Use of Digital Climate Services and Uptake of Climate Smart Technologies Among Smallholder Farmers in Africa: A Review

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Abstract:

Climate smart agriculture (CSA) technologies are being touted as sustainable responses to strengthen farmers' resilience against climate change whilst boosting agricultural productivity. In fact, a number of countries developed CSA investment plans as a way of placing CSA technologies at the centre of national development agenda. Nevertheless, the uptake of CSA technologies among smallholder farmers remains low. As such, profiling innovations which can sustainably scale-up adoption of CSA technologies cannot be overemphasized. Use of digital climate services is regarded as one of the key innovations with significant potential to boost the uptake of CSA technologies. It is therefore critical at this juncture to synthesize insights on the impact of digital climate services use and uptake of CSA technologies to inform policy programming. Towards that end, this study explored the nexus between use of digital climate services and uptake of CSA technologies based on extensive review of literature. A synthesis of 39 articles reviewed underscored that; digital climate services such as Esoko platform in Ghana significantly enhance uptake of CSA technologies among smallholder farmers. Increased investments towards delivery of tailored climate services and mobile network connectivity are therefore urgently needed to incentivize uptake of CSA technologies across Africa.

Keywords: climate change, climate smart agriculture, digital climate services, resilience & productivity.

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1. Introduction

Climate change shocks such as increased frequency and intensity of droughts have affected food systems globally. However, due to heavy reliance on rainfed farming systems, the effects are more felt in Africa. Indeed, climate change has affected food systems from Southern Africa through East and Central Africa to West and North Africa. For instance, Southern Africa region has been characterized by recurrent droughts resulting in crop failure and livestock losses for the past two decades [1]. A recent hunger hotspot report in June 2022 has also identified a number of African Member States as hotspots of food insecurity. In Southern Africa, the report noted that, the food insecurity situation is most severe in Democratic Republic of Congo (27.3 million), Zimbabwe (3.4 million), Mozambique (2.9 million) and Malawi (2.6 million) due to climate change among other factors [2]. Likewise, a number of countries in East Africa has been also identified as hotspots of food insecurity. About 16.8 million people in Ethiopia are estimated to be in acute food insecurity situation, 7.7 million in South Sudan, 6 million in Somalia and 3.5 million in Kenya [2]. Again, West Africa is no exception with Nigeria (19.5 million), Niger (4.4 million), Burkina Faso (3.5 million) and Mali (1.8 million) have been also identified as hotspots of food insecurity in the region [2]. If left unattended to, climate change will continue to jeopardize the livelihoods of farmers and heightening food insecurity crisis whilst slowing economic growth. As such, to strengthen farmers' resilience, a number of climate smart agriculture (CSA) technologies have been promoted [3-6].

In fact, a number of countries including Zimbabwe with support from World Bank has developed CSA investment plans as a way of placing CSA technologies at the centre of national adaptation and development agenda. The CSA technologies encompass measures, practices and technologies which support farmers to achieve the triple win of boosting agricultural productivity, strengthening climate change adaptation and mitigation [4, 6, 7-9]. Such practices include staggering planting dates, adoption of drought resistant varieties, crop diversification, soil and water conservation practices and weather index insurance among others [10-14]. These practices have been proven to be effective in strengthening farmers' resilience, conserving natural resources, increasing crop yields and hence food and income security [4, 8, 15-16]. Nevertheless, the uptake of CSA technologies especially among smallholder farmers in Africa remains low [5, 13]. As such, profiling innovations which can sustainably scale-up adoption of CSA technologies cannot be overemphasized given the context of escalating climate risks [17-18].

Use of digital climate services is regarded as one of the key innovations with significant potential to boost the uptake of CSA technologies especially among smallholder farmers [7, 12, 19-22]. To that end, a number of programmes with components of promoting the use of digital climate services are being implemented and mainly sponsored by CGIAR Research Program on Climate Change, Agriculture and Food Security projects [8, 17, 23]. The main argument is that, climate services provide farmers with weather forecast information to support effective planning of farm operations and selection of optimal crop varieties [7, 12, 24-25]. Climate services generally refers to the production, translation, dissemination and use of climate and weather forecast information [21, 26-30]. In this case, the digital climate services therefore refer to information and communication technology such as mobile phone-based weather forecast services like Esoko platform in Ghana and Radio listening Clubs in Rwanda [12, 31]. As the evidence on the interlinkages between use of digital climate services and uptake of CSA technologies is growing, it is crucial at this juncture to synthesize insights from review of literature to inform policy and projects programming.

It is against this background which prompt this study to answer the following research questions: is there a link between digital climate services use and uptake of CSA technologies; and what are the most adopted CSA technologies following the use of digital climate services? Insights from such a synthesis of existing evidence helps to draw lessons to accelerate upscaling and shape future initiatives [5, 17]. This is particularly important for Southern Africa where majority of farmers rely on rainfed farming systems [13, 32]. Concurrently, Southern Africa region is lagging behind on the use and investment towards delivery of tailored climate and weather forecast services as compared to other regions like East and West Africa [27, 33]. As such, grounded on random utility model (RUM) this review paper provide a synthesis of the effects of digital climate service use and uptake of CSA technologies. The main argument here is that, a rational farmer will use digital climate services if and only if the utility of such a decision is greater than the status quo (i.e., no use of digital climate services). Thus, a farmer will use digital climate services once he/she perceives the services as an effective decision supporting tool to enhance the choice and implementation of optimal CSA technologies [12, 34]. In addition to analysis of the link between digital climate services use and CSA technologies uptake, political economy variables which incentivizing wide use of digital climate services were also discussed.

Such a holistic analysis is critical to shape the narrative and influence policy towards creating an enabling environment for both public and private sector investments in delivery of tailored climate services [9, 35]. Successful uptake of new innovations among farmers does not just depends on deploying right technology but also on enabling policy environment [3, 36]. Again, documentation of evidence on the effect of digital climate services and farmers' decision to implement CSA technologies is important to justify the need for increased investments. This is because, the value of climate services is demonstrated through enhanced farming decisions (such as selection of optimal crop variety) and hence positive livelihood outcomes [4, 11, 37]. With less than 3 years before 2025, shaping policy actions towards accelerating both the use of digital climate services and uptake of CSA technologies is significant to accelerate progress towards achievement of the goals articulated in the Comprehensive Africa Agriculture Development Programme (CAADP) framework particularly raising agricultural growth by at least 6 percent across African Member States. This is also important for the attainment of Sustainable Development Goals (SDGs) in Africa particularly SDG 2 (zero hunger) and 13 (climate action) [38-40]

Although this review is not exhaustive in nature (since only articles written in English were reviewed), it significantly complements existing literature on upscaling CSA technologies however with particular attention on the role of digital climate services. This is an important policy area given that many countries across Africa are at different stages of operationalizing National Frameworks for Climate Services. The rest of the review paper is structured as follows: section 2 provides materials and methods and section 3 present the results of the systematic review whilst section 4 provides the discussion of the findings. In section 5, the conclusion and recommendations are articulated based on the insights from the analysis.

2. Materials and Methods

The Systematic literature review (SLR) was employed in this study to synthesize the link between digital climate services and uptake of CSA technologies. The SLR is an in-depth review of literature aimed at mining knowledge about a specific subject matter [41-42]. It is increasingly being employed to understand the current state of knowledge on climate change adaptation options to shape policy strategies and actions [5, 43-44]. In this case, the review of literature took stock of and synthesize existing evidence on the link between digital climate services use and CSA technologies uptake in Africa. The RepOrting Standards for Systematic Evidence Synthesis (ROSES) framework guided the review process since meta-analysis was not conducted [5, 45]. The ROSES framework is an alternative to Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) [45]. The ROSES framework provides a standard format in selecting and review literature on a specific topic [5, 45, 46]. As such, a review procedure was developed to guide the review and identification of articles through the use of key words such as "digital climate services/ mobile phone-based weather forecast services and climate smart agriculture practices".

The review process consisted 5 key steps which are: setting of eligibility criteria, search strategy, screening and selection of research studies, article management and data extraction and then synthesis of findings. These five steps are applied extensively in systematic review of literature in a number of socio-economic research studies [42, 45, 47].

The selected articles were not delimited by year of publication, but only articles published in English, peer-reviewed and conducted in Africa were included. Articles published in English were only included due to the proficiency of the researcher. The included articles were also restricted only to those focusing on the impact of digital climate services on adoption of CSA technologies in Africa. As such, to streamline the search process a population, indicator, comparison, outcome and study design (PICOS) strategy (table 1) was employed for eligibility criteria [42]. This strategy is essential to shape both search and screening of articles for inclusion in the study.

Table 1: PICOS Strategy employed

PICOS strategy	Description
Population	Peer reviewed articles (journal articles or book chapters) on solar powered irrigation uptake/adoption

Indicator	Digital climate services/mobile-based weather forecast services/ICT tools disseminating climate and weather forecasts
Comparison	Not Applicable
Outcome	Uptake of climate smart agriculture practices
Study design	Quantitative, qualitative and mixed methods

Guided by the PICOS strategy, a search command was developed to select relevant articles for review from online research articles databases mainly SCOPUS, AGORA, and Agriceconsearch. The use of multiple databases helped to optimize access of all potential eligible articles. These databases are reputable journals and were selected based on their known strength in covering high quality peer reviewed literature on the subject matter and other applied socio-economic literature. Articles (journal articles or book chapters) were also retrieved from Google scholar if the full-text of the selected article was not available through aforementioned databases. A Boolean logic operator was implemented which allows one to retrieve more accurate and precise results by linking 2 or more terms or related concepts. In this case logical connectors mainly "AND & OR" were employed in the search process where "AND" narrows a search whilst "OR" broadens it. The selected literature reviewed was not delimited by year of publication to allow review of all potentially eligible articles [48]. However, the analysis was restricted to research articles focusing on digital climate services and uptake of CSA technologies as well as those published in English. Only peer-reviewed articles were reviewed to ensure analysis of authentic documents. The following search strategy was used: [Digital climate services OR climate information OR mobile-based climate and weather forecast information OR ICT based weather forecast information AND uptake OR adoption of climate smart agriculture practices in Africa OR climate smart agriculture practices in Africa]. The literature search process commenced on 2 May 2022 and was completed on 2 August 2022.

The inclusion and exclusion criteria were based on title and abstract. This is a most common procedure employed in other review studies [8, 21, 47, 49-51]. Once the article's title and abstract failed to concisely elaborate issues around wider research objective, the article was dropped from analysis. However, efforts were made to reinforce consistency by thoroughly reviewing all the potentially eligible papers. Again, other articles were also identified through checking reference lists of selected eligible articles, a common strategy to increase chances of obtaining more relevant and eligible articles [52-54].

The retrieved articles were exported and merged in Zotero. Zotero is a reference management software which allows for easy and efficient reference management as well as removal of duplicate articles. A table format was used to present key themes and variables extracted from reviewed articles to allow clear coding and presentation. These key characteristics include first author name, year of publication, region, country of study, sample size and adopted CSA technologies after farmers receive climate and weather forecasts through digital tools or applications.

Analysis was mainly based on thematic analysis by picking key themes/variables related to the research objective. Thus, after a thorough review of the abstract, conclusion and recommendation sections of eligible articles, key themes of interest (CSA technologies adopted) were picked and concisely summarised per each eligible article. For other articles a full article review was employed if the abstract failed to provide full details to answer the research objective. The key findings were then summarized and presented mostly in table format for clear visualization and interpretation.

3. Results

3.1. Characteristics of reviewed articles

A total of 242 articles were identified through literature search including those obtained by checking reference lists. After removing duplicates and screening of articles based on titles and abstracts, 205 were excluded from the analysis as these papers failed to meet eligibility criteria. Only 39 articles were within the scope of the study and were selected for review.

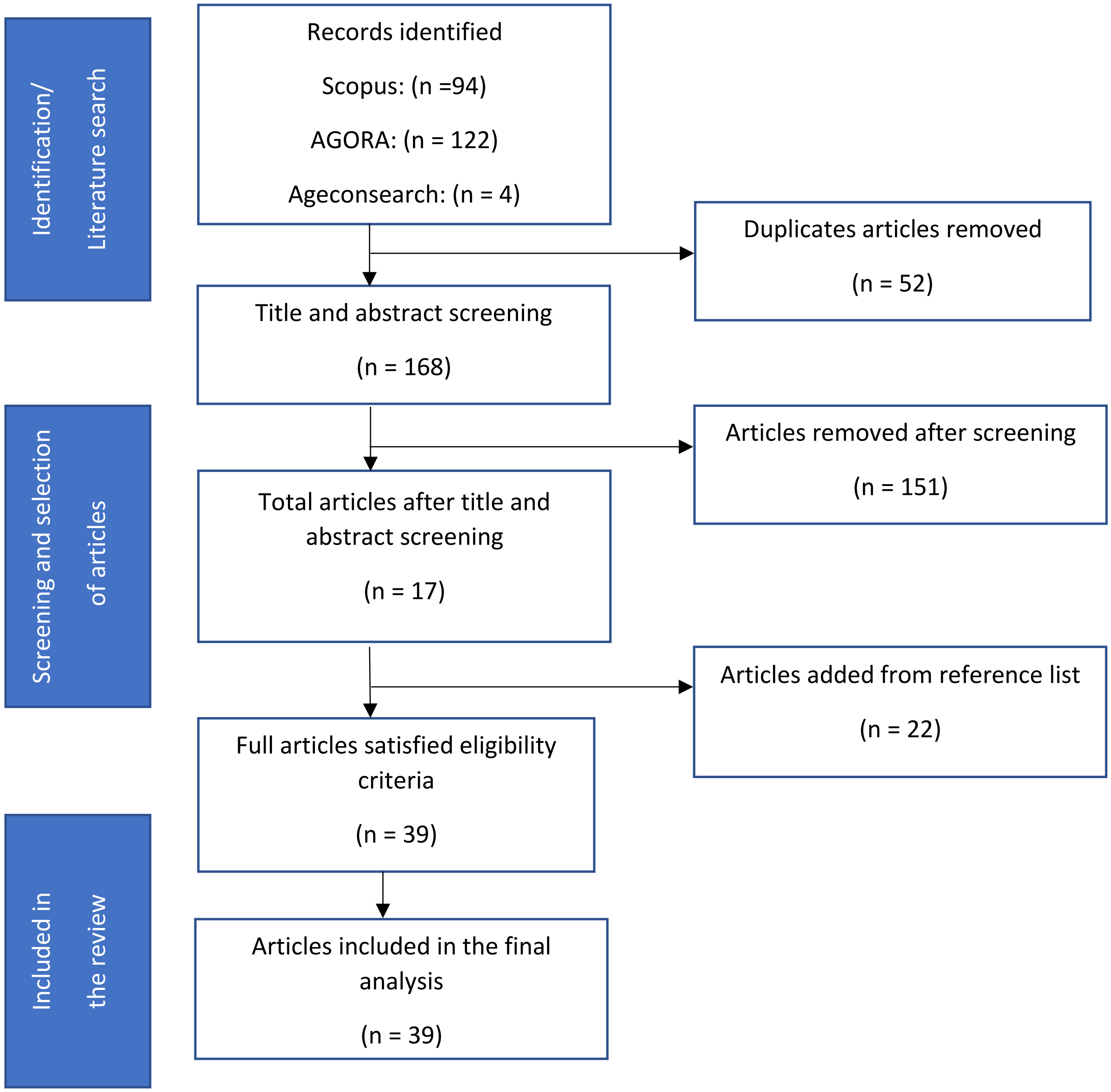

Figure 1: Review process and number of articles included

The review showed that, West Africa is leading in terms of digital climate service use across the continent. About 51% of the reviewed articles were exclusively from West Africa, 23% from Southern Africa and 13% from East Africa whilst 13% of the articles covered either both East and West Africa or across the whole continent. It has been noted that, West Africa is leading in digital climate service use mainly due to the implementation of various projects by multiple Non-Governmental Organizations (NGOs) in collaboration with local communities and Government agencies. Multi-disciplinary Working Group for example in Senegal is accelerating the use of climate services among smallholder farmers [10-11, 26-27]. However, most of these projects are externally funded/donor driven which threatens long-term sustainability. For instance, in Ghana, digital climate services are being disseminated mainly through project-based collaborations between different stakeholders including Consultative Group for International Agricultural Research (CGIAR) organizations, Esoko (private partner), Vodafone (private partner), Ghana Meteorological Agency and Ministry of Food and Agriculture since 2011 [12, 23]. Initially, the collaborations were spearheaded under the CGIAR Program on Climate Change, Agriculture and Food Security (CCAFS) and currently under the Accelerating Impacts of CGIAR Climate Research for Africa (ICCRA) project with support from World Bank [23, 34, 55]. In Burkina Faso, the climate information is being provided through the Climate Smart Village intervention. Again, this is an initiative of CGIAR program on CCAFS. Similar arrangements and interventions sponsored by CGIAR Program on CCAFS were also noted in Kenya, Mali and Senegal [7, 11, 17]. In Zimbabwe, project-based initiative (Scaling up Climate Change Adaptation project) was also implemented between 2014 and 2018 to provide climate services to farmers [37]. This project was implemented by a consortium of institutions led by Oxfam and was managed by United Nations Development Program with financial support from Global Environment Facility. Given that most of these projects are externally funded/donor driven it is therefore urgent to strengthen domestic resource mobilization to ensure long-term sustainability after withdrawal of external sponsorship.

3.2. Main digital climate services dissemination tools

The review showed that the main existing digital climate services include Esoko's mobile based weather forecast services in Ghana, Meteo Mbay platform in Senegal or eco-farmer in Zimbabwe [10-11, 20, 23, 35, 56-59]. These platforms provide farmers with seasonal or 10-day or daily weather forecasts through short message services (SMS) or interactive voice response or voice calls. There are also other digital or information and communication technology platforms being used to disseminate climate and weather forecasts to farmers such as (community) radios, television and electronic bulletins in Burkina Faso, Ethiopia, Tanzania, Ghana, Kenya, Malawi, Mali, Rwanda, Senegal, Zambia and Zimbabwe [7, 11, 17, 20, 28, 35, 57, 59-65]. The climate and weather forecast information provide through these platforms is key to support farmers to make informed adaptation decisions and investments [28, 34]. It is also important to note that, print media and agricultural extension agents are still playing a significant role in dissemination climate and weather forecast to farmers across Africa [66]. The use of websites and social media platforms such as twitter and Facebook in disseminating weather forecasts is also increasingly gaining popularity globally [56, 67-69].

3.3. The nexus between use of digital climate services and uptake of CSA technologies

The reviewed articles underscored that; digital climate services play a significant role in influencing uptake of CSA technologies in Africa. Thus, access of climate and weather forecast information through mobile-phone based SMSs, interactive voice recordings and calls as well as other digital tools such as radio is integral to up-scale uptake of CSA technologies among smallholder farmers [4, 7, 12, 23, 58, 60]. Apart from enhancing farmers to make informed farming decisions like scheduling planting dates, major CSA technologies and practices adopted as a result of digital climate services use include crop diversification, adoption of drought tolerant crops and varieties, soil and water conservation measures, reduced land allocation and input use [4, 10-12, 21, 60-61, 64]. In Ghana for instance, the use of digital climate services has increased uptake of these CSA technologies particularly multiple cropping by 5.6% and water management practices by 6.8% [12]. Agroforestry, irrigation and weather index insurance are also key CSA technologies being adopted because of digital climate services use across Africa [11, 59, 70]. Smallholder farmers are also implementing climate smart livestock production practices such as growing fodder legumes for supplementary feeding, adopting drought tolerant breeds, altering grazing practices, switching to small ruminants, destocking and moving livestock to areas with better pastures [4, 71-75]. A summary overview of CSA technologies adopted is provided in table 2 below and more detailed in Appendix A.

Table 2: Brief overview of reviewed literature and adopted CSA technologies

First author, publication year	Main objective	Country of study	Main CSA technologies adopted due to the use of digital climate services
[11]	Co-production and use of climate and weather forecast information	Senegal	Scheduling farm activities such as time of planting and fertilizer application, use of manure, choice of crop varieties, livelihood diversification and uptake of climate index-based insurance
[4]	Impact of climate smart agriculture on household welfare	Zimbabwe	Conservation agriculture, drought tolerant crop varieties, early maturity maize varieties, mulching, and uptake of forage legumes such as velvet bean
[60]	Factors affecting access to climate information services	Senegal	Make informed decisions including appropriate plating dates and adopting suitable crop varieties
[12]	Nexus between mobile phone-based weather forecast services and adoption of CSA practices	Ghana	Water management practices and multiple cropping/crop diversification
[61]	Role of seasonal weather forecasts	Zambia	Production of drought tolerant crops and varieties
[71]	Climate risk management information, sources and response strategies	Uganda	Shifting from grazing pasture to the other/ herd migration
[73]	Impact of adopting climate-smart crop varieties and livestock breeds	Kenya	Adoption of drought resilient crop varieties and livestock breeds
[64]	Response strategies to climate risks and role of information	Malawi	Soil and water conservation practices, crop diversification, planting drought tolerant crops and varieties as well as early planting

Adoption of these CSA technologies both for crop and livestock production resulted in improved welfare outcomes of smallholder farmers. For instance, adoption of drought resilient livestock breeds and crop varieties helped to boost household dietary diversity score by 38% and 40% respectively in Kenya [73]. In Rwanda, the use of Radio Listening Clubs led to smallholder farmers' income increase by 56% [31]. Again, in Zimbabwe it has been noted that, smallholder farmers who accessed weather forecasts through mobile phone implemented optimal CSA packages which translated to improved welfare in terms of both food and income security [4]. Likewise, in Senegal, due to the use of weather forecast information and hence adoption of CSA technologies resulted in 10-25% increase in farmers' income [10]. This evidence re-affirms the importance of both digital climate services and CSA technologies among smallholder farming systems in Africa. Indeed, digital climate services minimize the uncertainty and assist smallholder farmers to implement context-specific and optimal CSA technologies [34].

4. Discussion

The reviewed literature presented compelling evidence on the critical role of digital climate services in advancing the uptake of CSA technologies in Africa. This review paper significantly contributes to the growing knowledge body on this subject matter in Africa and provide crystallized insights to support inclusive and sustainable up-scaling of both delivery of tailored digital climate services and CSA technologies uptake among smallholder farmers. Smallholder farmers use digital climate services to make informed climate smart decisions and uptake of CSA technologies such as soil and water conservation measures, crop diversification, adoption of drought tolerant varieties and fodder legumes for livestock feed among others. These practices subsequently led to significant increase in crop yields and hence increased household income and food security. The use of digital climate services has also shown to be an effective strategy to remove gender disparities in access and use of climate and weather forecast information among smallholder farmers [28]. It is clear therefore that, digital climate services should be placed at the centre of national development and resilience agenda across Africa.

There are four key lessons drawn from literature and previous projects promoting digital climate services: a need for an enabling political economy environment to spur investments, co-production, strong mobile network connectivity and bundling weather forecasts with anticipatory actions (agronomic advice) and market information. These factors are essential to facilitate wide use of climate services and hence uptake of CSA technologies. Firstly, bundling of digital climate services with other context specific agronomic advisory and market information significantly support uptake of CSA technologies and strengthen farmers' resilience [60-61]. This ensures that the delivery of climate services is both supply and demand driven as well as aligning with the global call for early warning and early action for all. For instance, in Ghana, provision of weather forecasts together with market information incentivize farmers to make investment decisions in improved crop varieties, irrigation and diversify crop production since they are assured of market access [12, 72].

Secondly, supporting co-production with local communities and integrating with indigenous weather forecasts have been also proven to be effective in ensuring legitimacy, trust and inspire farmers to implement climate adaptation strategies [5, 10, 14, 63, 73, 76]. As African countries are at different stages of operationalizing National Frameworks of Climate Services, the role of co-production to strengthen access and use of climate services is critical.

The third key lesson is the availability of electricity and telecommunication infrastructure in rural areas. Investment in telecommunication infrastructure in rural areas is important to guarantee strong network connectivity and hence enhancing access and use of climate services among smallholder farmers [12, 72].

Finally, enabling political economy environment is crucial to incentivize public-private partnerships and collaboration with development partners and non-governmental organizations in the agricultural sector. For instance, multi-stakeholder platforms are spearheading use of digital climate services and uptake of CSA technologies in Senegal and Ghana [10, 12, 23]. Partnerships and collaboration of multiple organizations enable merging of expertise and financial resources as well as crowd-in private sector investments. Thus, to scale-up both the use of climate services and uptake of CSA technologies, enabling policies, political commitment, technical support, and financial resources are required [8, 20, 35, 77].

5. Conclusions

The reviewed literature showed that, despite being climate risk management tool on its own, access to digital climate services also create an enabling environment for farmers to adopt optimal CSA technologies. Digital climate services inform farmers on which suitable CSA practice to adopt given the seasonal outlook in a particular context. Thus, digital climate services are proving to be an effective entry point for wide up-scaling context specific CSA technologies in Africa. This presents a sterling opportunity to enhance decision making at farm level and uptake of optimal CSA technologies that resonates well with farmers realities and needs. Given this compelling evidence, policies and strategies aimed at promoting the use of digital climate services will be instrumental to up-scale CSA technologies in Africa. There is therefore a need to deliberately mainstream digital climate services at the centre of climate resilient and agricultural development agenda across Africa. Towards this end, the following recommendations are suggested:

Further investments in National Meteorological Agencies are urgently need for production and delivery of tailored climate and weather forecast services across Africa. Thus, political commitment is required to increase fiscal disbursement towards investment in state-of-the-art agro-meteorological equipment to ensure delivery of timely, accurate and actionable weather forecasts to farmers. Enabling policy environment to allow win-win collaborations and partnerships between government agencies, private sector actors, NGOs and farmer associations cannot be overemphasized in this regard. This will allow inclusive and sustainable operationalization of National Frameworks of Climate Services across Africa.

Bundling of digital climate services with other context specific agronomic advisory and market information will be instrumental to support uptake of CSA technologies and strengthen farmers' resilience. It is also important in this case for African governments to rethink national extension advisory policies through strengthening the use of digital advisory tools.

Further investments in telecommunication infrastructure are also critical to enhance digital connectivity in rural areas and hence use of digital climate services. Digital connectivity has emerged as one of the key factors of resilience and business continuity in these recent years especially given the context of COVID-19 pandemic.

To ensure legitimacy and to meet weather information needs of farmers, meteorological services agencies need to urgently co-produce climate services with local communities and embed indigenous weather forecasts with modern weather forecast services. This will ensure that the weather forecasts are context specific, and user driven. Local language should also be used in disseminating weather forecasts for smallholder farmers to easily comprehend the forecast information and translate into action.

Capacity building to farmers on the use of digital climate services is also essential to strengthen digital literacy and skill among farmers. Digital climate service providers should also tailor digital advisory content and use local language to ensure wide uptake.

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Appendix A

Summary of reviewed studies disaggregated by region.

Table A1: Summary of reviewed articles in West Africa

First author, publication year	Main objective	Country of study	Main CSA technologies adopted due to the use of digital climate services
[24]	Benefits of seasonal weather forecasts	Benin	Choice of crop varieties, scheduling planting dates, intensity of input use and area under production
[20]	Farmers' willingness to pay for climate information	Burkina Faso	Choice of crop varieties and plot size, scheduling farm activities such as planting, fertilizer applications and harvesting
[78]	Impact of weather and climate information	Burkina Faso	Soil erosion management practices, herd management practices including destocking, choice of when and where to move cattle, and supplementary fodder procurement and choice of area under crop cultivation
[58]	Gender and climate information service use	Ghana	Choice of suitable crop varieties, scheduling land preparation, planting dates and fertilizer application
[23]	Constraints and usefulness of mobile-based weather and weather information services	Ghana	Scheduling of production activities and informed marketing decisions
[79]	Effect of climate information use on climate change adaptation	Ghana	Although the causal effect was not established, farmers who received weather forecast responded by implementing the following measures: crop diversification, selecting suitable crop varieties and fertilizer as well as altering planting dates
[59]	Climate information services available to farmers	Ghana	Scheduling farm operations such as planting, fertilizer application and harvesting, selection of crop varieties, scheduling irrigation and implement water conservation practices
[12]	Nexus between mobile phone-based weather forecast services and adoption of CSA technologies	Ghana	Water management practices and multiple cropping/crop diversification
[8]	Lessons learnt and challenges in promoting CSA technologies	Ghana, Mali, Niger, Senegal and Burkina Faso	Selection of crop varieties, crop diversification, livestock stocking rate and feeding strategies and investment in irrigation
[75]	Climate information perception and needs	Mali	Scheduling land preparation and planting period, altering grazing practices and herd management techniques, destocking, scheduling fishing activities and choice of fishing location
[17]	Lessons learnt from the use of Participatory Integrated Climate Services for Agriculture (PICSA) in climate risk management	Mali and Senegal	Scheduling planting dates, fertilizer application and harvesting, implementation of soil and water management practices, choice of crop varieties and farm size under cultivation as well as regenerative agriculture techniques such agroforestry.
[80]	Climate change perception and willingness to subscribe to weather forecast services	Nigeria	Altering farm management practices to suit prevailing climate outlook
[74]	Access and use of climate information	Nigeria, Niger, Mali and Burkina Faso	Scheduling planting dates, choosing crop varieties, destocking and changing grazing practices
[11]	Co-production and use of climate and weather forecast information	Senegal	Scheduling farm activities such as time of planting and fertilizer application, use of manure, choice of crop varieties, livelihood diversification and uptake of climate index-based insurance

[35]	Impact of co-production models of climate and information	Senegal	Climate smart farm decisions such as selection of seed varieties
[60]	Needs and factors affecting access to climate information services	Senegal	Make informed decisions including appropriate plating dates and adopting suitable crop varieties,
[10]	Impact of tailored seasonal and daily weather forecasts	Senegal	Adjust farm decisions such as choice of crops and varieties to grow, land allocation, and inputs use
[77]	Lessons learnt from the use of climate information services	Senegal	Choice of crop varieties and field to cultivate, scheduling planting and fertilizer application dates as well as scheduling of fishing activities
[84]	Evaluation of public weather services	Ghana	Planning and altering day-day activities to fit prevailing weather conditions including sun drying food crops such as maize, pepper and cassava
[85]	Adoption of climate smart practices and its effect of farm performance	Ghana	Soil and water conservation practices (to control erosion and drainage), crop choices (uptake of drought tolerant and short season varieties crops)

Table A2: Summary of reviewed articles in Southern Africa

First author, publication year	Main objective	Country of study	Main CSA technologies adopted due to the use of digital climate services
[4]	Impact of climate smart agriculture on household welfare	Zimbabwe	Conservation agriculture, drought tolerant crop varieties, early maturity maize varieties, mulching, use of organic manure and uptake of forage legumes such as velvet bean
[37]	Impact of tailored climate information on farmers' livelihoods	Zimbabwe	Diversification of livelihood activities (including horticulture crops and bee-keeping in addition to field crops) and climate smart livestock management practices
[57]	Factors influencing behavioral intention to adapt to climate change	Zimbabwe	Climate smart farming decisions including choice of crops and varieties to grow
[61]	Role of seasonal weather forecasts on climate change adaptation	Zambia	Production of drought tolerant crops and varieties
[62]	Access and effect of weather forecast information	Zimbabwe	Choice of crop varieties, scheduling planting dates
[64]	Response strategies to climate risks and role of information	Malawi	Soil and water conservation practices, crop diversification, planting drought tolerant crops and varieties as well as early planting
[70]	Access and use of climate information	South Africa	Altering amount and type of fertilizers and herbicides to apply, irrigation, mulching, early harvesting, stopped planting, scheduling farm operations such as land preparation and weeding
[72]	Impact of climate information on adaptive capacity and food security	Namibia	Livestock de/restocking, procurement of livestock feed, moving livestock to other areas, switching to small livestock (goats and sheep), water harvesting, uptake drought tolerant crops, short season varieties and staggering planting dates
[81]	Effects of seasonal climate forecasts	Zimbabwe	Altering planting dates and choice of crop varieties (planting of short season varieties)

TableA3: Summary of reviewed articles in East Africa

First author, publication year	Main objective	Country of study	Main CSA technologies adopted due to the use of digital climate services
[63]	Determinants of access and use of climate information services	Kenya	Changing types and varieties of crops grown, altering area allocated to crop cultivation and planting dates
[71]	Climate risk management information, sources and response strategies	Uganda	Shifting from grazing pasture to the other/ herd migration
[73]	Impact of adopting climate-smart crop varieties and livestock breeds	Kenya	Adoption of drought resilient crop varieties and livestock breeds
[82]	Value of climate forecasts information	Ethiopia and Kenya	Choice of seed varieties, scheduling planting dates,
[83]	Adoption of agro-weather information and CSA technologies	Kenya and Ethiopia	Adopting drought tolerant varieties, short season varieties, intercropping and agro-forestry

Table A4: Summary of reviewed articles in across Africa

First author, publication year	Main objective	Country of study	Main CSA technologies adopted due to the use of digital climate services
[7]	Linkages between climate information services, uptake of CSA technologies and food security	Kenya and Senegal	Although no direct correlation was noted, farmers receiving climate services altered farming practices. Such practices include choice of crop varieties, cattle breeds, agroforestry, intensity of crop diversification and intercropping as well as grazing and crop rotation
[21]	Impact of agricultural weather and climate services	Across Africa	Choice of crops and varieties, scheduling of farm operations including inputs use and planting dates, water conservation practices and (de-)stocking decisions, fodder planting
[51]	The benefits of climate services	Africa and across the globe	Suitable crops and varieties selection
[65]	Access to weather forecasts and changes in farming operations	Uganda, Ethiopia, Kenya, Tanzania, Senegal, Niger, Mali, Ghana and Burkina Faso	Scheduling of farming activities including irrigation, altering input use, choice of crop type and varieties, soil and water conservation and use of manure
[68]	Effectiveness of weather information dissemination	Uganda, South Sudan and Nigeria	Scheduling planting dates, when to apply fertilizers and pesticides as well as irrigation activities

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