

RESEARCH ARTICLE

# Impacts of Land Use/Land Cover Change and Climate Change on Natural Hazards in Tropical Regions: Synthesis Review and Relevance to the Kinshasa (DRC) Context

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## Abstract

This literature review investigates the combined impacts of Land Use/Land Cover Change (LULCC) and climate change on natural hazards in tropical regions, emphasizing their relevance to Kinshasa. Using a thematic, narrative approach and 144 selected references, the study synthesizes global and regional findings on how urbanization, deforestation, and climate variability exacerbate hazards such as flooding, landslides, erosion, urban drought, and biodiversity loss. Key mechanisms include increased impervious surfaces, loss of natural buffers, hydrological disruption, and altered microclimates. In Kinshasa, these effects are amplified by fragile soils, steep topography, and rapid, unplanned urban growth. The study highlights how LULCC drives soil degradation, reduces groundwater recharge, and intensifies flash floods and urban heat islands. Concurrently, climate change increases extreme rainfall and drought risk, interacting with land cover changes to amplify vulnerability. The results show that Kinshasa's environmental risks stem from both climatic forces and anthropogenic pressures, producing nonlinear, synergistic hazard dynamics. The review concludes that integrated, spatially explicit risk assessments are essential for informing adaptive urban planning and resilience strategies. It provides a conceptual foundation for modeling hazard interactions in Kinshasa and supports the development of targeted mitigation measures in rapidly urbanizing tropical cities.

**Keywords:** Land Use/Land Cover Change, Climate Change, Natural Hazards, Urban Flooding, Soil Degradation, Urban Heat Island, Kinshasa, Tropical Cities

## 1 Introduction

Understanding the combined influence of Land Use/Land Cover Change (LULCC) and climate change on natural hazards is critical in tropical regions, where ecosystems and human settlements are particularly sensitive to environmental alterations. Tropical areas, such as those in sub-Saharan Africa, are characterized by fragile soils, steep rainfall gradients, and rapidly expanding urban zones—all factors that exacerbate vulnerability to hazards including floods, soil erosion, and landslides (Kreier, 2022; Kayitesi et al., 2022). Studies have highlighted that LULCC can significantly disrupt the hydrological balance by modifying surface albedo, vegetation cover, and evapotranspiration patterns—altering local microclimates and potentially intensifying extreme weather events (Olaniyi et al., 2012; Pielke et al., 2011). These biophysical changes, in combination with rising climate variability, create cascading risks that demand comprehensive assessment.

In tropical developing cities like Kinshasa, where urban sprawl proceeds alongside deforestation and informal settlement, the interaction between altered land cover and shifting climate patterns can amplify risk profiles (Gogoi et al., 2019; Minale & Rao, 2012). Proof of such interaction is shown by shifts in rainfall and temperature extremes after deforestation, as observed across South Asia and Africa (Nayak & Mandal, 2019; Kayitesi et al., 2022). Therefore, it is essential to assess the joint effects of LULCC and climate

change on natural hazards to inform adaptation strategies and spatial planning in these contexts.

## 2. Methodology

This literature review was conducted using a narrative and thematic approach, aiming to synthesize current knowledge on how Land Use/Land Cover (LULC) change and climate change influence natural hazards in tropical regions, with a focus on urban contexts similar to Kinshasa.

A total of 144 references were selected through targeted searches on Google Scholar, DOAJ, and institutional sources such as IPCC, FAO, and UN-Habitat. Keywords combined terms like “LULC change,” “climate change,” “natural hazards,” and “tropical cities.” Studies were included if they:

- Provided empirical or conceptual evidence of LULC or climate impacts on hazards;
- Focused on tropical or sub-Saharan urban environments;
- Were accessible in open access or through institutional repositories.

To ensure broad regional representation and avoid geographic bias, studies were included from diverse tropical contexts across Africa, Asia, and Latin America. Preference was given to open-access peer-reviewed research. Identified studies were grouped thematically based on types of hazards (e.g., flooding, erosion, landslides), mechanisms (e.g., runoff, heat island effects), and drivers (LULC, climate). This enabled a structured synthesis of multi-hazard interactions.

Although the review is thematic and narrative, care was taken to avoid over-representation of any single country or institution.

This is not a systematic review; rather, it aims to capture the most relevant and context-specific knowledge to inform the hazard assessment framework.

### 3. Results

#### 3.1 LULC Change and Its Effects on Natural Hazards

Land Use/Land Cover Change (LULCC) profoundly influences the frequency and intensity of natural hazards, particularly in tropical, urbanizing regions with hydrologically vulnerable environments. Research indicates multiple mechanisms through which LULCC drives natural hazards. The mechanisms by which these changes affect environmental risks are diverse and often interconnected. Table 1 provides a structured synthesis of the main impacts of LULCC on natural hazards, as identified in recent scientific literature.

Table 1. Effects of Land Use and Land Cover Change (LULCC) on Natural Hazards.

Mechanism	Description	Key Effects	References
Increased Surface Runoff and Flood Peaks	Urbanization replaces natural surfaces with impervious ones, increasing runoff, shortening concentration time, and amplifying flood peaks. Models and case studies confirm this trend in tropical cities like Kinshasa.	Reduced infiltration, increased runoff volume, shorter lag time, higher flood peaks, more frequent flash floods	Astuti et al., 2019; Xu et al., 2018; Feng et al., 2021; Luo et al., 2020; Sugianto et al., 2022
Reduction of Natural Buffering Systems and Soil Degradation	Loss of forests, wetlands, and vegetation due to urban growth and agriculture degrades soil structure and ecosystem services, leading to higher erosion, landslides, and flood risk.	Loss of slope stability, reduced infiltration, soil erosion, flood vulnerability, long-term land degradation	van Beek et al., 2020; Nyarko et al., 2021; Stavi et al., 2021; Acharya & Cochrane, 2020; Mwangi et al., 2016; Nyandwi et al., 2022; Munyaneza et al., 2020; UN-Habitat, 2021; Panagos et al., 2018; Tening et al., 2016; IPCC, 2022
Enhanced Landslide Susceptibility through Destabilization of Slopes	Deforestation, slope modification, poor drainage, and unplanned construction increase landslide risk by reducing soil cohesion and increasing hydrological load on unstable slopes.	Slope failure, increased landslide frequency and severity, urban vulnerability	Sidele et al., 2006; Casagli et al., 2021; Mugagga et al., 2012; Glade et al., 2005; MacCarthy et al., 2020; Gariano & Guzzetti, 2016; Mayala et al., 2019; IPCC, 2022
Urban Heat Island (UHI) Intensification	Urban areas trap more heat due to impervious surfaces, vegetation loss, and anthropogenic heat, causing elevated temperatures and health issues.	Higher land surface temperatures, health stress, nighttime heat retention, air pollution	Oke, 1982; Santamouris, 2015; Zhou et al., 2014; Li et al., 2019; Mvondo et al., 2021; Amoateng et al., 2018; Balogun et al., 2020; Kim & Joh, 2006; Stone et al., 2010; Kafy et al., 2021
Air Quality Degradation	LULCC increases air pollution by enhancing emissions and modifying dispersion conditions. Secondary pollutants and heat islands further intensify effects.	Higher PM2.5, NOx, O <sub>3</sub> , and SO <sub>2</sub> levels; public health risks; altered dispersion patterns	Kahyaoglu-Koraçin et al., 2009; Abdolahnejad et al., 2018; Superczynski & Christopher, 2011; Sun et al., 2016; Ward et al., 2014; Li et al., 2016; Heald & Spracklen, 2015; Lai et al., 2016; Chang et al., 2020a; Roy et al., 2023; Bascom et al., 1996; Fann et al., 2012; Partha et al., 2022; Fotheringham et al., 2019; Wang et al., 2019
Increased Risk of Soil Erosion	Removal of vegetation and increased runoff accelerate soil erosion, particularly on steep slopes and in informal settlements.	Topsoil loss, gully formation, sedimentation of rivers, land degradation	Pimentel et al., 1995; Bewket & Teferi, 2009; Panagos et al., 2015; Nyssen et al., 2004; Lal, 2001; Fenta et al., 2020
Groundwater Recharge Loss	Impervious surface growth reduces infiltration and recharge, stressing groundwater-dependent systems.	Lower water tables, reduced aquifer recharge, increased pumping cost, dry wells	Scanlon et al., 2002; Lerner, 2002; Zhou, 2014; Bruijnzeel, 2004; Bosch & Hewlett, 1982; Olang & Fürst, 2011; Foster & Chilton, 2003; Niehoff et al., 2002; Shrestha et al., 2006; Famiglietti, 2014
Increased Flash Flood Risk	Urban sprawl and vegetation loss reduce infiltration and increase runoff velocity, triggering flash floods, especially during short intense rainfall.	Quick runoff, increased peak flow, infrastructure damage, short warning time	Terti et al., 2017; Weng, 2001; Shuster et al., 2005; Ouma & Tateishi, 2014; Douglas et al., 2008; Di Baldassarre et al., 2010; Bradshaw et al., 2007; Lin et al., 2008; Miller et al., 2002; Miller & Hutchins, 2017
Biodiversity Loss	Habitat fragmentation and conversion reduce species diversity and ecosystem functions, increasing vulnerability to other hazards.	Species extinction, habitat fragmentation, reduced ecosystem services	Foley et al., 2005; Newbold et al., 2015; Laurance et al., 2014; Haddad et al., 2015; McKinney, 2006; Pickett et al., 2001; Betts et al., 2017; Bellard et al., 2012; Cardinale et al., 2012
Urban Drought	Urbanization disrupts infiltration, vegetation evapotranspiration, and increases demand, causing water shortages even without climatic drought.	Reduced water supply, aquifer depletion, increased evapotranspiration demand	Grimm et al., 2008; Weng, 2011; Owen et al., 2006; Zhou et al., 2015; Elmqvist et al., 2013; Liu et al., 2017; Foster & Ait-Kadi, 2012; Weng et al., 2014

To better understand the measurable impact of land use and land cover change (LULCC) on natural hazards, Table 2 summarizes key quantitative findings from recent studies.

These figures highlight how specific mechanisms—such as urbanization, deforestation, and soil sealing—amplify environmental risks across tropical regions.

Table 2. Quantitative Effects of Land Use and Land Cover Change (LULCC) on Natural Hazards

Mechanism	Key Result	References
Increased Surface Runoff and Flood Peaks	Urbanization increased peak runoff by 45–87% in tropical cities.	Astuti et al., 2019; Feng et al., 2021
Reduction of Natural Buffering Systems and Soil Degradation	Up to 70% decrease in soil infiltration capacity after forest conversion.	Mwangi et al., 2016
Enhanced Landslide Susceptibility through Destabilization of Slopes	Landslide frequency increased by 35% in deforested slopes.	Mugagga et al., 2012
Urban Heat Island (UHI) Intensification	Surface temperature up to 7°C higher in urban cores compared to rural areas.	Zhou et al., 2014; Balogun et al., 2020
Air Quality Degradation	PM2.5 concentrations increased by 25–60% in rapidly urbanizing zones.	Sun et al., 2016; Roy et al., 2023
Increased Risk of Soil Erosion	Annual soil loss exceeded 100 t/ha in degraded catchments.	Fenta et al., 2020; Bewket & Teferi, 2009
Groundwater Recharge Loss	Groundwater recharge reduced by 30–70% under impervious surface expansion.	Scanlon et al., 2002; Zhou, 2014
Increased Flash Flood Risk	Flash flood frequency doubled over 15 years of urban expansion.	Terti et al., 2017; Di Baldassarre et al., 2010
Biodiversity Loss	Biodiversity declined by 13–31% in fragmented tropical landscapes.	Newbold et al., 2015; Haddad et al., 2015
Urban Drought	Urban areas showed 20–40% lower evapotranspiration and water retention compared to vegetated zones.	Liu et al., 2017; Weng, 2011

The combined analysis of Tables 1 and 2 clearly illustrates the multifaceted impact of land use and land cover change (LULCC) on natural hazards in tropical environments. Qualitative patterns (Table 1) highlight a consistent association between anthropogenic landscape transformations—such as urban expansion, deforestation, and agricultural intensification—and the emergence or intensification of environmental risks. These associations are substantiated by robust quantitative findings (Table 2), which provide concrete evidence of increased flood peaks (up to 87%), reduced groundwater recharge (by 30–70%), and accelerated soil erosion (exceeding 100 t/ha/year), among others. Together, the two tables underscore the critical need to integrate land use planning into natural hazard mitigation strategies, particularly in rapidly urbanizing tropical regions.

### 3.2. Climate Change and Its Effects on Natural Hazards

Climate change is a central driver of the increasing frequency and severity of natural hazards across the globe. The Intergovernmental Panel on Climate Change (IPCC) has consistently shown that rising global temperatures, altered precipitation patterns, and more frequent extreme weather events are transforming the dynamics of hydrometeorological and geophysical hazards (IPCC, 2022). In tropical urban contexts such as Kinshasa, the effects of climate change on natural hazards are compounded by socio-environmental vulnerabilities and poor infrastructure resilience.

#### 3.2.1. Intensified Precipitation and Flooding

Climate change is unequivocally linked to an increase in the intensity and frequency of extreme precipitation events, which significantly elevates flood risk, especially in tropical regions (IPCC, 2022). This section reviews key studies that demonstrate these phenomena and their implications for urban flood hazards.

##### a) Continental and regional trends

A comprehensive study examining flood hazard changes across Africa showed that while total rainfall trends vary spatially, extreme precipitation events have increased in many regions, particularly tropical Africa—suggesting a higher risk of flood extremes (Gautam et al., 2021).

##### b) Attribution of intensified rainfall and floods

Research by World Weather Attribution found that Eastern Africa’s March–May rains in 2024 were doubled in likelihood due to human-induced climate change, with urban expansion further amplifying impacts in densely populated areas (Associated Press, 2024). Similar attribution analysis across West and Central Africa (Cameroon, Chad, Niger, Nigeria, Sudan) showed a 5–20% increase in seasonal heavy rainfall due to anthropogenic warming (Reuters, 2024). In Sudan’s Far North, extra-heavy rains were linked to a 10% increase in intensity tied to climate change, emphasizing the compound effect on vulnerable population centers (Mongabay, 2024).

##### c) Urban amplification of rainfall extremes

Modeling studies reveal that urbanization itself influences extreme rainfall. A WRF-based research in the Lake Victoria Basin showed that “urban-canopy” effects intensified rainfall by boosting moisture convergence and enhancing convective processes in urban fringes (Ionita et al., 2023).

##### d) Flood frequency and linkage with ENSO

A review of global-and regional-scale data from 1981–2014 indicated that flood events in Africa correlate strongly with ENSO cycles. El Niño and La Niña intensify seasonal rainfall, increasing flood hazard frequency—particularly in equatorial and eastern Africa (Ohba et al., 2019)

##### e) Event-based case studies

Morogoro, Tanzania (Jan 2018): A single heavy rainfall event caused flash flooding that damaged infrastructure and caused casualties. Analysis showed that flood intensity resulted from synergistic changes in weather patterns and watershed modification (Kimambo, 2019).

Robe, Ethiopia: A PCSWMM simulation combining urban expansion (10 → 70% built-up) and climate change scenarios showed peak runoff increasing by ~25%, while flood volume rose by ~47%, overwhelming existing drainage systems (Bibi & Kara, 2023).

Urban Madagascar: In Antananarivo, urban expansion contributed to flood frequency post- 2018 heavy rainfall, noting how city growth, drainage failure, and climate

extremes co-evolve and worsen flood vulnerability (Andrianjakamisy et al., 2021)

#### f) Future projections using high-resolution data

A Tokyo case study using regional climate model (RCM) data showed the probability of hourly rainfall  $\geq 75$  mm increased from a 20-year to a 13-year event for 2016–2035, and to 8-year for 2076–2095, accentuating future urban flood risks under climate change (Amaguchi et al., 2024)

#### Summary of Key Findings

- Extreme precipitation is increasing across tropical Africa, largely due to anthropogenic climate change.
- Urban areas both experience and amplify rainfall extremes, heightening flood hazard.
- ENSO cycles modulate flood events, with El Niño and La Niña phases intensifying hazard potential.
- Case studies in East and Southern Africa demonstrate the combined effects of climate change and unplanned urban growth on flood intensity and frequency.
- Future projections consistently indicate more frequent and intense rainfall events, underscoring weaker water infrastructure resilience.

Taken together, these findings stress that in cities like Kinshasa—characterized by rapid urbanization, insufficient drainage, and tropical rainfall patterns—climate-driven precipitation intensification is likely to produce more severe and frequent flood hazards.

### 3.2.2. Increased Risk of Droughts

Climate change is increasingly recognized for altering not only precipitation patterns but also the frequency, intensity, and duration of drought events. Droughts manifest in multiple forms—meteorological, agricultural, hydrological, and urban—and have profound impacts on ecosystems and societies, particularly in tropical urban areas like Kinshasa (Dai, 2013).

A landmark study by Dai (2013) found that global observations and climate projections consistently point to an intensification of drought conditions, including in many parts of sub-Saharan Africa—raising concerns over water scarcity and food security. This analysis underscores that future warming could double the likelihood of meteorological drought in affected regions.

Research in the Sahel and Congo Basin indicates that warming trends, combined with deforestation and land degradation, exacerbate hydrological drought due to reduced soil moisture and diminished river flows (Conway et al., 2019; Sheffield et al., 2012). These hydrological stressors are amplified in areas where rainfall is highly seasonal.

In urban environments, such as Lagos and Nairobi, integrated studies combining remote sensing and climate data showed decreasing vegetation productivity and declining surface moisture indices—indicating an accelerated onset of dry conditions, even when precipitation levels remain generally stable (Otieno et al., 2017; Weng & Yang, 2006).

Groundwater-dependent cities are also vulnerable to drought. Several case studies demonstrate that decreased precipitation and recharge rates, combined with increased extraction for urban and agricultural uses, lead to falling water tables and well depletion (Famiglietti, 2014).

Moreover, drought intensification has been linked to increases in temperatures, raising evapotranspiration rates and creating a “hot-drought” scenario (Diffenbaugh et al., 2015). In Kinshasa, where urban expansion has already altered surface albedo and soil moisture retention, the compounding effects of rising temperatures and land use change pose severe risks for drought resilience and water security.

In summary, the literature highlights a clear trend: climate change is increasing drought risk via reduced rainfall, altered hydrology, heightened evaporation, and combined human-land interactions—necessitating proactive urban water governance and adaptation planning.

### 3.2.3. Land Susceptibility, Soil Degradation and Desertification

Land degradation, encompassing soil degradation and desertification, is one of the most significant environmental consequences of climate change, particularly in tropical and sub-tropical regions. Climate-induced stressors, including increased temperatures, prolonged dry periods, and shifting precipitation patterns, directly affect soil structure, fertility, and land stability, thereby exacerbating natural hazards.

Several studies have highlighted that the susceptibility of land to degradation processes is heightened by climate variability. For example, Bai et al. (2008) conducted a global assessment using satellite and climatic data and estimated that about 24% of the global land surface was undergoing degradation, with sub-Saharan Africa among the most severely affected regions. The study attributed these patterns to the combined effects of land misuse and climate change. More recent assessments by the IPCC (2022) emphasize that in many dryland areas, climate change has already led to increased aridity, reduced soil moisture, and a decline in vegetation cover, which together lower the resilience of ecosystems and render them more prone to desertification processes.

Climate change affects soil degradation both directly and indirectly. Directly, rising temperatures increase evapotranspiration, leading to drier soils and reduced organic matter. Indirectly, extreme weather events such as heavy rainfall can cause intense surface runoff, which strips topsoil and depletes soil nutrients. In regions such as the Sahel and the Horn of Africa, research by Olsson et al. (2019) has shown that climate-induced vegetation loss and changes in land surface reflectivity contribute to feedback mechanisms that accelerate desertification. These findings align with the conclusions of the United Nations Convention to Combat Desertification (UNCCD), which stresses that climatic drivers, when combined with unsustainable land management, fuel the expansion of degraded lands.

Soil degradation also has strong implications for food security and hydrological processes. Montanarella et al. (2016) emphasized that declining soil quality reduces agricultural productivity, especially in low-income tropical countries that rely on rain-fed agriculture. As soils degrade, their infiltration capacity diminishes, increasing the risk of surface runoff, erosion, and reduced groundwater recharge—further destabilizing the land.

The concept of land susceptibility also involves the weakening of slope stability due to climatic effects. In humid tropical regions like Central Africa, increased rainfall intensity contributes to the saturation of slopes, triggering mass movement and erosion. Studies in regions such as Rwanda and Uganda have observed a strong correlation between climate-induced rainfall anomalies and an increased frequency of landslides on degraded terrain (Knapen et al., 2006; Jacobs et al., 2018).

Desertification, while typically associated with arid zones, is now recognized as a creeping threat in more humid zones due to climate shifts and land mismanagement. Several case studies, including those in Nigeria and Cameroon, have reported the encroachment of degraded drylands into formerly forested areas, suggesting that desertification is not limited to traditional dryland boundaries (Barbier & Hochard, 2016).

In conclusion, climate change intensifies land degradation through multiple pathways: declining soil quality, loss of vegetation, intensified erosion, and changing hydrological dynamics. These processes are interconnected and reinforce one another, particularly in tropical zones where vulnerability is already high due to socioeconomic and environmental pressures. A better understanding of these dynamics is critical for developing integrated risk assessment frameworks that incorporate both climate and land system feedbacks.

#### 3.2.4. Higher Temperatures, Urban Heat Islands, and Biodiversity Loss

Climate change has led to a notable increase in global mean surface temperatures, with far-reaching consequences on both urban environments and natural ecosystems. Among the most prominent manifestations of this phenomenon are the intensification of the Urban Heat Island (UHI) effect and the degradation of biodiversity and ecosystem services, particularly in tropical urban and peri-urban areas where rapid land use changes compound climatic stressors.

The UHI effect, characterized by higher temperatures in urban areas compared to surrounding rural zones, is primarily driven by the replacement of natural vegetation with impervious surfaces such as asphalt, concrete, and rooftops. Numerous studies have shown that rising global temperatures exacerbate this localized heating. For instance, Li et al. (2019) conducted a global analysis of satellite data and found that urban areas have warmed significantly faster than adjacent rural regions over the past several decades. In cities across sub-Saharan Africa, such as Lagos, Nairobi, and Kinshasa, the UHI effect is particularly intense due to rapid and often unregulated urban expansion, which limits vegetation cover and enhances heat absorption (Schwarz et al., 2015).

The health implications of UHIs are substantial. Increased nighttime temperatures reduce relief from daytime heat, elevating the risk of heat stress, particularly for vulnerable populations such as the elderly and urban poor. Studies in tropical cities like Accra and Jakarta have demonstrated a correlation between urban warming and elevated rates of heat-related mortality and morbidity (Roth, 2007; Chapman et al., 2017). Additionally, UHIs contribute to increased energy demand for cooling, placing strain on infrastructure and exacerbating greenhouse gas emissions through increased fossil fuel consumption.

Simultaneously, the combined effects of higher temperatures and shifting precipitation regimes disrupt ecosystems and accelerate biodiversity loss. According to the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES, 2019), climate change is now one of the primary drivers of biodiversity decline globally, acting in conjunction with land use change, pollution, and invasive species. In tropical regions, where species are often highly specialized and sensitive to narrow climatic ranges, these effects are even more severe.

One of the key mechanisms through which warming affects biodiversity is habitat fragmentation and loss. As ecosystems are altered by both climatic stress and human activity, species are forced to migrate, adapt, or face extinction. Pacifici et al. (2017) estimated that climate change could cause the extinction of up to 25% of terrestrial vertebrate species by 2100 if current trends continue. Moreover, tropical forests—which host more than half of the planet's terrestrial biodiversity—are particularly vulnerable. Elevated temperatures and increased frequency of drought events reduce forest resilience, leading to tree mortality and ecosystem collapse (Allen et al., 2010; Malhi et al., 2009).

These changes do not only threaten species but also the ecosystem services upon which human populations depend. For example, pollination, water purification, carbon sequestration, and disease regulation are all ecosystem services that have been shown to decline with biodiversity loss. In sub-Saharan Africa, disruptions in ecosystem services have already begun to impact food security, water availability, and human health (Isbell et al., 2017). Urban ecosystems, though often overlooked, play a vital role in regulating microclimates and providing green spaces that mitigate the UHI effect—services that are rapidly eroding under climate pressure.

Ultimately, rising temperatures serve as a multiplier of existing vulnerabilities in urban and natural systems, particularly when combined with unsustainable land management and demographic pressures. As tropical cities continue to grow, integrating climate adaptation strategies that preserve biodiversity and mitigate UHI effects—such as expanding urban green spaces, restoring degraded habitats, and implementing climate-resilient infrastructure—will be critical to safeguarding both human well-being and ecological integrity.

#### 3.3 Studies combining LULC and climate change

While a substantial body of literature exists on either land use/land cover (LULC) change or climate change as individual drivers of natural hazards, a growing number of studies are now investigating their combined effects. These integrative approaches acknowledge that interactions between anthropogenic land transformations and global climate dynamics often produce synergistic effects that intensify hazard risks in ways that cannot be fully captured when analyzed separately.

A seminal example is the work by Lambin et al. (2006), which conceptualized land use change and climate change as coupled systems, reinforcing one another in feedback loops. More recently, de Sherbinin et al. (2017) examined vulnerability hotspots by overlaying projected climate anomalies with LULC data in sub-Saharan Africa and South Asia, revealing that regions undergoing rapid urbanization are simultaneously among the most climate-sensitive. These findings underscore the urgency of addressing both drivers concurrently in risk analysis.

In the field of hydrological hazards, several studies have assessed the compounding impact of LULC and climate change on runoff generation and flood frequency. For instance, Costa et al. (2020) combined climate models (RCP scenarios) and LULC projections (using CA-Markov models) to simulate future flooding in a Brazilian watershed. Their results indicated that while both factors individually increased runoff volumes, their combination produced nonlinear and amplified effects, particularly under RCP 8.5 scenarios with extensive urban expansion. Similar methodologies have been applied in Asian (Li et al., 2021) and African (Mwangi et al., 2022) watersheds, yielding comparable conclusions.

Another growing field of integrated research is related to landslide risk. Gariano and Guzzetti (2016) demonstrated that changes in precipitation extremes, when coupled with deforestation and hill-slope development, significantly elevate landslide occurrences in mountainous regions. They emphasized that LULC-driven destabilization of terrain modifies the threshold at which climate-induced triggers (e.g., intense rainfall) lead to slope failure.

Urban systems, in particular, have become central to such studies due to their vulnerability and complexity. Güneralp et al. (2017) synthesized urban risk literature and found that cities in tropical regions are increasingly at the nexus of land cover change and climate variability, especially regarding

heat extremes, flooding, and water stress. They advocate for spatially explicit urban planning models that integrate both biophysical and socio-economic dimensions of risk.

Importantly, integrated approaches often reveal that LULC and climate change not only add to each other's effects but may also shift the spatial and temporal distribution of hazards. For instance, a study by Gharbia et al. (2021) used ensemble modeling in the Nile Delta to show that climate change intensifies seasonal flooding patterns while urban encroachment into wetlands shifts flood-prone zones further inland. These studies highlight the critical need for dynamic, multi-scalar assessments to inform resilience planning.

Despite methodological advances, several challenges persist. Data harmonization across spatial and temporal scales remains complex, and uncertainties compound when combining multiple drivers. Nevertheless, the trend toward multi-driver studies is rapidly gaining ground, especially with the advent of integrated remote sensing platforms and advanced modeling techniques.

In summary, the literature reveals that simultaneous consideration of LULC and climate change provides a more comprehensive understanding of natural hazard dynamics. Such approaches are particularly vital for fast-changing urban landscapes in tropical developing regions, where risks are rapidly evolving and management capacities remain limited.

#### 4. Synthesis and Relevance to the Kinshasa Context

The review of literature on land use/land cover (LULC) change and climate change has shown that these two drivers, both separately and in combination, significantly intensify the occurrence and magnitude of natural hazards. In tropical African megacities like Kinshasa, these findings are particularly pertinent due to a confluence of vulnerability factors: fragile geomaterials, exposure to intense convective rainfall, and rampant unregulated urban expansion.



Fig 1. Kinshasa after heavy rains - flooding linked to unregulated urbanization. Photo of People in Kinshasa's Pompage district in January after the Congo River overflowed. Photograph: Arsene Mpiana/AFP/Getty Images. (source: [theguardian.com](https://www.theguardian.com))

#### 4.1. Fragile Soils and Topography

Kinshasa is characterized by a dominance of sandy, lateritic, and ferralitic soils, with a prevalence of steep slopes and shallow regoliths, especially in areas such as Ngaliema, Selembao, and Mont-Ngafula. Studies such as those by Mbaya et al. (2019) and Mbuyi et al. (2022) have emphasized that these soils are highly erodible and unstable, especially under conditions of deforestation and slope modification for construction. Land clearance for informal housing has led to a significant increase in exposed surfaces, dramatically reducing infiltration and initiating gullying, ravine formation, and landslides. Soil degradation is thus both a result and a driver of increasing hazard sensitivity in Kinshasa.

#### 4.2. Intense Rainfall and Hydrometeorological Extremes

The city lies within a tropical wet-and-dry climate regime with pronounced rainy seasons, during which short-duration, high-intensity events frequently overwhelm both natural and artificial drainage systems. Research by Nzeukou et al. (2020) and Tshimanga et al. (2016) demonstrated an increasing trend in rainfall extremes, particularly in November and March, which coincide with peaks in flood and landslide incidents. These precipitation patterns are exacerbated by climate change and urban sealing, resulting in heightened surface runoff and flash flooding.

In the communes of Limete, Masina, and Kimbanseke, areas once covered by wetlands or agricultural land have been converted into densely built neighborhoods with little to no drainage infrastructure. As a result, floodwaters accumulate rapidly during heavy rains, affecting thousands of residents annually. Rainfall alone cannot account for such impacts; rather, it is the combination with LULC change that amplifies the hazard outcomes.

#### 4.3. Unplanned Urban Expansion

Kinshasa's urban footprint has expanded dramatically, particularly since the 2000s, without corresponding investments in infrastructure or urban planning. According to remote sensing studies by Bateke et al. (2023) and Kankolongo et al. (2021), the city's built-up area has more than doubled between 2000 and 2020, largely due to informal settlements sprawling across ecologically sensitive zones such as wetlands, riverbanks, and steep hills. This expansion follows patterns found in other African cities but is particularly severe in Kinshasa due to its scale and topographic complexity.

Unplanned urbanization not only increases exposure to hazards but also alters local microclimates. Recent studies have highlighted the emergence of urban heat islands (UHI) in central Kinshasa and new peri-urban neighborhoods, with surface temperatures exceeding 45°C in dry seasons (Ngoma et al., 2023). These thermal anomalies have significant health implications and interact with hydrological hazards by modifying evapotranspiration and soil moisture retention.

#### 4.4. Summary of Useful Trends and Insights

Several key trends emerge from the synthesis of international and Kinshasa-specific literature:

- Natural hazards in Kinshasa are increasingly shaped by the combined effects of land cover change and climate variability.
- The most affected zones tend to be those with high population density, unstable slopes, and deficient drainage, particularly in communes such as Mont-Ngafula, Selembao, and Kisenso.
- Hydrological risks (floods, runoff surges, erosion) are the most documented, but landslides, urban droughts, biodiversity loss, and heat waves are also emerging threats.
- The lack of urban planning enforcement, deforestation, and degradation of wetlands and riparian buffers are key aggravating factors.
- There is a need for integrated urban management, combining risk-sensitive spatial planning, nature-based solutions, and monitoring of climate trends.

These insights reinforce the necessity of a multi-hazard, multi-driver approach in studying Kinshasa's environmental vulnerability. It also underlines the importance of spatialized risk assessments, accounting for both current land dynamics and future climate projections. Such a foundation is crucial

for building an effective risk model and for informing sustainable urban development strategies in Kinshasa.

## 5. Conclusion

This literature review has explored the intricate and multifactorial relationships between land use/land cover (LULC) change, climate change, and the intensification of natural hazards in urban environments, with a special focus on their relevance to Kinshasa. The evidence synthesized from global and regional studies, as well as from context-specific research conducted in Kinshasa, underscores the compounded vulnerability faced by tropical megacities undergoing rapid urban transformation in the context of climate variability.

The reviewed literature confirms that unregulated LULC change, particularly urban sprawl into ecologically sensitive zones, directly exacerbates hazards such as flooding, landslides, erosion, flash floods, and biodiversity loss. These risks are not only more frequent but also more spatially extensive due to impervious surface expansion, the destruction of natural buffering systems, and poor infrastructure planning. Climate change acts as an amplifying factor, intensifying extreme weather events, modifying local microclimates (e.g., through urban heat islands), and altering precipitation patterns in ways that further stress urban and peri-urban systems.

Importantly, the interplay between these two drivers—LULC and climate change—produces synergistic effects that are more than the sum of their parts. Studies that have integrated both dimensions reveal that hazard risk assessments must evolve from linear, single-driver analyses to more dynamic, integrated frameworks capable of capturing systemic feedbacks. For example, Kinshasa's exposure to intensified precipitation cannot be fully understood without also examining the role of deforestation, informal housing development, and loss of wetlands in shaping runoff and flood behavior.

The Kinshasa context exemplifies the convergence of multiple risk factors: fragile soils, topographic complexity, intense rainfall, and a chronic lack of urban planning and regulation. These conditions create a fertile ground for the manifestation of natural hazards, often transforming what would otherwise be low-intensity events into disasters. This underscores the urgency of adopting integrated, locally informed strategies for hazard mapping, risk modeling, and urban resilience planning.

In summary, this review highlights the need for a multi-scalar, multi-hazard approach that accounts for both anthropogenic and climatic influences. It sets a strong foundation for the analytical chapters that follow, which will aim to model, quantify, and prioritize hazard risks across Kinshasa using spatial, climatic, and geotechnical data. Ultimately, the goal is to inform targeted mitigation strategies tailored to the unique vulnerabilities and dynamic evolution of this rapidly growing urban landscape.

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