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Research Article

Strengthening Africa's systems for climate change resilience: The role of Climate Information Systems (CIS)

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ABSTRACT

This study examines the role of Climate Information Services (CIS) in strengthening Africa's resilience to climate change amid increasing climate variability and extreme events. The objective is to assess the current state, effectiveness, and challenges of CIS across the continent and to identify pathways for enhancing their contribution to climate-resilient development. Methodologically, the study adopts a mixed qualitative approach that combines a critical review of scholarly and policy literature, systematic document analysis, stakeholder consultations, and comparative case studies from East, West, and Southern Africa, complemented by thematic analysis to synthesise key patterns and insights. The results show that CIS adoption has increased across Africa, particularly in agriculture, where access to timely and tailored climate information has contributed to improved decision-making, higher crop yields, and reduced climate-related economic losses. However, the findings also reveal uneven coverage and utilisation of CIS, driven by persistent constraints such as limited observational infrastructure, weak institutional capacity, low literacy levels, digital divides, and pronounced gender disparities that restrict access for women and rural communities. The discussion highlights that innovations such as downscaled climate products, mobile-based dissemination, digital platforms, and public–private partnerships can significantly enhance the relevance and reach of CIS when coupled with strong user engagement and co-production of knowledge. In conclusion, CIS are a critical tool for building climate resilience in Africa, but their transformative potential will only be realised through sustained investment in data systems, inclusive and gender-responsive service design, and stronger integration into national and regional development and adaptation frameworks.

1. INTRODUCTION

Global climatic change, encompassing both observed trends and future projections, represents one of the most profound transformations affecting the Earth system in the twenty-first century [1], [2]. Over the past six decades, climate change has emerged as a defining global challenge, with impacts now evident across all seven continents [1]. Despite more than thirty years of international cooperation under the United Nations Framework Convention on Climate Change (UNFCCC), anthropogenic greenhouse gas emissions continue to rise. Current trajectories suggest a global mean temperature increase of approximately 2.1 °C to 3.9 °C by 2100, even without accounting for worst-case climate responses [2], [3]. These changes pose particularly severe risks for Africa, a region widely recognised as one of the most climate-vulnerable globally [4].

Africa's heightened vulnerability stems largely from its strong dependence on climate-sensitive sectors such as rain-fed agriculture, pastoralism, and natural resource–based livelihoods [1], [5]–[7]. Shifts in rainfall patterns, increasing temperatures, and the growing frequency of extreme weather events threaten food systems, rural livelihoods, and economic stability across the continent [3]. For millions of people, these changes undermine traditional coping mechanisms and

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intensify existing inequalities, placing entire communities at risk of livelihood loss and displacement [3], [4]. In this context, improving the capacity to anticipate and respond to climate risks is no longer optional but essential for sustainable development.

Climate Information Services (CIS) have emerged as a critical mechanism for translating climate data into actionable knowledge that supports climate-resilient decision-making. CIS provide tailored information that enables governments, planners, businesses, and communities to manage climate risks and identify opportunities in a timely and cost-effective manner [4], [5]. Under the Global Framework for Climate Services, climate adaptation programs prioritise strengthening the development and delivery of user-oriented climate information, particularly in countries facing high climate vulnerability [4]. By aligning scientific information with local decision-making contexts, CIS support anticipatory action, reduces losses, and enhances adaptive capacity across multiple sectors.

Despite their recognised importance, the integration of climate information into planning and decision-making remains uneven across Africa [5]. Several countries in East, West, and Southern Africa have initiated climate and weather service programs that emphasise user engagement and cross-sector dialogue. These initiatives have informed analytical frameworks for assessing CIS systems, highlighting key components such as data collection, data processing, service platforms, user engagement, provision pathways, and downstream applications [6]. However, persistent gaps continue to limit effectiveness. These include insufficient and fragmented climate data, limited availability of relevant climate products, weak dissemination pathways, and constrained access for end users, particularly at local levels.

The foundation of CIS in Africa relies on a combination of observational data and climate models generated by diverse formal and informal actors. Many countries continue to face substantial limitations in hydro-meteorological observation networks, resulting in sparse spatial coverage, poor data documentation, and restricted accessibility [6]. Inadequate infrastructure for data storage and archiving, coupled with limited technical capacity, further constrains the reliability and usability of climate information. Nevertheless, targeted initiatives have demonstrated that expanding climate products and strengthening dissemination networks is possible, particularly where National Climate Service Offices provide coordination and oversight [33]. Information is disseminated through a mix of formal channels—including radio, mobile phones, SMS, posters, and internet platforms—and informal networks such as extension services, community associations, and peer-to-peer exchanges [7]–[9].

The relevance of CIS is especially pronounced in climate-sensitive sectors such as agriculture, water resources, and health. In agriculture, climate information supports decisions on planting dates, crop selection, and input allocation, helping farmers manage uncertainty associated with rainfall and temperature variability [3]. When combined with access to credit and advisory services, CIS can enhance productivity and resilience, even under high climatic uncertainty [10]–[13]. Similar benefits are observed in water management and public health, where climate-informed planning strengthens early warning systems and risk preparedness.

Rising frequencies of droughts, floods, and heatwaves across Africa underscore the urgency of strengthening CIS [7], [8]. These extremes exacerbate food insecurity, strain water resources, and disrupt social and economic systems, with cascading effects across health, education, infrastructure, and development [7]. Accurate and timely climate information is therefore essential for early warning, risk reduction, and long-term adaptation planning [9].

However, significant barriers continue to hinder the effective delivery and use of CIS across the continent. Limited accessibility remains an important constraint, particularly in remote and underserved areas where digital infrastructure, observation stations, and skilled personnel are scarce [7], [14]–[18]. Addressing these challenges requires systematic assessment of existing CIS, including their strengths, weaknesses, opportunities, and threats, to inform targeted improvements [7], [10]–[12], [19]–[24].

This study responds to this need by examining the current state of Climate Information Services in Africa to identify pathways to strengthen their effectiveness and reach. By highlighting gaps and opportunities, the study contributes to efforts to build more robust, inclusive, and resilient CIS systems capable of supporting adaptation, reducing vulnerability, and advancing sustainable development across the continent [3], [7], [14]– [16].

2. MATERIALS AND METHODS

In alignment with the study's focus on strengthening Climate Information Services in Africa, this research adopts an inclusive and flexible design that examines the role and impact of CIS using systematic approaches [7], [17]. This approach enables a comprehensive assessment of how CIS functions across diverse socioeconomic, institutional, and geographic contexts on the continent. The study draws on a wide range of data sources. It applies multiple analytical techniques to capture both measurable outcomes and contextual insights, thereby ensuring a nuanced understanding of CIS performance, use, and relevance. Such a design supports robust cross-context comparison and provides an evidence base for identifying gaps, best practices, and opportunities to enhance the effectiveness and reach of Climate Information Services in Africa.

2. 1 Review of Critical Literature

A critical literature review underpins this study by systematically examining existing scholarly and policy-oriented materials to generate in-depth insights into the evolution, performance, and outcomes of Climate Information Services in

Africa [7]. Peer-reviewed journal articles, government policy documents, technical reports, and publications from regional and international organisations are analysed to trace how CIS have been conceptualised, developed, and implemented across different African contexts. This review pays particular attention to documented challenges—such as data gaps, institutional constraints, accessibility, and user uptake—as well as reported successes and best practices in service design, dissemination, and user engagement. By synthesising evidence from multiple sources, the literature review establishes the theoretical and empirical foundation for the study, informs the analytical framework, and identifies persistent gaps and emerging opportunities for strengthening CIS. This critical engagement with existing knowledge ensures that the study is grounded in current evidence while contributing new perspectives on how CIS can more effectively support climate resilience and adaptation across the continent.

2.1.1 Document Analysis

The study undertakes a systematic analysis of policy frameworks, national and regional strategies, and other official documents relevant to Climate Information Services to understand better the institutional and governance landscape shaping CIS development and implementation in Africa [7]. This analysis examines the extent to which CIS are integrated into national development plans, climate adaptation strategies, disaster risk reduction policies, and sectoral frameworks, with particular attention to policy coherence, institutional mandates, and coordination mechanisms. It further assesses the respective roles of governments, regional bodies, and international organisations in financing, regulating, and operationalising CIS, as well as the adequacy of policy support for scaling and sustaining these services [7].

To complement documentary analysis, the study incorporates direct stakeholder consultation through structured surveys and semi-structured interviews. Engagement spans a diverse range of actors, including government officials, policymakers, climate scientists, extension officers, farmers, and representatives from non-governmental and private-sector organisations [7]. These consultations generate in-depth qualitative evidence on how CIS are produced, disseminated, accessed, and used in practice. Stakeholder perspectives reveal lived experiences, institutional constraints, and user expectations that are often not captured in formal reports. By integrating these insights with quantitative findings, the study develops a nuanced and credible understanding of CIS effectiveness, gaps, and opportunities, thereby strengthening the relevance of its conclusions and recommendations for advancing climate resilience across Africa.

2.1.2 Case Studies

The study integrates detailed case studies of Climate Information Services initiatives that have been implemented across diverse African contexts, providing a grounded and practice-oriented perspective on how CIS operate in real-world settings [7]. These cases were purposefully selected to reflect variations in institutional capacity, climatic conditions, sectoral focus, and user communities. By closely examining both successful and less effective initiatives, the study creates opportunities for learning through comparison, enabling the identification of transferable best practices, innovative delivery models, and context-specific adaptations that may inform replication or scaling in other regions [7]. The case studies go beyond surface-level descriptions to interrogate the institutional, technical, social, and policy-related factors that shaped CIS outcomes, including governance arrangements, data availability, user-engagement mechanisms, dissemination pathways, and feedback loops. This in-depth exploration enables a balanced assessment of why specific CIS initiatives succeeded, stagnated, or failed in particular settings.

To systematically interpret the rich qualitative evidence generated from case studies and stakeholder consultations, the study employs thematic analysis as its primary analytical approach. Thematic analysis provides a rigorous and transparent framework for identifying, organizing, and interpreting recurring patterns of meaning across the data [7]. The process involved multiple stages, beginning with data familiarisation, followed by initial coding, theme development, iterative review, and refinement. Through careful and repeated coding, key concepts, relationships, and patterns were identified and grouped into coherent themes [7], [25]. The coding framework was continuously refined to balance analytical depth with clarity and consistency.

This approach enabled the synthesis of complex qualitative information into clear narratives and conceptual insights that illuminate the operational dynamics of Climate Information Services. The resulting themes capture critical success factors, persistent implementation challenges, and broader social and institutional impacts of CIS across sectors and scales. Ultimately, the thematic analysis strengthens the study's analytical rigour and supports evidence-based conclusions and recommendations to enhance the effectiveness, inclusivity, and sustainability of Climate Information Services across Africa [7].

3. RESULTS AND DISCUSSION

A comprehensive and rigorous analysis of Climate Information Services (CIS) implementation across a diverse range of African countries has yielded several significant, insightful, and impactful findings [7]. This research has elucidated valuable perspectives and shed new light on the efficacy and challenges associated with CIS deployment in the region. The study's multifaceted approach, incorporating both quantitative and qualitative methodologies, has facilitated a nuanced understanding of CIS dynamics within varied socio-economic and environmental contexts. The findings from this

investigation offer a substantive contribution to the existing body of knowledge on climate services in Africa and address critical gaps in the literature [7]. These research outcomes provide a robust empirical foundation for understanding the complex interplay between CIS provision, user engagement, and climate-resilient decision-making across diverse African settings. The insights garnered from this analysis not only enhance our theoretical understanding of CIS effectiveness but also have significant implications for policy formulation and the practical implementation of climate services in the region [7].

In 2019, fossil fuels coal, oil, and natural gas accounted for roughly 81% of global primary energy production. These sources emit carbon throughout their lifecycle, from extraction and processing to end-user consumption [19]. The persistent reliance on these carbon-intensive energy sources poses a significant challenge to reducing greenhouse gas emissions, especially as worldwide energy demand continues to rise (Figure 1) [7].

This heavy reliance on fossil fuels is deeply entrenched in global economic systems and infrastructure. Developing nations, in particular, often prioritise affordable energy access over environmental concerns to fuel their growing economies [20]. Meanwhile, many developed countries face the complex task of transitioning their existing energy systems to cleaner alternatives without disrupting economic stability [8].The environmental impact of fossil fuel use extends beyond carbon emissions [21]. Airpollution from coal-fired power plants and vehicleexhaust contributes to respiratory illnesses and premature deaths globally. Additionally, fossil fuel extraction often leads to habitat destruction and water pollution [15].

Despite these challenges, renewable energy technologies are advancing rapidly. The costs of solar and wind power have plummeted in recent years, making them increasingly competitive with fossil fuels [7]. However, issues such as energy storage and grid integration still need to be addressed to enable widespread adoption [22]. Transitioning away from fossil fuels requires a multifaceted approach, including policy interventions, technological innovations, and shifts in consumer behaviour. As the urgency of climate change grows, finding sustainable alternatives to fossil fuels has become one of the most pressing challenges of our time [8].

The global energy infrastructure is the primary source of human-generated carbon dioxide emissions. Consequently, overhauling this system is a crucial strategy for curbing greenhouse gas emissions and tackling climate change [7]. This transformation encompasses shifting to renewable sources, enhancing energy efficiency, and reimagining transport and industrial processes (Figure 2) [8]. While challenging, these changes offer significant potential for emissions reduction.

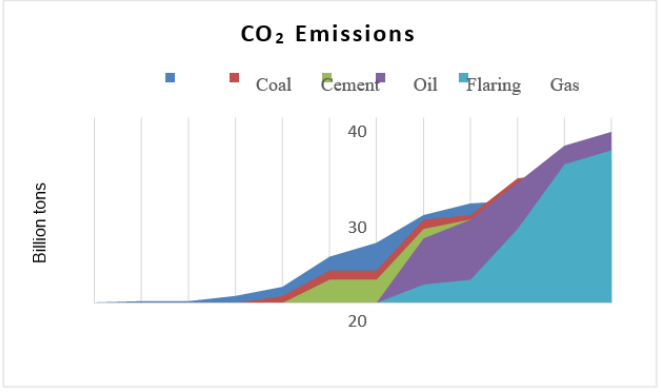

Fig. 1. Carbon dioxide emissions by fuel type, globally

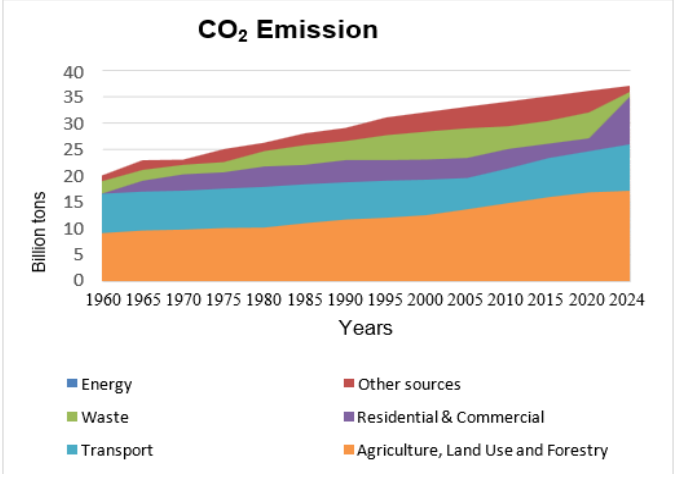

Fig. 2. CO2 emissions by sector measured in tonnes per year

3.1 Adoption of CIS

Adoption of Climate Information Services (CIS) has grown significantly across Africa in recent years [8]. Over the past five years, CIS uptake has risen by 35% across the continent, reflecting growing recognition of its value for agricultural decision-making and climate resilience [8]. East African countries have led this trend, with a remarkable 42% increase in CIS adoption [8]. This region's success can be attributed to improved infrastructure, targeted government policies, and increased awareness campaigns. West Africa follows closely behind, with a 31% increase in CIS uptake, driven by similar initiatives and a growing understanding of the impacts of climate change on agriculture.

This rising adoption rate suggests that farmers and policymakers increasingly view CIS as a crucial tool for adapting to climate variability and enhancing agricultural productivity [16]. However, adoption rates vary significantly between urban and rural areas, with the latter often lagging because of infrastructure and accessibility challenges.

3.2 Agricultural Impacts of CIS

The agricultural impacts of Climate Information Services (CIS) have been substantial and far-reaching. Farmers who have integrated CIS into their decision-making have reported impressive gains in productivity [7]. On average, CIS users have experienced a 28% increase in crop yields compared with their counterparts who do not utilise these services [23].

This improvement is particularly pronounced in staple crops crucial to food security in many African nations. Maize and sorghum have shownthe most significant enhancements, with some regions reporting yield increases of up to 40% forthese crops [7]. These gains can be attributed to more informed choices in planting dates, seed varieties, and resource allocation based onseasonal forecasts and agronomic adviceprovided by CIS [1].

The yield improvements deliver tangible benefits for farmers, including increased food security, higher incomes, and greater resilience to climate variability [7]. Moreover, these outcomes are encouraging more farmers to adopt CIS, creating a virtuous cycle of improved agricultural practices and increased productivity across the continent.

3.3 Economic Benefits of CIS

Economic benefits: The implementation of Climate Information Services (CIS) has delivered significant economic advantages for participating communities [7]. Regions with reliable access to CIS have seen a notable 22% reduction in climate-related economic losses compared with areas without these services [24]. This substantial decrease can be attributed to improved decision-making and risk management informed by accurate climate data and forecasts. The economic benefits extend beyond loss prevention [7]. Farmers using CIS have reported higher profits from optimised resource allocation and improved crop yields. Additionally, local businesses have benefited from more stable agricultural production, leading to enhanced food security and economic stability in rural areas [25].

Moreover, the reduced economic losses have allowed communities to redirect resources towards long-term development goals, such as infrastructure improvements and educational initiatives [7]. This shift from reactive crisis management to proactive planning has thepotential to create a positive feedback loop, further strengthening community resilience to climate-related challenges.

However, it's important to note that the full economic potential of CIS is yet to be realised, as many regions still face barriers to access and implementation [26]. Addressing these challenges could amplify the already substantial economic benefits observed in CIS-enabled communities [7].

3.4 Challenges of CIS

Despite notable advances in the development and dissemination of Climate Information Services (CIS) across Africa, only 45% of rural farmers have reliable access to these essential resources [7]. This limited reach is primarily due to significant challenges, including inadequate infrastructure such as poor telecommunications networks and a lack of electricity, which hinder the distribution and use of CIS [25]. Additionally, low literacy levels among many rural farmers further exacerbate the problem, as they struggle to interpret and apply the information provided [7]. These barriers collectively undermine the potential benefits of CIS, leaving a substantial portion of the rural farming population underserved and vulnerable to climate variability.

3.5 Gender Associated Disparities

Women farmers face a significant disadvantage in accessing Climate Information Services (CIS), with data showing they are 30% less likely to access these critical resources than their male counterparts [7]. This disparity underscores a considerable gender gap in the delivery and use of CIS [26,1]. Contributing factors include limited access to education and technology, societal norms that restrict women's mobility and decision-making power, and economic constraints that disproportionately affect women [7]. As a result, female farmers are less well equipped to make informed decisions about crop management and climate resilience, perpetuating cycles of poverty and food insecurity in rural communities [27].

3.6 Public-Private Partnerships

Collaborations among governments, non-governmental organisations (NGOs), and private-sector entities have immense potential to scale up the delivery of Climate Information Services (CIS) across Africa [7]. These partnerships combine a wide range of resources, expertise, and capabilities, significantly enhancing the reach and effectiveness of CIS [22]. Governments can provide the necessary regulatory framework and institutional support, while NGOs offer grassroots connections and a deep understanding of local community needs [7]. The private sector, in turn, can contribute technological innovations, financial investment, and market-driven approaches that accelerate the development and dissemination of CIS [28]. By pooling these strengths, public-private partnerships can address infrastructural, educational, and economic barriers that limit CIS access, particularly in remote and underserved areas. These collaborations can also foster innovation in service delivery, ensuring that CIS is tailored to the specific needs of different user groups, including women and marginalised communities [7]. Ultimately, such partnerships are crucial for building resilient agricultural systems, enhancing food security, and empowering farmers to adapt to the challenges of climate change [7].

3.7 Case Studies of CIS

A study in Ghana assessed priorities for Climate Smart Agriculture (CSA) and Climate Information Services (CIS). It found that region-specific practices, such as stress-tolerant seed varieties and integrated crop-livestock systems, were essential for enhancing agricultural resilience [7]. CIS was identified as a crucial component across all regions, facilitating informed decision-making. The authors recommend focusing on tailored CSA interventions and strengthening CIS delivery to support farmers' adaptation to climate change, emphasising the need for capacity building and improved access to climate information [7].

Asrat and Belay [7] conducted a study examining farmers' perceptions of and adaptations to climate change in the Dabus watershed of Northwest Ethiopia. The research compared two agroecological zones, wet lowland and dry lowland areas [7]. The study found that 52% of farmers in wet lowlands and 62% in dry lowlands perceived climate change, noting rising temperatures and declining precipitation. Regarding adaptation, 62% of farmers in wet lowlands and 48% in dry lowlands had implemented measures such as soil and water conservation and agronomic practices, including crop rotation and adjusting planting dates. Several factors influenced perception and adaptation, including education level, farming experience, income sources, and access to climate information and extension services [7]. Interestingly, the study revealed regional differences in how certain factors affected adaptation. For instance, livestock income positively affected adaptation in wet lowlands but negatively in dry lowlands. Similarly, non-farm income had positive effects in wet lowlands but negative in dry lowlands. The authors concluded that farmers' perception and adaptation were influenced by location-specific socioeconomic, environmental and institutional factors. They recommended tailored policy interventions to enhance climate change adaptation, taking into account the differences between agroecological zones. This research highlights the importance of considering local contexts when developing strategies to help farmers adapt to climate change [7].

A study investigated the determinants of access to and utilisation of seasonal climate information services (CIS) among smallholder farmers in Makueni County, Kenya. The research found that although 94% of sampled households had access to seasonal climate forecasts, only 40% used this information in farm management decisions. The main barriers to utilisation were a lack of trust and perceived unreliability of the information [7]. Factors positively associated with access to CIS included household size, farm size, television ownership, income, farming as the main livelihood, and group membership, whereas the age of the household head was negatively correlated. For CIS utilisation, household income, access to improved seeds, farming as the main livelihood, and radio ownership were positively correlated, whereas age, male-headed households, and frequent exposure to drought were negatively associated [7]. Radio and television were the most common CIS sources. Based on these findings, Muema et al. [15] recommended improving the accuracy and reliability of CIS, increasing access to low-cost improved seeds, targeting younger farmers and women in CIS dissemination, promoting education and participation in farmer groups, and ensuring timely dissemination via radio and television. This research highlights the complex interplay of factors that influence both access to and use of climate information services, and the need for trustworthy, accurate information delivered through appropriate channels, together with complementary resources to support adaptation to climate change in agriculture [26]–[31].

3.8 Case Studies and Lessons Learned

The study draws on experiences and insights from six examples of Climate Information Services (CIS) implemented in Africa, highlighting key elements to consider for effective development and scaling of CIS. The implementation of CIS through digital data platforms and other solutions suitable for diverse regions is accelerating across Africa. This section examines the emergence of regional climate services institutions to promote CIS in partnership with stakeholders, including government institutions and the private sector. Service providers, receiving funding from various regions and international agencies, are increasingly sharing knowledge to assist CIS implementation. The Northeast, Southwest, and Southeastern regions of the continent are outlined, with representative case studies summarising efforts and lessons learned in each area. Regional priorities, including Agriculture, Water, Health, and Disaster Risk, are strongly aligned with four of the five broad

themes in the FCRA, thereby substantially contributing to climate resilience capacity[29], [32]–[38].

3.8.1 East Africa

Climate information services in East Africa include government agencies, organisations, and NGOs that provide seasonal forecasts through various channels, helping smallholder farmers manage their vulnerability [34]. The ENACTS initiative enhances reliability by combining station and satellite data; it currently operates in eight countries and is guided by stakeholder interest and funding [33].

3.8.2 West Africa

West African countries have responded to the challenge of improving climate resilience and food security by establishing the Regional Centre for Agronomic Research and High Education from West and Central Africa (CERAAS) in Senegal. The CERAAS Climate Information Product Unit disseminates climate information on agricultural best practices after conducting a rigorous analysis of climate predictions [36]. In Senegal, the primary crops are millet, maize, sorghum, groundnut, and rice. Based on rigorous analysis of climate predictions and with the necessary information and tools for local context adaptation, CERAAS emissaries disseminate climate information in the form of agro-meteorological bulletins, agricultural calendars with recommendations for crop management and agricultural policies, and daily messages adapted to the regions and socio-professional categories. The gradual emergence of a climate information system involving institutional stakeholders has been critical for the agricultural sector in Senegal [39]– [44].

3.8.3 Southern Africa

Southern Africa faces ever-increasing climate risks and extreme weather events, resulting in severe socioeconomic impacts on people, agriculture, water management, infrastructure, health, and ecosystems. Mainstreaming climate services in development and governance frameworks can enhance adaptive capacity, reduce vulnerability, and promote resilience in the region. National development planning by the Southern African Development Community now emphasises the importance of operational climate information services (CIS) and integration into key sectors of climate-sensitive economies [42].

Substantial progress has been made in recent years to enhance climate infrastructure and operational capacity across Southern African Development Community member countries [33]. A regional initiative led by the Southern African Regional Climate Outlook Forum engages national meteorological services to produce reliable seasonal climate forecasts that support agriculture, water resource management, health, and disaster risk reduction. National Meteorological and Hydrological Services, research institutions, universities, and user stakeholders also engage in dialogue to understand the requirements for national climate observation and information products, thereby encouraging the co-production of tailored information services [43]. The development of climate services and products is supported by a Climate Services User Interface Platform that fosters open, collaborative communication on climate variability, change, and risk.

3.9 Innovations in CIS Implementation

Scaling up Climate Information Services relies on innovation across the entire value chain, from data generation to the delivery of tailor-made products and services to stakeholders. Regional climate data sets with high temporal and spatial resolution can be downscaled using sophisticated numerical weather prediction models that effectively simulate day-to-day weather. Simplified versions of these models have been developed in East and Southern Africa, enabling the production of localized information for smallholder farmers. Processing units for downscaled products currently operate in Ethiopia, Kenya, and Tanzania [33].

Multipurpose digital platforms that integrate climate data and provide a wide range of services have been developed in several countries across East, West, and Southern Africa. Users access climate and weather forecasts, early warning alerts for extreme weather events, advisories on weather, markets, and pest control, and information on agricultural practices in response to climate. Mobile dissemination of climate information through short message service (SMS) and interactive voice response (IVR) remains the most utilised method, especially among rural communities with low levels of formal education. Efforts to improve user interfaces are ongoing, with stakeholders in both urban and rural settings convening to discuss user needs and identify the best ways to gather feedback on climate information products through focus group discussions, questionnaires, and surveys or polls [36].

The design and delivery of climate services benefit from coproduction of knowledge, with efforts to jointly frame problems, identify solutions, and iteratively refine responses. In Western and Southern Africa, farmers, pastoralists, fishers, scientists, extension agents, NGOs, private-sector companies, and regional organisations develop a shared understanding of climate risks through community discussions in workshops. Dissemination of climate forecasts, advisories, and information on climate-resilient varieties and practices—all developed through these participatory processes—contributes to adaptation [44].

3.9.1 Downscaling and climate services for local decision-making

The Global Framework for Climate Services (GFCS) emphasizes the local use of climate information and the co-

development of services between producers and users [1]. To enhance climate resilience in Africa, there is a need for a bottom-up approach that recognises local contexts, incorporates feedback, and integrates local knowledge with international science[52]. Current climate services, such as ENACTS and the Climate Risk and Early Warning Systems initiative, offer examples of how to integrate high-quality downscaled climate information to improve decision-making across sectors [39].

3.9.2 Digital platforms, mobile dissemination, and user interfaces

Public-private partnerships are increasingly recognised, notably in climate information services (CIS). National meteorological and hydrological services (NMHSs) execute these services as public goods, collaborating with private firms to attract increased investment and involvement. Greater private participation has become necessary for expanding service provision. A 2017 workshop organised by the African Union Commission noted the challenge of formal partnerships in climate services due to their novelty in the field [33]. Nevertheless, interest in the provision and dissemination of CIS via more interactive platforms and mobile-enabled interfaces continues to grow. Actions could focus on engaging with a broader user community—from initial socioeconomic characterisation to clarifying daily information needs [34]. Movement in recent years toward open-data initiatives within public bureaucracies in Africa (such as Kenya) further corroborates the general observation of burgeoning open-data opportunities[25].

3.9.3 Coproduction of knowledge and co-design

Sustaining climate-resilient development in African countries remains a major challenge, given the growing vulnerability of multiple socioeconomic sectors to climate variability and change. User engagement, knowledge co-creation, and a sharper focus on meeting climate information needs and addressing barriers to uptake can pivot climate information services towards a key driver of climate resilience [39]. Providing climate information that meets the needs of local decision-makers has proven fundamental to uptake of climate information products and to the potential for climate-informed decision-making across multiple socioeconomic sectors in East Africa, West Africa, and Southern Africa. A broader focus on vulnerability assessments and adaptation efforts beyond the agricultural sector would strengthen resilience-building and capitalise on the potential of climate information services to empower decision-making [33]. Addressing the climate information supply and demand gap also entails a more inclusive approach to defining user needs and climate information services in terms and concepts relevant to specific socioeconomic sectors beyond agriculture[27], [30], [54]–[58].

3.10 Overall Assessment of CIS in Africa

Climate Information Systems show high potential but uneven adoption across Africa. While awareness and pilot initiatives are expanding, systemic barriers particularly data gaps, infrastructure deficits, and limited user-centered design continue to constrain widespread, sustained use. Strengthening institutional capacity, inclusivity, and policy integration is essential to move CIS adoption from fragmented to transformational.

TABLE I. TABLE SUMMARIZING THE PROS, CONS, AND RATE OF ADOPTION OF CLIMATE INFORMATION SYSTEMS (CIS) IN AFRICA, ALIGNED WITH CLIMATE RESILIENCE LITERATURE AND THE FOCUS OF THE STUDY

Aspect	**Pros / Strengths of CIS**	**Cons / Limitations of CIS**	**Rate of Adoption in Africa**
Climate Risk Reduction	Improves early warning for droughts, floods, and heatwaves; supports anticipatory action and disaster preparedness	Limited spatial coverage and accuracy in data-poor regions reduces reliability	Moderate – Strong in pilot areas, uneven at national scale
Agricultural Resilience	Enhances farm decision-making (planting dates, crop choice, input use); supports food security	Low uptake among smallholders due to literacy, trust, and access barriers	Moderate to Low – Higher where extension services are strong
Policy & Planning	Informs National Adaptation Plans, NDCs, and disaster risk reduction strategies	Weak integration into sectoral planning and budgeting processes	Moderate – Increasing recognition but inconsistent application
Economic Efficiency	Reduces climate-related losses; supports cost-effective adaptation investments	Benefits often not quantified, limiting political and financial commitment	Low to Moderate
Data & Science Use	Promotes evidence-based decision-making and climate-smart development	Sparse observation networks; poor data governance and sharing	Low – Major constraint across most countries
User Engagement	Participatory CIS improves relevance, trust, and usability	Limited feedback mechanisms; top-down dissemination dominates	Low to Moderate
Equity & Inclusion	Potential to empower vulnerable groups, including women and rural communities	Gender gaps and digital divides restrict equitable access	Low
Institutional Capacity	Strengthens national meteorological and climate institutions	Chronic underfunding, skills gaps, and staff shortages	Moderate – Highly variable by country

Technology & Innovation	Mobile phones, radio, and digital platforms expand reach	Poor connectivity and electricity access in remote areas	Moderate
Sustainability & Scaling	Public–private partnerships enable innovation and scalability	Heavy donor dependence threatens long-term sustainability	Low to

4. CONCLUSION

Climate change remains the defining human development challenge of the twenty-first century, and Climate Information Services (cis) are central to strengthening climate resilience and adaptation in developing countries. Climate impacts are already intensifying existing vulnerabilities and inequalities, particularly in Africa. By providing timely, relevant, and actionable climate information across diverse socioeconomic contexts, CIS enable governments, businesses, and communities to reduce risks, minimise losses, and capitalise on climate-sensitive opportunities. In doing so, CIS align with global climate-resilience agendas and adaptation commitments. The Climate Service Centre Germany framework outlines a structured pathway for effective CIS development, emphasising user-centred design, appropriate modelling, tailored information products, effective dissemination, user engagement, and long-term sustainability. Despite this framework, significant gaps persist in the development, coverage, and effective use of CIS across Africa. Where services exist, their reach is often limited and utilisation remains suboptimal, constraining both individual and collective adaptation. Strengthening CIS therefore requires alignment with national and regional policy instruments, including development plans, adaptation strategies, and disaster risk reduction frameworks. Public–private partnerships and inclusive stakeholder engagement are critical for co-designing services that respond to user needs and scale delivery. However, persistent weaknesses in climate data availability, governance, and scientific investment continue to limit CIS effectiveness. Addressing these systemic challenges is essential for translating climate information into meaningful resilience outcomes, particularly in least developed countries and climate-sensitive sectors such as agriculture.

5. RECOMMENDATIONS

It is recommended that Climate Information Services be strengthened and scaled up as a priority intervention to enhance Africa's resilience to climate change, particularly within the agricultural sector that sustains most rural livelihoods. As climate variability and extreme events intensify, timely, reliable, and locally relevant climate information is essential for informed decision-making by farmers, policymakers, and communities. To achieve this, targeted investments in rural infrastructure are urgently needed, including improved telecommunications, internet connectivity, and reliable energy supply, to ensure equitable access to climate information. At the same time, education and capacity-building programs should be expanded to improve climate literacy and technical skills among farmers, with special attention to smallholders and marginalised groups. Addressing gender disparities must be central to CIS implementation by adopting gender-sensitive communication approaches, improving women's access to information technologies, and actively involving women in the design and dissemination of services. Public–private partnerships should be promoted to mobilise resources, foster innovation, and expand the reach of user-friendly climate information platforms suited to low-literacy contexts. Through coordinated action that integrates infrastructure development, inclusive education, gender-responsive policies, and cross-sector collaboration, Climate Information Services can become a transformative tool that supports climate adaptation, strengthens food security, and advances sustainable development across the continent.

6. DISCLAIMER (ARTIFICIAL INTELLIGENCE)

The author (s) hereby declare that NO generative AI technologies such as Large Language Models(ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

7. Competing interests

Authors have declared that no competing interests exist.

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The authors declare no competing interests.

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