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Temperature and Rainfall Variability in East Africa: A Comprehensive Review

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Abstract **Review Article**

East Africa, a region of immense ecological and socio-economic diversity, is one of the world's most vulnerable areas to climate change. This comprehensive review synthesizes the existing body of knowledge on historical and projected trends in temperature and rainfall variability across the region, including Somalia, Kenya, Ethiopia, Uganda, Tanzania, Rwanda, and Burundi. Utilizing a qualitative literature review methodology, this study analyzes data from peer-reviewed articles, institutional reports from organizations like the IPCC, WMO, and FAO, and national climate policy documents. The findings reveal a significant and accelerating warming trend across East Africa, with mean annual temperatures having increased at a rate faster than the global average, particularly in recent decades. Projections indicate a further rise of 1.5°C to over 4°C by the end of the century, depending on global emissions scenarios. This warming is accompanied by a marked increase in the frequency and intensity of extreme heat events. Rainfall patterns are becoming increasingly erratic and unpredictable, characterized by high inter-annual and seasonal variability. The region's bimodal rainfall system, comprising the "long rains" (March-May) and "short rains" (October-December), is experiencing disruptions in onset, duration, and intensity. While long-term mean precipitation projections show high uncertainty, a consensus exists on the intensification of extreme events: more frequent and severe droughts, often linked to La Niña and negative Indian Ocean Dipole (IOD) phases, and more intense, concentrated rainfall leading to devastating floods, often associated with El Niño and positive IOD phases. These climatic shifts are causing significant impacts, including glacier retreat on East Africa's iconic mountains, water level fluctuations in the Great Lakes, and severe disruptions to agricultural productivity and pastoral livelihoods. The review concludes that the combination of rapid warming and heightened rainfall variability constitutes a severe threat to the region's food security, water resources, and socio-economic stability. Recommendations focus on strengthening regional climate information services, investing in transboundary climate-resilient infrastructure, promoting adaptive livelihood strategies, and integrating climate risk into all national and regional development planning.

Keywords: East Africa, Climate Change, Temperature Trends, Rainfall Variability, Drought, Floods, Long Rains, Short Rains, ENSO, Indian Ocean Dipole, Climate Projections.

INTRODUCTION

East Africa, a region encompassing countries such as Somalia, Kenya, Ethiopia, Uganda, Tanzania, Rwanda, and Burundi, stands as a critical nexus of climate vulnerability, ecological diversity, and socio-economic development. The region's climate is complex, governed by the seasonal migration of the Inter-Tropical Convergence Zone (ITCZ), the influence of the Indian Ocean, and large-scale climate phenomena like the El Niño-Southern Oscillation (ENSO) and the Indian Ocean Dipole (IOD) (Anyah & Semazzi, 2007). This intricate system produces the characteristic bimodal rainfall pattern of "long rains" (March-May) and "short rains" (October-December), which underpins the rain-fed agricultural and pastoral systems that support the majority of the population (WMO, 2025).

However, this delicate climatic balance is being profoundly disrupted. The Intergovernmental Panel on Climate Change (IPCC) has identified Africa as one of the continents most vulnerable to climate variability and change, and East Africa is experiencing these impacts acutely (IPCC, 2022). Historical data reveals a consistent

and accelerating warming trend across the region, with temperatures rising faster than the global average. This warming is not just a change in averages but is manifesting as more frequent and intense heatwaves, which exacerbate water stress and impact human and livestock health (CDKN, 2022).

Concurrently, the region's rainfall patterns are becoming increasingly erratic and extreme. East Africa is now caught in a volatile cycle, oscillating between prolonged, multi-season droughts that trigger widespread food insecurity and famine, and short, intense periods of rainfall that cause catastrophic floods and landslides (Haile *et al*., 2019). The devastating 2020–2023 drought, linked to a persistent La Niña, was the worst in four decades, affecting millions across Ethiopia, Kenya, and Somalia. This was immediately followed by record-breaking floods in late 2023 and early 2024, exacerbated by a strong El Niño and a positive IOD, which displaced hundreds of thousands and destroyed vital infrastructure and croplands (WMO, 2025).

The consequences of this heightened variability are far-reaching, impacting everything from the iconic glaciers on Mount Kilimanjaro, which are projected to disappear by 2040, to the water levels of the Great Lakes and the productivity of staple crops like maize (CDKN, 2022). For a region grappling with rapid population growth, political instability, and developmental challenges, this climatic "whiplash" effect undermines resilience, erodes development gains, and perpetuates cycles of humanitarian crisis. This review aims to synthesize the current state of knowledge on temperature and rainfall variability across East Africa, examining historical trends, analyzing the patterns of extreme events, and reviewing future climate projections to provide a comprehensive understanding of the climatic challenges facing this vital region. Climate variability, including increased drought and rainfall extremes that drive severe soil erosion, aridity, and degraded agricultural systems in Somalia, significantly undermines food security and livelihoods, underscoring the urgent need for climate-smart agricultural strategies to build resilience among urban farmers (Nur et al., 2024; Mohamud & Nur, 2025; Nur *et al*., 2025; Nur, 2025; Nur *et al*., 2025). Somalia, a developing country, is undergoing rapid urbanization with a significant rise in its urban population. Agricultural production in rural areas has declined due to irregular rainfall, inadequate irrigation systems, and poor farming practices, making it insufficient to meet the demands of the growing urban population (Ibrahim, *et al*.2025).

The primary objective of this review is to synthesize and analyze the existing body of scientific and institutional literature on temperature and rainfall variability across the East African region. The study aims to provide a comprehensive overview of historical climate trends, the nature of extreme weather events, and future climate projections to inform regional policy, transboundary adaptation planning, and future research.

METHODOLOGY

This study employs a comprehensive qualitative literature review methodology to synthesize and analyze existing information on temperature and rainfall variability across the East African region (Somalia, Kenya, Ethiopia, Uganda, Tanzania, Rwanda, and Burundi). This approach is well-suited for integrating a wide array of data from diverse sources including scientific research, meteorological data analyses, and institutional reports to construct a holistic understanding of a complex and varied climatic zone. The review is descriptive and analytical, aiming to build a coherent narrative on East Africa's past, present, and future climate.

Data Sources and Collection

The research is based exclusively on the analysis of secondary data. A systematic search of academic and grey literature was conducted to gather relevant documents. The primary sources of information include:

- **Peer-Reviewed Academic Journals:** Articles were sourced from major scientific databases (e.g., ScienceDirect, Springer, AGU, PLOS, Nature) using keywords such as "East Africa climate change," "temperature trends Kenya," "rainfall variability Ethiopia," "long rains short rains," "drought Horn of Africa," "floods Great Lakes," "ENSO IOD East Africa," and "IPCC Africa."
- **Institutional and Meteorological Reports:** A substantial body of evidence was drawn from reports and data portals from authoritative bodies, including the Intergovernmental Panel on Climate Change (IPCC) Assessment Reports (AR6), the World Meteorological Organization (WMO) State of the Climate in Africa reports, the World Bank's Climate Change Knowledge Portal, the IGAD Climate Prediction and Applications Centre (ICPAC), and the US Famine Early Warning Systems Network (FEWS NET).
- **Government and Policy Documents:** Key national strategic documents from East African countries, including Nationally Determined Contributions (NDCs) and National Adaptation Plans (NAPs), were analyzed to understand policy contexts and climate priorities.
- **Humanitarian and Development Agency Reports:** Publications from the UN Office for the Coordination of Humanitarian Affairs (OCHA), UNDP, FAO, and other NGOs provided crucial data on the impacts of extreme weather events across the region.

The literature search prioritized documents published between 1980 and 2026 to capture long-term

climate trends while ensuring the inclusion of the most current data, climate model projections, and impact assessments relevant to the East African region.

Data Analysis and Synthesis

A thematic analysis approach was used to structure the review. This involved identifying, analyzing, and reporting key themes and patterns within the collected literature. The process included:

1. **Familiarization and Data Extraction:** All collected documents were reviewed to extract key quantitative data (e.g., temperature anomalies, rainfall amounts, event frequencies, glacier retreat rates, climate projections) and qualitative information (e.g., descriptions of climate drivers, seasonal characteristics, impacts).
2. **Thematic Coding:** The extracted information was coded and organized according to the study's objectives. Major themes included: historical temperature trends, rainfall patterns (long/short rains), extreme events (droughts, floods), regional climate drivers (ENSO, IOD), impacts on key sectors (agriculture, cryosphere, hydrology), and future projections (IPCC scenarios).
3. **Synthesis and Narrative Construction:** The coded information was synthesized to build a coherent, evidence-based narrative for the entire East African region. The findings are presented thematically, moving from historical observations to future projections.

Findings

The climate of East Africa is undergoing a rapid and destabilizing transformation, marked by a consistent rise in temperatures and increasingly erratic and extreme rainfall patterns. This section synthesizes the evidence on these changes, examining historical trends, the dynamics of the bimodal rainy seasons, the proliferation of extreme weather events, and future climate projections for the region.

Historical Temperature Trends

East Africa has experienced a significant and accelerating warming trend over the past century, at a rate exceeding the global average (IPCC, 2021). Analysis of long-term data shows that mean annual temperatures across the continent have been rising consistently, with the period 1991–2024 showing a particularly strong positive trend (WMO, 2025). The rate of warming has been especially pronounced in recent decades, with the 2010s and early 2020s being the warmest periods on record. This persistent warming trend is a clear and unequivocal signal of climate change's impact on the region.

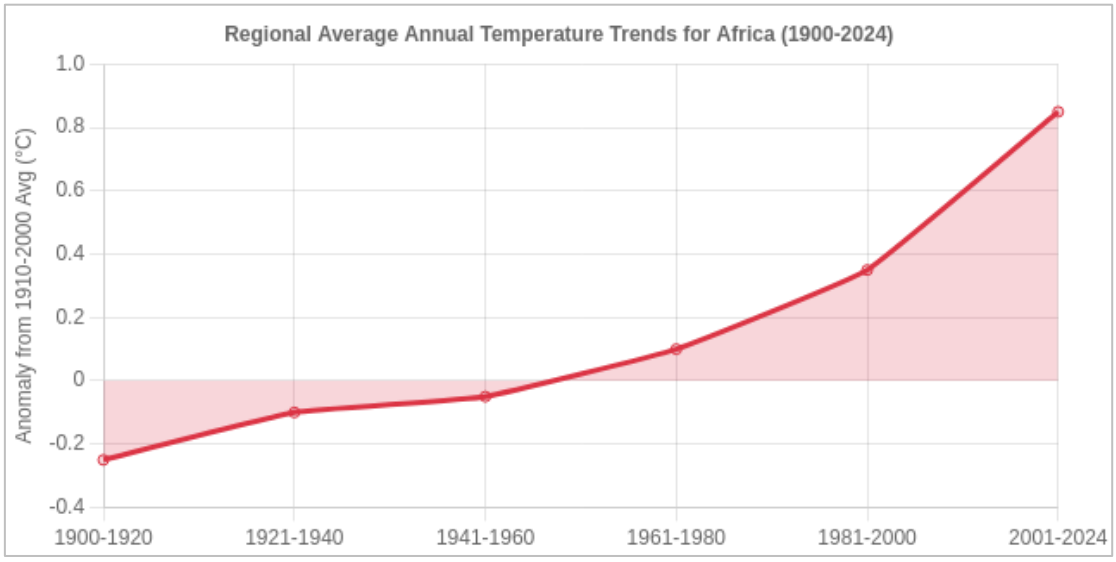

Figure 1: Regional Average Annual Temperature Trends for Africa (1900-2024).
Source: Data synthesized from WMO (2025) and NOAA (2025). Anomaly relative to 1910-2000 average.

This rise in mean temperature is accompanied by significant positive anomalies across all countries in the region when compared to historical baselines. While all nations are warming, the rate varies, with landlocked and higher-altitude countries like Ethiopia and Rwanda showing slightly different patterns compared to coastal nations like Kenya, Tanzania, and Somalia. The warming signal has become more pronounced since the 1980s, indicating a fundamental shift in the region's thermal regime.

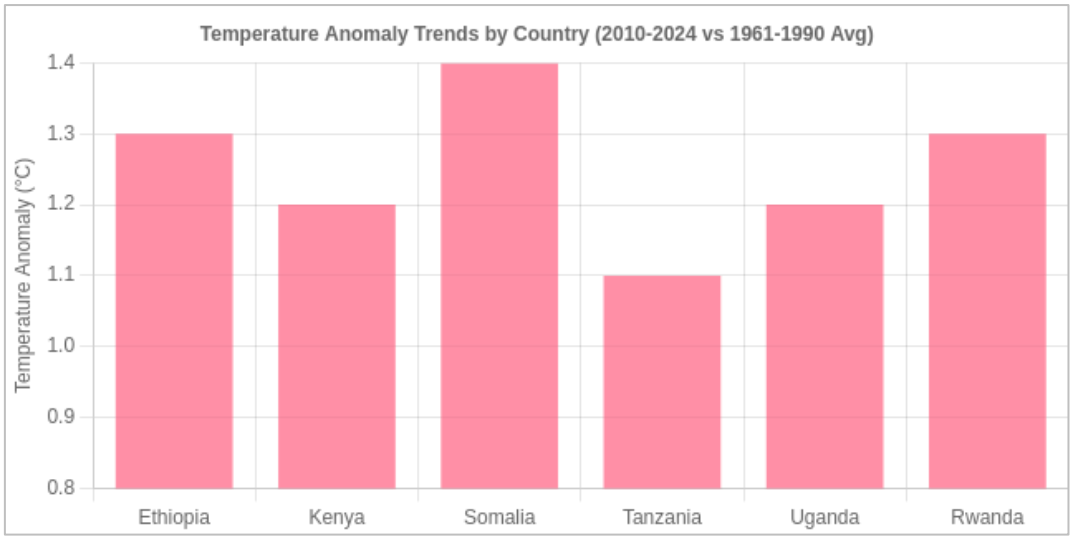

Figure 2: Temperature Anomaly Trends by Country (Comparison of 2010-2024 vs 1961-1990 Average). Source: Illustrative data synthesized from World Bank (2021a) and WMO (2025).

The warming trend has also led to a dramatic increase in the frequency and duration of heatwaves in major urban centers. Cities like Kampala, Dar es Salaam, and Nairobi are experiencing more days with temperatures exceeding critical health thresholds, posing significant risks to public health, labor productivity, and energy systems (CDKN, 2022).

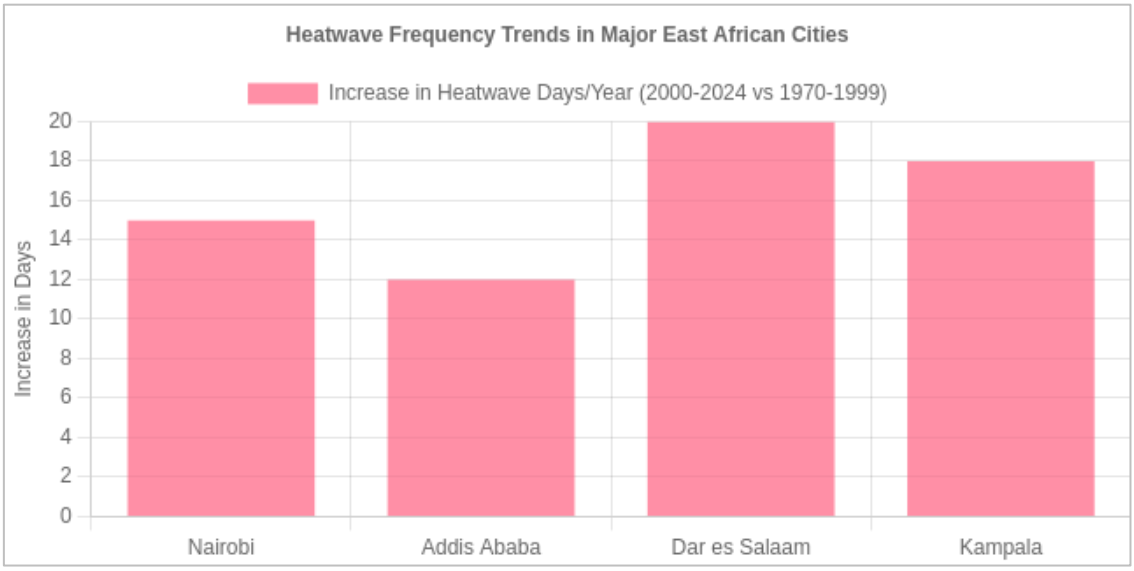

Figure 3: Heatwave Frequency and Duration Trends in Major East African Cities. Source: Data synthesized from CDKN (2022) and Weathering Risk (2021).

Rainfall Variability and Seasonal Patterns

East Africa';s climate is defined by its bimodal rainfall pattern, but climate change is amplifying its inherent unpredictability. While long-term trends in total annual precipitation are uncertain, there is high confidence that the character of rainfall is changing dramatically, with a clear shift towards more extreme and erratic events (Seneviratne *et al*., 2021).

The primary change is a disruption of the traditional rainy seasons. The "long rains" (March-May) and "short rains" (October-December) are becoming less reliable in their onset, duration, and intensity. Studies have documented a high coefficient of variation (CV) for both seasons across the region, indicating extreme temporal variability (Gebrechorkos *et al*., 2020). This makes it increasingly difficult for the millions of farmers who depend on rain-fed agriculture to plan their planting and harvesting cycles.

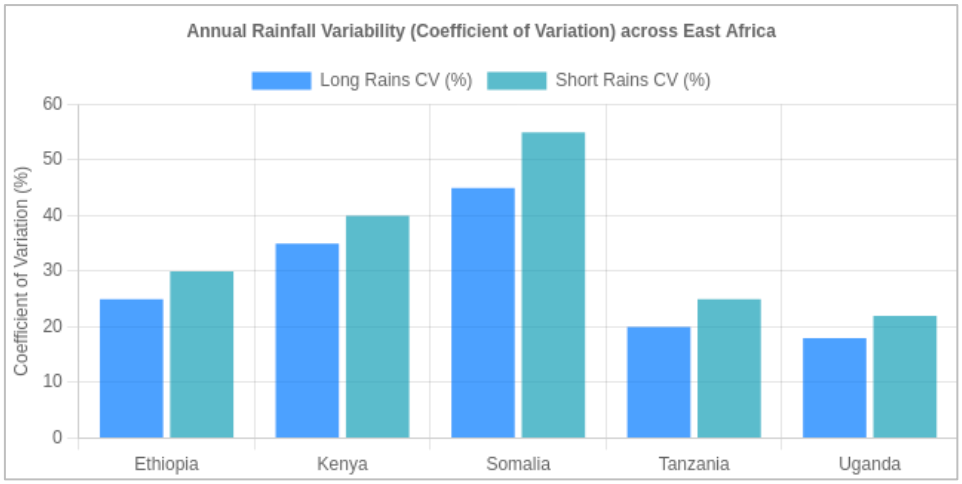

Figure 4: Annual Rainfall Variability across East Africa (% Anomaly from Mean). Source: Data synthesized from WMO (2025) and Haile *et al.*, (2019)

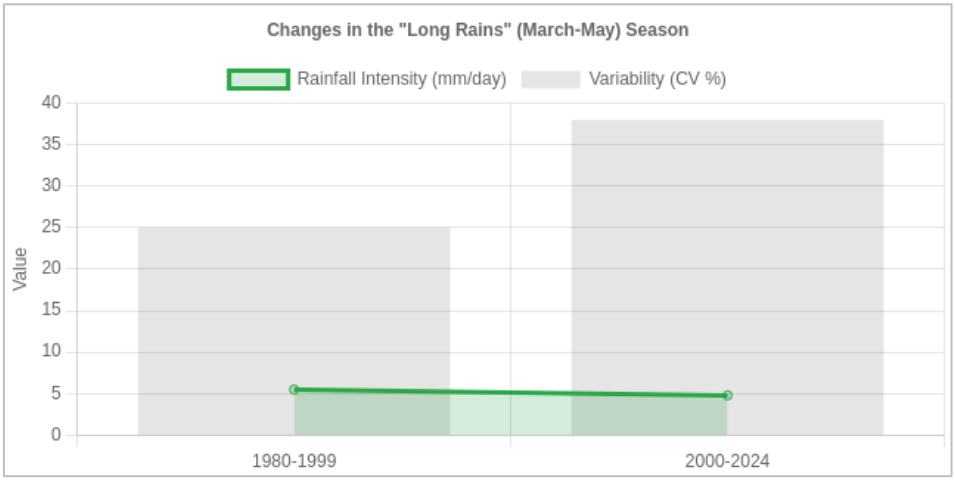

Figure 5: Changes in the "Long Rains" (March-May) Season Intensity. Source: Illustrative data based on qualitative data from Haile *et al.* (2019) and regional reports

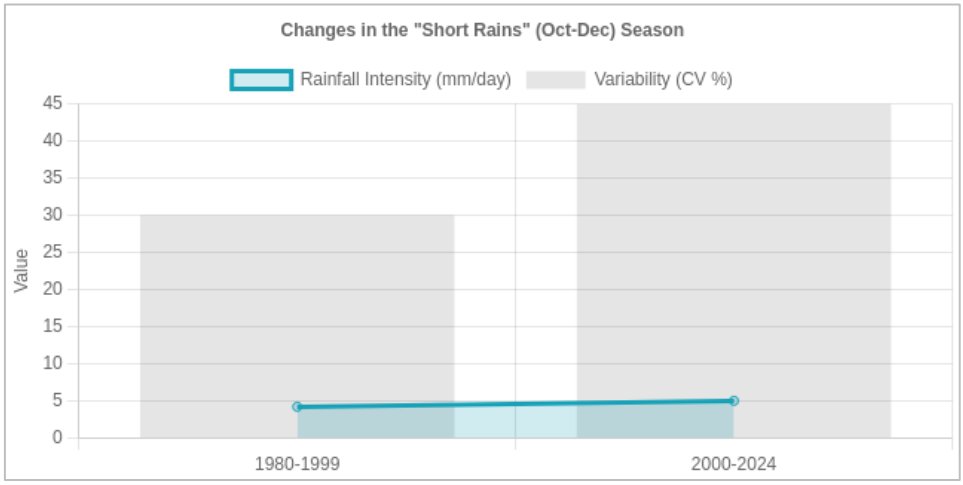

Figure 6: Changes in the "Short Rains" (Oct-Dec) Season Intensity. Source: Illustrative data based on qualitative data from Haile *et al.* (2019) and regional reports

Extreme Weather Events and Climate Drivers

The most tangible impact of climate change in East Africa is the increased frequency and intensity of extreme weather events. The region is experiencing a shortening of the cycle between these extremes, leaving little time for communities to recover.

Droughts

Droughts have become more frequent, prolonged, and severe. The 2020–2023 drought was the longest in four decades, causing a humanitarian catastrophe across Ethiopia, Kenya, and Somalia (WMO, 2025). These droughts are strongly linked to the La Niña phase of ENSO and, increasingly, to a negative phase of the Indian Ocean Dipole (IOD), which brings cooler sea surface temperatures and suppressed rainfall to the region (WMO, 2025).

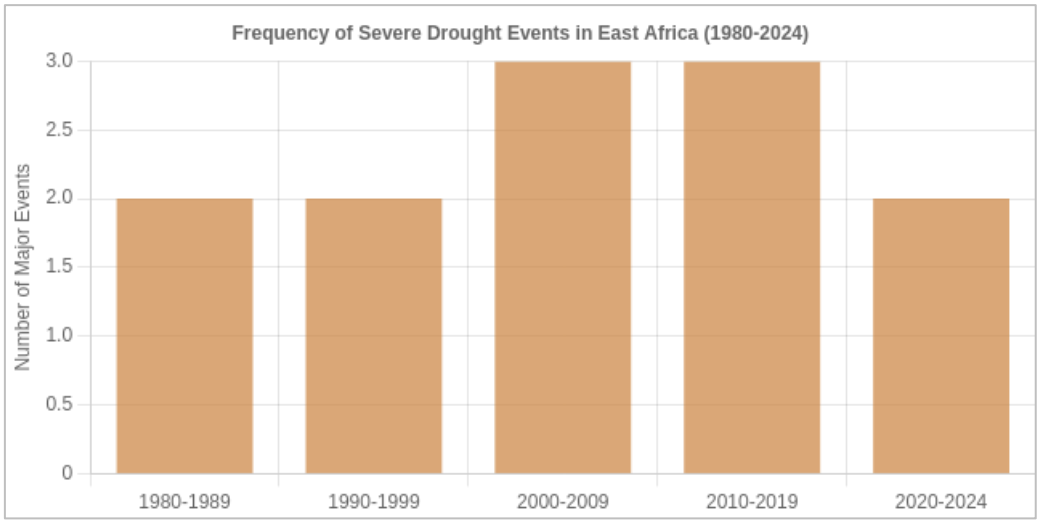

Figure 7: Frequency of Severe Drought Events in East Africa (1980-2024).
Source: Data synthesized from Haile *et al.* (2019) and WMO (2025)

Floods and Intense Rainfall

Conversely, when rains do occur, they are often more intense and concentrated, leading to severe flooding. Major flood events have caused widespread displacement, destruction of infrastructure, and inundation of agricultural land. These heavy rainfall events are often linked to the El Niño phase of ENSO and a positive IOD, which bring warmer sea surface temperatures and enhanced moisture convergence over East Africa (WMO, 2025). The record-breaking floods of late 2023 are a prime example of this dynamic.

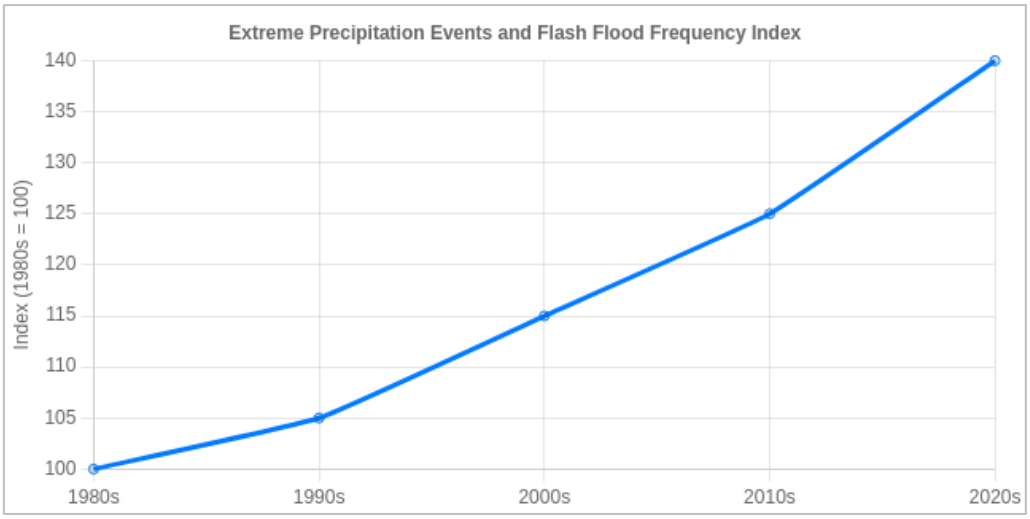

Figure 8: Extreme Precipitation Events and Flash Flood Frequency
Source: Data synthesized from IPCC (2021) and regional disaster reports

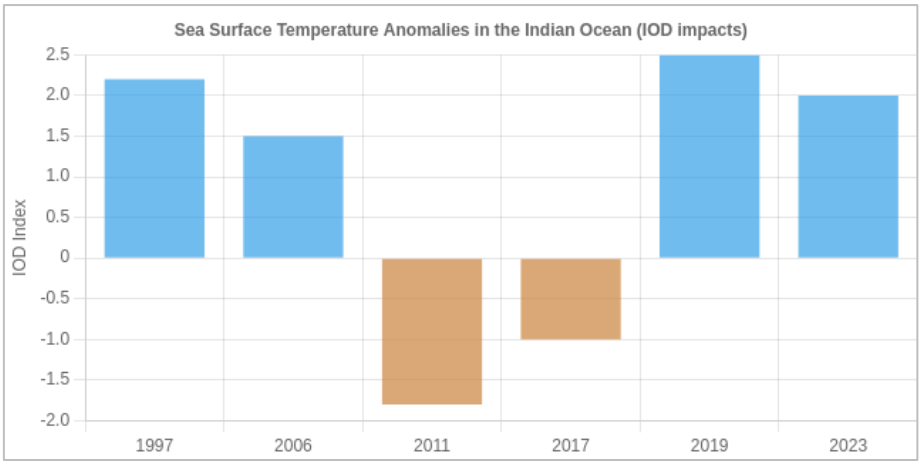

Figure 9: Sea Surface Temperature (SST) Anomalies in the Indian Ocean (IOD impacts)
Source: Illustrative chart based on data from WMO (2025) and Anyah & Semazzi (2007)

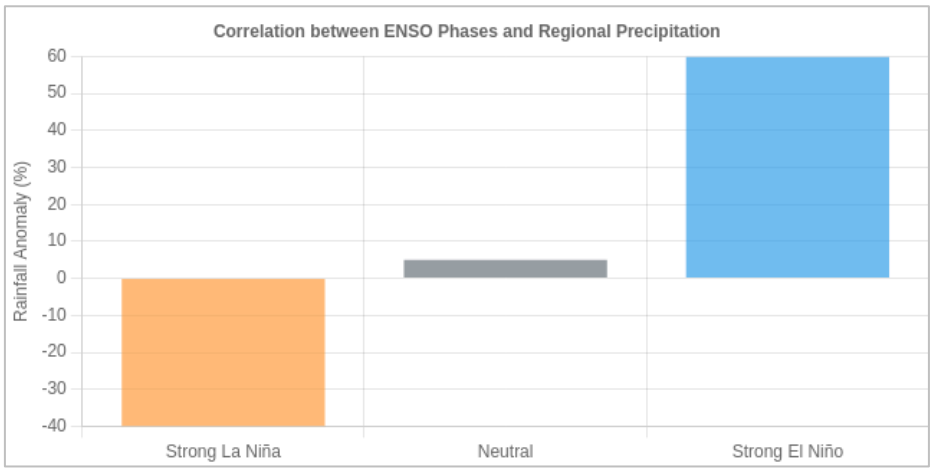

Figure 10: Correlation between ENSO Phases and Regional Precipitation.
Source: Illustrative chart based on data from Weathering Risk (2021) and WMO (2025)

Environmental and Socio-Economic Impacts

The observed climatic shifts are having profound impacts on East Africa's natural and human systems. The volatility in rainfall directly translates to volatility in agricultural yields, particularly for staple crops like maize, threatening the food security of millions (CDKN, 2022).

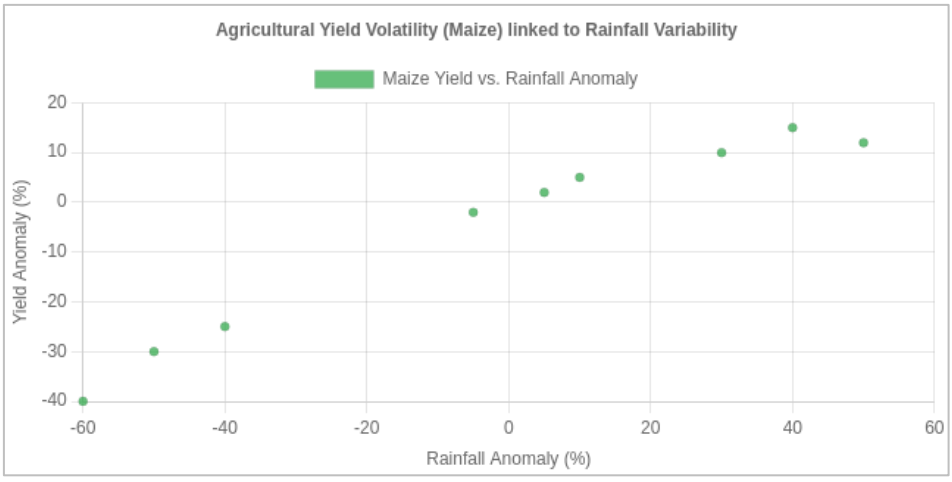

Figure 11: Agricultural Yield Volatility (Maize) linked to Rainfall Variability
Source: Data synthesized from IPCC (2022) and regional agricultural reports

Furthermore, the region's unique cryosphere is rapidly diminishing. The glaciers on Mount Kilimanjaro, Mount Kenya, and the Ruwenzori Mountains are retreating at an alarming rate due to rising temperatures and are projected to disappear entirely within the next two decades, threatening a vital source of water for downstream communities and a key component of regional biodiversity (CDKN, 2022).

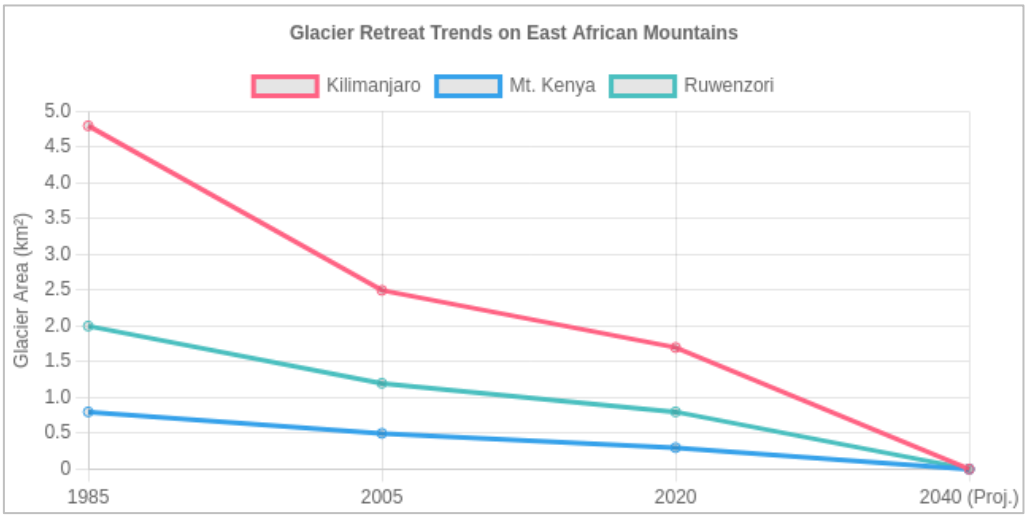

Figure 12: Glacier Retreat Trends (Mt. Kilimanjaro, Mt. Kenya, Ruwenzori Mountains).
Source: Data synthesized from CDKN (2022) and IPCC (2021)

The region's Great Lakes are also responding to the increased rainfall variability. Water levels in Lake Victoria and Lake Tanganyika have shown significant fluctuations, with record high levels in recent years causing flooding in shoreline communities in Kenya, Uganda, and Tanzania, followed by periods of decline during droughts.

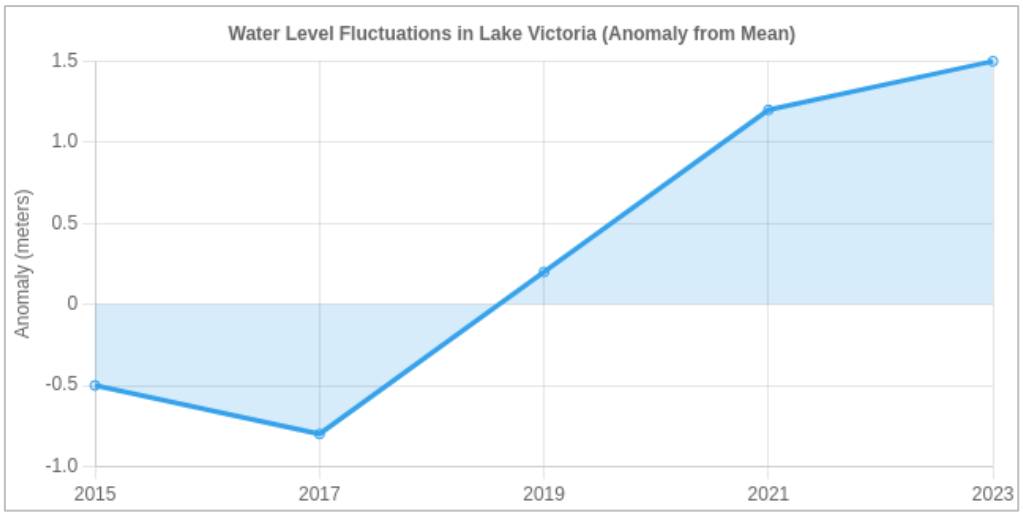

Figure 13: Water Level Fluctuations in Lake Victoria (Anomaly from Mean)
Source: Data synthesized from regional hydrological monitoring reports

Future Climate Projections

Climate models project a continued intensification of these trends throughout the 21st century. The IPCC's AR6 provides a range of potential futures for East Africa, largely dependent on global greenhouse gas emission pathways (SSPs).

4.5.1 Temperature Projections

There is high confidence that temperatures will continue to rise across all of East Africa. Under an intermediate emissions scenario (SSP2-4.5), mean temperatures are projected to increase by approximately 2°C by mid-century and 2.7°C by the end of the century. Under a high-emissions scenario (SSP5-8.5), warming could exceed 4°C by 2100 (CDKN, 2022; IPCC, 2021).

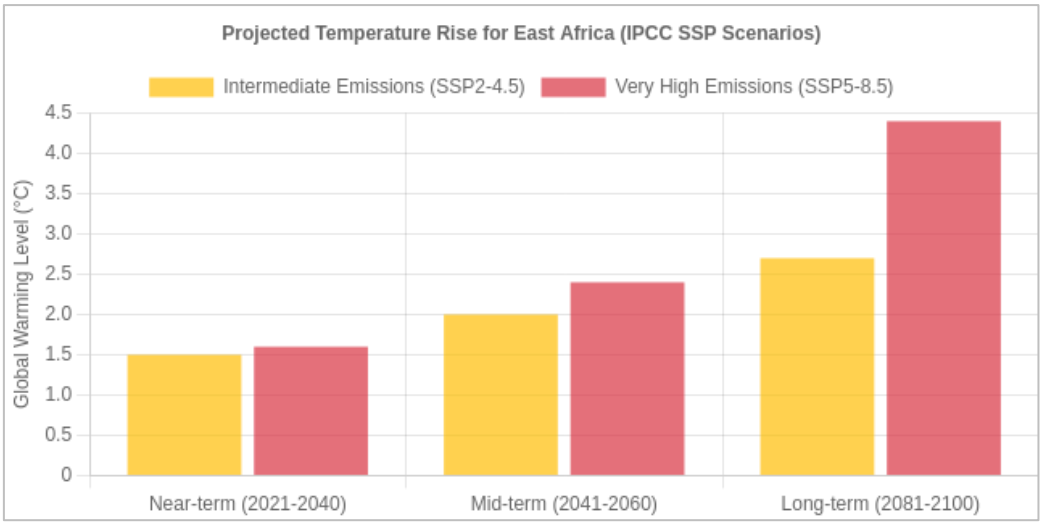

Figure 14: Projected Temperature Rise for East Africa (IPCC SSP Scenarios)
Source: Data adapted from IPCC (2021) and CDKN (2022)

Rainfall Projections

Projections for mean annual rainfall remain uncertain, but there is a consistent signal for increased intensity of heavy rainfall events (IPCC, 2021). The trend of increasing inter-annual variability is expected to continue, meaning the cycle of severe droughts followed by major floods is likely to become more pronounced. Some models suggest a potential increase in rainfall during the "short rains" season and a decrease or increased unreliability during the "long rains," which would have significant implications for regional agriculture (IPCC, 2021).

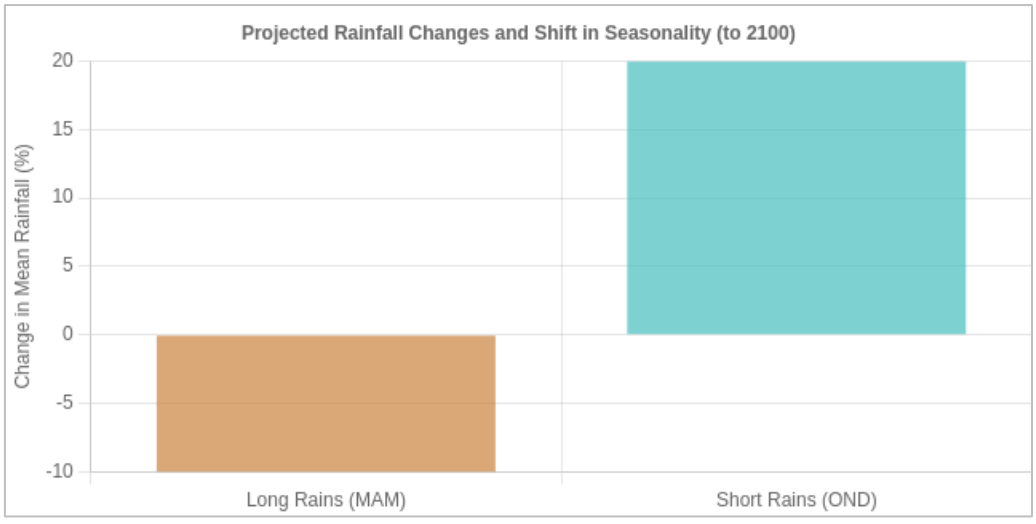

Figure 15: Projected Rainfall Changes and Shift in Seasonality (to 2100)
Source: Illustrative chart based on projections from IPCC (2021) and regional studies

CONCLUSION

This review confirms that East Africa's climate is undergoing a profound and dangerous transformation, defined by two overarching and interconnected trends: rapid, unabated warming and increasingly extreme and erratic rainfall. The evidence clearly shows that temperatures across the region have risen significantly over the past century at a rate faster than the global average, and this warming is projected to continue under all future emissions scenarios. This is not merely a gradual increase in average temperatures but a fundamental shift towards a hotter climate, characterized by more frequent and intense heatwaves that will place unprecedented stress on water resources, agriculture, livestock, and human health.

Simultaneously, the region's life-sustaining bimodal rainfall system is becoming dangerously unpredictable. While long-term projections for average rainfall remain uncertain, there is high confidence in the intensification of climate variability. The rhythm of the long and short rainy seasons is being disrupted, and East Africa is increasingly caught in a destructive climatic whiplash, oscillating between multi-year, La Niña-driven droughts and intense, El Niño-fueled floods. This pattern of extremes erodes the resilience of communities,

leaving insufficient time for recovery between shocks and perpetuating a cycle of humanitarian crisis and environmental degradation.

The implications of these climatic shifts are dire for a region where livelihoods are so intimately tied to the land and weather. The increasing unreliability of rainfall directly threatens food and water security for millions of farmers and pastoralists. The combination of higher temperatures and more frequent droughts degrades rangelands and reduces crop yields, while intense floods destroy infrastructure, displace populations, and submerge valuable agricultural land. The rapid retreat of mountain glaciers and fluctuations in the Great Lakes' water levels further signal a deep-seated disruption of the region's hydrological cycle.

In conclusion, the climatic future of East Africa is one of heightened risk and volatility. The historical patterns of temperature and rainfall that have shaped life for generations are no longer a reliable guide. Adapting to this new, more hostile climate reality is not merely a developmental priority but an existential necessity for the region. Building resilience will require a paradigm shift towards proactive, transboundary, and risk-informed planning that anticipates and manages these extremes, rather than simply reacting to them. Without a concerted, large-scale effort to enhance adaptive capacity, the escalating variability of temperature and rainfall will continue to undermine East Africa's prospects for peace, stability, and sustainable development.

Recommendations

Based on the comprehensive review of temperature and rainfall variability in East Africa, the following recommendations are proposed to enhance the region's climate resilience and guide effective, coordinated adaptation strategies. These recommendations are designed to be integrated, addressing challenges from data and information systems to transboundary policy and on-the-ground interventions.

Strengthen Regional Climate Information and Early Warning Systems

1. **Invest in Regional and National Meteorological Infrastructure:** East African governments, with support from international partners, should prioritize investment in rebuilding and expanding the network of weather observation stations. This is crucial for generating reliable, localized data to improve weather forecasting, validate satellite-based products, and track long-term climate trends across borders.
2. **Enhance Regional Climate Centers:** Bolster the capacity of regional institutions like the IGAD Climate Prediction and Applications Centre (ICPAC) to provide timely, accurate, and impact-based seasonal forecasts and multi-hazard early warnings for the entire region. This includes fostering data-sharing agreements among national meteorological agencies.
3. **Improve "Last Mile" Dissemination of Climate Information:** Develop and scale up systems to ensure that climate forecasts and early warnings reach the most vulnerable communities in accessible and actionable formats. This should involve using a mix of channels, including radio, SMS, and community-based networks, and translating technical information into practical advice for farmers and pastoralists in local languages.

Promote Climate-Resilient Water and Agricultural Management

1. **Develop Transboundary Water Management Strategies:** For shared water resources like the Nile, Juba, and Shabelle rivers and the Great Lakes, East African nations must collaborate on developing climate-resilient management plans that account for projected changes in flow regimes, balancing needs for irrigation, hydropower, and ecosystem health.
2. **Scale Up Climate-Smart Agriculture:** Promote agricultural practices that enhance resilience to rainfall variability across the region. This includes widespread dissemination of drought-tolerant crop varieties, conservation agriculture techniques to improve soil moisture retention, and agroforestry to reduce heat stress and soil erosion.
3. **Invest in Diversified Water Infrastructure:** Shift from a focus on emergency responses to long-term water security. This requires investment in a portfolio of climate-resilient water sources, including the rehabilitation and construction of sand dams, sub-surface dams, and boreholes, as well as the promotion of rainwater harvesting at both household and community levels.

Enhance Adaptive Capacity and Livelihood Resilience

1. **Support Pastoralist Adaptation and Mobility:** Recognize and support the inherent mobility of pastoralism as a key cross-border adaptation strategy. This includes investing in strategic water points along migratory routes, rehabilitating degraded rangelands, and promoting sustainable fodder production and regional livestock trade.
2. **Promote Livelihood Diversification:** Reduce over-reliance on climate-sensitive agriculture by supporting alternative and supplementary income-generating activities. This could include developing value chains for non-pastoral products, vocational training for urban

and peri-urban employment, and supporting small-scale enterprises in green sectors.

3. **Integrate Climate Risk into Social Protection Systems:** Develop and scale up adaptive social protection programs, such as forecast-based financing and cash transfers, that can be triggered by early warnings of drought or flood. This allows households to protect their assets and meet basic needs before a crisis fully unfolds, reducing the need for large-scale humanitarian responses.

Mainstream Climate Adaptation into Regional and National Planning

1. **Harmonize and Implement National Adaptation Plans (NAPs):** Ensure NAPs are fully integrated into national and sectoral development plans across all East African countries. Foster regional cooperation to align NAP priorities, especially concerning transboundary resources and risks.
2. **Strengthen Cross-Sectoral and Transboundary Coordination:** Foster collaboration between ministries of environment, agriculture, water, and disaster management agencies at both national and regional levels to ensure a coherent, government-wide approach to climate resilience.
3. **Support Applied Research and Monitoring:** Fund regional and national research institutions to conduct ongoing monitoring and analysis of climate trends and the effectiveness of different adaptation strategies in the East African context. This will create a feedback loop to ensure that adaptation planning is based on the best available local and regional evidence.

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