OR "São Tomé and Príncipe" OR "São Toméan" OR Senegal* OR Seychell* OR "Sierra Leone*" OR Somalia* OR "South Africa*" OR Sudan* OR Tanzania* OR Togo* OR Tunisia* OR Uganda* OR Zambia* OR Zimbabwe*	Topic
AND	years 2015-2025	Date

The application of the above search criteria initially yielded 1832 articles. Because the search strategy intentionally remained broad with respect to hazards, risks, impacts, and methodologies, the resulting body of literature also included many climate-related urban studies that were not directly concerned with climate hazards or risk assessment.

The resulting list of articles was subsequently subject to further analysis and screening. Relevance screening was conducted manually, based primarily on article titles and, where necessary, abstracts. Since all retrieved records already satisfied the urban and African focus criteria embedded in the search query, the screening process mainly aimed to identify studies explicitly addressing climate-related hazards, risks, vulnerability, impacts, or urban climate processes directly relevant to hazard assessment in African cities.

A conservative inclusion strategy was adopted throughout the screening process. In cases of uncertainty, articles were preferentially retained rather than excluded in order to minimise the risk of omitting potentially relevant studies. This exercise ultimately resulted in a final selection of 273 articles. The resulting WoS Excel database contained, for each article, bibliographic metadata including authors, journal title, volume, page range, month and year of publication, together with abstracts, author keywords, WoS "Keywords Plus", DOI identifiers, and links to the publisher websites.

Application of the WoS "Analyse" function to the selected body of articles revealed that authors with at least one African affiliation accounted for 48.1% of the sample. The countries contributing most strongly to the publication record were found to be non-African, particularly the United Kingdom and the United States. Among African countries, the largest contributions originated from South Africa, Nigeria, Ethiopia, and Ghana.

2.2 Brief overview of analysis steps

The method to conduct the analysis of the selected articles is outlined in Figure 2. The upper row of the figure shows, from left to right, the progression from the WoS export list towards bibliographic (Zotero) and PDF files-archive for each of the article records.

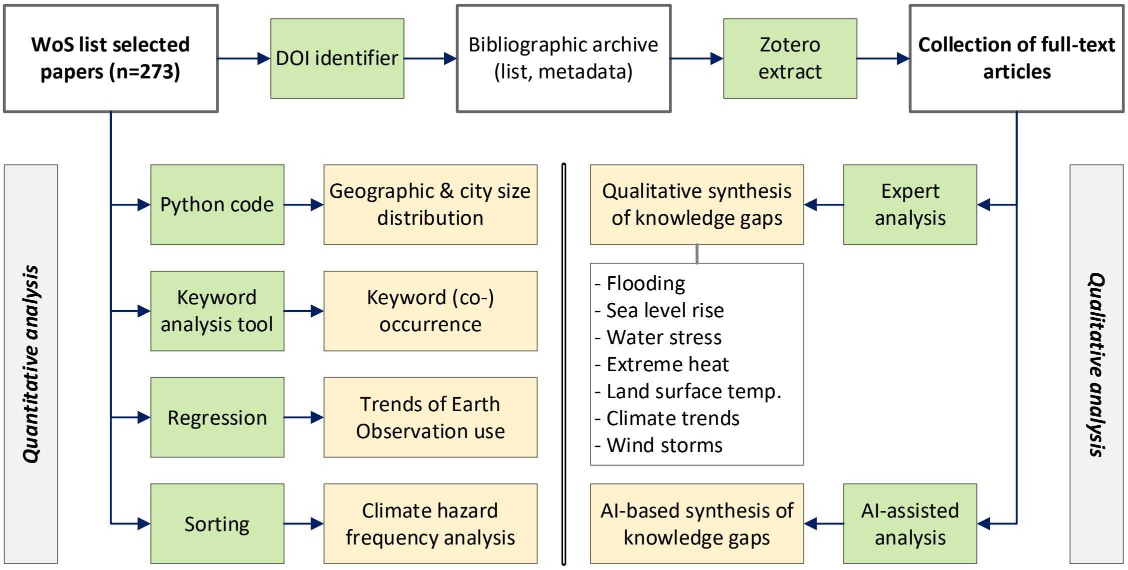

Figure 2. Schematic representation of the analysis steps used in this article. The left half covers the quantitative analysis, the right half covers the qualitative analysis.

The WoS article list was analysed quantitatively (left half of Figure 2) with respect to the representativeness of the sampled cities in terms of Köppen-Geiger climate zone and population size; keyword (co-)occurrence in the selected articles; trends of Earth Observation (EO) use; and climate hazard frequency analysis. The PDF archive containing all 273 articles was analysed qualitatively (right half of Figure 2) by conducting an expert-based thematic analysis organised by climatic hazard; and running an AI-assisted assessment of knowledge gaps occurring in the scientific articles.

3 Quantitative mapping of the literature

3.1 Climate zone representation

The WoS list of 273 selected articles was examined for city names in the Title and Abstract fields by extracting all capitalised words from these texts, enabling rapid identification of potential city names. This was implemented in MS Excel using a Visual Basic for Applications (VBA) function that identifies and extracts words starting with a capital letter and stores them in a separate column.

This column was then reviewed to identify city names, by comparing city names occurring in the GHS Urban Centre Database (GHS-UCDB) R2024A from the Copernicus Global Human Settlement Layer (GHSL), which includes population estimates for each city (Melchiorri, 2022). If an extracted name from a selected article matched a city in the list, it was retained. If the same city had already been identified earlier, its occurrence count was increased by one. Nouns that resembled city names but were not present in the GHS-UCDB list were further checked using Wikipedia and Google Maps to determine whether they referred to neighbourhoods or sub-units of larger cities. In such cases, the names were assigned to the corresponding host urban agglomeration.

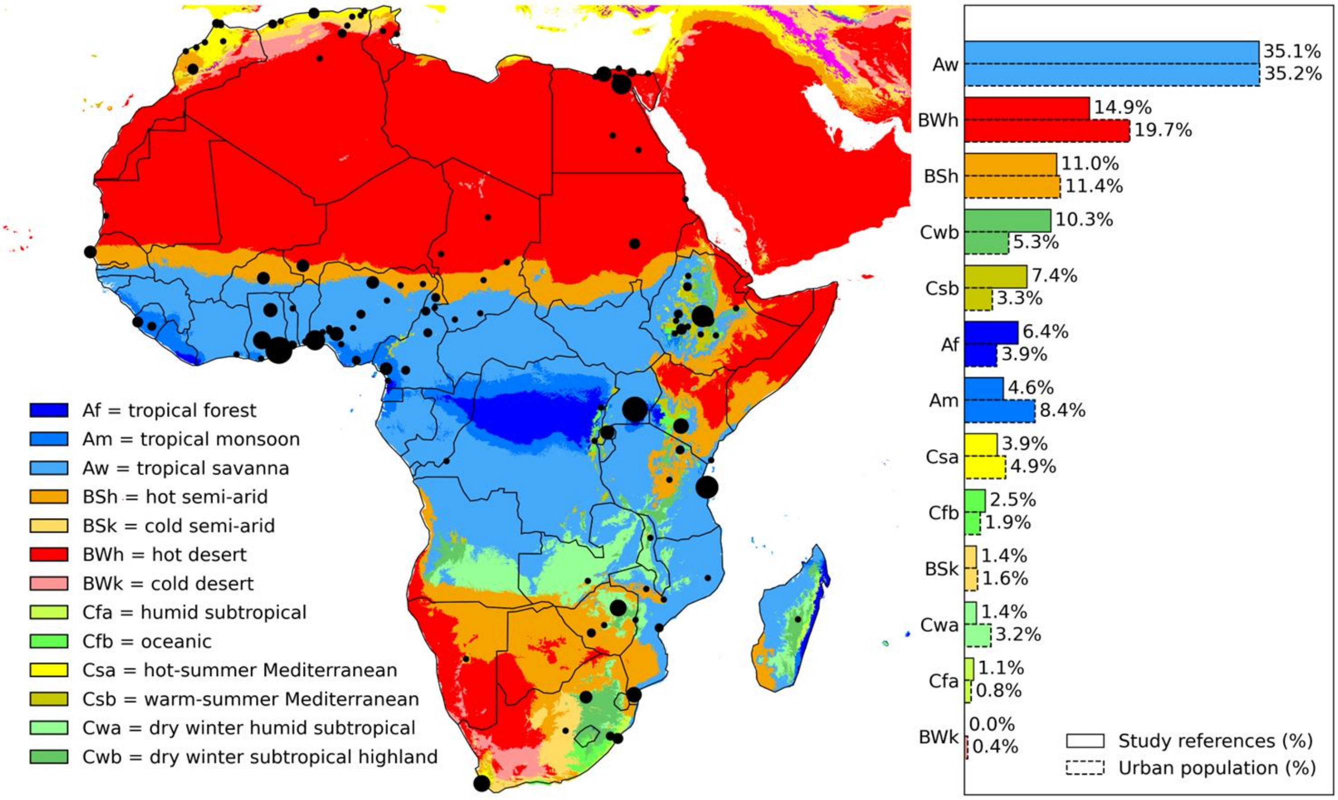

Figure 3. Distribution of the reviewed literature across Köppen–Geiger climate zones, compared with the baseline distribution of African urban populations. The bars representing the literature (solid border) correspond to the number of reviewed articles referring to cities located within each climate zone. Cities may appear in multiple articles, so counts represent occurrences in the literature rather than unique cities. The baseline population distribution was derived from the GHSL Urban Centre Database (GHS-UCDB R2024A, Melchiorri, 2022), aggregated by Köppen–Geiger climate (Beck et al., 2023). The comparison illustrates the extent to which research attention across climate zones reflects (or diverges from) the distribution of urban populations across Africa.

The analysis focused on urban agglomerations as defined in the GHS-UCDB list rather than on smaller units such as sub-cities or neighbourhoods. This choice was made for reasons of cross-country consistency, as the administrative subdivision of cities differs between countries. For example, a large city in one country may be recorded as a single entity, while in another it may be subdivided into multiple smaller administrative units.

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The cities thus identified are shown in Figure 3 as solid dots, scaled to the number of mentions (references) in the literature sample. For each of the cities, the Köppen-Geiger climate zone (Beck et al., 2023) was determined. This enabled a comparison of the frequency of climate zones represented in the literature sample with the baseline distribution of African urban populations across climate zones. The comparison shows that the climate zones represented in the sample of urban climate studies reflect the actual distribution of African agglomerations fairly well. The tropical savanna (Aw) zone, for instance, dominates both the literature sample and the population baseline.

Some imbalances are nevertheless apparent. Cities in highland (Cwb) and Mediterranean (Csa, Csb) climates receive disproportionately high attention relative to their urban population share, likely reflecting the visibility of climate impacts (e.g., flooding, landslides) and/or the presence of strong local research infrastructures. Conversely, urban populations in monsoon (Am), tropical forest (Af), and hot desert (BWh) climates are somewhat underrepresented, despite their demographic significance. These patterns highlight that, while the overall distribution across climate zones is well captured, there remains a tendency for research to concentrate in hazard-prone or research-intensive regions, leaving important populations in other climate zones relatively less studied.

From a geographical point of view, Figure 3 shows a relatively higher coverage of referenced cities (1) near the Gulf of Guinea (West Africa), (2) along an axis extending from East to Southern Africa, and (3) in North Africa along the Mediterranean. Such a pattern is consistent with findings by other researchers (e.g. Leal Filho et al., 2023; Montfort et al., 2025). From Figure 3 it also emerges that a considerable number of the frequently studied cities are located along the coast.

3.2 City size representation

We compared the city size distribution (measured by number of inhabitants) of the city sample with the actual population distribution across different size categories: small cities (< 100,000 inhabitants); medium-sized cities (100,000 – 1,000,000); large cities (1,000,000 – 10,000,000); megacities (> 10,000,000).

Figure 4 shows the distribution of the sampled cities (green bars) compared with the actual city size distribution (white bars). A most striking feature resides in the strong underrepresentation of small cities in the sample, whereas large cities are overrepresented. This lesser inclusion of smaller cities was also noticed by other researchers (e.g. Montfort et al., 2025). In contrast, medium-size and megacities are represented at proportions that closely match the actual distribution.

We also examined the distinction between capital and non-capital cities in the sample. Out of 112 cities, 28 (25%) are capitals. However, when weighting by the number of times each city is referenced in the selected articles (as represented by dot size in Figure 3), the share of capital cities rises to 45%. This reflects the tendency for capital cities to appear in multiple studies, while smaller cities are typically mentioned only once.

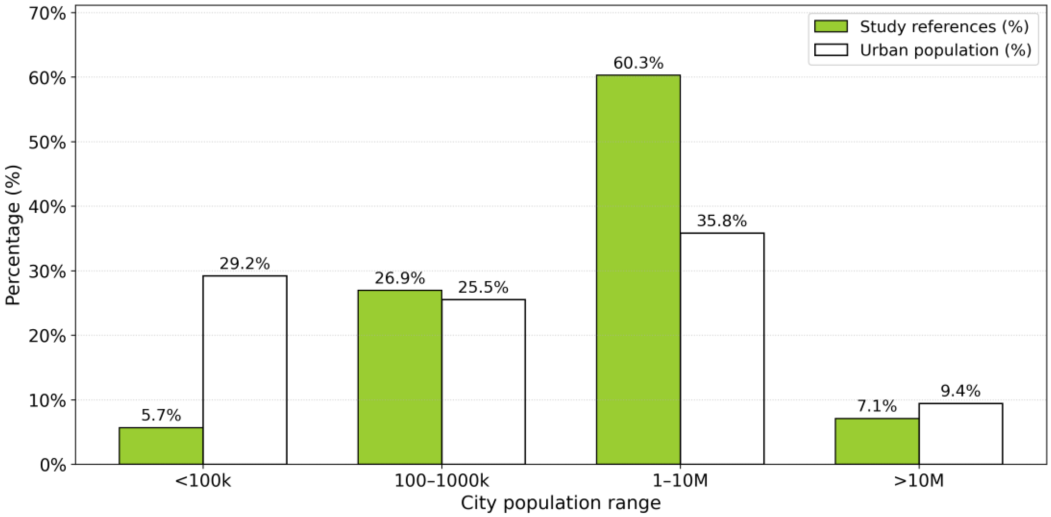

Figure 4. Comparison of the proportion of study references (green bars) with the distribution of the urban population (outlined bars) across city population ranges in Africa.

3.3 Keyword (co-)occurrence analysis

A keyword analysis was conducted using VOSviewer, a software tool for constructing and visualizing bibliometric networks (www.vosviewer.com) (Van Eck and Waltman, 2017). Using VOSviewer, a network map (Figure 5) was created from the bibliographic data contained in the WoS output file, based on a co-occurrence analysis of both author keywords and Keywords Plus.

The terms ‘climate (change)’ and ‘urban/city’ were excluded from the keywords, given they were the primary search keywords (hence should not re-appear on the network map). Our focus was on identifying *additional* keywords that emerged from the search. To reduce clutter and avoid less relevant terms, only keywords appearing at least nine times were retained, resulting in a final list of 48 keywords. This threshold of 48 was determined through trial and error, aiming for a balance between including as many relevant terms as possible while maintaining a clear visualization. A VOSviewer ‘thesaurus’ file (Van Eck and Waltman, 2017) was developed and applied to (1) filter out non-relevant keywords (e.g. city names); (2) merge spelling variants (e.g. ‘heat island’ vs. ‘heat-island’); (3) unify conceptually similar terms (e.g. ‘earth observation’ and ‘remote sensing’).

For visualization, the VOSviewer *Scale* parameter was set to 100%, fully allowing circle sizes to reflect keyword frequency (larger circles representing more frequent keywords); the *Size Variation* parameter was set to 50%, in order to avoid excessively small labels for less frequent keywords.

Figure 5 shows the keyword co-occurrence network generated by VOSviewer. Node size reflects the frequency of keyword occurrence, while the thickness of the connecting lines indicates the strength of co-occurrence. Colours represent clusters, the algorithm positioning related terms closer together to reveal strong internal relationships. In Figure 5, four clusters

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emerge. The red cluster is dense and cohesive around heat-related terms (UHI, LST, thermal comfort). The green cluster centres on flooding and social aspects (risk, vulnerability, poverty). Smaller clusters focus on hydrological extremes (blue) and water- and health-related issues (yellow).

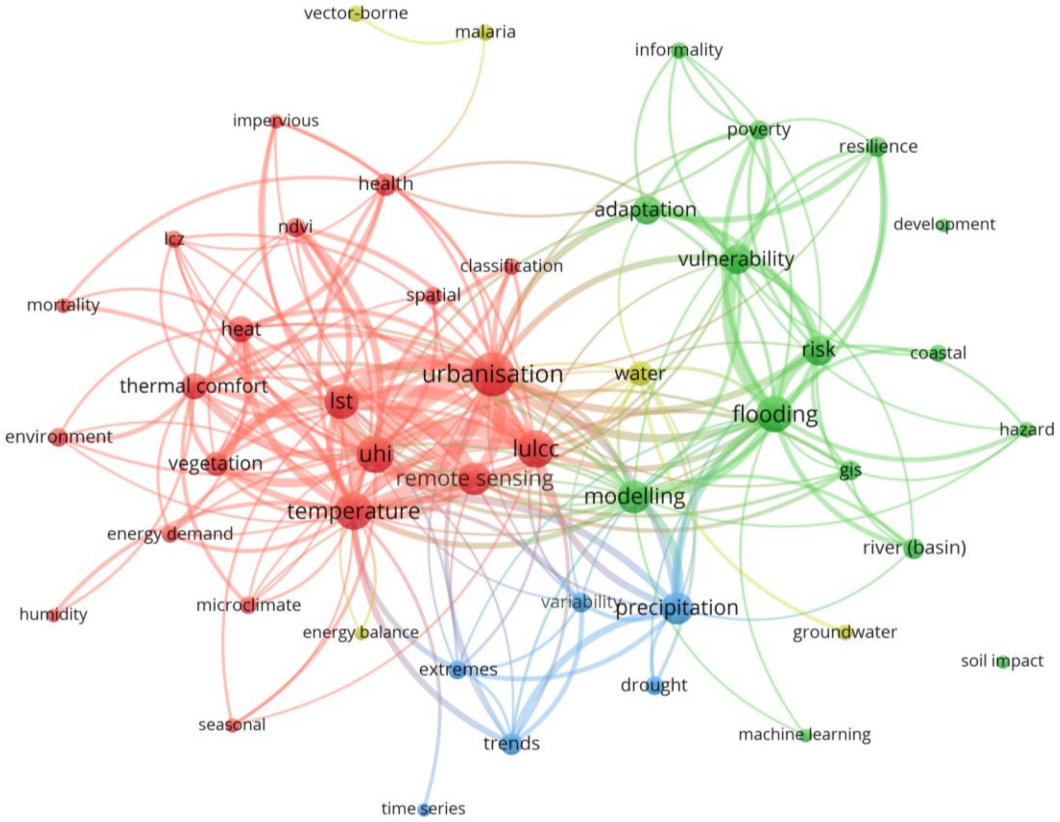

Figure 5. Keyword co-occurrence network generated with VOSviewer. Colours indicate clusters of related keywords, and the thickness of connecting lines reflects the frequency of co-occurrence. Larger nodes represent keywords that appear more frequently across the dataset. For layout reasons, some keywords are abbreviated: 'ndvi' = normalized difference vegetation index; 'lst' = land surface temperature; 'uhi' = urban heat island; 'lulcc' = land use/land cover change; 'lcz' = local climate zone.

Several nodes occupy central positions in the network, bridging across clusters: these include *urbanisation*, *remote sensing*, *LULCC* (land use/land cover change), and *modelling*. Unlike hazard-specific terms such as *heat* or *flooding*, these concepts represent methodological tools or overarching processes that naturally connect different research areas. For instance, *remote sensing* is strongly tied to *land surface temperature* (*LST*), *urban heat island (UHI)*, and *urbanisation* in the red cluster but also links to flooding and land-use studies. *Modelling* serves as another methodological bridge, connecting the flooding and vulnerability literature with research on precipitation and variability.

Peripheral nodes represent less frequent or more isolated keywords. Strikingly, many of these are impact-related, such as *mortality*, *vector-borne disease*, *malaria*, or the aggregated term *soil impacts* (covering landslides, soil erosion, and subsidence). Broader socio-economic dimensions like *poverty*, *informality*, and *hazard* also appear in the periphery. Their position suggests that explicit links to concrete societal impacts remain less developed and relatively fragmented. Emerging methodological terms, such as *machine learning*, are also visible at the margins, indicating directions that are beginning to enter the field but have not yet reached central importance.

Taken together, Figure 5 demonstrates that hazard-specific research (e.g. heat, flooding) forms the structural backbone of the network, while methodological concepts such as remote sensing and modelling provide essential connections across themes. At the same time, the peripheral position of impact-related keywords highlights a gap in the literature: despite frequent references to hazards and methods, systematic integration of health, poverty, and other vulnerability dimensions into the research is still relatively limited. This suggests an important direction for future work, namely the stronger linkage of urban climate hazard research to the societal impacts most directly affecting populations.

3.4 Trends of EO data use

Considering that Earth Observation (EO) constitutes a rapidly evolving field, the selected articles were analysed with respect to the trend of the use of EO data. A regression was done over the time span 2015-2024, i.e., excluding articles published in 2025 as that might not be complete (the sampling of the 2015-2025 articles having been finalised in early January 2026), which could introduce a bias.

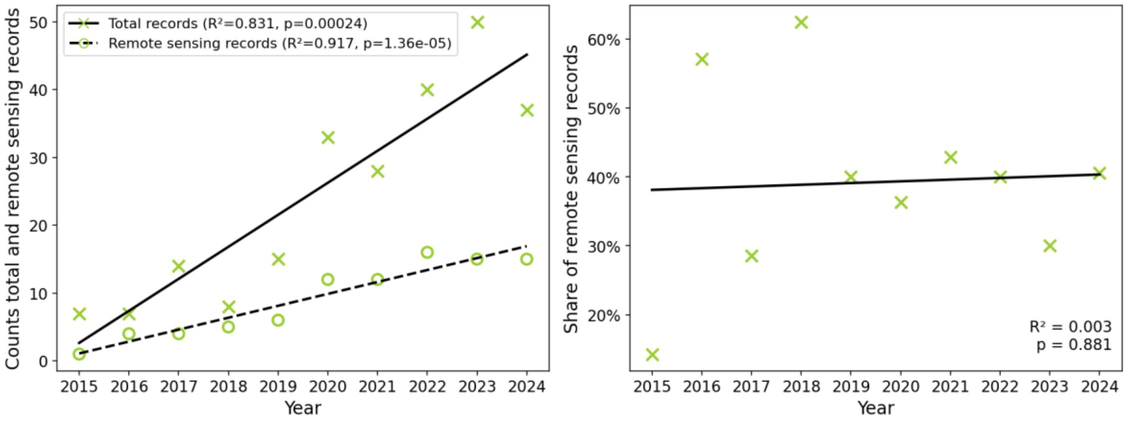

Figure 6. (left) Total number of articles (crosses and solid regression line) and EO-using articles (circles and dashed regression line) published per year throughout the period 2015-2024. (right) Share of the number of EO using articles (crosses and solid regression line).

The total annual output of articles shows a strong and statistically significant upward trend (Figure 6, left), with publications increasing from only a few articles in 2015 to more than 40 in 2024. Both the overall corpus ($R^2 = 0.83$, $p < 0.001$) and the subset of studies using satellite remote sensing ($R^2 = 0.92$, $p < 0.001$) exhibit robust growth. However, the relative share of remote sensing studies has remained statistically stable over the decade (Figure 6, right), fluctuating around 40%, without a significant trend ($R^2 = 0.003$, $p = 0.88$). This indicates that while EO is increasingly used in the studied articles, its proportional contribution to the field has not expanded.

3.5 Climate hazard frequency

The list of selected articles was further analysed in terms of the climate hazards covered. This was done by experts in the respective hazard domains, screening the title and abstracts of each article, labelling them with a hazard indication, including windstorms, sea level rise, water stress, extreme heat, climate trends, land surface temperature (LST), and flooding.

In cases where an article covered multiple hazards, the dominant hazard was identified. In addition, each article was labelled for the occurrence of (or reference to) one or more conceptual or methodological aspects, including urbanisation (including such terms as urban growth, or urban dynamics), modelling, informality, data science, future climate, remote sensing.

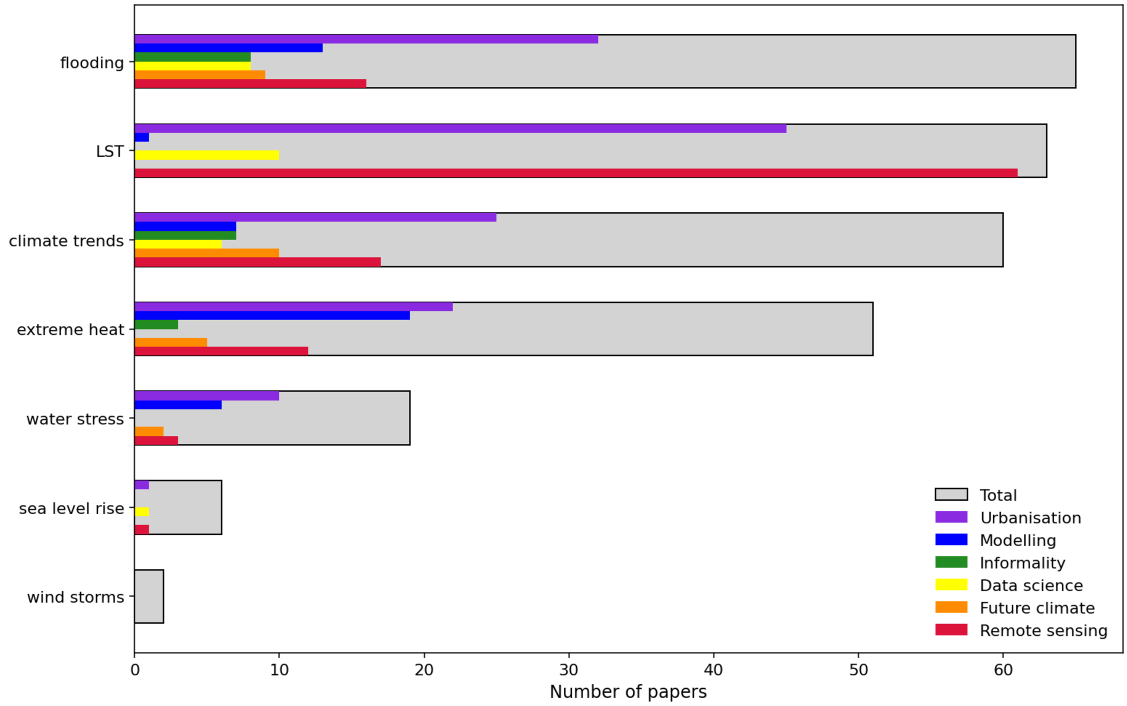

Figure 7. Distribution of reviewed articles across different hazard types. Grey bars show the number of articles for each hazard, while coloured bars indicate the occurrence of methodological/contextual themes (urbanisation, modelling, informality, data science, future climate, and remote sensing). In this figure, 'LST' refers to land surface temperature. 'Modelling' refers to deterministic climate or hydrological modelling, and 'Data Science' refers to artificial intelligence, machine learning, deep learning, etc.

The outcome of this exercise is shown in Figure 7. A close look at the distribution of hazards reveals clear thematic imbalances. Research on flooding and LST dominate the field, together accounting for nearly half of all publications. Studies on slow-onset climate trends and extreme heat are also well represented, underlining the importance of both gradual climate variability and acute heat extremes in African cities. It is worth noting that the two heat-related categories (extreme heat and LST) were separated in our classification. While this provides analytical clarity, it may also dilute the apparent weight of heat-related hazards in the dataset: taken together, these account for well over a hundred articles, confirming heat as one of

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the most prominently studied urban climate risks in Africa. The prominence of land surface temperature in particular reflects the reliance on remote sensing, which offers a consistent and widely accessible data source in data-sparse regions such as Africa. By contrast, water stress, sea level rise, and windstorms are covered only sparsely, despite their known relevance for urban vulnerability. This thematic skew suggests a concentration of research attention on hazards that are both visible in cities and relatively straightforward to monitor, while other critical but less studied risks remain underexplored.

In addition to classifying articles by their dominant climate hazard, we also identified several recurring methodological and contextual themes that characterise how climate risks in African cities are studied. These include urbanisation processes (urban growth and land-use change), deterministic modelling approaches (e.g. urban climate or hydrological models), Earth Observation, and data science techniques such as machine learning. We further assessed whether studies explicitly consider future climate projections and whether they address urban informality, a key structural feature influencing exposure and vulnerability in many African cities.

Analysing Figure 7 in terms of these conceptual and methodological aspects reveals a host of information:

- Remote sensing data is used in a minority (10-20%) of studies, except within the land surface temperature (LST) topic, for obvious reasons. A deeper analysis showed that most remote sensing-related literature cases made use of Landsat imagery, either to observe patterns of land surface temperature, or to assess historical urban growth.
- Urbanisation, urban growth or urban dynamics is mentioned in nearly half of the articles, yet nearly all of these have an exclusively historical focus, i.e., they consider past urban growth; only 10 (out of 273) articles concern forward-looking urban growth studies.
- The use of artificial intelligence (AI), machine learning (ML) and similar techniques is limited, while these could offer a way to overcome scaling challenges as well as challenges of access to high-performance computational infrastructure for African researchers.
- Most studies focus on historical or present-day climate periods; relatively few (around 10%) consider future climate projections.
- Deterministic modelling (urban climate and hydrology) is used to a limited extent only; studies often interpolate climate data from coarse model output fields, thus ignoring the impact of the urban fabric on its local microclimate (e.g. urban heat island).
- Considerations of informality remain limited, being mentioned in less than 10% of the selected articles.

4 Qualitative assessment of the state-of-the-art

The bibliometric analysis presented in Section 3 reveals clear patterns in the thematic focus of the literature on climate risks in African cities. In the following section, we complement this quantitative overview with a qualitative synthesis, with the aim of describing the current state of the art and identifying scientific knowledge gaps. This qualitative analysis consists of

1. a meta-review, based on a small number of recent review articles;

2. expert-based thematic reviews, organised by hazard type as identified in Figure 7;
3. an AI-assisted synthesis to compare with (and validate) the expert interpretation.

Those aspects are described in the following subsections.

4.1 Meta-review

A few recent review studies provide important context for understanding recent urban climate research in Africa. These include systematic mapping of adaptation responses (Hunter et al., 2020), bibliometric analyses of research trends (Mhedhbi et al., 2023), thematic assessments of urban thermal change (Li et al., 2022b), emerging multi-risk perspectives (Fekete and Subramanian, 2024), and broader scoping reviews of urban climate risk and governance (Ansah et al., 2024). Together, these review articles describe a rapidly expanding but unevenly developed knowledge base.

A consistent finding is the strong growth in publications since the mid-2010s (Mhedhbi et al., 2023). However, research remains geographically concentrated. A limited number of countries – particularly South Africa, Nigeria, Kenya, Egypt and Ghana (also see the findings of Section 2.1) – account for a disproportionate share of studies, while large parts of Central Africa and many secondary cities remain sparsely represented (Hunter et al., 2020; Mhedhbi et al., 2023). Capital cities and economically prominent agglomerations dominate the record.

Thematically, heat and flooding receive substantial attention within the urban climate literature, reflecting their relevance for African cities. Flooding is frequently examined through hydrological modelling, exposure assessments and spatial analyses (Hunter et al., 2020). Heat-related research often focuses on land surface temperature and urban heat island characteristics derived from satellite data (Li et al., 2022b). Other hazards, such as windstorms, coastal flooding and water stress, appear less consistently across the literature. Also, even though calls for integrated multi-hazard perspectives are increasing (Fekete and Subramanian, 2024), most studies still address hazards in isolation.

Methodologically, the literature combines Earth Observation, spatial analysis and a range of modelling approaches. While these methods present substantially improved spatial diagnostics in data-scarce environments, high-resolution urban climate modelling and physically detailed representations of urban processes remain limited (Fekete and Subramanian, 2024; Li et al., 2022b). Explicit coupling of hazard, exposure, vulnerability and adaptive capacity is comparatively uncommon (Ansah et al., 2024; Hunter et al., 2020). Although social dimensions (poverty, informality, governance capacity and inequality) are frequently acknowledged, they are less often incorporated into quantitative risk assessments.

Forward-looking assessments also remain limited. While some studies employ downscaled climate model outputs, very few integrate future climate scenarios with projected urban growth, demographic change or adaptation pathways (Fekete and Subramanian, 2024; Li et al., 2022b). As a result, the literature provides important diagnostics of present-day patterns but offers fewer insights into long-term urban transformation under climate change.

4.2 Expert-based thematic reviews

In the following subsections, the selected articles – organised by hazard type as occurring in Section 0 – were assessed by thematic experts. While the subsections are organised by *hazard* type, they cover the broader *risks* within each hazard, i.e., they account for exposure and vulnerability elements.

4.2.1 Flooding

Flooding has always been a critical urban hazard across Africa, but its frequency and severity are rising as climate change reshapes some of its drivers, such as intense rain (Abiodun et al., 2017; Douglas, 2017; Muller, 2016; Seidou et al., 2025) and the fact that a warmer atmosphere potentially carries more moisture (Engel et al., 2017). In many African records, the signal appears not as higher annual totals but as sharper sub-daily bursts and shifts in seasonality (Bulti et al., 2020, 2021; Garba and Abdourahamane, 2023; Singirankabo and Iyamuremye, 2022). Several cities in the continent (e.g. Kigali, Rwanda) report steeper intensity-duration-frequency (IDF) relationships and heavier tails (Padji et al., 2024; Tazen et al., 2018), implying a higher likelihood of short, intense storms (Bibi and Tekesa, 2024). Along the coast, the East African margin shows the fastest mean sea-level rise (up to more than 5 mm/year), and its bimodal rainy seasons often coincide with high tides or cyclone-driven surges, amplifying backwater effects. West Africa faces similar overlaps during monsoons, though with smaller tidal ranges (Brown et al., 2012; Muis et al., 2016; Pajak et al., 2024; Woodworth et al., 2019). As a result, the same storm total can now breach street-flooding thresholds that once held (Matos et al., 2023; Mugume et al., 2023). These climate pressures meet brittle infrastructure (Andreasen et al., 2022; Arinabo, 2022), scarce storage, and undersized or poorly maintained drains (Lameche et al., 2023). Event analyses show that even small increases in short-duration rainfall can flip nuisance ponding into disruptive floods (Bouamrane et al., 2024; Mzava et al., 2020; Nkeki et al., 2022). Community surveys from West, Central, and North Africa's coastal cities confirm the trend with reports of longer rainy seasons, more flash flooding, and widening neighbourhood hotspots (Antwi-Agyei et al., 2023; Attipo et al., 2023; Bouramtane et al., 2021; Shiwomeh et al., 2024).

While these dynamics are universally applicable, they exert a more pronounced effect on numerous African cities, where rapid, often unplanned growth and persistent infrastructure and maintenance gaps amplify storm impacts (Beshir and Song, 2021; Loots et al., 2022). As urban growth expands into floodplains and wetlands, impervious cover spreads and exposure increases. Depression storage in wetlands and natural surfaces that once slowed runoff disappears (Abass, 2020; Dumedah et al., 2021; Ramiaramanana and Teller, 2021). Encroachment into drainage rights-of-way concentrates overland flow at hydraulic constrictions (Neves et al., 2022). Undersized or poorly maintained drainage infrastructure reduces conveyance, so small increases in short-duration rainfall add centimetres to water depth and can exceed road-closure thresholds (Lameche et al., 2023). In Alexandra, South Africa, along the Jukskei River, increased paving and infill produce sharper, earlier downstream peaks. Events that once ponded now cause street-scale inundation (Mawasha and Britz, 2022). Guiding expansion by mapped flow paths and documented bottlenecks helps. With prioritized maintenance and selective upsizing, small targeted upgrades reduce inundation more than uniform area-wide retrofits (Carr et al., 2024; Gumindoga et al., 2024; Nkonu and Antwi, 2024).

Across many African cities, urban floods damage homes and disrupt core systems such as road and transit services, water and electricity, and trigger adverse socio-economic impacts on households and businesses (Kayaga et al., 2020; Koroma et al., 2024; Perera et al., 2020). Impacts are most severe where low-lying exposure overlaps with social vulnerability and weak infrastructure (Herslund et al., 2015; Kita, 2017). For instance, In Accra's Odaw basin, brief cloudbursts routinely strand commuters and disrupt local commerce, and the resulting cleanup and lost business hours cascade through household incomes (Abeka et al., 2019; Atakorah et al., 2023). Because a large share of losses stems from functional disruption rather than structural failure, the literature emphasizes multiple operational levers such as pre-storm inlet clearing, fixing bottleneck culverts, and protecting informal right-of-way drains. Timely local warnings also enable asset relocation before peak water. Across cases, such targeted measures shorten flood duration, reduce service interruptions, and curb downstream social and economic losses (Miller et al., 2022; Santos et al., 2023; Tedla et al., 2022; Zehra et al., 2019).

Despite the problem's urgency, Africa's capacity to track and plan for changing flood patterns still lags. Sub-hourly rain gauges, river and tide level loggers, and reliable drainage inventories are sparse or outdated. This scarcity hampers detection of shifts in short-duration extremes and hinders routine non-stationary IDF updates (Boko et al., 2020; Mohamed and El-Raey, 2019; Shikangalah and Mapani, 2019). Event-based datasets that link rainfall, inundation extent, and losses in a consistent format are rare (Dufitimana et al., 2025a; Weday et al., 2023). Earth observation (EO) and machine learning tools help overcome challenges accompanied with data scarcity, but their transferability across cities is limited without ground truth and open, maintained asset maps (Ekwueme, 2022; Umer et al., 2022). There is a clear need in Africa for more sustained and comparative studies to trace how a warming climate is reshaping urban floods. These studies should also examine how those shifts interact with rapid urban growth and infrastructure constraints (Dos Santos et al., 2017; Schütte and Schulze, 2017). The goal is not just to detect change, but to turn evidence into practice by supporting adaptive design standards, more reliable warnings, and maintenance and upgrade programs that keep pace with a moving hazard profile (Abass, 2020; Hassan et al., 2022).

4.2.2 Sea level rise

Another consequence of climate change is sea level rise. African coasts are already seeing a higher baseline and more frequent coastal extremes that reshape urban flood risk (Halecki and Bedla, 2025). Notably, compound flooding occurs when intense rainfall coincides with high-tide or surge. Less freeboard and higher tailwater at outfalls mean storms that once stayed below street-flood thresholds now inundate roads (Mugume et al., 2023). Because these thresholds are highly local, decision-relevant mapping must be coupled with fine topography, drainage inventories, and tide stages. This combination identifies first-disruption corridors and critical facilities. Risk is highest in embankments, back-beach lagoons and river deltas, where shallow slopes and constricted outlets amplify backwater (Abdrabo et al., 2022). An important example is the

Nile Delta, where limited gradients and constrained outfalls mean that even modest sea level rise can flood low-lying corridors and leave the most exposed tracts adjacent to critical urban functions (Kamal et al., 2025).

There are several structural factors that make Africa especially vulnerable. Rapid coastal cities' growth outpaces natural and constructed defences. Risks are compounded by low-lying topography with constricted outlets, maintenance backlogs in drainage systems, concentration of critical services along the shoreline, high social vulnerability and sparse monitoring (Abdrabo et al., 2022; Yankson et al., 2017). Urban expansion also increases the population and assets along the coastal edge. Relative sea level rise is accelerated by land subsidence, which also worsens chronic flooding. Increased exposure and the loss of natural buffers can result from expansion into wetlands, beach areas, and drainage corridors (Noby et al., 2024). Studies propose some management measures including updating zoning and setbacks to new water levels and restoring natural buffers. Drainage upgrades, such as clearing or upsizing outfalls and adding tide or flap gates and pumps, plus compound flood allowances, are also recommended (Halecki and Bedla, 2025; Mugume et al., 2023). Even so, Africa still needs stronger coastal hydro-climatologic data assimilation means, sustained research, dedicated funding, and governance reforms to make these measures standard practice (Yankson et al., 2017).

4.2.3 Water stress

Water stress in Africa in general, and African cities in particular, is rising as climate variability reduces supply and increases demand (Angelina et al., 2015; Dos Santos et al., 2017; Muller, 2016). Climate change is driving longer drought periods across Africa (Gumbo and Kapangaziwiri, 2023; Rusca et al., 2023). Long-term droughts and dry spells can depress river flows, shrink reservoir storage, and thin aquifer recharge (Boko et al., 2020; Foster and Gathu, 2024), making access to water less reliable. Even when annual rainfall changes are modest, shifts in timing and longer hot spells raise outage risk (Shikangalah and Mapani, 2019). As utilities fall short, households turn to private boreholes and vendors (Schütte and Schulze, 2017). This shift typically accelerates groundwater drawdown, raises salinity and contamination risks, and pushes higher costs onto poorer areas (Analy and Laftouhi, 2021; Ayanlade, 2024; Safa et al., 2020). Two well-documented cases are from Nairobi and Lagos, where shortfalls in piped water supply have pushed households toward private wells and water vendors (Oiro et al., 2020; Shiru et al., 2020). The result is groundwater depletion, risks of salinity and contamination, and higher costs that hit low-income communities hardest.

Just as in flood and sea-level rise catastrophes, rapid and often unplanned urban expansion in Africa is a powerful co-driver of water stress (Congedo and Macchi, 2015; Mohamed et al., 2017). Fast growth lifts demand and reduces recharge. Encroachment on recharge lands and wetlands further weakens natural buffers (Kiflay et al., 2025; Olarinoye et al., 2020). In coastal aquifers, heavy pumping together with rising seas increases the risk of saline intrusion. Therefore, a workable response should combine solutions centred on demand-side efficiency with diversified supply (Santos et al., 2023).

4.2.4 Extreme heat

A considerable share of articles in our sample concerns the topic of extreme heat. Among these articles, urbanisation takes an important position: many authors highlight the role of rapid urban growth and associated land-cover change in amplifying local heat risk in African cities (Bacha et al., 2024; Dessu et al., 2020; Deton et al., 2025; Galal et al., 2020; Igun et al., 2023b; Mushore et al., 2017a; Zhao et al., 2025). However, most analyses emphasise historical change; future urban growth projections appear less frequently, with fewer articles explicitly integrating scenarios of urban expansion into heat risk analysis (Arsiso et al., 2018a; Avordeh et al., 2021; Brousse et al., 2020b; Cheng et al., 2022; Fahmy et al., 2020; Huang et al., 2024; Marcotullio et al., 2021; Mengistu et al., 2024; Nematchoua et al., 2015; Pereira Marghidan et al., 2023).
In the context of urbanisation, informal settlements occupy a special place in relation to heat. Several studies connect informal housing, material characteristics, service deficits, and social vulnerability with heightened heat exposure and risk (Baruti et al., 2020; Benjamin Obe et al., 2023; Egondi et al., 2015; Van De Walle et al., 2021). Urban green space is frequently invoked as a mitigation pathway: trees, parks and broader greening are framed as practical cooling strategies. Yet relatively few articles quantify the magnitude of cooling benefits. Many mention greening as a recommendation without robust effect assessments or experimental/modelling designs (Frimpong et al., 2022; Mahmoud and Gan, 2018; Morakinyo et al., 2016; Parker et al., 2025; Souverijns et al., 2023).
The number of articles that measure or model impacts of extreme heat is limited. While slow-onset heating trends generate substantial work on vector-borne disease, the direct health effects of extreme heat are treated less consistently, despite projections of much more severe heat to come. Still, there are notable contributions linking heat to health outcomes and vulnerability (Benbrahim et al., 2025; Omonijo, 2017; Souverijns et al., 2022). A smaller subset evaluates energy demand for cooling, sometimes using Cooling Degree Days to estimate or project electricity needs (Ghribi and Dahech, 2023; Mushore et al., 2017b; Wemegah et al., 2025). By contrast, there is little documentation on infrastructure impacts, such as asphalt softening or thermal constraints on power generation and transmission (Gaber et al., 2020; Ngoungue Langue et al., 2023).
Only a relatively small number of articles perform numerical urban climate modelling with explicit urban physics (e.g. WRF, UrbClim, ENVI-met). Where present, these studies demonstrate the added value of resolving urban form and materials for heat stress (Bounoua et al., 2025; Limona et al., 2019; Obe et al., 2024; Souverijns et al., 2022, 2023; Yahia et al., 2018). More commonly, modelling is limited to downscaling or interpolating coarse GCM/RCM output to city locations, which risks overlooking local-scale effects (Arsiso et al., 2018a; Deton et al., 2025; Marcotullio et al., 2021; Mengistu et al., 2024; Nematchoua et al., 2015; Ngoungue Langue et al., 2023). Detialed metre-scale microclimate studies (e.g. ENVI-met) remain limited, though this area is bound to grow given the emergence of detailed building and vegetation data. At still smaller scales, indoor heat stress and occupational exposure are rarely addressed (Ayanlade et al., 2019; Benbrahim et al., 2025; Mengistu et al., 2024; Mushore et al., 2017b; Wilby et al., 2021).

Regarding future climate, only a minority of modelling and risk studies include explicit future climate projections (time horizons to mid- or late-century) in a way that couples climate scenarios with urban growth or adaptation measures (Arsiso et al., 2018a; Avordeh et al., 2021; Brousse et al., 2020b; Cheng et al., 2022; Deton et al., 2025; Fahmy et al., 2020; Huang et al., 2024; Igun et al., 2023b; Marcotullio et al., 2021; Mengistu et al., 2024; Nematchoua et al., 2015; Pereira Marghidan et al., 2023).

On heat stress indicators, authors mention Universal Thermal Climate Index (UTCI), Physiological Equivalent Temperature (PET), Predicted Mean Vote (PMV), Temperature-Humidity Index (THI), Standard Effective Temperature (SET), Wet-Bulb Globe Temperature (WBGT), and related metrics. Nonetheless, many studies still rely primarily on air temperature as the main indicator (Arsiso et al., 2018a; Avordeh et al., 2021; Ayanlade et al., 2019; Bacha et al., 2024; Balogun and Daramola, 2019; Baruti et al., 2020; Bassett et al., 2020; Benaomar and Outzourhit, 2024; Benbrahim et al., 2025; Boumaraf and Amireche, 2021; Bounoua et al., 2025; Brousse et al., 2020b).

Finally, the use of satellite remote sensing in the extreme-heat subset is limited relative to the broader UHI literature, which is unsurprising given that much EO work is funnelled into "LST/UHI" diagnostics rather than personal heat exposure (see next section). Still, several articles do use EO: Landsat appears frequently, often to delineate land cover/greening trends (Arsiso et al., 2018a; Dessu et al., 2020; Deton et al., 2025; Lachkham et al., 2025; Mahmoud and Gan, 2018; Mushore et al., 2017a). Some also employ Local Climate Zones (LCZ) for urban form classification, occasionally drawing on EO-derived LCZ maps (Benjamin Obe et al., 2023; Brousse et al., 2020a; Obe et al., 2024; Van De Walle et al., 2021).

4.2.5 Land surface temperature

Land Surface Temperature (LST) is the radiometric "skin" temperature retrieved by satellite sensors, representing the thermal state of the uppermost surface layer at the time of overpass. Unlike near-surface air temperature, which is shaped by atmospheric mixing, humidity and synoptic forcing, LST is governed by surface emissivity, morphology and energy balance. It is therefore not merely a climatic variable but a spatial expression of how cities are built. Although correlated with air temperature, LST captures a distinct component of the urban heat system (Li et al., 2022a). In semi-arid basins, impervious expansion alters runoff dynamics and erosion risk (Mahgoub et al., 2025); surface warming is thus coupled to shifts in land-atmosphere and land-water processes. LST operates as an integrative signal of urban environmental change rather than a standalone metric.

In African contexts, where meteorological station networks are sparse and unevenly distributed, satellite-derived LST has become foundational for diagnosing urban climate dynamics (Arsiso et al., 2018b; Tarawally et al., 2018) . The Landsat thermal archive, spanning four decades, enables consistent, multi-temporal observation of surface thermal change at neighbourhood scale. Urban climate research across Africa converges on a robust empirical pattern: land use and land cover change is the dominant driver of surface warming. Conversion of vegetated land to impervious surfaces systematically increases LST and intensifies surface urban heat island (SUHI) patterns (Gyimah, 2023; Koko et al., 2021b, a; Mensah et al., 2020; Odindi et al., 2022). Reduced evapotranspiration, increased heat storage and artificially reduced surface albedos amplify heat stress (Mushore et al., 2017a).

City-level studies illustrate this structural production of heat. In Addis Ababa, urban expansion has intensified surface temperatures and reshaped UHI patterns (Arsiso et al., 2018a; Eshetie, 2024; Moisa and Gemeda, 2022). In Bahir Dar, multi-decadal analysis links built-up growth to sustained LST increases (Melese et al., 2025). Oran exhibits a widening urban-rural thermal gradient over four decades, with implications for human thermal comfort (Bendib and Boutrid, 2024; Soufiane et al., 2025). Comparable dynamics are reported in Akure and Osogbo (Oyeniyi et al., 2025), Sekondi-Takoradi (Biney et al., 2024), Kano (Koko et al., 2021b) and Kumasi (Mensah et al., 2020). A continental synthesis confirms that persistent surface "hot zones" in Africa are overwhelmingly urban (Gyimah, 2023).

Recent research efforts have moved beyond descriptive mapping to identify drivers and spatial differentiation. Urban expansion is consistently identified as a primary instigator of SUHI formation in Ethiopian cities such as Gondar and Adama (Mekonnen et al., 2024b; Melese et al., 2025). In Western Ethiopia, land use and land cover change alters surface temperature and energy fluxes, linking land transformation to modified land–atmosphere exchange (Dibaba, 2023). Across East Africa, SUHI intensity varies with urban form, development trajectory and seasonal dynamics (Garuma, 2023; Li et al., 2021). Heat exposure is therefore spatially uneven and temporally dynamic, reflecting both morphology and climate regime. The Local Climate Zone (LCZ) framework has strengthened the attribution of LST variability to specific urban forms and enhance cross-city comparability in data-scarce contexts (Li et al., 2022b; Manyanya et al., 2024; Tarawally et al., 2018). Empirical studies demonstrate LST reductions associated with vegetated and blue–green surfaces (Athukorala and Murayama, 2020). LCZ-informed analysis clarifies how structural urban form mediates these cooling benefits (Li et al., 2022c; Mushore et al., 2019). The spatial distribution of cooling infrastructure is therefore a determinant of thermal inequality.

Since surface temperature concentrates in densely built, vegetation-deprived neighbourhoods that often coincide with lower-income populations (Mushore et al., 2017a), LST also reveals the geography of vulnerability. It has been demonstrated how remotely sensed thermal patterns can be combined with demographic indicators to assess extreme heat vulnerability (Mushore et al., 2019), and how incorporating surface characteristics into machine learning models significantly improves urban hazard and vulnerability mapping accuracy (Dufitimana et al., 2025b).

Looking forward, the strategic potential of LST in Africa lies in closing adaptation gaps through systematic, scalable monitoring. First, the Landsat archive provides a consistent baseline against which future expansion trajectories can be evaluated. Historical LST trends can support accountability in urban planning by revealing how land allocation decisions shape thermal risk. Second, integration with machine learning and socio-economic datasets enables anticipatory modelling of heat exposure under alternative urban growth scenarios (Dufitimana et al., 2025b; Mushore et al., 2017a). Third, LCZ-based standardisation supports cross-city comparison and the transfer of mitigation strategies across diverse climatic and governance contexts (Li et al., 2022b; Mushore et al., 2019).

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4.2.6 Slow-onset climate trends

Climate change impacts are most visible through extreme events with a sudden impact, such as extreme precipitation leading to floods. However, a considerable number of climate change consequences develop on the long term and are only perceived gradually.

One impactful long-term climate change impact in Africa is vector-borne diseases. Due to climate change, the suitability areas for disease vectors (in Africa mainly mosquitos) are expanding, impacting a higher amount of the population. Most studies focus on malaria (Brousse et al., 2019, 2020a; Damte et al., 2023; Diriba et al., 2024; File and Dinka, 2020; Flückiger and Ludwig, 2020; Ibrahim et al., 2022; Kamkuemah et al., 2024; Moha et al., 2020; Morlighem et al., 2022, 2023; Oluwatimilehin et al., 2022) and dengue (Aliaga-Samanez et al., 2024; Kamkuemah et al., 2024; Montgomery et al., 2025; Noureldin and Shaffer, 2019; Osalla et al., 2025), while only one article in the sample focusses on yellow fever (Aliaga-Samanez et al., 2024), and one on zika and chikungunya (Montgomery et al., 2025). Vector suitability maps are constructed using climate modelling, remote sensing, and Local Climate Zone (LCZ) and GIS mapping. Interestingly, most articles denote the link between (future) urbanisation, (future) climate change and higher impacts of vector-borne diseases (Rose et al., 2020).

Urbanisation and growing urban populations are a distinct problem in Africa, the number of urban dwellers expected to double between 2025 and 2050, from around 700 million to almost 1.5 billion (UN-Habitat, 2022). The conversion of natural land to the growing urban extents and densities impacts the local urban climate (temperature, humidity and rainfall). The interactions between the urban canopy and the atmosphere are investigated using high-resolution models (Anande and Park, 2021; Daramola and Balogun, 2019; Zeleke et al., 2023), remote sensing (Frimpong et al., 2022; Ibrahim Mahmoud et al., 2016; Sun et al., 2023; Traore et al., 2025) or ground-based observations (Igun et al., 2023a; Kabano et al., 2022). Downstream impacts focus on various health aspects related to higher temperatures (Adelekan et al., 2015; Codjoe et al., 2020; Rother, 2020) and a specific focus on unequal impacts within cities, more specifically informal settlements (Corburn et al., 2022; Damte et al., 2023; Hlahla and Hill, 2018; Nwankwo et al., 2022; Owusu and Nursey-Bray, 2019; Williams et al., 2019).

Apart from impacts on humans, growing urban extents also impact ecosystems and biodiversity. Growing cities (which often occur in uncontrolled ways in Africa) lead to the disappearance of natural ecosystems, habitats and green cover, which are essential urban climate resilience tools (Corburn et al., 2022; Senbore and Oke, 2023; Traore et al., 2025). Several studies track the loss of natural ecosystems via remote sensing tools to monitor environmental quality over time and space (Ibrahim Mahmoud et al., 2016; Sun et al., 2023). Nature-based solutions are proposed to restore biodiversity in cities, while furthermore supporting adaptation to other climate-related consequences (Abraha et al., 2022; Daramola and Balogun, 2019; Igun et al., 2023a).

While increased extreme precipitation events pose direct impacts on populations (Azagoun et al., 2025), slower long-term changes in rainfall patterns and dynamics also create challenges. Changes in precipitation patterns stress agriculture and urban food security (Atiem et al., 2022; Bassirou and Bitondo, 2023) and water resource management (Abraha et al., 2022; Bizimana et al., 2024; Mekonnen et al., 2024a; Pattnayak et al., 2019), which will increase towards the future (Gamal et al., 2024; Klutse et al., 2024). Even though rainfall trends vary significantly per region and season, it often leads to a more irregular water availability and water quality (Gule et al., 2024; Senbore and Oke, 2023) with negative impacts on urban populations (Iradukunda et al., 2023; Mohamed et al., 2024).

Land degradation constitutes an important downstream climate impact of variability in rainfall patterns and extreme precipitation, strengthened by urbanisation. Uncontrolled urban expansion and human pressure hinder effective land management and conservation practices, leading to increased soil erosion rates (Marondedze and Schütt, 2021; Salhi et al., 2023). Apart from the negative consequences for soil quality, they can trigger soil instability, leading to landslides (Bourenane et al., 2015; Dille et al., 2022; Obda et al., 2022) or coastal erosion (Marzouk et al., 2021).

A general consequence of these slowly evolving climate trends is the long-term socio-economic impact. Infrastructure (Lane-Visser and Vanderschuren, 2024), economic assets (De Wit et al., 2023) and human capital (Iradukunda et al., 2023) are at significant risk towards the future.

4.2.7 Windstorms

Winds are a climate-related hazard, affecting not only coastal areas, but also inland areas and cities in Africa. The southeastern part of Africa is especially vulnerable for high wind speeds, due to the occurrence of tropical cyclones in the region, not only accounting for high wind speeds, but also heavy precipitation (Williamson et al., 2023). Wind-driven disasters can cause severe damage to buildings and essential infrastructure, with particularly high impacts in more vulnerable urban areas (Kafi et al., 2021). Beyond physical destruction, wind-related disasters can also trigger longer-lasting and interconnected disruptions to basic services and resources (such as access to key household needs), which can compound vulnerability and contribute to rising inequality after the event (Williamson et al., 2023).

4.3 AI-assisted synthesis

As a final qualitative analysis, we conducted an AI-assisted synthesis to test the robustness of the expert interpretation presented in Section 0. To this end, we applied the AI-based tool SciSpace (https://www.scispace.com) to the 273 selected articles to identify knowledge gaps, activating the 'Research Gaps' and 'Future Research' options within SciSpace's *Library* environment. This resulted in a table with 'Research Gaps' and 'Future Research' columns, and one row for each of the 273 articles.

As this procedure generated more than 50,000 words of output (nearly 100 A4 text editor pages), we analysed these results using a GPT-5.2 large language model. Specifically, we prompted the model as follows: "Using the 'Research Gap' and 'Future Research' columns of the uploaded table, identify the key knowledge gaps regarding climate risk in African cities and generate one paragraph of text for each." Subsequently, we prompted the model to present the results in a structured (tabular) rather than in a narrative form. Based on this procedure, the key knowledge gaps presented in Table 2 emerged. Each row synthesises recurring themes across multiple studies.

Table 2. Key knowledge gaps identified by an AI-assisted procedure, based on the list of selected articles, and using the SciSpace tool's 'Research Gaps' and 'Future Research' options.

Knowledge gap	Core issue	Consequences	Research needs
Limited high-resolution data	Lack of fine-scale spatial and temporal climate, infrastructure and socio-economic data	Constrains modelling of UHI, flooding and exposure	Enhanced monitoring networks, improved remote sensing, granular datasets
Limited geographic coverage	Overreliance on single-city case studies	Limited generalisability	Multi-city comparative studies, standardised methodologies
Urbanisation–climate interactions	Poor understanding of feedbacks between growth and hazards	Uncertain projections of heat and flood risks	Coupled urban–climate models, morphology-sensitive analyses
Compound and cascading risks	Hazards studied in isolation	Underestimation of systemic vulnerability	Integrated multi-hazard frameworks
Adaptation effectiveness	Limited empirical evaluation	Uncertain performance of greening interventions	Performance-based studies (e.g., tree-based cooling)
Informal settlements	Weak integration of social vulnerability	Incomplete risk representation	Interdisciplinary hazard–vulnerability integration
Modelling uncertainty	Coarse projections and simplified growth assumptions	Weak long-term planning support	Explicit uncertainty treatment, improved scenario coupling
Translation to planning	Weak policy uptake	Research–practice gap	Governance studies, decision-support tools
Health impacts	Limited epidemiological evidence	Underestimated public health burden	Exposure–health linkage studies

A comparison between the AI-assisted and the expert-based reviews (Section 0) shows substantial overlaps in the knowledge gaps identified. Both approaches point to structural deficiencies in the literature, including the limited availability of high-resolution data, the geographic concentration of case studies in a small number of countries, and the insufficient integration of hazard, exposure and vulnerability dimensions. Similarly, both assessments emphasise the weak coupling of future climate projections with urban growth scenarios, the limited evaluation of adaptation effectiveness, and the underrepresentation of informal settlements and socially vulnerable populations.

At the same time, the AI-assisted synthesis articulates certain aspects more explicitly compared to the expert assessment. In particular, it highlights the overreliance on single-case studies, the absence of standardised cross-city comparison, and the

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limited use of uncertainty-aware modelling approaches. It also more clearly frames the weak translation of research findings into urban planning and governance practice as a distinct knowledge gap.

Overall, the qualitative assessment confirms the patterns identified in the bibliometric analysis, notably the strong focus on flooding and surface temperature and heat studies, and the comparatively limited attention to other climate hazards affecting African cities.

5. Conclusions

This assessment selected and examined 273 peer-reviewed articles (2015-2025) addressing climate hazard and risk in African cities, combining quantitative mapping, hazard-based expert review and an AI-assisted synthesis of reported knowledge gaps. Together, these approaches reveal a rapidly expanding but methodologically constrained knowledge base. The main findings are as follows:

1. A fundamental limitation concerns the availability of high-resolution data. Many studies rely on coarse climate projections or sparse in-situ monitoring networks that are not tailored for urban-scale assessments. Sub-hourly rainfall records, dense temperature observations and modelling, and fine-scale socio-economic datasets remain scarce across much of the continent. High-resolution urban climate modelling with explicit representation of urban morphology and materials is also relatively rare. As a result, urban heat islands, pluvial flooding, compound coastal risks and exposure patterns are often assessed at spatial and temporal resolutions insufficient to capture intra-urban variability. This limits the ability to move towards actionable and contextually specific adaptation planning.
2. Earth Observation (EO) has become a central methodological pillar of the field, particularly through the use of Landsat imagery for land surface temperature and urban growth analysis. In data-scarce regions, EO provides a consistent and scalable source of information that partly compensates for limited ground-based monitoring. However, its application remains concentrated on surface temperature diagnostics and historical land-cover change. The relative share of EO-based studies has remained stable over the past decade. This suggests that, despite significant advances in sensor resolution and data availability, its broader potential remains underexploited.
3. The geographic distribution of research is highly imbalanced. A small number of countries accounts for a disproportionate share of publications. Central Africa in particular remains a blind spot. Capital cities dominate the literature, and fast-growing secondary cities are underrepresented. This skewed view carries a risk of reinforcing existing disparities in climate knowledge and planning capacity.
4. Thematic coverage remains uneven. Flooding and heat-related topics dominate the literature, whereas hazards such as sea-level rise, windstorms and urban water stress receive comparatively limited attention. Hazards are generally analysed in isolation rather than within multi-hazard or cascading risk frameworks. Explicit coupling between hazard, exposure, vulnerability and adaptive capacity remains uncommon.

5. Social dimensions are insufficiently embedded in quantitative assessments. Informal settlements, poverty, governance capacity and inequality are frequently acknowledged but rarely integrated systematically into modelling or risk frameworks. Health impacts, particularly those directly linked to extreme heat, remain underdeveloped relative to projected climate trends.
6. The literature is predominantly retrospective. Most studies assess historical climate variability or past urban growth. Only a limited number integrate future climate scenarios with projected urban expansion or demographic change. As a consequence, while present-day patterns are increasingly well documented, robust assessments of long-term urban transformation under climate change remain scarce.
7. Finally, the AI-assisted synthesis highlighted additional structural issues: a systemic overreliance on single-city case studies, limited use of standardised cross-city comparison frameworks, weak treatment of modelling uncertainty, and a persistent gap between scientific findings and their translation into urban planning and governance practice.

Summarising, urban climate research in Africa has grown substantially over the past decade, but it remains constrained by data scarcity, limited high-resolution modelling capacity, geographic imbalance, and insufficient integration of social and forward-looking dimensions. Addressing these gaps will require strengthened monitoring networks and improved urban-scale modelling. In data-scarce regions, Earth Observation offers a particularly valuable source of consistent and scalable information, but its potential remains only partially exploited, especially beyond land surface temperature diagnostics. Broader geographic representation, particularly in Central Africa and secondary cities, is also needed, together with closer integration of hazard, vulnerability and governance perspectives. Such efforts are essential to support evidence-based adaptation and resilience planning in one of the world's most climate-vulnerable urban regions.

Author contributions

KDR: conceptualization, methodology, formal analysis, visualisation, writing. OS: conceptualisation, methodology, writing. NV: funding acquisition, supervision, writing. TC and IU: visualization, writing. MA, HB, BL, JL-T, AN, MS, NS: writing. KDR prepared the manuscript with contributions from all co-authors.

Competing interests

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