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Extreme Climate Events, Governance Deficits and Adaptation Failure in Africa: A Critical Review and the Africa Climate Resilience and Justice Framework

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ABSTRACT
Africa is highly exposed to climate extremes, yet growing evidence has not produced adaptation that holds up when extremes arrive. This critical narrative review asks why. We synthesised peer-reviewed studies and intergovernmental reports from January 2019 to August 2026 on climate extremes, hydrological change, adaptation governance, finance and social vulnerability across Africa's sub-regions, checking every claim against its source. Five recurring failure patterns emerged: weak links between evidence and policy, sector-by-sector governance of cross-sector hazards, finance that is small and poorly matched to need, design that bypasses the most exposed groups, and water narratives that contradict the hydrology. Hydrology connects them: recharge depends on episodic heavy rainfall, surface storage swings with multi-year drought, and river gauging has contracted. We then derive the Africa Climate Resilience and Justice Framework (ACRJF), with four domains on a hydrological foundation: science-policy interface, sectoral governance, climate finance and intersectional vulnerability. The ACRJF treats monitoring as governance infrastructure, makes justice measurable, states the dependencies between domains, nests its indicators under UAE Framework targets and sets a rule for choosing sub-regional entry points. It points to water governance in North and West Africa, monitoring in Central and East Africa, and loss and damage finance in Southern Africa.

Keywords: Adaptation governance; Hydrological extremes; Groundwater; Climate finance; Climate justice; Africa

1. Introduction

Since 2019, the record of climate extremes in Africa has been long and costly. Cyclone Idai struck Mozambique, Zimbabwe and Malawi in March 2019 and displaced hundreds of thousands of people (Mashula et al., 2021). The 2023/24 El Niño drought placed about 40% of Zambia under drought conditions and cut surface water in parts of Lake Kariba and other reservoirs that supply hydropower and irrigation (Ghosh et al., 2025). In 2024, rainy-season rainfall in the Niger and Lake Chad basins was heavier than it would have been without climate change, and dam failures turned high water into disaster (World Weather Attribution, 2024). In 2025, floods accounted for more than half of the extreme events reported across the continent (WMO, 2026). The mean surface temperature of Africa in 2024 was about 0.86 °C above the

1991 to 2020 average, and North Africa warmed fastest (WMO, 2025). These hazards fall on societies that contributed little to the problem: Africa accounts for roughly 7% of historical cumulative net anthropogenic CO_2 emissions since 1850, and a smaller share of fossil-fuel emissions (IPCC, 2022).

The scientific record on these hazards has grown quickly. Continental analyses of satellite rainfall (Alahacoon et al., 2022; Marra et al., 2022), regional climate projections (Almazroui et al., 2020; Gebrechorkos et al., 2023) and the Africa chapter of the IPCC Sixth Assessment Report (Trisos et al., 2022) give a far clearer picture of exposure than was available a decade ago. Reviews have mapped the research itself. Baninla et al. (2022) and Tamasiga et al. (2023) traced the growth and thematic spread of African adaptation and mitigation research, and Mehra et al. (2024) examined how climate, agriculture, health and nutrition interact. Global stocktakes are less encouraging about what this knowledge has achieved. Most documented adaptation is fragmented, local and incremental, and there is little evidence that it has reduced risk (Berrang-Ford et al., 2021). Effectiveness is seldom defined in measurable terms (Owen, 2020), and some interventions in low-income countries have reinforced the vulnerability they were meant to reduce (Eriksen et al., 2021).

Three gaps in this literature motivate the present review. First, studies of African adaptation governance seldom engage with hydrological processes, even though most climate impacts reach African households through water: groundwater recharge, river flow, reservoir storage and floods. Without that link, governance analysis can prescribe responses to water problems that the hydrology does not support. Second, justice is usually treated as a principle that frames an analysis rather than as something to be implemented and measured. Third, continental and global frameworks say little about where to begin in a particular sub-region, and the adaptation indicators adopted under the UNFCCC in 2025 (UNFCCC, 2025a) have not yet been connected to the governance deficits documented for Africa.

This review asks why adaptation to climate extremes in Africa so often falls short of what the available evidence would support, and what a governance framework would need to address. It has four objectives: (i) to synthesise recent evidence on climate extremes and their hydrological pathways in each African sub-region; (ii) to identify recurring patterns of governance failure and the evidence behind each; (iii) to derive from those patterns the Africa Climate Resilience and Justice Framework (ACRJF), compare it with existing frameworks and specify indicators for it; and (iv) to apply the framework to the five sub-regions using an explicit prioritisation rule. Because the terms adaptation failure, governance deficit and resilience are used loosely in the literature, Table 1 gives the working definitions used throughout.

Table 1. Working definitions of key terms used in this review.

Term	Working definition in this review
Adaptation failure	Adaptation plans or actions that do not reduce climate risk for the exposed population over the period for which they were designed, or that shift risk to other groups or places. The term covers non-implementation, ineffective implementation and maladaptation (Eriksen et al., 2021).
Governance deficit	A gap between formally adopted climate commitments and the institutional capacity, coordination, data, finance or accountability needed to implement them.
Resilience	The capacity of social, economic and hydrological systems to absorb, cope with and recover from hazardous events while keeping their essential functions, following IPCC usage (Trisos et al., 2022).
Hydrological pathway	The sequence through which a climate extreme alters water stores and fluxes (soil moisture, groundwater, river flow, lake and reservoir storage) before it affects people and sectors.
Climate justice (operational)	The distribution of climate risk, adaptation resources and decision-making power across social groups, assessed through measurable indicators rather than stated principles.

2. Material and Methods

2.1. Review design

We used a critical narrative review design. The question is interpretive, and the relevant evidence is heterogeneous: climate model projections, hydrological observations, satellite products, policy and legal analyses, finance accounts and qualitative field studies. Narrative reviews are suited to integrating evidence of this kind and to building conceptual frameworks from it (Greenhalgh et al., 2018). The design and reporting follow the six items of the SANRA scale for narrative reviews: justification of the topic, statement of aims, description of the literature search, referencing, scientific reasoning and appropriate presentation of evidence (Baethge et al., 2019). We do not claim exhaustive coverage. The claim we make is narrower and checkable: each conclusion can be traced to cited evidence, and each cited source says what we report it as saying. Figure 1 summarises the workflow.

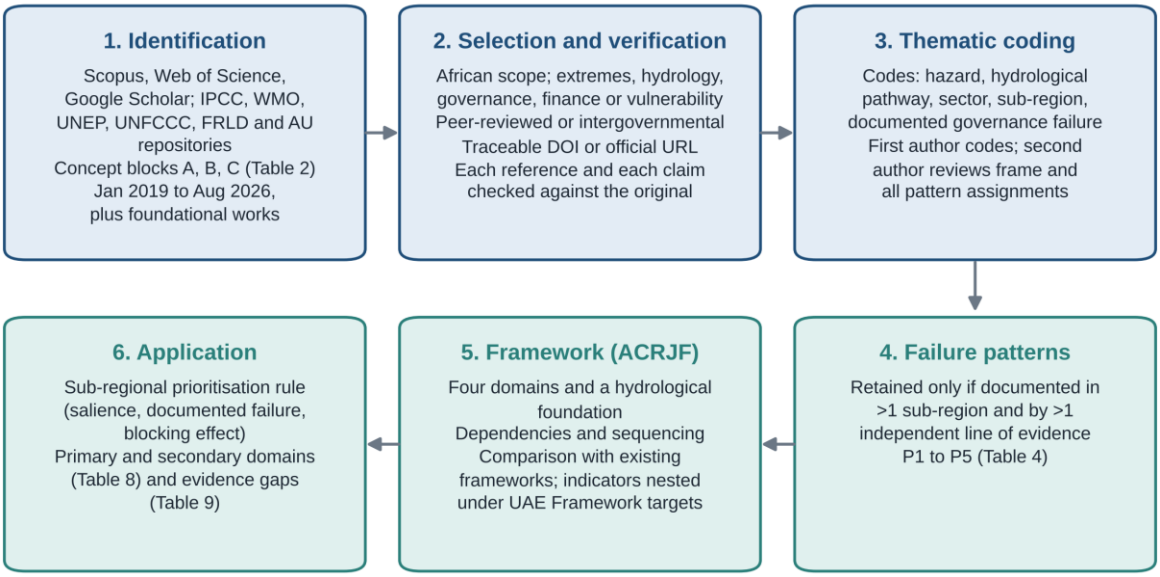


Figure 1. Workflow of the critical narrative review, from literature identification to framework derivation and sub-regional application.

2.2. Literature identification and selection

Searches were run in Scopus, Web of Science and Google Scholar and in the repositories of the IPCC, the World Meteorological Organization (WMO), the United Nations Environment Programme (UNEP), the UNFCCC, the Fund for responding to Loss and Damage (FRLD) and the African Union. Search terms were organised in three concept blocks (Table 2) and combined in the pairings shown. The search window ran from January 2019 to August 2026, and the last update was made in October 2026. Earlier works were admitted only when they established a hydrological mechanism or a methodological standard that later studies rely on (for example, MacDonald et al., 2012; Taylor et al., 2013). Backward and forward citation checks from key papers supplemented the database searches.

Table 2. Search concept blocks, example terms and combinations.

Block	Focus	Example terms
A	Hazards and hydrology	"extreme rainfall", flood*, drought*, heatwave*, cyclone*, "compound event*", groundwater, recharge, "river discharge", reservoir*, GRACE
B	Governance and response	adaptation, "national adaptation plan*", governance, "climate finance", "loss and damage", "early warning", "indigenous knowledge", gender, vulnerability
C	Geography	Africa*, "sub-Saharan", Sahel, Maghreb, "West Africa", "East Africa", "Central Africa", "Southern Africa", "North Africa", Nile, Niger, Volta, Zambezi, Congo, "Lake Chad"
Combinations	Run separately	A AND C; B AND C; A AND B AND C. Example (Scopus): TITLE-ABS-KEY((drought* OR flood* OR "extreme rainfall" OR groundwater) AND (adaptation OR governance OR "climate finance") AND (Africa* OR Sahel OR "sub-Saharan")) AND PUBYEAR > 2018

Sources were included if they (a) concerned Africa, an African sub-region or an African river basin; (b) addressed climate extremes, hydrological change, adaptation governance, climate finance or differential vulnerability; (c) were peer-reviewed or issued by an intergovernmental or United Nations body; and (d) could be traced to a DOI or a stable official URL. We excluded outlets without credible peer review, judged by indexing in Scopus or Web of Science and by publisher practice; study protocols that report no findings; conference abstracts where a peer-reviewed version existed; and sources that could not be traced to an original record. Each reference was checked against its original record for authors, year, title, volume and pages. Each factual claim was then checked against the content of the cited source. Where a widely repeated figure could not be traced to a primary source, it was replaced with a traceable figure or removed. Rapid attribution studies and humanitarian figures are cited where no peer-reviewed equivalent exists and are identified as such in the text.

2.3. Synthesis and framework derivation

Synthesis followed the logic of thematic analysis (Braun and Clarke, 2006) in three passes. In the first pass, each source was coded for hazard type, hydrological pathway, sector, sub-region and any governance failure it documented. In the second, codes were grouped into recurring failure patterns. A pattern was retained only if it was documented in more than one sub-region and by more than one independent line of evidence, for example a peer-reviewed study and an intergovernmental assessment. In the third pass, each

retained pattern was assigned to a framework domain, and relationships between domains were drawn only where the literature documented a dependency, for example that access to adaptation finance depends on risk assessments, which in turn depend on monitoring data. The first author coded the sources. The second author reviewed the coding frame and every pattern assignment, and disagreements were resolved by discussion. Table 4 sets out the evidence behind each pattern.

To make the regional analysis transparent, we applied a fixed prioritisation rule to each sub-region. The primary domain is the one that addresses the constraint judged most limiting for risk reduction along the dominant hydrological pathway, assessed against three criteria: (1) the salience of that pathway in the regional evidence; (2) a documented governance failure attached to it; and (3) whether the failure blocks progress in other domains. The secondary domain is the next most limiting. The assignments and the evidence for them appear in Table 8, and Section 7 discusses the sub-regions in the same order. The rule involves judgement, and Section 9 discusses how it could be tested.

3. Climate Extremes Across Africa's Sub-Regions

3.1. Temperature and heat

Warming is observed in every sub-region. Africa's 2024 mean surface temperature was about 0.86 °C above the 1991 to 2020 average, and North Africa was about 1.28 °C above it, the largest anomaly of any sub-region (WMO, 2025). Projections from 27 CMIP6 models show warming across all African sub-regions, scaling with the emission pathway (Almazroui et al., 2020). For West Africa, Macadam et al. (2020) narrowed the range of projected warming, and Fitzpatrick et al. (2020) found that under RCP8.5 at the end of the century the maximum and minimum temperatures of a typical day across much of the region would exceed the 99.5th percentile of present-day values. Projected increases in warm extremes over Côte d'Ivoire (Yapo et al., 2019) fit this regional pattern. In East Africa, high-resolution datasets show significant warming trends over recent decades (Gebrechorkos et al., 2019). Heat matters hydrologically because it raises evaporative demand, which speeds the depletion of soil moisture and open water during dry spells.

3.2. Rainfall extremes, drought and compound events

Rainfall change is regionally divergent. Continental satellite records for 1983 to 2020 show contrasting trends between sub-regions (Alahacoon et al., 2022), and changes in extreme daily rainfall since 1981 have been driven largely by a shift in the share of very extreme events (Marra et al., 2022). In the Sahel, the frequency of extreme mesoscale storms has roughly tripled since 1982, a change linked to warming over the Sahara (Taylor et al., 2017). Trend analyses for West Africa (Muthoni, 2020) and of extreme rainfall over East Africa (Ojara et al., 2021) show significant changes over parts of both regions, and changes in the African monsoon systems alter the timing of the rains on which river flow and recharge depend (Cook and Vizy, 2019).

Projections sharpen the picture without simplifying it. A convection-permitting model projects more intense extreme rainfall over Eastern Africa (Chapman et al., 2022). Downscaled CMIP6 projections coupled with a hydrological model indicate March to May rainfall increases of up to 43% over southern Ethiopia, Kenya and Uganda but decreases of up to 20% over parts of Tanzania (Gebrechorkos et al., 2023), while drought is projected to intensify across much of East Africa (Haile et al., 2020). In North Africa, projections point to drying along the Mediterranean coast, against a background of strong interannual and decadal variability (Tanarhte et al., 2026). Drought projections for Morocco show intensifying conditions with consequences for rain-fed cereals (Gumus et al., 2024), and in Morocco's semi-arid farming regions severe meteorological drought turns into agricultural drought within one to three months (Dahhane et al., 2025). In Southern Africa, a large climate ensemble projects more frequent and more intense extremes under high emissions (Thomas et al., 2022).

Compound events add a further layer. Risk from co-occurring or sequential hazards can greatly exceed the sum of single-hazard risks (Zscheischler et al., 2018). Impact-model projections for East Africa show co-occurring extremes becoming more frequent and more extensive under every warming scenario considered, with the largest increases for pairs that involve river floods, heatwaves and wildfires and with hotspots near the Nile and Congo basins (Muheki et al., 2024). A global extension of this analysis reaches a similar conclusion (Messori et al., 2025). These are projections rather than observed trends, but they indicate that planning built on single hazards and stationary statistics will understate risk.

3.3. Sub-regional synthesis

Table 3 summarises the dominant hazard signals and the main hydrological pathway in each sub-region, with the sources that support each entry. The table describes exposure only. Governance priorities are derived later (Section 7), once the hydrological and institutional evidence has been examined.

Table 3. Dominant hazard signals and hydrological pathways by sub-region.

Sub-region	Dominant hazard signals	Main hydrological pathway	Supporting sources
North Africa	Fastest observed warming; multi-year drought; projected drying of the Mediterranean coast	Rapid propagation from meteorological to agricultural drought; depletion of largely non-renewable aquifer storage	WMO (2025); Tanarhte et al. (2026); Gumus et al. (2024); Dahhane et al. (2025); Mohasseb et al. (2025)
West Africa	More frequent extreme Sahelian storms; heavier rainy seasons; extreme heat	Flood peaks and dam overtopping; floods causing harvest failure	Taylor et al. (2017); World Weather Attribution (2024); Fitzpatrick et al. (2020); Muller et al. (2023)
Central Africa	Floods; compound-event hotspots near the Congo basin	Lake and floodplain storage; poorly gauged river flows	Pham-Duc et al. (2020); Muheki et al. (2024); Akpoti et al. (2024); WMO (2026)
East Africa	Divergent rainfall projections; drought and flood in close succession; compound events	Recharge driven by episodic heavy rainfall; drought in pastoral rangelands	Gebrechorkos et al. (2023); Haile et al. (2020); Taylor et al. (2013); Muheki et al. (2024)
Southern Africa	Tropical cyclones; El Niño drought; projected increases in extremes	Reservoir storage loss in shared basins; cyclone flooding	Ghosh et al. (2025); Thomas et al. (2022); Mashula et al. (2021)

4. Hydrological Pathways from Extremes to Adaptation Outcomes

Most climate impacts in Africa are mediated by water. A heavy rainfall season, a multi-year drought or a heatwave matters to a farmer, a utility or a hydropower operator through what it does to soil moisture, groundwater, river flow and stored water. Figure 2 sets out these pathways and marks the points at which governance commonly fails. Four pathways stand out in the evidence.

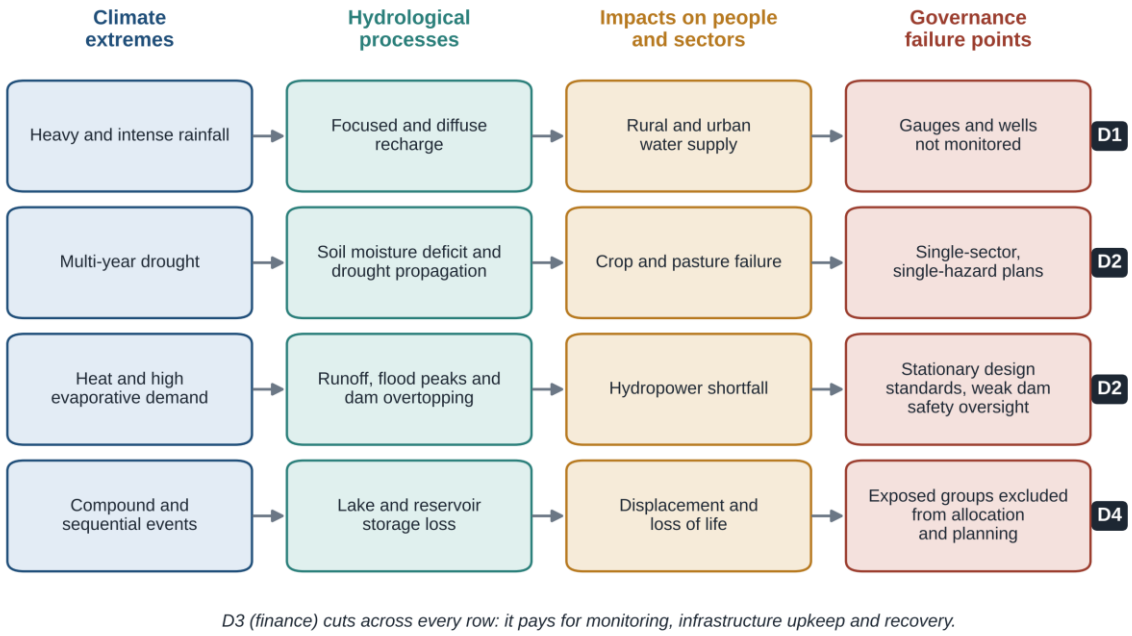


Figure 2. Hydrological pathways linking climate extremes to impacts, and the governance failure points at which adaptation commonly breaks down. Rows are illustrative; in practice pathways cross between rows. Labels D1 to D4 mark the ACRJF domain that addresses each failure point.

4.1. Groundwater: the buffer and its recharge

Groundwater is Africa's largest freshwater store. MacDonald et al. (2012) estimated total groundwater storage at about 0.66 million km³, more than 100 times the continent's annual renewable freshwater resources. This storage helps rural water supplies through droughts. The important question for adaptation is how it is replenished. A 55-year record from central Tanzania showed recharge dominated by episodic, extreme seasonal rainfall, often associated with El Niño Southern Oscillation events (Taylor et al., 2013). Multidecadal records from nine sub-Saharan countries showed that a drier climate does not necessarily mean less recharge (Cuthbert et al., 2019). In drylands, much recharge is focused, occurring beneath ephemeral streams and ponds after heavy rain, whereas in humid zones diffuse recharge through soils dominates. Isotopic evidence from the south-western Lake Chad Basin points the same way: groundwater there matches rainfall from months with above roughly the 60th percentile of intensity, which suggests that heavier tropical rainfall could favour recharge (Goni et al., 2021). In the Inner Niger Delta, groundwater recharge explained about 58% to 78% of the variance in GRACE terrestrial water storage in semi-arid and Sahelian zones (Fatolazadeh and Goïta, 2025).

Continental and basin-scale analyses based on GRACE show contrasting storage trajectories across African basins (Mohasseb et al., 2024; Ferreira et al., 2024). North Africa is different in kind. Its large sedimentary aquifers, including the Nubian Sandstone, North-Western Sahara and Murzuk systems, hold mostly non-renewable water, and GRACE-observed storage losses there largely reflect abstraction (Mohasseb et al., 2025). The policy implications follow directly. In much of sub-Saharan Africa the problem is not a uniform decline in recharge but how to manage recharge that is episodic and concentrated in particular places: protecting ephemeral channels and floodplains that act as recharge zones, and pacing abstraction to multi-year recharge cycles. In North Africa the problem is the allocation of a largely fixed stock, which is a question of governance more than of climate response. A single continental narrative of declining groundwater would misdirect policy in both settings.

4.2. Surface storage: lakes, reservoirs and shared basins

Lake Chad is the clearest case of a water narrative that has moved ahead of the hydrology. Its open water fell from about 25,000 km² in the 1960s to less than 2,000 km² during the 1980s. Multi-satellite and GRACE analyses, however, show the lake's extent broadly stable over the past two decades, with groundwater rising since the early 2000s and contributing about 70% of annual water storage change (Pham-Duc et al., 2020). The northern pool has not recovered, but the claim that the lake continues to shrink is not supported by recent observations. This matters for governance. Interventions designed around continuing shrinkage, such as large inter-basin transfers, may address the wrong problem. Insecurity, livelihood loss and contested access to land and water call for different responses, and the wider links between climate stress, resource competition and conflict in Africa are reviewed by Scheffran et al. (2019). Climate impacts on Africa's other major lakes are reviewed by Mutanda and Nhamo (2024).

Reservoirs bring the problem into energy and food systems. During the 2023/24 El Niño drought, Earth observation data showed surface water losses of about 117 km² at Itezhi-Tezhi and about 59 km² in parts of Lake Kariba between December 2023 and April 2024 (Ghosh et al., 2025). Kariba is shared by Zambia and Zimbabwe, so drought operating rules for it are transboundary decisions. The same holds for many African reservoirs and rivers. Akpoti et al. (2024) note that gauging is limited across Africa's 63 transboundary basins, which makes it harder to agree on allocation rules when flows fall.

4.3. Floods and water infrastructure

Flood risk is rising with rainfall intensity, and infrastructure often converts high water into disaster. Rapid attribution of the 2024 floods found that climate change had made seasonal rainfall in the Niger and Lake Chad basins heavier, and that failures of the Alau Dam in north-eastern Nigeria and the Arba'at Dam in Sudan worsened the impacts (World Weather Attribution, 2024). This study is a rapid attribution report rather than a peer-reviewed paper, but its conclusions about dam failure are consistent with the wider evidence on African flood management, which identifies weak institutional arrangements and poor data as

persistent constraints (Lumbroso, 2020). In coastal West Africa, areas prone to drought and to flooding overlap (Kodja et al., 2024), and in Burkina Faso floods are associated with harvest failure (Muller et al., 2023). In 2025, floods in Nigeria and the Democratic Republic of the Congo each killed more than 160 people (WMO, 2026). Design standards based on stationary rainfall statistics, and dam safety regimes that are weakly enforced, are governance failures with hydrological consequences.

4.4. The hydrometric data gap

Each of the pathways above depends on observations. Dinku (2019) documents sparse and uneven meteorological networks, long gaps in records and restrictions on data access across Africa. For rivers the situation is worse. The number of African stations with data available in the Global Runoff Data Centre has declined, and the limited gauging of rivers, including transboundary basins, leaves large gaps in the Congo, Niger and Okavango systems (Akpoti et al., 2024). Satellite gravimetry and global models fill some of the gap, as the GRACE studies above show, but they still need ground observations for calibration and validation. The consequence reaches beyond science. A country that cannot measure river flow or groundwater levels cannot produce the risk assessments that adaptation finance applications require, cannot set defensible design standards and cannot verify whether its adaptation investments work. The data gap is also a finance gap and an accountability gap.

5. Governance Deficits Behind Adaptation Failure

5.1. The implementation gap

Most African states have the formal architecture of climate governance in place: Nationally Determined Contributions, climate policies and, increasingly, national adaptation plans. The evidence suggests that implementation, rather than planning, is where adaptation most often stalls. A review of adaptation policies in 16 West African countries found that nutrition and health were weakly integrated into policies for agriculture and food security (Sorgho et al., 2020). Chevallier (2023) identifies weak policy coherence and coordination between continental, regional and national levels as a barrier to climate-resilient agriculture and food systems. Kooffreh et al. (2023) trace adaptation inaction in sub-Saharan Africa to legal and policy gaps, and Lumbroso (2020) reports similar institutional constraints in flood risk management. Globally, adaptation responses remain largely fragmented and incremental (Berrang-Ford et al., 2021).

These findings support a cautious conclusion. In the literature reviewed, institutional constraints such as coordination, mandates, enforcement and budgets are documented more often as the binding limit on risk reduction than a lack of scientific knowledge. Technical gaps are real, however. Sparse monitoring, crop models poorly calibrated to African conditions and limited compound-event modelling all constrain planning, and they interact with institutional weaknesses. We treat the primacy of institutional constraints as a reasoned inference from the reviewed evidence, not as a tested proposition.

5.2. The finance gap

The adaptation finance gap is large and widening. UNEP (2025) estimates adaptation needs in developing countries at US$310 to 365 billion per year by 2035, against international public adaptation finance of about US$26 billion in 2023, down from US$28 billion in 2022 (Figure 3). The gap is roughly 12 to 14 times current flows. The new collective quantified goal agreed in 2024 sets a target of at least US$300 billion per year by 2035 for climate finance as a whole, with a call to scale total flows to US$1.3 trillion, but it contains no separate adaptation goal (UNFCCC, 2024). Flows to Africa are also poorly targeted. Savvidou et al. (2021) found that the distribution of international public adaptation finance across African countries was poorly aligned with their vulnerability, and Overland et al. (2022) showed that most funding for climate research on Africa comes from outside the continent and much of it goes to institutions in Europe and North America. Mungai et al. (2021) discuss the potential and the constraints of financing climate-smart agriculture in sub-Saharan Africa.

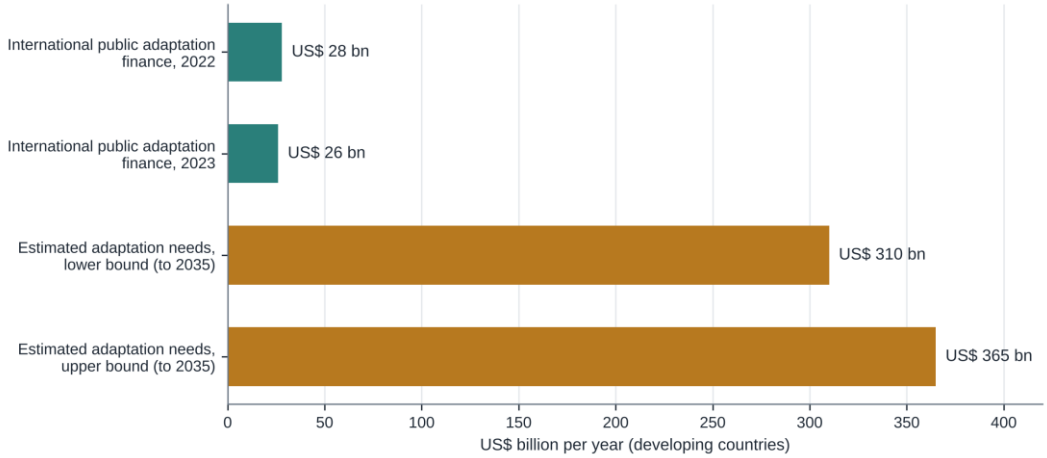


Figure 3. Estimated annual adaptation finance needs of developing countries to 2035 compared with international public adaptation finance flows in 2022 and 2023. Data from UNEP (2025).

Loss and damage finance is beginning to operate but at a small scale. The FRLD opened its first call for funding requests in November 2025 under a start-up phase of US$250 million for 2025 and 2026 (FRLD, 2025), against total pledges of about US$768 million (UNFCCC, 2025b). A single event shows the mismatch: the post-disaster needs assessment for Cyclone Idai put Mozambique's recovery needs at about US$3.2 billion (Government of Mozambique, 2019). The macroeconomic costs extend further, since climate change is projected to reduce incomes and slow convergence across Africa (Baarsch et al., 2020), and extreme weather events raise inflation (Kunawotor et al., 2022). The finance gap therefore has two parts: too little money, and access arrangements that favour countries already able to produce the required risk evidence.

5.3. The knowledge gap

Indigenous and local knowledge is widely used in African adaptation, for weather prediction, crop and planting decisions and water management, yet it is rarely recognised in formal planning (Leal Filho et al.,

2022). Evidence from several African regions shows that indigenous weather indicators shape farmers' decisions but are seldom institutionalised in policy (Leal Filho et al., 2023). In Zimbabwe's Chirumhanzu district, formal drought programmes that ignored local knowledge had limited success with smallholders (Grey et al., 2020). There are workable alternatives. An assessment of anticipatory action in Zimbabwe recommends combining indigenous and scientific seasonal forecasts to set action triggers and building a national database of indigenous indicators (Dube et al., 2024). The research agenda itself is part of the gap, since priorities set and funded outside Africa may not match the questions African decision-makers need answered (Overland et al., 2022).

5.4. The distributional gap

Climate risk is unevenly distributed within societies. Gendered differences in exposure and adaptive capacity are well documented in West African agriculture (Deji, 2021) and across the continent (Okesanya et al., 2024). A systematic review of African climate change research found that most studies describe gender differences but few examine the mechanisms that produce them (Vercillo et al., 2022). Adaptation that ignores distribution can widen inequalities in access to water, energy and food even while it reduces aggregate exposure (Nyiwul, 2021). The burden extends to mental health, which receives little attention in African climate policy (Atwoli et al., 2022), and to progress on the Sustainable Development Goals more broadly (Codjoe and Atiglo, 2020). Table 4 brings the evidence on all five failure patterns together.

Table 4. Evidence matrix linking recurring failure patterns to ACRJF domains.

Failure pattern	What the evidence shows	Key sources	Sub-regions documented	Domain
P1. Weak link between evidence and policy	Sparse and declining gauging; restricted data access; indigenous knowledge excluded from formal planning; research agendas set outside Africa	Dinku (2019); Akpoti et al. (2024); WMO (2026); Leal Filho et al. (2023); Grey et al. (2020); Overland et al. (2022)	All; strongest for Central, West and Southern	D1
P2. Sectoral fragmentation and weak enforcement	Hazards managed sector by sector; weak policy coherence across levels; legal gaps behind inaction; weak flood and dam safety arrangements	Sorgho et al. (2020); Chevallier (2023); Kooffreh et al. (2023); Lumbroso (2020); World Weather Attribution (2024)	West, East, Southern; continental	D2
P3. Finance volume and access mismatch	Needs 12 to 14 times flows; allocation not matched to vulnerability; small loss and damage window; research funding held outside Africa	UNEP (2025); Savvidou et al. (2021); Overland et al. (2022); FRLD (2025); UNFCCC (2025b)	Continental; acute in Southern after cyclones and drought	D3
P4. Distributional blindness	Gender differences described but mechanisms rarely examined; adaptation can widen inequality; maladaptation documented	Vercillo et al. (2022); Okesanya et al. (2024); Deji (2021); Nyiwul (2021); Eriksen et al. (2021)	West, Southern; continental	D4
P5. Hydrological misdiagnosis	Water narratives that do not match observations (Lake Chad); recharge treated as uniformly declining; fossil and renewable groundwater not distinguished	Pham-Duc et al. (2020); Cuthbert et al. (2019); Taylor et al. (2013); Mohasseb et al. (2025)	Central, East, North	Foundation (D1, D2)

6. The Africa Climate Resilience and Justice Framework (ACRJF)

6.1. Design principles

The ACRJF is an analytical and operational framework. It organises the evidence above, identifies where adaptation breaks down and specifies the institutional conditions and indicators needed to address each breakdown. Four principles shape it. First, hydrological monitoring is treated as governance infrastructure rather than as a research activity, because every domain depends on knowing what is happening to water. Second, justice is an operational domain with its own instruments and indicators instead of a principle stated at the outset. Third, the dependencies between domains are stated explicitly, so that weaknesses in one domain can be traced to their effects on the others. Fourth, indicators are nested under the targets of the UAE Framework for Global Climate Resilience (UNFCCC, 2023) so that reporting on the ACRJF adds no parallel system. Figure 4 shows the structure and Table 5 sets out each domain.

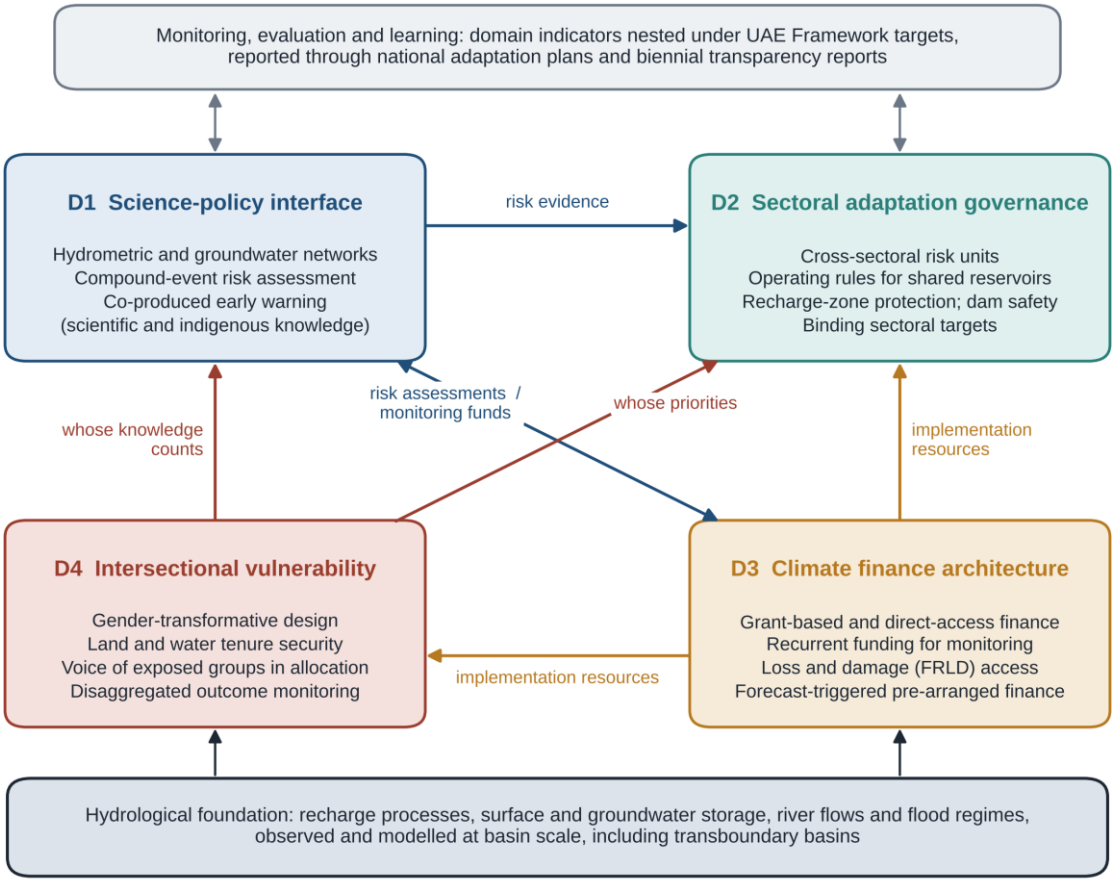


Figure 4. Structure of the Africa Climate Resilience and Justice Framework (ACRJF): four domains resting on a hydrological foundation, the documented dependencies between them, and the monitoring, evaluation and learning loop linked to UAE Framework targets.

Table 5. ACRJF domains: objectives, instruments, actors and the failure patterns they address.

Domain	Policy objective	Key instruments	Main institutional actors	Addresses
D1. Science-policy interface	Close the evidence-policy gap, including the hydrometric data gap	Restored river gauging and groundwater monitoring; open data agreements for shared basins; compound-event risk assessment; early warning co-produced with indigenous knowledge holders	National meteorological and hydrological services; universities; river basin organisations; community knowledge holders	P1, P5

Domain	Policy objective	Key instruments	Main institutional actors	Addresses
D2. Sectoral adaptation governance	Govern hazards across sectors and borders	Cross-sectoral climate risk units; drought and flood operating rules for shared reservoirs; recharge-zone protection in land-use plans; dam safety regulation; binding sectoral targets	Planning, water, agriculture, health and energy ministries; ECOWAS, SADC, EAC; basin bodies such as the Niger Basin Authority, Lake Chad Basin Commission and Nile Basin Initiative	P2, P5
D3. Climate finance architecture	Match finance volume and access to need	Grant-based adaptation finance for the most vulnerable countries; direct access modalities; recurrent funding for monitoring; FRLD access; forecast-triggered pre-arranged finance; domestic instruments	Finance ministries; African Development Bank; GCF, Adaptation Fund and FRLD; national designated authorities	P3
D4. Intersectional vulnerability reduction	Shift risk and decision power toward the most exposed	Gender-transformative programmes; land and water tenure security, including access to groundwater; participation of exposed groups in allocation decisions; disaggregated outcome monitoring; youth inclusion	Gender and social ministries; local governments; community and civil society organisations	P4

6.2. The four domains

Domain 1, the science-policy interface, addresses patterns P1 and P5. Its first task is to restore and sustain hydrometric and groundwater monitoring, including monitoring of the ephemeral channels and floodplains where focused recharge occurs (Cuthbert et al., 2019), and to agree data-sharing arrangements in transboundary basins (Akpoti et al., 2024). Its second task is to build risk assessment capacity for compound and sequential events, which single-hazard planning misses (Muheki et al., 2024). Its third is to co-produce early warning with indigenous knowledge holders. Combining indigenous and scientific forecasts to set anticipatory action triggers, as proposed for Zimbabwe (Dube et al., 2024), is a concrete model. Research funding should support African-led agendas (Overland et al., 2022).

Domain 2, sectoral adaptation governance, addresses P2 and the governance side of P5. Climate hazards move across agriculture, water, health and energy, so planning needs cross-sectoral risk units with a mandate to track cascading risks (Sorgho et al., 2020; Chevallier, 2023). The domain also covers water infrastructure governance: drought and flood operating rules for shared reservoirs such as Kariba, dam safety regulation informed by the 2024 failures, design standards that allow for non-stationary rainfall, and protection of recharge zones in land-use plans. Regional economic communities and river basin organisations are the natural forum for transboundary rules. Because legal and policy gaps underlie much adaptation inaction (Kooffreh et al., 2023), the domain also calls for binding sectoral targets that give these arrangements force.

Domain 3, climate finance architecture, addresses P3. The scale of the gap (UNEP, 2025) argues for grant-based adaptation finance for the most vulnerable countries, simpler direct access, and finance for recurrent costs such as keeping gauging stations running, which project-based funding rarely covers. Loss and damage finance through the FRLD should be accessible on timelines that match disaster response (FRLD, 2025). Pre-arranged finance released when forecasts cross agreed thresholds links this domain to the early

warning work in Domain 1. Domestic instruments and the integration of adaptation into development planning complete the domain (Alemaw and Simatele, 2020).

Domain 4, intersectional vulnerability reduction, addresses P4. Adaptation programmes should aim to change the conditions that produce unequal exposure. Acknowledging that exposure is unequal is a first step, and most studies stop there (Vercillo et al., 2022). In water terms this means secure land and water tenure, including access to groundwater, for women, smallholders and indigenous communities; a voice for exposed groups in allocation decisions; and outcome monitoring disaggregated by sex, age and livelihood. Without this domain, adaptation can widen the very gaps it should close (Nyiwul, 2021; Eriksen et al., 2021).

6.3. Integration and sequencing

The domains depend on one another in documented ways (Figure 4). Domain 1 produces the risk evidence that Domain 2 needs to design interventions and that Domain 3 needs for finance applications. Domain 3 pays for the recurrent monitoring in Domain 1 and for implementation in Domains 2 and 4. Domain 4 determines whose knowledge enters Domain 1 and whose priorities shape Domain 2. The hydrological foundation underlies all four, since each relies on an accurate account of water stores and fluxes. Two sequencing conclusions follow. Domains 1 and 3 are enabling: weaknesses there propagate to the other domains, so they should be addressed early wherever they are binding. Progress in Domain 2 or Domain 4 alone will not be sustained if monitoring and finance are left unaddressed.

6.4. Comparison with existing frameworks

The ACRJF does not replace existing frameworks; it is designed to operate within them. Table 6 compares it with the IPCC concept of climate-resilient development and its enabling conditions (Trisos et al., 2022), the UNFCCC technical guidelines for national adaptation plans (LEG, 2012), the UAE Framework for Global Climate Resilience and its indicators (UNFCCC, 2023, 2025a), and the African Union Climate Change and Resilient Development Strategy and Action Plan (African Union, 2022). Its contribution lies in four specific features: hydrological monitoring treated as governance infrastructure; justice as an operational domain with indicators; explicit dependencies and sequencing between domains; and a stated rule for sub-regional prioritisation.

Table 6. Comparison of the ACRJF with existing adaptation and resilience frameworks.

Framework	Scale and purpose	Treatment of hydrology and data	Treatment of justice	Sub-regional guidance and indicators
IPCC climate-resilient development (Trisos et al., 2022)	Global assessment concept; enabling conditions include governance, finance, knowledge and inclusion	Data and knowledge recognised as enabling conditions; no operational monitoring requirement	Equity and inclusion as enabling conditions	Africa chapter assesses sub-regional risks; no operational indicators
NAP technical guidelines (LEG, 2012)	National planning process in four elements, from groundwork to monitoring and review	Vulnerability assessment step; monitoring not specified	Participation encouraged; not operationalised	Country-generic process; national choice of indicators

Framework	Scale and purpose	Treatment of hydrology and data	Treatment of justice	Sub-regional guidance and indicators
UAE Framework and Belém indicators (UNFCCC, 2023, 2025a)	Global targets: seven thematic (including water) and four dimensional (risk assessment to learning)	Water target and risk assessment target; indicators voluntary	Cross-cutting considerations	Global and voluntary; not tailored to African governance deficits
AU Climate Change and Resilient Development Strategy (African Union, 2022)	Continental strategy for 2022 to 2032 with priority interventions and enablers	Climate information services among enablers	Inclusion and vulnerable groups addressed	Continental; limited sub-regional differentiation
ACRJF (this review)	Analytical and operational framework derived from African evidence	Hydrological foundation; monitoring treated as governance infrastructure (D1)	Operational domain with indicators (D4)	Explicit prioritisation rule; indicators nested under UAE Framework targets

6.5. Implementation and indicators

A framework that cannot be measured cannot be held to account. Table 7 proposes indicators for each domain and links each to a target of the UAE Framework, so that countries can report on them through national adaptation plans and biennial transparency reports rather than through a separate system. Baselines and targets should be set nationally. Progress should be reviewed on the cycle of the global stocktake, and the indicator set itself revised as the evidence gaps in Section 8 are filled. UNEP (2025) notes that countries report many implemented adaptation actions but few report outcomes, so the emphasis here is on indicators that measure outcomes and capacity rather than the number of plans adopted.

Table 7. Proposed ACRJF indicators and their link to UAE Framework targets.

Domain	Indicator	UAE Framework target	Data source
D1	Operational river gauging stations reporting data, per 10,000 km² of basin area, against a 1990 baseline	Risk assessment; water	National hydrological services; GRDC
D1	Share of the population covered by multi-hazard early warning, and whether indigenous indicators are formally included	Risk assessment; planning	WMO; national disaster agencies
D1	Monitored groundwater wells per major aquifer, with recharge-zone mapping completed	Water	Geological surveys; basin bodies
D2	Shared reservoirs and basins with agreed drought and flood operating rules	Water; infrastructure	River basin organisations
D2	Dams with a current safety inspection and an emergency action plan	Infrastructure; implementation	Dam safety regulators
D2	Sectoral adaptation targets that are legally binding and costed in national adaptation plans	Planning; implementation	National adaptation plans
D3	International public adaptation finance received per capita, compared with assessed needs	Implementation	UNEP; OECD; national budgets
D3	Share of adaptation finance received as grants and through direct access entities	Implementation	GCF; Adaptation Fund; FRLD
D3	Recurrent budget for hydrometeorological services as a share of their operating requirement	Implementation; risk assessment	Finance ministries
D4	Adaptation projects reporting sex- and age-disaggregated outcome data	Monitoring, evaluation and learning; poverty and livelihoods	Project monitoring systems
D4	Women and smallholders with documented land and water rights in project areas	Poverty and livelihoods; food	Land registries; surveys

7. Applying the Framework to Africa's Sub-Regions

Applying the prioritisation rule in Section 2.3 gives the assignments in Table 8. The text below follows the order of the table, and each primary and secondary assignment is the same in both.

Table 8. Primary and secondary ACRJF domains by sub-region, with the evidence for each assignment.

Sub-region	Primary domain	Secondary domain	Rationale under the prioritisation rule	Key sources
North Africa	D2	D1	Dominant pathway is drought on a largely non-renewable groundwater base; documented failure is the governance of fossil aquifers and shared water; this blocks other domains because allocation decisions fix future options. Monitoring of drought propagation and abstraction is the next constraint.	Mohasseb et al. (2025); Tanarhte et al. (2026); Gumus et al. (2024); Dahhane et al. (2025)
West Africa	D2	D4	Dominant pathway is flood peaks and harvest failure; documented failures are sectoral fragmentation and weak dam safety; these block effective use of forecasts and finance. Smallholder and gendered exposure is the next constraint.	Sorgho et al. (2020); World Weather Attribution (2024); Muller et al. (2023); Deji (2021); Okesanya et al. (2024)
Central Africa	D1	D2	Dominant pathways are flooding and lake and floodplain storage in poorly gauged basins; documented failure is the monitoring gap; this blocks risk assessment and finance access. Basin governance in the Lake Chad and Congo systems is the next constraint.	Akpoti et al. (2024); Pham-Duc et al. (2020); Muheki et al. (2024); Scheffran et al. (2019)
East Africa	D1	D2	Dominant pathways are compound drought and flood and recharge from episodic heavy rain; documented failure is single-hazard risk assessment; this blocks multi-hazard planning. Multi-hazard planning is the next constraint.	Muheki et al. (2024); Gebrechorkos et al. (2023); Taylor et al. (2013); Haile et al. (2020)
Southern Africa	D3	D2	Dominant pathways are cyclone flooding and drought-driven reservoir losses; documented failure is the mismatch between losses and available finance; this blocks recovery and reinvestment. Operating rules for shared reservoirs are the next constraint.	Government of Mozambique (2019); Ghosh et al. (2025); Thomas et al. (2022); FRLD (2025)

7.1. North Africa: shared water on a fixed stock

North Africa has the fastest observed warming on the continent (WMO, 2025), projected drying along its Mediterranean coast (Tanarhte et al., 2026) and a recent sequence of severe droughts in Morocco (Gumus et al., 2024). Its water security rests heavily on large aquifers that are mostly non-renewable and on the Nile, which is shared by eleven riparian states. Because GRACE-observed storage losses in the major aquifers largely reflect abstraction (Mohasseb et al., 2025), the binding constraint is the governance of allocation, both within countries and across borders. Domain 2 is therefore the primary entry point. Domain 1 is secondary: drought propagates quickly from rainfall deficits to crop stress in the region's semi-arid farmland (Dahhane et al., 2025), so monitoring of drought propagation and of abstraction is needed to inform allocation decisions in time.

7.2. West Africa: floods, food and fragmented policy

West Africa combines more frequent extreme storms (Taylor et al., 2017), heat that is projected, under high emissions, to make today's extremes ordinary by late century (Fitzpatrick et al., 2020) and floods that destroy harvests (Muller et al., 2023). The 2024 floods showed how dam failures convert heavy rain into disaster (World Weather Attribution, 2024). The documented governance failures are sectoral fragmentation (Sorgho et al., 2020) and weak oversight of water infrastructure, both of which fall under

Domain 2, the primary entry point. Domain 4 is secondary. Smallholder farmers, many of them women, are concentrated where exposure is highest and institutional support weakest (Deji, 2021; Okesanya et al., 2024).

7.3. Central Africa: the monitoring gap

Central Africa includes the Congo basin, one of the least gauged large river systems in the world (Akpoti et al., 2024), and is projected to be a hotspot of co-occurring extremes (Muheki et al., 2024). The Lake Chad case shows what follows from weak monitoring: a narrative of continuing shrinkage persisted for years after satellite and gravimetric observations showed stabilisation (Pham-Duc et al., 2020). Domain 1 is the primary entry point, because without monitoring neither risk assessment nor finance applications can proceed. Domain 2 is secondary, given the governance challenges of shared basins and the documented links between climate stress, resource competition and insecurity (Scheffran et al., 2019).

7.4. East Africa: compound events and episodic recharge

East Africa faces drought and flood in close succession and divergent rainfall projections within the region (Gebrechorkos et al., 2023; Haile et al., 2020). In 2025, drought affected more than 8.5 million people in the region (WMO, 2026). Groundwater, the main drought buffer, is recharged mainly by episodic heavy rainfall (Taylor et al., 2013), so wet years matter as much as dry years for water security. The documented failure is risk assessment that treats hazards one at a time, which places Domain 1, through compound-event modelling and groundwater monitoring, as the primary entry point (Muheki et al., 2024). Domain 2 is secondary: multi-hazard planning across ministries is needed to act on that evidence.

7.5. Southern Africa: losses that outrun finance

Southern Africa faces tropical cyclones, recurrent El Niño drought and projected increases in the frequency and intensity of extremes (Thomas et al., 2022). Cyclone Idai displaced hundreds of thousands of people (Mashula et al., 2021) and left Mozambique alone with recovery needs of about US$3.2 billion (Government of Mozambique, 2019). The 2023/24 drought reduced storage in reservoirs that supply hydropower and irrigation (Ghosh et al., 2025). The documented failure is the mismatch between losses of this size and the finance available, so Domain 3, with its loss and damage component, is the primary entry point. Domain 2 is secondary, because drought operating rules for shared reservoirs such as Kariba are transboundary decisions that determine how losses are distributed when storage falls.

Two conclusions apply across sub-regions. The monitoring gap (Domain 1) and the finance gap (Domain 3) are documented in every sub-region, even where they are not the primary entry point. Other findings are region-specific and should not be generalised: the dominance of fossil groundwater in North Africa, for example, or the evidence that Lake Chad has stabilised.

8. Research and Policy Gaps

The review identifies eight gaps that limit the precision of the framework (Table 9). Each corresponds to a weakness in the evidence base, and filling any of them would allow the ACRJF indicators and priorities to be refined. Two stand out. From a planning perspective, the most urgent is the lack of compound-event risk estimates calibrated to African basins, since single-hazard assessments remain the norm while co-occurring extremes are projected to become common (Muheki et al., 2024). From a policy perspective, the most urgent is country-level evidence on the procedural barriers that keep African governments from accessing GCF, Adaptation Fund and FRLD resources. General arguments about inequity are well rehearsed; documented barriers are harder to dismiss.

Table 9. Priority research and policy gaps.

No.	Gap	Why it matters	Research priority	Policy priority	Domain
1	Compound-event risk calibrated to African basins	Single-hazard assessments understate risk as co-occurring extremes become more common	Critical	Critical	D1
2	Recharge processes and groundwater monitoring in drylands; accounting of fossil aquifer stocks	Determines whether groundwater can buffer longer droughts and how fixed stocks should be allocated	Critical	High	Foundation, D1
3	Restoration of hydrometric networks and transboundary data sharing	Without observations, risk assessment, design standards and verification fail	High	Critical	D1, D2
4	National cost-of-inaction and loss and damage accounting	Needed to support finance claims and set priorities	High	Critical	D3
5	Evaluation of indigenous knowledge co-production in early warning	Few evaluations show whether co-produced warnings change outcomes	High	High	D1, D4
6	Evaluation of gender-transformative interventions	Studies describe gendered vulnerability but seldom test what reduces it	High	Moderate	D4
7	Country-level barriers to GCF, Adaptation Fund and FRLD access	Documented procedural barriers are needed to reform access	Moderate	Critical	D3
8	Longitudinal tracking of adaptation outcomes against UAE Framework indicators	Cross-sectional studies dominate; outcomes over time are rarely measured	Moderate	High	All

9. Limitations

This is a narrative review, and its coverage is not exhaustive. The databases searched favour English-language publications, so Francophone, Lusophone and Arabic literature, which is substantial for West, Central and North Africa, is likely under-represented. Grey literature was limited to intergovernmental and United Nations sources, which excludes some national government and civil society evidence. The evidence base is uneven across sub-regions, being thinner for Central and North Africa than for East and West Africa, and the regional assignments are correspondingly less certain there. Several key figures come from rapid attribution studies or institutional reports rather than peer-reviewed papers, and we have identified these in the text. The ACRJF is derived from evidence but has not been tested in practice. The prioritisation rule involves judgement, and its assignments should be tested with national and basin

stakeholders, for example through structured expert elicitation. The proposed indicators also require national baselines before progress can be assessed.

10. Conclusions

Adaptation to climate extremes in Africa most often falls short where evidence, institutions, finance and the most exposed people are poorly connected, and these failures are most visible in how water is managed. This review found five recurring failure patterns and showed that hydrology runs through all of them: episodic recharge, swinging surface storage, rising flood peaks and a shrinking observation network. The ACRJF organises the response in four domains on a hydrological foundation, with explicit dependencies, indicators nested under the UAE Framework and a stated rule for sub-regional entry points. The framework should next be tested with basin and national stakeholders, and its indicators baselined in pilot countries.

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References

African Union. (2022). *African Union Climate Change and Resilient Development Strategy and Action Plan (2022-2032)*. African Union Commission, Addis Ababa.

Akpoti, K., Mekonnen, K., Leh, M., Owusu, A., Dembélé, M., Tinonetsana, P., Seid, A., & Velpuri, N. M. (2024). State of continental discharge estimation and modelling: Challenges and opportunities for Africa. *Hydrological Sciences Journal, 69*(15), 2124–2152. https://doi.org/10.1080/02626667.2024.2402938

Alahacoon, N., Edirisinghe, M., Simwanda, M., Perera, E., Nyirenda, V., & Ranagalage, M. (2022). Rainfall variability and trends over the African continent using TAMSAT data (1983–2020): Towards climate change resilience and adaptation. *Remote Sensing, 14*(1), 96. https://doi.org/10.3390/rs14010096

Alemaw, B. F., & Simatele, D. (2020). Integrating climate change adaptation and mitigation into sustainable development planning: The policy dimension. In *Sustainable Development in Africa*. Springer, Cham. https://doi.org/10.1007/978-3-030-31543-6_15

Almazroui, M., Saeed, F., Saeed, S., Islam, M. N., Ismail, M., Klutse, N., & Siddiqui, M. H. (2020). Projected change in temperature and precipitation over Africa from CMIP6. *Earth Systems and Environment, 4*(3), 455–475. https://doi.org/10.1007/s41748-020-00161-x

Atwoli, L., Muhia, J., & Merali, Z. (2022). Mental health and climate change in Africa. *BJPsych International, 19*(4), 86–89. https://doi.org/10.1192/bji.2022.14

Baarsch, F., Granadillos, J., Hare, W., Knaus, M., Krapp, M., Schaeffer, M., & Lotze-Campen, H. (2020). The impact of climate change on incomes and convergence in Africa. *World Development, 126*, 104699. https://doi.org/10.1016/j.worlddev.2019.104699

Baethge, C., Goldbeck-Wood, S., & Mertens, S. (2019). SANRA: A scale for the quality assessment of narrative review articles. *Research Integrity and Peer Review, 4*, 5. https://doi.org/10.1186/s41073-019-0064-8

Baninla, Y., Sharifi, A., Allam, Z., et al. (2022). An overview of climate change adaptation and mitigation research in Africa. *Frontiers in Climate, 4*, 976427. https://doi.org/10.3389/fclim.2022.976427

Berrang-Ford, L., Siders, A. R., Lesnikowski, A., et al. (2021). A systematic global stocktake of evidence on human adaptation to climate change. *Nature Climate Change, 11*(11), 989–1000. https://doi.org/10.1038/s41558-021-01170-y

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology, 3*(2), 77–101. https://doi.org/10.1191/1478088706qp063oa

Chapman, S., Bacon, J., Birch, C., Pope, E., Marsham, J., Msemo, H. E., Nkonde, E., Sinachikupo, K., & Vanya, C. (2022). Climate change impacts on extreme rainfall in Eastern Africa in a convection-permitting climate model. *Journal of Climate*. https://doi.org/10.1175/JCLI-D-21-0851.1

Chevallier, R. (2023). Strengthening Africa's climate-smart agriculture and food systems through enhanced policy coherence and coordinated action. *South African Journal of International Affairs, 30*(4), 595–618. https://doi.org/10.1080/10220461.2024.2318712

Codjoe, S., & Atiglo, D. Y. (2020). The implications of extreme weather events for attaining the Sustainable Development Goals in sub-Saharan Africa. *Frontiers in Climate, 2*, 592658. https://doi.org/10.3389/fclim.2020.592658

Cook, K., & Vizy, E. (2019). Contemporary climate change of the African monsoon systems. *Current Climate Change Reports, 5*. https://doi.org/10.1007/s40641-019-00130-1

Cuthbert, M. O., Taylor, R. G., Favreau, G., Todd, M. C., Shamsudduha, M., Villholth, K. G., MacDonald, A. M., Scanlon, B. R., et al. (2019). Observed controls on resilience of groundwater to climate variability in sub-Saharan Africa. *Nature, 572*, 230–234. https://doi.org/10.1038/s41586-019-1441-7

Dahhane, Y., Ongoma, V., Hadri, A., Kharrou, M. H., Hakam, O., & Chehbouni, A. (2025). Probabilistic linkages of propagation from meteorological to agricultural drought in the North African semi-arid region. *Frontiers in Water, 7*, 1559046. https://doi.org/10.3389/frwa.2025.1559046

Deji, O. F. (2021). Gender implications of farmers' indigenous climate change adaptation strategies along agriculture value chain in Nigeria. In W. Leal Filho, N. Oguge, D. Ayal, L. Adeleke, & I. da Silva (Eds.), *African Handbook of Climate Change Adaptation*. Springer, Cham. https://doi.org/10.1007/978-3-030-45106-6_13

Dinku, T. (2019). Challenges with availability and quality of climate data in Africa. In A. M. Melesse, W. Abtew, & G. Senay (Eds.), *Extreme Hydrology and Climate Variability* (pp. 7–15). Elsevier. https://doi.org/10.1016/B978-0-12-815998-9.00007-5

Dube, T., Huhn, A. L., Guimarães Nobre, G., Moyo, E. N., & Enenkel, M. (2024). Incorporating indigenous knowledge systems-based climate services in anticipatory action in Zimbabwe: An ex-ante assessment. *Frontiers in Climate, 6*, 1301908. https://doi.org/10.3389/fclim.2024.1301908

Eriksen, S., Schipper, E. L. F., Scoville-Simonds, M., et al. (2021). Adaptation interventions and their effect on vulnerability in developing countries: Help, hindrance or irrelevance? *World Development, 141*, 105383. https://doi.org/10.1016/j.worlddev.2020.105383

Fatolazadeh, F., & Goïta, K. (2025). Understanding terrestrial water storage changes derived from the GRACE/GRACE-FO in the Inner Niger Delta in West Africa. *Water, 17*(8), 1121. https://doi.org/10.3390/w17081121

Ferreira, V. G., Yang, H., Ndehedehe, C., Wang, H., Ge, Y., Xu, J., Xia, M., Kalu, I., Jing, M., & Agutu, N. (2024). Estimating groundwater recharge across Africa during 2003–2023 using GRACE-derived groundwater storage changes. *Journal of Hydrology: Regional Studies, 56*, 102046. https://doi.org/10.1016/j.ejrh.2024.102046

Fitzpatrick, R. G. J., Parker, D. J., Marsham, J. H., Rowell, D. P., Jackson, L. S., Finney, D., Deva, C., Tucker, S., & Stratton, R. (2020). How a typical West African day in the future-climate compares with current-climate conditions in a convection-permitting and parameterised convection climate model. *Climatic Change, 163*(1), 267–296. https://doi.org/10.1007/s10584-020-02881-5

FRLD (Fund for responding to Loss and Damage). (2025). *The Fund for responding to Loss and Damage launches call for funding requests* [Press release, 10 November 2025]. https://www.frld.org/nodebim (accessed 29 October 2026)

Gebrechorkos, S. H., Hülsmann, S., & Bernhofer, C. (2019). Long-term trends in rainfall and temperature using high-resolution climate datasets in East Africa. *Scientific Reports, 9*, 11376. https://doi.org/10.1038/s41598-019-47933-8

Gebrechorkos, S. H., Taye, M. T., Birhanu, B., Solomon, D., & Demissie, T. (2023). Future changes in climate and hydroclimate extremes in East Africa. *Earth's Future, 11*(2), e2022EF003011. https://doi.org/10.1029/2022EF003011

Ghosh, S., Kour, S., Taron, A., Kaywala, K., & Rajakaruna, P. (2025). Assessing El Niño-induced drought in Zambia and its effects using earth observation data. *Natural Hazards, 121*(4), 4505–4530. https://doi.org/10.1007/s11069-024-06976-5

Goni, I. B., Taylor, R. G., Favreau, G., Shamsudduha, M., Nazoumou, Y., & Ngatcha, B. N. (2021). Groundwater recharge from heavy rainfall in the southwestern Lake Chad Basin: Evidence from isotopic observations. *Hydrological Sciences Journal*. https://doi.org/10.1080/02626667.2021.1937630

Government of Mozambique. (2019). *Mozambique Cyclone Idai Post Disaster Needs Assessment*. Government of Mozambique, Maputo.

Greenhalgh, T., Thorne, S., & Malterud, K. (2018). Time to challenge the spurious hierarchy of systematic over narrative reviews? *European Journal of Clinical Investigation, 48*(6), e12931. https://doi.org/10.1111/eci.12931

Grey, M. S., Masunungure, C., & Manyani, A. (2020). Integrating local indigenous knowledge to enhance risk reduction and adaptation strategies to drought and climate variability: The plight of smallholder farmers in Chirumhanzu district, Zimbabwe. *Jàmbá: Journal of Disaster Risk Studies, 12*(1), a924. https://doi.org/10.4102/jamba.v12i1.924

Gumus, V., El Moçayd, N., Seker, M., & Seaid, M. (2024). Future projection of droughts in Morocco and potential impact on agriculture. *Journal of Environmental Management, 367*, 122019. https://doi.org/10.1016/j.jenvman.2024.122019

Haile, G. G., Tang, Q., Hosseini-Moghari, S.-M., Liu, X., Gebremicael, T. G., Leng, G., Kebede, A., Xu, X., & Yun, X. (2020). Projected impacts of climate change on drought patterns over East Africa. *Earth's Future, 8*, e2020EF001502. https://doi.org/10.1029/2020EF001502

IPCC. (2022). Summary for policymakers. In P. R. Shukla et al. (Eds.), *Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press. https://doi.org/10.1017/9781009157926.001

Kodja, D. J., Quenum, G. M., Koubodana, H. D., Amoussou, E., Akoteyon, I., Akognongbe, A. J. S., Yedo, M. F. A., Mahe, G., Paturel, J., & Vissin, E. (2024). Investigation of drought and flooding areas in coastal countries of West Africa in the context of global warming. *Proceedings of IAHS, 385*, 359–375. https://doi.org/10.5194/piahs-385-359-2024

Kooffreh, B., Anyatang, B. F., & Aminone, V. T. (2023). The inaction in climate change adaptation and mitigation in sub-Saharan Africa: Some policy and legal issues. *Environmental Policy and Law*. https://doi.org/10.3233/EPL-230079

Kunawotor, M. E., Bokpin, G., Asuming, P., & Amoateng, K. A. (2022). The impacts of extreme weather events on inflation and the implications for monetary policy in Africa. *Progress in Development Studies, 22*(2), 130–148. https://doi.org/10.1177/14649934211063357

Leal Filho, W., Barbir, J., Gwenzi, J., Ayal, D., Simpson, N. P., Adeleke, L., Tilahun, B., Chirisa, I., Gbedemah, S. F., Nzengya, D. M., Sharifi, A., Theodory, T., & Yaffa, S. (2022). The role of indigenous knowledge in climate change adaptation in Africa. *Environmental Science & Policy, 136*, 250–260. https://doi.org/10.1016/j.envsci.2022.06.004

Leal Filho, W., et al. (2023). Is indigenous knowledge serving climate adaptation? Evidence from various African regions. *Development Policy Review, 41*(2), e12664. https://doi.org/10.1111/dpr.12664

LEG (Least Developed Countries Expert Group). (2012). *National Adaptation Plans: Technical guidelines for the national adaptation plan process*. UNFCCC Secretariat, Bonn.

Lumbroso, D. (2020). Flood risk management in Africa. *Journal of Flood Risk Management, 13*(2), e12612. https://doi.org/10.1111/jfr3.12612

Macadam, I., Rowell, D. P., & Steptoe, H. (2020). Refining projections of future temperature change in West Africa. *Climate Research, 82*, 1–14. https://doi.org/10.3354/cr01618

MacDonald, A. M., Bonsor, H. C., Ó Dochartaigh, B. É., & Taylor, R. G. (2012). Quantitative maps of groundwater resources in Africa. *Environmental Research Letters, 7*(2), 024009. https://doi.org/10.1088/1748-9326/7/2/024009

Marra, F., Levizzani, V., & Cattani, E. (2022). Changes in extreme daily precipitation over Africa: Insights from a non-asymptotic statistical approach. *Journal of Hydrology X, 16*, 100130. https://doi.org/10.1016/j.hydroa.2022.100130

Mashula, N., Ntombela, N., Kunene, H. P., Sehlapelo, D., & Pophiwa, N. (2021). Exploring the migration effects of cyclones and floods in Southern Africa. In *Sustainable Development Goals Series*. Springer, Cham. https://doi.org/10.1007/978-3-030-74192-1_10

Mehra, D., Rael, T., & Bloem, M. W. (2024). A review of the intersection between climate change, agriculture, health, and nutrition in Africa. *Frontiers in Sustainable Food Systems, 8*, 1389730. https://doi.org/10.3389/fsufs.2024.1389730

Messori, G., Muheki, D., Batibeniz, F., Bevacqua, E., Suarez-Gutierrez, L., & Thiery, W. (2025). Global mapping of concurrent hazards and impacts associated with climate extremes under climate change. *Earth's Future*. https://doi.org/10.1029/2025EF006325

Mohasseb, H. A., Negm, A. M., Yi, S., & Shen, W. (2025). Groundwater storage variations in the MENA transboundary aquifer systems using GRACE: Response to global climate change. In *Groundwater in Developing Countries*. Springer Water. Springer, Cham. https://doi.org/10.1007/978-3-031-79122-2_2

Mohasseb, H. A., Shen, W., Jiao, J., & Hassan, A. A. (2024). Estimation of groundwater storage variations in African river basins: Response to global climate change using GRACE and GRACE-FO among past two decades. *Advances in Space Research, 74*(3), 1164–1182. https://doi.org/10.1016/j.asr.2024.05.003

Muheki, D., Deijns, A. A. J., Bevacqua, E., Messori, G., Zscheischler, J., & Thiery, W. (2024). The perfect storm? Co-occurring climate extremes in East Africa. *Earth System Dynamics, 15*(2), 429–466. https://doi.org/10.5194/esd-15-429-2024

Muller, C. T., Ouedraogo, W. A., Schwarz, M., Barteit, S., & Sauerborn, R. (2023). The effects of climate change-induced flooding on harvest failure in Burkina Faso. *Frontiers in Public Health, 11*, 1166913. https://doi.org/10.3389/fpubh.2023.1166913

Mungai, E. M., Ndiritu, S. W., & da Silva, I. (2021). Unlocking climate finance potential for climate adaptation: Climate smart agricultural financing in sub-Saharan Africa. In W. Leal Filho, N. Oguge, D. Ayal, L. Adeleke, & I. da Silva (Eds.), *African Handbook of Climate Change Adaptation*. Springer, Cham. https://doi.org/10.1007/978-3-030-45106-6_172

Mutanda, G. W., & Nhamo, G. (2024). Impact of climate change on Africa's major lakes: A systematic review. *Frontiers in Water, 6*, 1443989. https://doi.org/10.3389/frwa.2024.1443989

Muthoni, F. (2020). Spatial-temporal trends of rainfall, maximum and minimum temperatures over West Africa. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 13*, 2960–2973. https://doi.org/10.1109/JSTARS.2020.2997075

Nyiwul, L. (2021). Climate change adaptation and inequality in Africa: Case of water, energy and food insecurity. *Journal of Cleaner Production, 278*, 123393. https://doi.org/10.1016/j.jclepro.2020.123393

Ojara, M., Lou, Y., Babaousmail, H., & Wasswa, P. (2021). Trends and zonal variability of extreme rainfall events over East Africa during 1960–2017. *Natural Hazards, 109*(1), 33–61. https://doi.org/10.1007/s11069-021-04824-4

Okesanya, O., Alnaeem, K. F. H., Hassan, H. K., Oso, A. T., Adigun, O. A., Bouaddi, O., Olaleke, N., Kheir, S. G. M., Haruna, U. A., Shomuyiwa, D., Manirambona, E., & Asebot, M. T. (2024). The intersectional impact of climate change and gender inequalities in Africa. *Public Health Challenges*. https://doi.org/10.1002/puh2.169

Overland, I., Sagbakken, H. F., Isataeva, A., Kolodzinskaia, G., Simpson, N., Trisos, C., & Vakulchuk, R. (2022). Funding flows for climate change research on Africa: Where do they come from and where do they go? *Climate and Development, 14*(8), 705–724. https://doi.org/10.1080/17565529.2021.1976609

Owen, G. (2020). What makes climate change adaptation effective? A systematic review of the literature. *Global Environmental Change, 62*, 102071. https://doi.org/10.1016/j.gloenvcha.2020.102071

Pham-Duc, B., Sylvestre, F., Papa, F., Frappart, F., Bouchez, C., & Crétaux, J.-F. (2020). The Lake Chad hydrology under current climate change. *Scientific Reports, 10*, 5498. https://doi.org/10.1038/s41598-020-62417-w

Savvidou, G., Atteridge, A., Omari-Motsumi, K., & Trisos, C. (2021). Quantifying international public finance for climate change adaptation in Africa. *Climate Policy, 21*(8), 1020–1036. https://doi.org/10.1080/14693062.2021.1978053

Scheffran, J., Link, P. M., & Schilling, J. (2019). Climate and conflict in Africa. In *Oxford Research Encyclopedia of Climate Science*. Oxford University Press. https://doi.org/10.1093/acrefore/9780190228620.013.557

Sorgho, R., Quiñonez, C. A. M., Louis, V., Winkler, V., Dambach, P., Sauerborn, R., & Horstick, O. (2020). Climate change policies in 16 West African countries: A systematic review of adaptation with focus on agriculture, food security, and nutrition. *International Journal of Environmental Research and Public Health, 17*(23), 8897. https://doi.org/10.3390/ijerph17238897

Tamasiga, P., Onyeaka, H., Akinsemolu, A., & Bakwena, M. (2023). The inter-relationship between climate change, inequality, poverty and food security in Africa: A bibliometric review. *Sustainability, 15*(7), 5628. https://doi.org/10.3390/su15075628

Tanarhte, M., De Vries, A. J., Zittis, G., Armon, M., Hochman, A., Karpasitis, A., Kaskaoutis, D., & Khodayar, S. (2026). Atmospheric drivers and socioeconomic impacts of precipitation variability in North Africa. *Communications Earth & Environment, 7*, 597. https://doi.org/10.1038/s43247-026-03801-8

Taylor, C. M., Belušić, D., Guichard, F., Parker, D. J., Vischel, T., Bock, O., Harris, P. P., Janicot, S., Klein, C., & Panthou, G. (2017). Frequency of extreme Sahelian storms tripled since 1982 in satellite observations. *Nature, 544*, 475–478. https://doi.org/10.1038/nature22069

Taylor, R. G., Todd, M. C., Kongola, L., Maurice, L., Nahozya, E., Sanga, H., & MacDonald, A. M. (2013). Evidence of the dependence of groundwater resources on extreme rainfall in East Africa. *Nature Climate Change, 3*(4), 374–378. https://doi.org/10.1038/nclimate1731

Thomas, T., Schlosser, C., Strzepek, K., Robertson, R., & Arndt, C. (2022). Using a large climate ensemble to assess the frequency and intensity of future extreme climate events in Southern Africa. *Frontiers in Climate, 4*, 787721. https://doi.org/10.3389/fclim.2022.787721

Trisos, C. H., Adelekan, I. O., Totin, E., et al. (2022). Africa. In H.-O. Pörtner et al. (Eds.), *Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 1285–1455). Cambridge University Press. https://doi.org/10.1017/9781009325844.011

UNEP (United Nations Environment Programme). (2025). *Adaptation Gap Report 2025: Running on Empty*. UNEP, Nairobi. https://wedocs.unep.org/items/b547996e-14ee-4f1c-a6d4-b811dd373ae9 (accessed 29 October 2026)

UNFCCC. (2023). *Decision 2/CMA.5: Global goal on adaptation*. FCCC/PA/CMA/2023/16/Add.1. United Nations Framework Convention on Climate Change, Bonn.

UNFCCC. (2024). *Decision 1/CMA.6: New collective quantified goal on climate finance*. FCCC/PA/CMA/2024/17/Add.1. United Nations Framework Convention on Climate Change, Bonn.

UNFCCC. (2025a). *Global goal on adaptation: Belém adaptation indicators*. https://unfccc.int/topics/adaptation-and-resilience/workstreams/gga (accessed 29 October 2026)

UNFCCC. (2025b). *Report of the Fund for responding to Loss and Damage*. FCCC/CP/2025/10 and FCCC/PA/CMA/2025/14. https://unfccc.int/sites/default/files/resource/cp2025_10_cma2025_14_adv.pdf (accessed 29 October 2026)

Vercillo, S., Huggins, C., & Cochrane, L. (2022). How is gender investigated in African climate change research? A systematic review of the literature. *Ambio, 51*(5), 1045–1062. https://doi.org/10.1007/s13280-021-01631-w

WMO (World Meteorological Organization). (2025). *State of the Climate in Africa 2024*. WMO, Geneva. https://wmo.int/publication-series/state-of-climate-africa-2024 (accessed 29 October 2026)

WMO (World Meteorological Organization). (2026). *State of the Climate in Africa 2025*. WMO, Geneva. https://wmo.int/resources/publication-series/state-of-climate-africa/state-of-climate-africa-2025 (accessed 29 October 2026)

World Weather Attribution. (2024). *Conflict, poverty and water management issues exposing vulnerable communities in Africa to extreme floods that are now common events because of climate change*. https://www.worldweatherattribution.org/conflict-poverty-and-water-management-issues-exposing-vulnerable-communities-in-africa-to-extreme-floods-that-are-now-common-events-because-of-climate-change/ (accessed 29 October 2026)

Yapo, A. L. M., Diawara, A., Yoroba, F., Kouassi, B. K., Sylla, M. B., Kouadio, K., Odoulami, R. C., & Tiémoko, D. T. (2019). Twenty-first century projected changes in extreme temperature over Côte d'Ivoire (West Africa). *International Journal of Geophysics, 2019*, 5610328. https://doi.org/10.1155/2019/5610328

Zscheischler, J., Westra, S., van den Hurk, B. J. J. M., Seneviratne, S. I., Ward, P. J., Pitman, A., AghaKouchak, A., Bresch, D. N., Leonard, M., Wahl, T., & Zhang, X. (2018). Future climate risk from compound events. *Nature Climate Change, 8*(6), 469–477. https://doi.org/10.1038/s41558-018-0156-3

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