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Effectiveness of climate information services in Sub-Saharan Africa's agricultural sector: a systematic review of what works, what doesn't work, and why

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Introduction: This study examines effectiveness of Climate Information Services (CIS) in improving agricultural resilience in Sub-Saharan Africa (SSA), where their potential remains underutilized despite their significance in climate change adaptation.

Methods: Employing PRISMA methodology, we systematically reviewed 53 peer-reviewed articles published between 2010-2023, using inferential statistical analysis to assess factors influencing CIS adoption and effectiveness.

Results: The results reveal that "*What Works*" are participatory models like Participatory Integrated Climate Services for Agriculture (PICSA), which significantly enhance adoption rates, because they involve local communities in climate service design. "*What Does not Work*" are top-down models that do not consider local contexts, leading to low adoption. Barriers to CIS success include poor digital infrastructure, low literacy rates, and gender biases, hindering effective use.

Discussion: "*Why*" these approaches fail is due to disconnect between services offered and actual needs of farmers, with a lack of trust in externally provided information. In conclusion, CIS can significantly contribute to agricultural resilience if designed to be inclusive, context-specific, and participatory. The study recommends scaling up participatory models, enhancing digital infrastructure, and integrating CIS into national agricultural policies to improve accessibility, usability, and farmer engagement, thereby strengthening climate adaptation and resilience in SSA.

KEYWORDS

Climate Information Services (CIS), Sub-Saharan Africa agriculture, climate adaptation strategies, smallholder farmers and CIS adoption, CIS adoption success and failure

1 Introduction

Climate change is among the most pressing global challenges, characterized by increasing variability in rainfall, temperature shifts, and more frequent extreme weather events such as floods and droughts (Forsgren et al., 2019; Intergovernmental Panel on Climate Change, 2020; Serdeczny et al., 2021). These impacts are particularly severe in Sub-Saharan Africa (SSA), a region heavily dependent on climate-sensitive sectors like agriculture (Trisos et al., 2022; Abdallah et al., 2021; Mkonda and He, 2017). The Intergovernmental Panel on Climate Change (Intergovernmental Panel on Climate Change, 2020) projects that SSA will face intensified climate pressures by 2050, including higher temperatures, unpredictable precipitation patterns, increase frequency and intensity of extreme events. Such changes threaten the region's

agricultural sector, which relies on stable rainfall and favorable temperature ranges for productivity.

As the primary source of livelihood for much of SSA's population, agriculture is directly exposed to climate variability, leaving millions vulnerable to food insecurityand economic instability (Alamu, 2024; Ofori et al., 2021). To address these challenges, Climate Information Services (CIS) have emerged as a crucial tool to support proactive decision-making in agriculture (Barrett and Headey, 2014; Clarkson et al., 2021; Hansen et al., 2020; Debebe, 2022). CIS provides essential insights into climate trends, enabling farmers to make informed decisions on crop selection, planting schedules, and farming techniques. These capabilities are critical for stabilizing or improving agricultural yields under adverse climatic conditions (Ngigi and Muange, 2022). The strategic application of CIS aligns with Sustainable Development Goals (SDGs), particularly those focused on poverty reduction (SDG 1), food security (SDG 2), and climate action (SDG 13), reinforcing its importance as a tool for sustainable development (FAO, 2016).

Over the years, significant efforts have been made to promote CIS in SSA through initiatives led by various stakeholders, including governments and international organizations. Examples include the African Center of Meteorological Applications for Development (established in 1995), the Climate Services Partnership (2011), the Global Framework for Climate Services Adaptation in Africa (2012), and the Climate Services for Resilient Development Partnership (2017). These initiatives aim to develop and disseminate user-tailored climate information to support local adaptation strategies and enhance resilience (Kijazi et al., 2019; WMO, 2015; Nkiaka et al., 2020; Dinku et al., 2022). Despite these advancements, however, the adoption and effectiveness of CIS remain inconsistent across the region. Comprehensive studies analyzing the integration of CIS into agricultural practices are still limited.

Existing research highlights the potential of CIS to mitigate climate-related agricultural risks (Buontempo and Hewitt, 2018; Kumar et al., 2020) and highlight the importance of understanding users' specific needs (Dayamba et al., 2018; Guido et al., 2020; Ofoegbu and New, 2022). However, findings vary significantly, with studies offering differing perspectives on the effectiveness and accessibility of CIS in diverse contexts (Mungai et al., 2018; Shikuku et al., 2017; Giuliani et al., 2017; Antwi-Agyei et al., 2021; Singh et al., 2021). These disparities point to challenges in CIS design, delivery, and uptake, emphasizing the need for tailored, context-specific solutions to enhance its utility for SSA farmers.

This study seeks to critically examine existing literature on the use of CIS among SSA farmers, aiming to understand how these services are integrated into agricultural decision-making. Specifically, it investigates success stories, identifies barriers, and explores underlying factors that facilitate or hinder CIS adoption. To achieve these objectives, the study addresses three core research questions: (1) What are the main components of CIS disseminated in SSA, and how are they incorporated into farmers' decision-making processes? (2) What examples demonstrate successful CIS implementation in SSA? (3) What challenges impede CIS adoption, and what factors contribute to these barriers? By addressing these questions, this systematic review aims to provide actionable insights into effective CIS strategies while identifying areas for improvement in meeting the unique needs of SSA farmers in the face of climate change.

2 Methodology

This study employed a systematic approach to review literature focusing on Climate Information Services (CIS) in Sub-Saharan Africa's (SSA) agricultural sector. A three-step methodology was utilized to ensure comprehensive data collection, assessment, and analysis: *search strategy, screening process,* and *data extraction and analysis.*

2.1 Search strategy

An exhaustive literature search was conducted using multiple databases, including *Emerald Insight, Dimensions, JSTOR*, and *EBSCO*, to minimize the risk of omitting relevant studies. This multi-database approach adheres to best practices for systematic reviews, ensuring comprehensive coverage of the topic. Boolean operators "OR" and "AND" were employed to combine keywords, synonyms, related terms, and their variations. The search keywords included:

- "Climate information services."
- "Agriculture in SSA countries,"
- "Climate information for agriculture in SSA countries,"
- "Climate forecast for agriculture in SSA countries,"
- "Weather information for agriculture in SSA countries,"
- "Weather services for agriculture in SSA countries," and
- "Weather forecast for agriculture in SSA countries."

The search focused on publications from *2010 to 2023*, a period that saw significant advancements in CIS initiatives, such as the establishment of the *Climate Services Partnership (CSP)* in 2011, the *Global Framework for Climate Services (GFCS)* adaptation focus for Africa in 2012, and the launch of the *Climate Services for Resilient Development (CSRD) Partnership* in 2017 (Kijazi et al., 2019; Wilke and Wright, 2015; WMO, 2015).

Database search results ranged from *68,200 to 2,740,000 articles* on Dimensions, *531 to 6,437 articles* on Emerald Insight, *56 to 254,722 items* on JSTOR, and *12,980 articles* on EBSCO. Relevant articles cited within the identified publications were also reviewed for inclusion.

2.2 Screening process

This systematic review began with 5,714 records identified databases selected. The screening process involved removing duplicate articles and evaluating the relevance of search results based on their titles and abstracts. The process excluded 5,050 records for not focusing study criteria. The following inclusion criteria were applied:

i. Studies focused on *smallholder farmers* in SSA countries.

ii. Highlighted CIS interventions based on *daily or seasonal weather forecasts*.
iii. Reported data and analysis at the *farmer, farm, or household level*.

Studies which are non-SSA focus, non-farmers-level data, not in 2010–2023, duplicates, lack climate information services relevance, not accessible and non-peer reviewed regarded not meeting these criteria and were excluded. Of the 664 full-text article retrieved, 263 were excluded due to publication range (n = 241) or inaccessible (n = 22). Eligibility assessment of 401 articles led to the exclusion of 348 studies, primarily for lacking focus on small-holder farmers, CIS internensions of farm-level data. Ultimately, 53 studies were included. This process refined the selection to *53 articles,* representing *14%* of the initially screened papers. These articles were included in the systematic review, following the *Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA)* guidelines (Figure 1).

2.3 Geographica scope and Exlusion

The systematic review iclused 53 peer reviewed studies from six Sub-Saharan African countries (Ghana, Kenya, Senegal, Tanzania, South Afica and Burkina Faso) identified through searches in Emerlad Insight, Dimenssions, JSTOR and EBSCO that met inclusion criteria. These criteria were focusing on small-holder farmers, daily or seasonal Climate Information Services (CIS) intervations, and farmer-level data, published between 2010 and 2023. Other Sub-Saharan African countries were exluded because were not identified in these databases that fully satisfies these criterias, often due to focus on broader climate

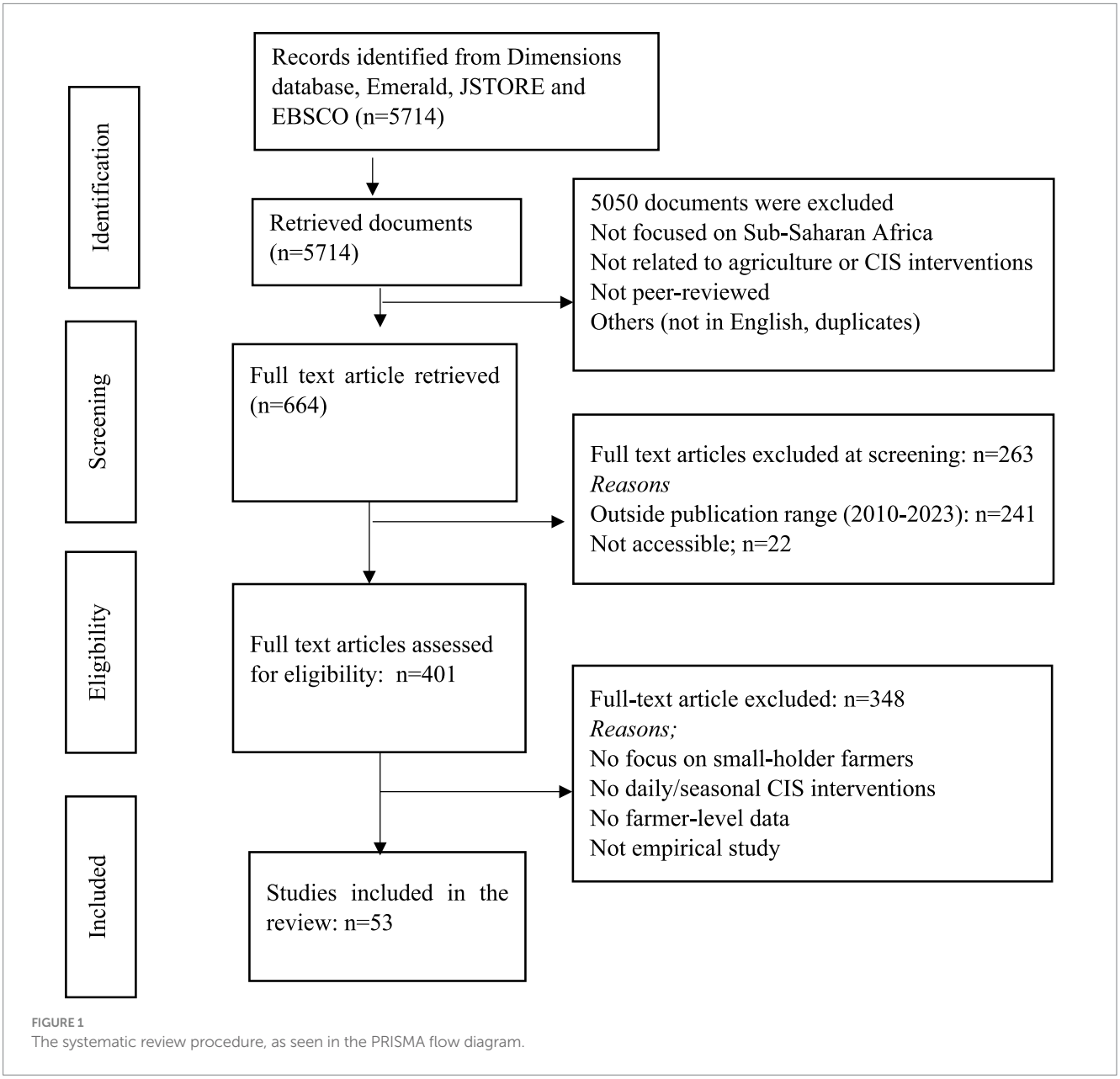

FIGURE 1
The systematic review procedure, as seen in the PRISMA flow diagram.

adaptation strategies rather than specific CIS intervetions or lack on farmer-level outcomes (specifically small-holders). These absence may reflect a gap in accessible peer-reviewed CIS literature for majority agricultural significant countries within the scope of our search, highlighting an area of future research.

2.4 Data extraction and analysis

To ensure consistency and comparability across studies, a *standardized extraction form* was developed. This form was designed to capture key data elements across four critical categories:

2.4.1 Study characteristics

This category included details such as the author(s), year of publication, and the geographical location of each study. These details not only provided essential context but also helped establish the authenticity of the research, ensuring that the studies were grounded in relevant regional and temporal frameworks.

2.4.2 Population

Focused on smallholder farmers, who are the primary recipients of Climate Information Services (CIS) in the context of Sub-Saharan Africa's agricultural sector. Understanding the demographic and socioeconomic profile of the population enabled a more targeted analysis of how CIS interventions impact farming communities at the household level.

2.4.3 Interventions

The form recorded the specific types of CIS provided, including but not limited to *daily weather forecasts, seasonal climate predictions*, and *early warning systems*. As such, by cataloguing the diversity of interventions, we were able to assess the range and nature of climate services delivered to smallholder farmers, highlighting the most common and innovative approaches used in the region.

2.4.4 Outcomes

This category detailed the observed effects of CIS on agricultural practices and productivity. It covered changes in *farming techniques, crop yield improvements,* and other adaptive measures implemented by farmers as a result of receiving climate information. This provided insights into the tangible impacts of CIS on farming productivity and the effectiveness of these services in driving agricultural adaptation to climate variability.

The *data extraction process* was rigorously executed, involving cross-verification by multiple reviewers to ensure accuracy and consistency. Any inconsistencies identified during the extraction phase were promptly addressed through discussions among the reviewers, leading to a consensus-driven approach to resolve discrepancies. This collaborative process ensured the integrity of the extracted data.

The data analysis integrated *both qualitative and quantitative methods,* allowing for a comprehensive understanding of the effectiveness of CIS in Sub-Saharan Africa's agricultural sector. The analysis was structured as follows:

2.4.5 Qualitative synthesis

This component focused on identifying and synthesizing recurring themes across the studies. We explored *implementation challenges, operational issues,* and the *contextual factors* that influenced the success or failure of CIS interventions. The qualitative synthesis provided valuable insights into the practical aspects of deploying CIS in smallholder farming communities, including barriers to adoption, stakeholder engagement, and institutional support.

2.4.6 Quantitative analysis

In parallel, a quantitative analysis was conducted to assess the documented effects of CIS on agricultural outcomes. Where applicable, *meta-analytic techniques* were employed to aggregate and summarize results across studies. These techniques enabled the identification of patterns and the quantification of the impact of CIS on farm productivity, providing a statistical overview of their effectiveness in improving agricultural resilience to climate change.

To ensure the credibility and reliability of the findings, the study adhered to a *comprehensive and systematic methodology*. The use of a standardized extraction form and a *cross-verification process* by multiple reviewers served as critical safeguards for data accuracy and consistency. Additionally, the combination of *qualitative and quantitative approaches* facilitated a multi-dimensional analysis of CIS interventions, providing a deeper and more nuanced understanding of their effectiveness.

Therefore, by synthesizing both qualitative insights into the operational challenges and quantitative data on outcomes, this review not only assesses the success of CIS in addressing climate-related challenges but also sheds light on the factors that influence their effectiveness in Sub-Saharan Africa's agricultural sector. Ultimately, this approach contributes to a more holistic understanding of how CIS can be optimized to support climate adaptation and improve food security for smallholder farmers in the region.

3 Results

A total of *664 publications* (Table 1) were initially identified through a systematic search using predefined keywords, document types (research articles and technical reports), language (English), and a period from *2010 to 2023*. These publications were distributed across the following countries: South Africa (66), Senegal (93), Tanzania (65), Kenya (172), Burkina Faso (92), and Ghana (176).

In the screening phase, each publication was evaluated based on the title, abstract, and keywords, leading to the exclusion of *263 articles* due to duplication or failure to meet the inclusion criteria. After a comprehensive review of the full texts of the remaining *163 articles*, an additional *110 publications* were excluded, leaving *53 publications* that met the final criteria for inclusion. The research predominantly focused on *Climate Information Services (CIS)* and their relationship with agriculture.

The final distribution of the 53 research publications across the countries is as follows: South Africa (9), Tanzania (8), Senegal (8), Kenya (11), Ghana (12), and Burkina Faso (5).

The results of the *ANOVA test* (Table 1) indicated significant variability in the number of publications by country (F (5, 47) = 8.62, $p < 0.001$). This suggests that the number of studies published in each country differs significantly. *Kenya* and *Ghana* had notably higher

TABLE 1 Summary of frequency of publications by country across Sub-Saharan Africa.

Country	Initial publications	Final publications	Percentage of total (%)	Mean (publications)	Standard deviation	ANOVA *F*-statistic	*p*-value
South Africa	66	9	17.0	9	3.5	8.62	0.0001
Tanzania	65	8	15.1	8	3.2		
Senegal	93	8	15.1	8	2.8		
Kenya	172	11	20.8	11	4.1		
Ghana	176	12	22.6	12	4.4		
Burkina Faso	92	5	9.4	5	2.9		

The ANOVA test conducted to compare the means across countries revealed a significant difference (F (5, 47) = 8.62, p = 0.0001). This indicates that the number of publications from different countries is significantly different, with Kenya and Ghana contributing more publications compared to countries like South Africa and Burkina Faso.

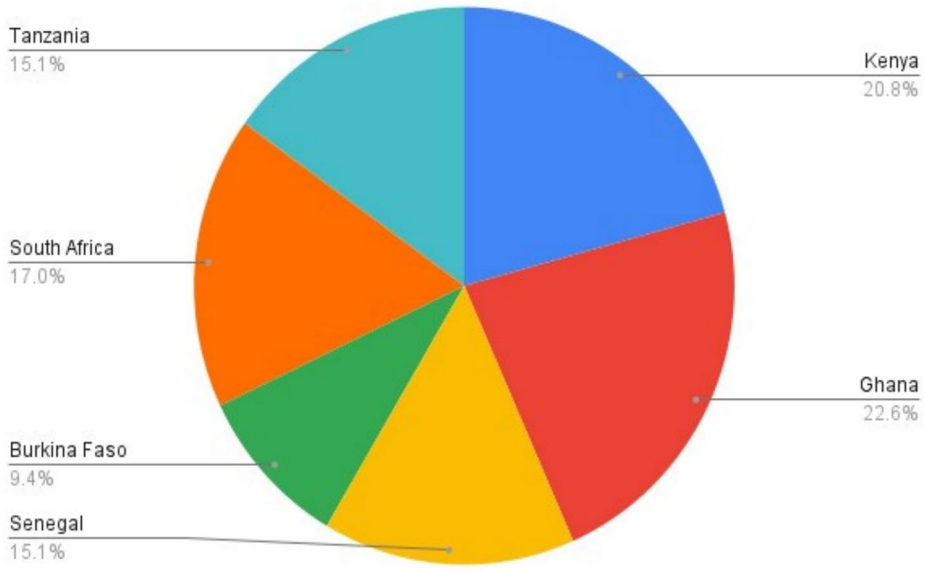

FIGURE 2
Displays a pie chart illustrating the number of studies included for each Country.

publication frequencies, while *Burkina Faso* and *South Africa* exhibited lower numbers.

Furthermore, the *Bonferroni post-hoc analysis* revealed that Kenya and Ghana had significantly more publications than Burkina Faso ($p < 0.05$) and South Africa ($p < 0.05$), pointing to a possible regional trend where East and West African countries may be prioritizing research on climate information services.

Figure 2 presents a pie chart that provides a clear visual representation of the number of studies included for each country, highlighting the proportion of studies contributed by each nation.

The geographical distribution of the publications was also visually represented in Figure 3, which shows the frequency of publications by country across Sub-Saharan Africa. The intensity of the *green color* in the map reflects the relative frequency of publications, with *Kenya* and *Ghana* exhibiting the darkest shades, indicating a higher volume of research on CIS and agriculture.

Similarly, An analysis was conducted to explore the most influential studies on climate information services (CIS) in the agricultural sectors of selected Sub-Saharan African (SSA) countries. The findings revealed the top ten most cited articles, providing a detailed overview of the current state and challenges of CIS in SSA. These studies highlighted several key themes: the need for more comprehensive, long-term CIS, the importance of addressing gender and geographic disparities, the benefits of utilizing diverse dissemination methods, and the crucial role of socio-economic, cultural, and institutional factors. Table 2 below summarizes these top-cited studies.

The data reveals a dominant focus on short-term and situation-specific CIS in SSA countries, while medium- to long-term CIS is notably underrepresented. This gap in the availability of long-term forecasts presents a challenge to effective planning and decision-making. The findings suggest that, although short-term forecasts are beneficial, the absence of comprehensive medium- and long-term data hampers local stakeholders' capacity for informed agricultural planning and resource management. Studies emphasize the need to broaden the scope of CIS to include long-term forecasts, which could improve the sustainability of agricultural practices in the face of climate variability.

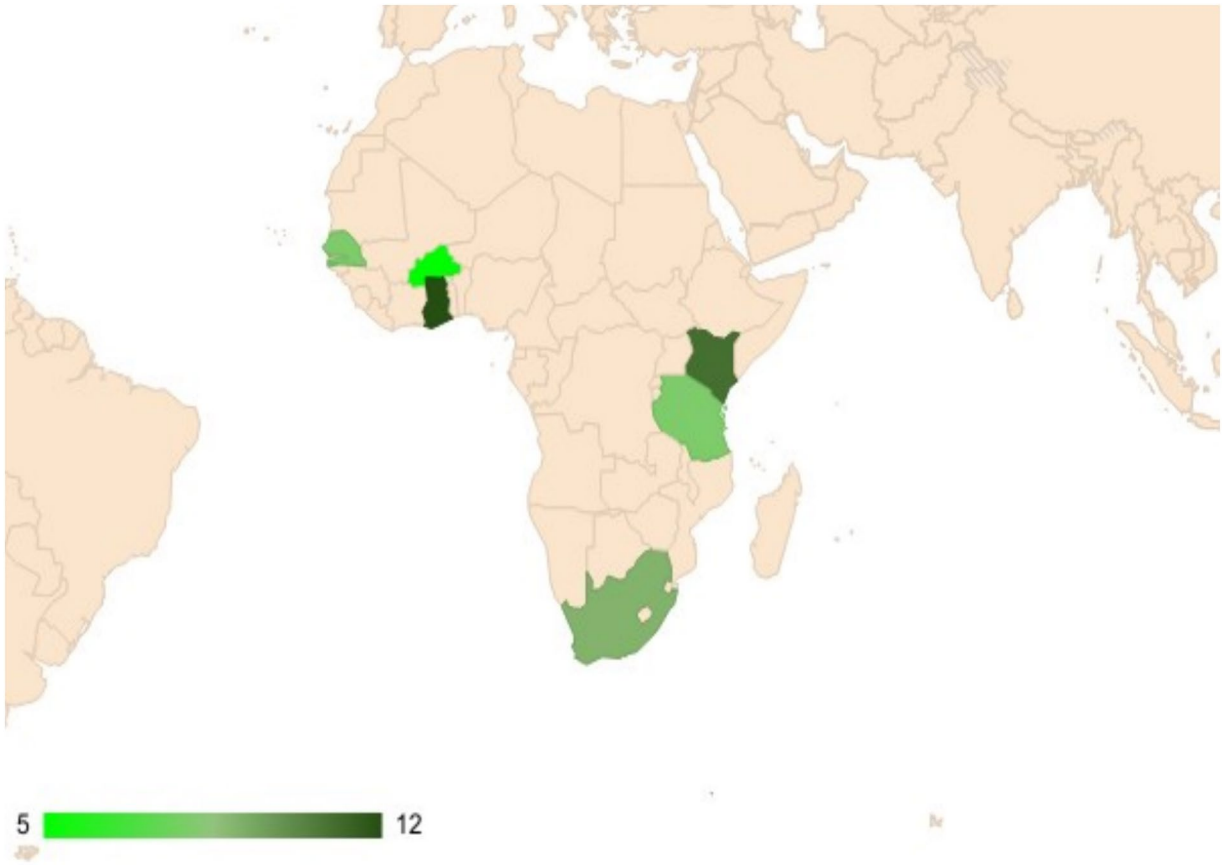

FIGURE 3
Frequency of publications per Country under review.

TABLE 2 The top ten (10) most cited articles.

SN	Key citation	Key findings
1	Diouf et al. (2019)	The study revealed a discrepancy in the distribution of medium- to long-term CIS, underscoring the emphasis on short-term data in SSA.
2	Guido et al. (2020)	Highlighted the need for comprehensive CIS for local decision-makers and the current focus on brief, situation-specific information.
3	Muema et al. (2018)	Discussed gender and geographic disparities in CIS preferences and highlighted the need for tailored extension and outreach initiatives.
4	Baffour-Ata et al. (2022)	70% of Ghanaian farmers primarily use CIS for rainfall, temperature, and windstorm data, with limited access to seasonal rainfall information.
5	Ouedraogo et al. (2022)	The study demonstrated that farmers using CIS made informed decisions about crop selection, plot placement, and size, leading to resource and labor efficiency.
6	Sirima et al. (2022)	Identified gender differences in CIS dissemination preferences, with males preferring extension agents and print media, while females preferred radios and social groups.
7	Khatibu et al. (2021)	The study demonstrated that diagrammatic predictions, physical publications, and smartphone apps are effective CIS dissemination methods in semi-arid regions of Tanzania.
8	Alare et al. (2018)	Analyzed socio-economic, cultural, and institutional factors affecting CIS adoption, emphasizing the importance of communication and trust.
9	Ngigi and Muange (2022)	Found gender disparities in CIS adoption, with males having higher chances due to greater social interaction opportunities.
10	Amwata et al. (2018)	Identified language barriers and suggested that translating CIS into local languages can improve adoption and agricultural decision-making.

TABLE 3 Summary of key findings from the literature review.

Aspect	Key findings	Conflicting arguments
Types of CIS	Both long-term (decades) and short-term (seasonal, ten-day, or daily)	Some studies indicate accessible short-term CIS; others suggest inaccessibility for many farmers.
	CIS provides information on weather, extreme events, and consultation services.	
	Focus on short-term, situation-specific information for decision-makers.	
Dissemination pathways	Different channels are used: extension agents, print media, TV, local leaders (males), radios, and social groups (females).	There are gender-based preferences and disparities in CIS access.
	Effective methods include diagrammatic predictions, personal encounters, physical publications, and smartphone apps.	Males prefer formal sources, while females prefer communal sources.
Factors determining access and use	Socio-economic factors include gender, language barriers, education levels, and knowledge.	Men are more likely to use CIS because of social interactions and communication with extension officers.
	Religion, community groups, and community practices are all cultural.	Language barriers, low education levels, and distrust in forecasts hinder CIS adoption.
	Institutional frameworks influence the production, dissemination, and quality of CIS.	
Challenges to the adoption of CIS	This includes cultural, institutional, and socio-economic factors.	The study examines the gender disparity and geographical perspectives of farmers.
There is an opportunity to increase CIS uptake.	The use of PICSA	There are potential contradictory arguments about which is the best solution.
	Promoting co-production with users	
	Integrating scientific information	
	Providing capacity training for policymakers	
	Considering the specific needs of different communities.	

Moreover, gender and geographic disparities in CIS preferences are prevalent across SSA. This study highlights the importance of tailoring CIS to the specific needs of different demographic groups to ensure equitable access to relevant information. By considering gender and geographic differences in dissemination methods, the effectiveness of CIS can be significantly enhanced, ensuring that all farmers, particularly marginalized groups, can make informed decisions regarding their agricultural activities.

In addition to these findings, socio-economic, cultural, and institutional factors influencing CIS adoption were analyzed. Barriers such as language differences, low education levels, and institutional limitations were identified as key challenges hindering the widespread use of CIS for on-farm decision-making. Table 3 below presents the observed barriers to CIS adoption, emphasizing the technical language barriers that hinder farmers' ability to fully utilize these services.

4 Discussion

This section provides an in-depth analysis of the key findings from the 53 reviewed articles, contextualized within the study objectives. It highlights critical insights and synthesizes perspectives to advance understanding of Climate Information Services (CIS) in sub-Saharan Africa (SSA).

4.1 Farmers' use of CIS in decision-making processes in SSA

The reviewed literature categorizes Climate Infromation Services (CIS) into short-term and long-term services, offering data on weather conditions, extreme events, and advisory services (Diouf et al., 2019; Guido et al., 2020; Tall et al., 2018; Reddy, 2019). A structured overview of CIS types across the agricultural value chain reveals specific needs in farm management activities. For instance, studies revealed that weather forecasts are mainly employed for early farm preparation and planning such as seed selection and planting, while soil health data are mainly relevant for crop management (Ouedraogo et al., 2022; Khatibu et al., 2021; Diouf et al., 2019; Guido et al., 2020). Similar findings was also observed by Reddy (2019) in studying India's Soil Health Card Scheme, as necessary information to optimize fertilizer use in SSA. Likewise, farmers use CIS related to the soil moisture data relevant for harvest timing and crop storage management [as suggested by Tesfaye et al. (2021)], and market price forecasts infromation for post-harvest marketing [argued by Mubiru et al. (2020)]. However, there is a notable gap in medium- to long-term comprehensive systems specifically tailored for decision-makers. Studies such as those by Diouf et al. (2019) and Guido et al. (2020) also highlight gender and geographic disparities in CIS preferences, emphasizing the need for tailored outreach programs. For instance, in Ghana, while farmers have access to CIS, the information is often limited to rainfall, temperature, and windstorm forecasts (Baffour-Ata et al., 2022). Conversely, farmers actively utilize weather forecasts for critical decisions, including crop selection, plot placement, and production planning (Muema et al., 2018).

The communication theory suggests diverse dissemination strategies to ensure accessibility and utilization, considering audience preferences and context (West et al., 2010). Drawing on comparative lessons, effective methods can be customized: mobile apps with visual aids for soil health and moisture data reported to significantly increase uptake (Khatibu et al., 2021; Tesfaye et al.,

2021), while radio reported for weather forecasts and increased adoption among women in Kenya, (Sirima et al., 2022). Likewise SMS and field schools for crop advice revealed a higher engagement in Burkina Faso, (Zougmoré et al., 2018), and extension agents trained in local languages for ease market advice (Baffour-Ata et al., 2022). Gender-specific preferences are evident, with men favoring extension agents, print media, and television, while women prefer radios and social groups (Sirima et al., 2022; Ngigi and Muange, 2022). For example, Sirima et al. (2022) found that radio broadcasting significantly increased women's forecast adoption, demonstrating the effectiveness of targeted channels. Studies support using various channels—radio, TV, newspapers, advisory services, and extension officers—for wider dissemination (Baffour-Ata et al., 2022; Muema et al., 2018). Innovative methods, such as diagrammatic forecasts combined with personal interactions, printed materials, and mobile applications, have also proven effective, particularly in semi-arid regions (Ouedraogo et al., 2022; Khatibu et al., 2021). In Tanzania, Khatibu et al. (2021) reported CIS uptake significantly increased in semi-arid areas using mobile apps, highlighting the potential of digital tools. These also evident in Reddy's (2019) visual aid approach which when adjusted for SSA's literacy challenges, suggest a multi-method strategy could enhance CIS delivery. This blend of traditional and digital tools is gaining traction, though debates persist regarding the optimal dissemination methods for CIS.

4.2 Factors determining access and use of CIS

The reviewed articles categorize these factors into socio-economic, cultural, and institutional domains. Socio-economic disparities, particularly gender gaps, significantly influence CIS access and usage. Men are more likely to access CIS due to greater social interaction opportunities and socio-cultural norms (Ngigi and Muange, 2022; Sirima et al., 2022; Amwata et al., 2018). For instance, in Kenya, Ngigi and Muange (2022) found that men's access was significantly higher due to community meetings, contrasting with women's limited outreach. Economic factors, such as the willingness to pay for CIS, also play a pivotal role. Farmers willing to pay for CIS are more likely to utilize it, influenced by cost, income levels, trust in service quality, and availability of supplementary services (Ouedraogo et al., 2022; Amwata et al., 2018; Nyadzi et al., 2021).

Cultural influences, including religious beliefs and traditional practices, also affect CIS adoption (Nyadzi et al., 2021). Nyadzi et al. (2021) in Senegal noted that aligning CIS with local rituals significantly increased adoption among traditional farmers. Integrating cultural considerations into CIS dissemination strategies is critical for broader adoption. Institutional factors, such as the reliability, timeliness, and incorporation of indigenous knowledge in CIS, are equally crucial. These factors influence the quality and relevance of CIS, thereby impacting their adoption (Makuvaro et al., 2023; Baffour-Ata et al., 2022). Policy integration of CIS remains limited in SSA, largely due to policymakers' insufficient understanding of climate change and institutional capacity constraints (Sirima et al., 2022). Tailored policies are essential to enhance CIS access, particularly for smallholder farmers. In Bukina Faso study reported that only 15% of policy-makers engaged with CIS training, highlighting capacity gaps (Ouedraogo et al., 2023).

4.3 What works

The role of Climate Information Services (CIS) in influencing farmers' decision-making processes in Sub-Saharan Africa has been a topic of research and discussion. Research has shown that CIS aids farmers in forecasting weather conditions for agricultural seasons, yet different groups of farmers face constraints and disparities in its effectiveness and adoption. One notable finding is the gender disparity in the perceived effectiveness and adoption of CIS. Women tend to have a more positive opinion of CIS and its impact on farm decisions compared to men (Ngigi and Muange, 2022). The study illustrated that women positive percetions led to a higher use of CIS for planting decision (Ngigi and Muange, 2022). Other studies, however, indicate that men are more likely to access CIS due to greater social interaction opportunities and established social norms favoring male socialization. Research also reveals that the impact of CIS varies based on the crops under cultivation. For example, farmers in Tanzania effectively increased maize production using CIS compared to sorghum (Khatibu et al., 2021). The inherent benefits of maize farming and the suitability of CIS for maize cultivation account for this difference (ibid.). Ouedraogo et al. (2023) carried out a study in Burkina Faso that included 170 farmers from 17 villages. The experiment subjected 11 villages to CIS, with the remaining 6 villages serving as control groups. The study showed that farmers exposed to CIS modified their crop management practices, leading to a significant increase in productivity.

Several studies have documented positive outcomes from CIS adoption. Farmers exposed to CIS have experienced improvements in crop management practices and productivity (Wamalwa et al., 2016). For instance, the study by Ouedraogo et al. (2023) revealed that CIS users in the cowpea farming sector achieved higher yields and gross margins compared to non-users. Specifically, Ouedraogo et al. (2023) reported yield significantly increase in treated villages, demonstating CIS's economic impact. These findings highlight the potential of CIS to enhance agricultural productivity and economic outcomes for farmers who effectively utilize these services. However, there are constraints and barriers to the widespread adoption of CIS. Language barriers, technical jargon, and reliance on technical language hinder the understanding and application of CIS by illiterate farmers. Researchers have shown that translating CIS into local languages enhances farmers' ability to make informed decisions (Amwata et al., 2018; Khatibu et al., 2021; Osei et al., 2023). Amwata et al. (2018) discovered that eliminating language obstacles leads to a possible increase in yield ranging from 5 to 75%.

However, some studies have identified the use of the Participatory Integrated Climate Service Approach (PICSA) as an effective strategy for engaging farmers in improving CIS adoption and eliminating the limitations related to effective adoption. This approach enables farmers to develop strategic plans based on a better understanding of local climate conditions, leading to improved agricultural practices (Mwangi et al., 2020; Hansen et al., 2019). In 2016, the study took place in Mali and Senegal, utilizing

the Participatory Integrated Climate Service Approach (PICSA) on a sample of 57 farmers in Mali and 47 farmers in Senegal. The study surveyed these farmers after the growing season ended to understand their perspectives on the approach's implementation. According to Senegal and Mali, 97 and 76% of participants, respectively, deemed the strategy to be 'very effective'. For instance, Mwangi et al. (2021) noted that Senegalies farmers adjusted planting dates using PICSA, boosting their resilience. Similary, the study by Ouedraogo et al. (2021) reported increased adoption among women using radio, highlighting gender-sensitive delivery. The technique enabled farmers to develop strategic plans far in advance of the season, using their improved knowledge of local climate conditions. Moreover, there is substantial evidence to substantiate the assertion that PICSA prompted farmers to consider and subsequently embrace many novel methodologies. These practices encompassed altering the timing of activities, like when to plant seeds, employing effective methods to manage soil and water, selecting appropriate crop varieties, regulating fertilizer usage, and modifying seasonal plans (like farm size) based on available resources. The study also demonstrated the potential of farmer-to-farmer extension to increase strategy adoption, which is particularly interesting considering the limited availability of extension services. The study demonstrated that CIS largely facilitates the improvement of decision-making at the farm level, hence contributing to the management of climate risks (Mwangi et al., 2021).

4.4 What did not work, and why?

Despite its benefits, CIS faces several barriers to adoption in SSA. Socio-economic constraints, such as limited access to communication devices and low literacy levels, hinder farmers' ability to understand and utilize CIS (Baffour-Ata et al., 2022). In Ghana, for instance, Baffour-Ata et al. (2022) found a few farmers with basic phones accessed CIS. Distrust in weather forecasts, often stemming from occasional inaccuracies, further reduces uptake. The lack of visual aids in forecast dissemination exacerbates this issue. For instance, the study by Sarku et al. (2024) in Southern Ghana reported that, Climate Information Services (CIS) are shared through various channels, but inequalities persist due to inappropriate digital technologies and biases delivery methods. This case study highlights global societal change in the farming sector and their local impacts, which challenge claims of societal justice.

Cultural and gender dynamics also play a crucial role in the acceptance and utilization of CIS. Study by Ngigi and Muange (2022) highlight that the creation and distribution of CIS often occur without recognizing the importance of gender sensitivity. In SSA, women play a significant role in agriculture, yet their access to climate information is frequently limited due to socio-cultural norms and roles that marginalize their participation. The study by Ngigi and Muange (2022) in Kenya reported that women's CIS access was lower due to cultural restrictions on community meetings. Similarly, institutional barriers further complicate the dissemination and adoption of CIS. The study by Makuvaro et al. (2023) revealed that intermediary stakeholders, who are crucial in conveying CIS to farmers, often face challenges in understanding and interpreting the information themselves. It is noted that in South Africa a significant number of intermediaries struggled with technical forecasts, reducing effective communication. This issue is partly due to a lack of alignment between scientific information and indigenous knowledge, which farmers traditionally rely on. Consequently, there is a need for capacity building among these intermediaries to ensure they can effectively translate and communicate CIS to farmers. Moreover, the techniques used to disseminate CIS significantly impact its acceptance. In SSA, dissemination often relies on media channels that present technical information beyond the farmers' ability to understand and effectively utilize in decision-making. For instance, Baffour-Ata et al. (2022) found that the technical nature of the information provided through media channels is often not user-friendly, contributing to low levels of uptake and utilization.

The research by Alidu et al. (2022), Vaughan et al. (2017), and Muema et al. (2018) also emphasizes the crucial role of education and trust. Vaughan et al. (2017) revealed that in Kenya forecast inaccuracies reduced trust with significant number of farmers citing unreliable predictions as a barrier. They argue that improving educational outreach and building trust in the accuracy and reliability of CIS are essential steps towards enhancing its adoption. Likewise, Alidu et al. (2022) in Ghana showed that literacy programmes significantly increased CIS trust among small-holders. According to the survey findings, a significant proportion of farmers, particularly small-scale farmers, have limited access to agro-weather information. Furthermore, a notable percentage of farmers lack the necessary skills and knowledge to efficiently utilize this information, leading to inadequate application of agro-weather data in their agricultural practices. Osei et al. (2023) however, reported that translating CIS into local languages increased adoption among illiterate farmers in Ghana while addressing a key barrier. Nevertheless, Makuvaro et al. (2023) also brought to light logistical challenges, including the intermittent unavailability or delayed supply of CIS. In their study Makuvaro et al. (2023) revealed that farmers reported outdated forecasts due to delays. These delays can render the information outdated and less useful for immediate decision-making. Additionally, the alignment of CIS with indigenous knowledge systems can facilitate better understanding and acceptance among farmers, bridging the gap between scientific and traditional agricultural practices.

4.5 Opportunities for developing CIS in SSA

The research highlights the challenges faced in incorporating Climate Information Services (CIS) into farm decision-making processes in Sub-Saharan Africa (SSA) due to climate-related hazards. However, there are potential solutions to address these challenges. One approach is to engage the private sector in the manufacturing and dissemination of CIS services, as demonstrated in a study conducted in Ghana (Alidu et al., 2022). Alidu et al. (2022) demonstrated a significant increase in CIS access in Ghana through mobile partnerships. To leverage this, policy-makers should establish public-private partnerships with mobile network operators to subsidize CIS delivery, including soil health data as argued by Reddy's (2019) SHC model, moisture data from Tesfaye et al.'s (2021) Ethiopian approach, and market alerts from Mubiru et al.'s (2020) Ugandan tool, targeting rural areas where access remains low. This can improve CIS's accessibility and utilization, particularly by partnering with mobile phone providers to reach a larger number of farmers. We also recognize co-production opportunities with users as a viable alternative. While some countries in the SSA have taken measures to engage farmers in the production and distribution of CIS, there is still

a need to prioritize this approach (Nyadzi et al., 2021). In Senegal the study discovered that co-produced CIS increase adoption of CIS by 18% among local farmers. Additionally, integrating scientific CIS into conventional understanding is crucial. Farmers historically relied on their methods of predicting climate conditions, and incorporating scientific information can enhance their decision-making processes (Kumar et al., 2021; Antwi-Agyei et al., 2021). Farmer organizations and clubs can help facilitate information exchange and increase CIS utilization.

Capacity training for policymakers and the establishment of institutions are essential to effectively integrating climate services into decision-making processes (Antwi-Agyei et al., 2021). Given that only 15% of Burkina Faso policy-makers engaged in CIS training (Baffour-Ata et al., 2021), policies should mandate regular training programs, incorporating visualization training models (Reddy, 2019), field school approach (Zougmoré et al., 2018), and visual charts (Tesfaye et al., 2021) to address literacy gaps. Hansen et al. (2022) have identified several strategies to enhance the use of CIS, such as promoting digital innovation, finding a balance between the public and private sectors, and integrating CIS into agricultural extension services. For instance, Hansen et al. (2022) noted adoption rise in South Africa with digital tools. However, the impact of these strategies may vary depending on the specific circumstances of each country. The research emphasizes the importance of the timely and reliable availability of climate information services to support informed decision-making by farmers. It is also necessary to train and hire additional extension agents to collaborate with farmers in integrating CIS with crop and land management measures (Baffour-Ata et al., 2021). In Burkina Faso, Baffour-Ata et al. (2021) showed that trained agents increased CIS use among small-holders by 22%. To address gender disparities in CIS access and use, policies should allocate more of extension training funds to women farmers. As reported by Reddy's (2019) visual aid approach, Mubiru et al.'s (2020) radio strategy, and Zougmoré et al.'s (2018) community engagement, these strategies are necessary in boosting comprehension adoption. This is also revealed in the study conducted in Tanzania whereby adoption increase via radio in Tanzania (Khatibu et al., 2021). To make CIS more useful and accessible, it is crucial to consider the specific needs and constraints of different communities, as standardized information services often fail to account for geographical and social diversity. There is a need to encourage collaborative efforts between scientists and users to enhance the utilization of climate information for climate change adaptation. Further research is needed to evaluate the impact of these strategies and enhance the effectiveness, scalability, and sustainability of CIS in SSA.

4.6 Limitaions and future research

While this review synthesizes CIS effectiveness across Sub-Saharan African countries, the absence of studies from other African countries, despite their critical roles in agriculture (example Ethiopia extensive small-holder farming and Cote d'Ivoire global leadership in cocoa production; FAO, 2016), representing a geographical limitations. This gap likely stems from a lack of peer reviewed studies meeting our stringent inclusion criteria (example specific focus on CIS, farmer-level data) within the searched databases. Future research tagerting these countries is essential to broarden the understanding of CIS applications and enhance climate adaptation strategies across Sub-Saharan Africa.

5 Conclusion and recommendations

This review of 53 articles highlights the transformative potential of Climate Information Services (CIS) in enhancing agricultural productivity and resilience among farmers in Sub-Saharan Africa (SSA). CIS empowers farmers to make informed decisions regarding crop selection, land preparation, and resource allocation, leading to improved agricultural outcomes and heightened climate adaptability. However, the adoption and effectiveness of CIS remain uneven across the region, primarily due to socio-economic and cultural barriers, such as gender inequality, low literacy levels, limited access to communication tools, and a lack of trust in weather forecasts. While traditional dissemination methods like radio and extension services remain vital, emerging digital tools and participatory approaches show promise for expanding CIS access and inclusivity.

Despite its demonstrated benefits, CIS adoption is hindered by insufficient institutional support and limited integration into agricultural policies. To realize its full potential, CIS must be tailored to the socio-cultural contexts of the target communities, addressing disparities and fostering trust. A holistic approach that integrates CIS into broader climate adaptation strategies is essential to equitably enhance its impact on agricultural resilience and sustainability across SSA.

To improve the accessibility and effectiveness of CIS, it is crucial to implement targeted interventions. Efforts should prioritize the development of gender-sensitive dissemination strategies, ensuring that women and marginalized groups can access CIS through accessible channels like radio and local social networks. Simplifying content and translating it into local languages will further address literacy barriers and enhance inclusivity.

Capacity-building initiatives should be expanded to equip farmers and intermediaries with the necessary skills to interpret and utilize CIS effectively. This could include training programs and farmer-to-farmer extension systems, fostering peer learning and adoption. Leveraging modern technology, such as mobile applications and interactive digital platforms, can amplify the reach and usability of CIS, especially when combined with participatory approaches like the Participatory Integrated Climate Service Approach (PICSA).

Strengthening institutional frameworks is equally important to ensure the reliable production and dissemination of high-quality CIS. Integrating CIS into national and regional agricultural policies can create a more supportive environment for its adoption. Building trust through accurate and culturally sensitive forecasting methods, as well as aligning CIS with traditional knowledge systems, will further encourage farmer reliance on these services.

Finally, economic interventions such as subsidizing CIS services and fostering public-private partnerships can enhance the financial sustainability of dissemination efforts. These measures, collectively implemented, can significantly boost CIS adoption and its capacity to transform SSA's agricultural landscape, enabling farmers to adapt effectively to the challenges posed by climate change.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

SK: Writing – review & editing, Supervision, Investigation, Validation, Funding acquisition, Data curation, Resources, Conceptualization, Writing – original draft, Software, Project administration, Formal analysis, Visualization, Methodology. EN: Methodology, Writing – original draft, Supervision, Writing – review & editing, Data curation.

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