Climate Services 34 (2024) 100450

Contents lists available at ScienceDirect

Climate Services

journal homepage: www.elsevier.com/locate/cliser

Review article

Targeting smallholder farmers for climate information services adoption in Africa: A systematic literature review

Rejoice S. Nyoni [a,b,*], Guillaume Bruelle [b,c,d], Regis Chikowo [d,e], Nadine Andrieu [b,f]

[a] CIRAD, UMR INNOVATION, F-34398 Montpellier, France
[b] INNOVATION, Univ Montpellier, CIRAD, INRAE, Institut Agro, Montpellier, France
[c] CIRAD, UMR INNOVATION, Harare, Zimbabwe
[d] Department of Plant Production Sciences and Technologies, University of Zimbabwe, Harare, Zimbabwe
[e] Plant, Soil and Microbial Sciences Department, Michigan State University, East Lansing, MI 48824, USA
[f] CIRAD, UMR INNOVATION, F-97130 Capesterre-Belle-Eau, Guadeloupe, France

ARTICLE INFO

Keywords:
Climate information
Access
Use
Uptake
Value
Resources

ABSTRACT

Seventy percent of smallholder farmers in Africa depend on rainfed farming systems, making them vulnerable to climate variability and extremes. Climate information services (CIS) adoption by smallholder farmers in Africa presents a promising solution for adaptation to climate variability. This paper unravels the complexities around climate services for smallholder farmers and explores opportunities to tailor CIS for the resources of smallholder farmers. We use a systematic literature review approach to assess how the human, social, physical/technical, natural and financial capitals may affect awareness, access and use of CIS by smallholder farmers. The study is based on 33 papers from Africa. Majority of the studies gave emphasis on education, information communication and technology literacy levels and advisory services as influencing CIS access, use and uptake. The results highlight that better resourced smallholder farmers have higher access and are more likely to adopt CIS. The human capital emerged as an important component of CIS adoption as it directly determines how the farmer makes decisions on the farm. The natural capital determines the specific preference for CIS when the financial and economic capitals enable farmers acting according to the information received. The social capital provides a basis for farmers to benefit from compounded resources. Thus, the livelihood resource capitals of the target farmers must be considered in CIS information production and dissemination to improve the chances of CIS adoption by vulnerable groups that is illiterate, women, elderly, farmers in agroecological zones prone to climate extremes and poorly resourced farmers.

Introduction

Over the last few decades, observable shift in climate patterns have been noted, including changes in temperature across the globe and increased occurrences of weather-related disasters (Masson-Delmotte et al., 2021; Thomas and Lopez, 2015; WMO, 2021). Effects of climate variability have great impact on agricultural production systems especially those that are rainfed (Conde et al., 2006; Fellmann, 2012; Ray et al., 2015). The frequent occurrence of droughts, floods and dry spells, coupled with a shift in starting and ending times of agricultural seasons across the globe is causing tremendous yield losses putting countries at risk of famine (WMO, 2022). Rainfall variability culminate in agricultural water scarcity principally in Africa where 94.5 % of the agricultural activities are rainfed (Abrams, 2018; Lemi and Hailu, 2019). Wani et al., (2009), mentions that there is a correlation between water stress and poverty prevalence. In developing countries, crop yield under irrigation is 50 % higher than that of rainfed crops, indicating that farmers who rely on rainfed agriculture are at great risk of crop failure (Jaramillo et al., 2020; Wani et al., 2009). Climate variability causes it to be difficult for the farmers to plan agricultural activities from planting to post harvest and planting choice of cropping pattern each season reducing productivity (Hordofa and Yazew, 2023).

Smallholder famers produce a third of the world's food (Lowder et al., 2021). In Africa, 70 % of the population rely on smallholder farming (Biteye, 2016) based on rainfed agriculture. Hence a large proportion of global population is exposed to an increased risk to food

* Corresponding author at: CIRAD, UMR INNOVATION, F-34398 Montpellier, France.
E-mail address: rejoice.nyoni@cirad.fr (R.S. Nyoni).

https://doi.org/10.1016/j.cliser.2024.100450
Received 1 June 2023; Received in revised form 25 January 2024; Accepted 1 February 2024
Available online 7 February 2024

insecurity as a result of climate variability. Smallholder farmers require sustainable adaptation strategies that assist them to offset the effect of environmental and biological stressors which surfaces as a result of climate variability (WMO, 2022). This makes the smallholder farmer a key target for climate information services as a resilience building tool against climate variability.

In the recent past, global efforts have been made to find ways to adapt to climate variability through the provision of climate information services to farmers. The World Metrological Organization in 2009 formed the Global Framework for Climate Services bringing together governments, researchers and service providers to map a policy framework for the coordination of climate services at a national, regional and global level (WMO, 2011). Climate information services involve the transformation of climate related data into products and information for decision making in various organizational settings of the society (Directorate-General for Research and Innovation (European Commission) et al., 2015). The products can be in form of forecasts, projections, agronomic advice, rainfall trend analysis, early warning services and sustainable approaches (Warner et al., 2022). The most popular type of climate information service distributed is the early warning which was triggered by frequent occurrences of droughts and floods in the past two decades (WMO, 2020).

Promoting CIS as an intervention to mitigate the effects of climate variability requires understanding smallholder farmers and farm characteristics, then actively involving them in the design and targeting of CIS (Carr et al., 2020). A number of studies have been conducted on *Awareness* (Knowledge or perception of CIS), *Access* (obtaining CIS via different channels of communication), *Use* (application of climate information in farm management decisions), *Value* (benefits or importance attributed to CIS by farmers (Tall et al., 2018)), and *Uptake* (adoption of CIS as an integral component of farm decision making in climate adaptation) (Birachi et al., 2020; Bullock and Katothya, 2022; Tarchiani et al., 2021). Research on production of tailored CIS mainly focus on the needs of the farmers (Nkiaka et al., 2019). Nevertheless, Carr et al. (2020) mentioned that it may not be possible for farmers who have never been exposed to CIS or who have little knowledge on CIS to be able to articulate their information needs. Studying the factors that promote uptake and use of CIS is therefore fundamental in developing a profile of CIS that is adaptable to farmers. In a recent literature review, Warner et al. (2022) detailed 22 factors influencing the use of climate information services for agriculture under three thematic areas which are i) demographic socio- cultural, ii) programming mechanisms (CIS program design and quality) and iii) institutional support and community resource allocation factors. However, it is necessary to understand how all the livelihood assets of the smallholder farmers in Africa influence the adoption of CIS.

Smallholder farmers generally have fewer asset resources at their disposal (Rapsomanikis, 2015). The sustainable livelihood approach is used to understand the elements that improve or diminish the livelihood opportunities providing an evaluation going beyond the individual's resource map to the farm structure (Quandt, 2018; Serrat, 2017; Ulukan et al., 2022). This approach can be used to assess how agricultural technologies fit into the livelihood strategies of households or individuals (Adato and Meinzen-Dick, 2002). An emphasis is made on the combination of financial, natural, physical, human and social resources in a particular setting, determining the combination of livelihood strategies that farmers implement and their outcomes (Serrat, 2017). The role of the institutions and social structures in supporting the implementation of the strategies is of major importance.

This study reviews existing literature to assess how the human, social, technical, and financial capitals may affect awareness, access, use, value, or uptake of CIS by smallholder farmers. The focal point of the study is on the African countries. The study uses a systematic literature review approach to address the research objective.

Methodology

The systematic literature review method was selected to address the research objectives. Specifically, the research followed the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines which set out steps for synthesis of existing literature while maintaining a high level of scientific integrity, transparency and reproducibility of the results (Page et al., 2021).

Search

The literature search was conducted in two journal databases, Scopus and Web of Science to broaden the scope of the search. The objective of the search was to understand the livelihood assets that contribute to the adoption of CIS (including awareness, access and use). The search terms were selected firstly to include all the various types of CIS (forecast, weather, agroclimatic information, forecast, weather, rainfall). Secondly, terms related to the study objective (smallholder, farm), and lastly the type of scientific studies on the topic of CIS (impact, evaluation, assess).The specific key words used in the search were "Climate services", "Climate information", "Agroclimatic information", "Forecast", "Weather", "Rainfall", "Farm", "Smallholder", "Impact", "Evaluation", "Assess" and the search was limited to peer-reviewed research and review articles forming the following equation:

(TITLE (("climate service" OR "climat* information" OR "agroclimatic information" OR forecast* OR weather OR rainfall) AND (farm* OR smallholder*)) AND ABS ((impact* OR assess* OR evaluat*))) AND (LIMIT-TO (DOCTYPE, "ar") OR LIMIT-TO (DOCTYPE, "re"))*

The "*" used to identify the words with the same stem in either the title or abstract and the search was limited to document types "ar" articles and "re" reviews. The total number of articles that were retrieved from both databases was 523 and after the removal of duplicates, 302 unique articles were subjected to the abstract screening.

Screening

The criteria for inclusion of articles into the study was 1) Articles documenting the design and implementation of climate/weather information services in agriculture, 2) Articles addressing user awareness or access or value or uptake or use or impact of CIS 3) Articles including a description of the target population and the farm settings. The screening was not based on the research methodologies and study designs. A total of 69 articles were selected for full text screening. Thirty-three articles were selected as eligible for the study; these were studies that included a description of the targeted population and the farm settings. However, the study focused on 21 papers from Africa shown in Fig. 2 and 12 papers from Asia, North and South America were used as supporting evidence in the discussion. Fig. 1 shows the detailed screening process of the articles. Afterwards, the snowball method (Sayers, 2007) whereby we looked for relevant articles cited in the 21 papers from Africa was then employed. This ensured that we capture most of the relevant literature in our study to support arguments in the discussion. An additional 12 papers from Africa were included from the snowball method shown in Appendix 3.

The list of publications selected for the study is provided in the Appendix 2.

Data extraction and analysis

According to Jacobs et al. (2016), a household is supposed to have a balance of the five capital resources in order to maintain adaptive capacity which is the ability to withstand the impact of climate change. In this case to increase chances of adoption of CIS for making decisions on the farm, we assessed how the presence or absence of the attributes of the five capital resources plays a role in awareness, access, use, and uptake of CIS as an integral part of the farming system.

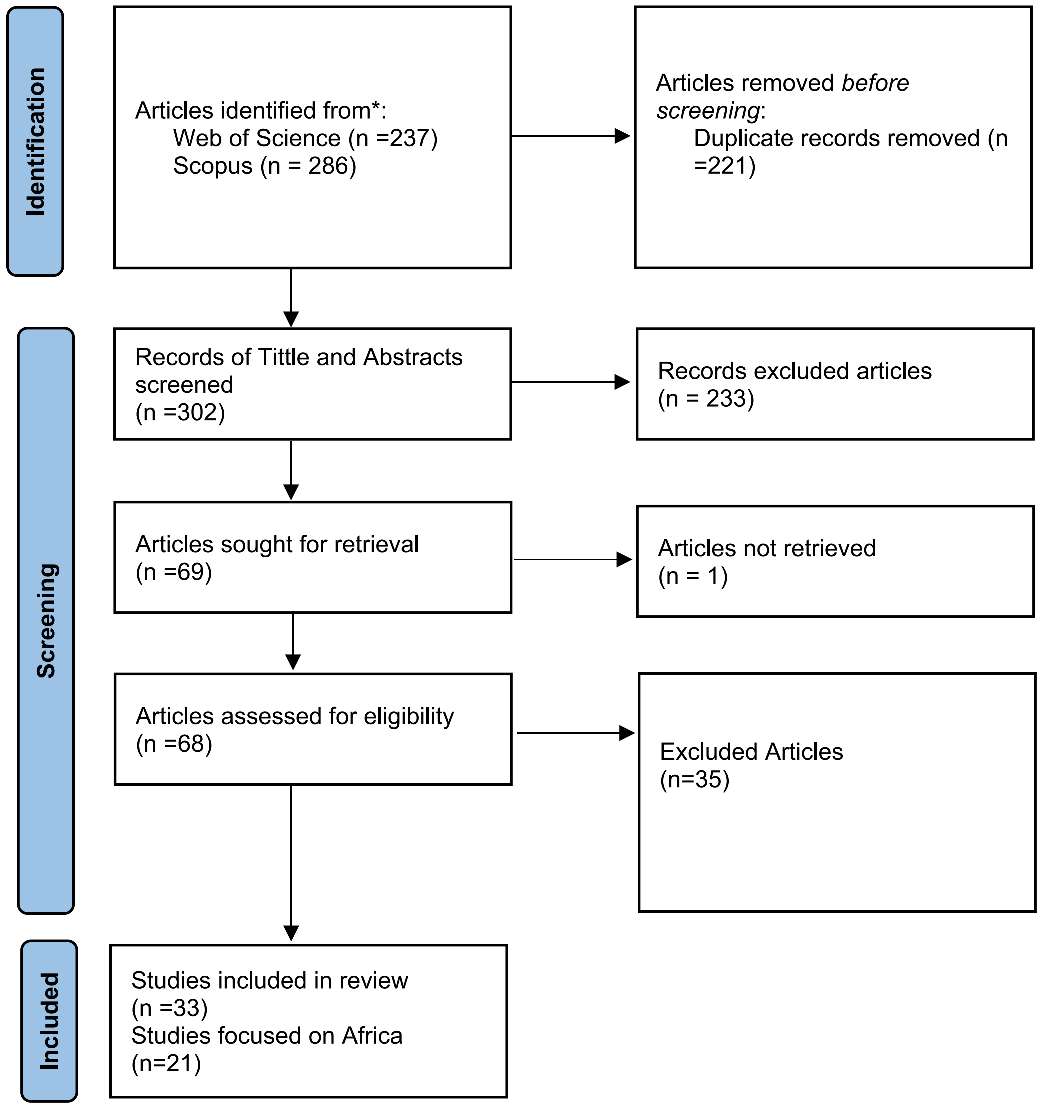


Fig. 1. PRISMA flow diagram showing selection and screening process of the articles included in the review (Page et al., 2021).

The farm and farmer characteristics identified from the papers were classified under the five livelihood capital resources. Table 1 highlights the main component generally associated to each capital resource based on studies focusing on the sustainable livelihoods' framework. The table also describes the specific criteria we used to classify the resources based on the farmer and farm attributes in the reviewed papers, 18 farm and farmer attributes were considered.

The financial and physical capitals were merged due to the similarities following Scoones (1998) in the analysis.

The selected articles were then reviewed, extracting information on region of study, type of climate information, and the attributes presented in Table 1 with regards to their effect on awareness, access, or use and CIS. The information was extracted into Excel for data analysis (descriptive statistics). CorText (https://www.cortext.net/) was used for network mapping of the most occurring terms in the reviewed articles using the title, abstract and keywords.

Results and discussion

Attributes of the reviewed papers

The articles used in the literature review gave emphasis on climate change, climate forecasts, climate information production, dissemination and the focus on subsistence farming as shown in Fig. 3. The network mapping pointed out important themes and indicators under three livelihood capitals; *human capital* – emphasis on level of education and ICT (information communication and technology) literacy, indigenous knowledge, attitudes, *social capital* – advisory services and *natural capital* – farm size, farm management.

In most of the studies, farmers received short term weather forecasts ranging from daily to 2–7 days forecast and seasonal climate forecasts Fig. 4; (Chiputwa et al., 2020; Muema et al., 2018; Muita et al., 2021; Ncoyini et al., 2022). Most farmers were interested in receiving information on the start and cessation session of the rainfall season in addition to the expected amount of rainfall for the season (Nyadzi et al., 2019; Sutanto et al., 2022).

The five livelihood capital resources affecting CIS adoption

It was of interest to understand how different capital assets smallholder farmers possessed influenced their awareness, access, use and finally uptake of CIS within the different studies. A summary table of farmer attributes discussed under the five capitals is found in Appendix 1 showing the different types of CIS provided for each study.

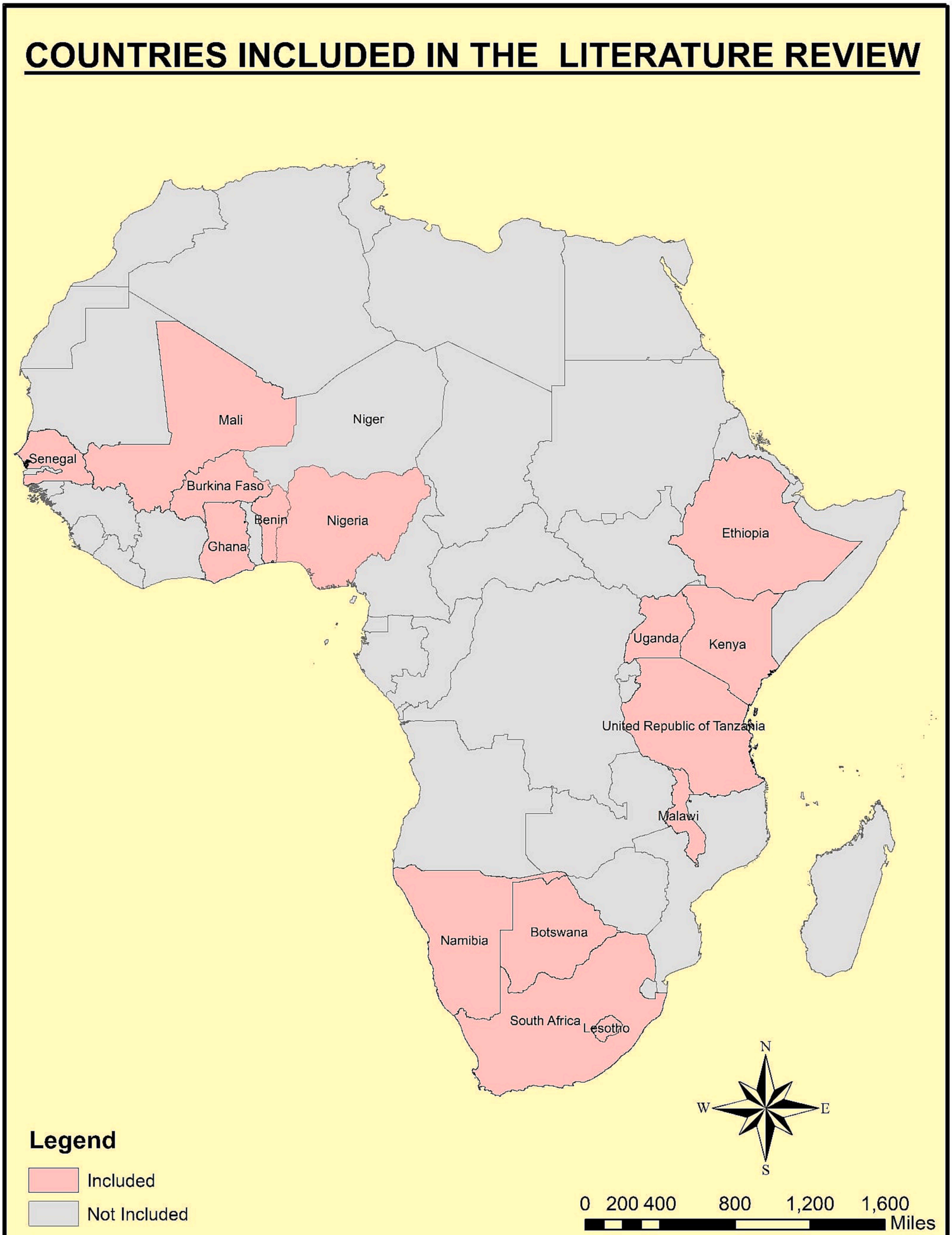


Fig. 2. The map of showing countries included in the study (*Diagram be published in colour*).

Table 1
Components of five capitals of the Sustainable Livelihoods Framework.

Type of capital	Components from the literature	Attributes considered in the synthesis	Reference
Natural	Farm size, annual rainfall, herd size, water resources, soil fertility, grazing resources, land quality and quantity	Farm size, farming systems, crop species, agro-ecological zone	Campbell et al., 2001; Erenstein, 2007
Financial/ Economic	Savings, credit societies, state transfers, remittances, farm size, heard size	Access to capital, credit, subsidies, hired labour, off farm activities	Adato and Meinzen-Dick, 2002; Erenstein, 2007
Physical	Household assets, agricultural implements, infrastructure, technology and communication	Ownership of communication gadgets	Adato and Meinzen-Dick, 2002; Campbell et al., 2001
Human	Skills, labour, education, female literacy, knowledge	Age, farming experience, household size, education, gender, exposure to prior climate shocks	Adato and Meinzen-Dick, 2002; Erenstein, 2007; Scoones, 1998
Social	Social networks, affiliation, cooperative societies, leadership, ethnic networks	Group affiliation, extension services	Erenstein, 2007; Scoones, 1998

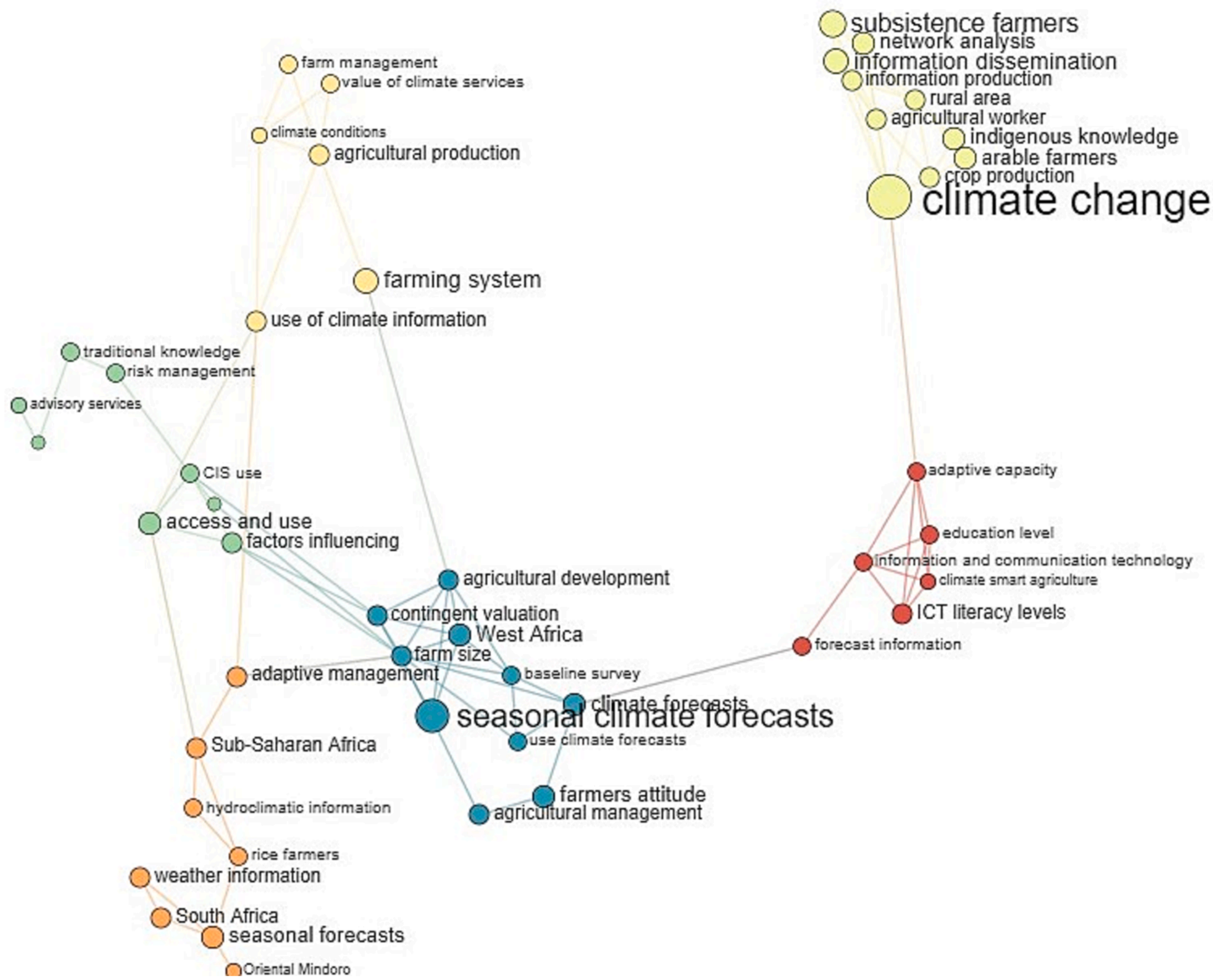


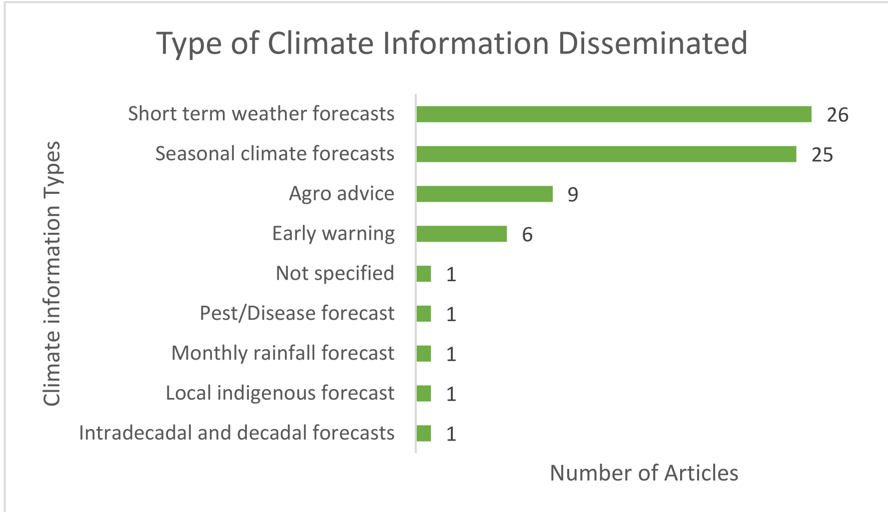
Fig. 3. The most occurring terms in the 33 articles included for the literature review (*Diagram be published in colour*).

Human capital

The synthesis shows that the human capital which consists of age, farming experience, prior exposure to climate risks, education level, household size and gender determines how a farmer become aware of, access, use and adopt CIS. The human capital directly influences how the farmer makes decisions hence education increases the chance of adoption of CIS (Anang et al., 2020). We looked closely at each of the components of the human capital:

Age, Farming experience and prior exposure to climate shocks

The age of the famer was observed to markedly influence access and use of CIS positively or negatively depending on the community, education level and farming experience of the farmers. Muema et al. (2018), in a study conducted in arid and semi-arid regions of Kenya, highlighted that the age of the farmer is correlated to reduced access to climate services. As the age of the farmer increases so does the farming experience, leading to a lesser dependency on climate services (Muema et al., 2018). Older farmers generally have a good appreciation of indigenous knowledge indicators (Gbangou et al., 2020; Kolawole et al., 2014). In contradiction, in a study done in Clarendon, Jamaica, Buckland and Campbell (2021) found that older (greater than 50) and middle aged (30–49) farmers were more aware and had greater access to CIS compared to young farmers. This was due to the fact that older farmers



Row Labels	Count of Type of CIS
Intradecadal and decadal forecasts	1
Local indigenous forecast	1
Monthly rainfall forecast	1
Pest/Disease forecast	1
Not specified	1
Early warning	6
Agro advice	9
Seasonal climate forecasts	25
Short term weather forecasts	26

Fig. 4. Summary of the type of Climate Information distributed to farmers in the reviewed papers.

were likely to be part of institutions and more elderly people were likely to be committed to farming as a livelihood source. In the same study, they showed that younger farmers were more likely to use online forms of CIS than older farmers despite their higher access and awareness. The age of the famer coupled with low literacy level may hinder the desire to learn and understand information communication technologies (Alant and Bakare, 2021).The findings of Alidu et al. (2022), in a study conducted in Ghana shows that middle aged (approximately 40 years old) farmers who also had more years of education had better access to climate information and would implement climate adaptation strategies. Older farmers were also shown to not value CIS due to improved farming experience, however training achieved positive results (Paparrizos et al., 2021a).

Farming experience gained over a period of time in the same location causes the farmer to rely more on their own knowledge as they perceive that the scientific forecast sources are inaccurate (Antwi-Agyei et al., 2021b; Chisadza et al., 2020; Kabobah et al., 2018). A low degree in reliability, accuracy, timeliness and inequitable distribution of weather and climate forecasts translate to reduced confidence in the information hence low uptake (Antwi-Agyei et al., 2021b; Jiri et al., 2016; Ziervogel et al., 2005). Older farmers with low education level and more farming experience mostly rely on indigenous knowledge as compared to scientific forecasts (Kolawole et al., 2014; Muema et al., 2018). Nevertheless, the shift in the seasonality and frequent occurrences of droughts are causing farmers to turn to scientific forecasts (Jiri et al., 2016; Partey et al., 2020). In most of the articles reviewed, older farmers were low users of CIS than younger farmers attributed to their farming experience (Antwi-Agyei et al., 2021a; Muema et al., 2018). In contrast, some studies show that increased farming experience enhances use of CIS due to improved knowledge (Antwi-Agyei et al., 2021a; Djido et al., 2021).

Prior exposure to drought conditions reduced the likelihood of utilizing CIS by 15 percent due to lack of confidence in CIS and also a shift from concentrating on farming as the only source of livelihood in the case of Machakos county in Kenya (Muema et al., 2018).

Education

The consideration of the education level is important in the design of CIS in Africa as it determines how the farmer perceives and understand the information related (Partey et al., 2020). Education improves the farmer's ability to seek for information and participate in agriculture extension activities (Anang et al., 2020).The more literate farmers were more skilled in using weather and climate tools such as phone applications and rain gauges compared to farmers with lower literacy (Gbangou, 2020). As a result, the literate farmers have better access to information through various channels and can utilize the information. Higher levels of education allow farmers to adopt CIS and its technologies (Kumar et al., 2020; Muita et al., 2021). Education was also noted to be an important factor in determining use and perception of CIS (Austen et al., 2002; Chiputwa et al., 2022; Djido et al., 2021). Buckland and Campbell (2021) highlighted that all the farmers in the study area who were using modern media had attained secondary level of education showing the significant role of education in CIS access and use. In contrast, research conducted in Botswana revealed that in some communities, indigenous forecasts (knowledge from local cultural observations (Roncoli et al., 2002)) are most preferred because they are easy to understand and no formal education is required in the interpreting the forecasts (Kolawole et al., 2014). Low literacy level creates difficulties in accessing information particularly due to language barriers, lack of understanding and inability to access information shared online (Cinco et al., 2020; Kumar et al., 2020; Ncoyini et al., 2022). The language barrier has also been reported as crippling the rapid delivery and use of climate information (Antwi-Agyei and Stringer, 2021). Education and training had a positive influence on the value farmers give to CIS

(Lechthaler and Vinogradova, 2017; Paparrizos et al., 2021a).

Education was a key characteristic which influenced awareness, access, use and uptake of climate information (Alidu et al., 2022; Oyekale, 2015). Hence, Tall et al. (2014) suggested that weather information must be accompanied by decision making information which is explicitly articulated in a language that is understandable for users. Dayamba et al. (2018) also proposes that the use of participatory approaches to raise awareness and to disseminate climate information can overcome this barrier.

Gender

In Africa, ownership of resources is influenced by the patriarchal norms, this reduces the chances of female famers having access and use to CIS due to limited capital resources (Amenyah and Puplampu, 2013; Antwi-Agyei et al., 2021a; Warner et al., 2022). Females farmers had a notable lower usage of CIS in the reviewed articles (Buckland and Campbell, 2022; Henriksson et al., 2021; Oyekale, 2015). Henriksson et al. (2021) pointed out that twice as much women than men did not have access and did not use CIS in a study conducted in Malawi, as similarly observed by Oyekale (2015) in a baseline survey conducted in East and West Africa. Furthermore, they were observed differences in the preferred channels of receiving CIS. Women preferred to receive information through village leaders, extension officers, out grower management and SMS whilst men preferred SMS, internet, newspapers and mobile applications (Henriksson et al., 2021; Oyekale, 2015). However, Muema et al. (2018) in a study in Kenya also noted that female headed households had a higher chance of utilizing CIS in comparison with male headed households. This may be accounted for by the fact that there is a higher percentage of women in farming rural communities in the study area. Additionally, in another study women had the responsibility of identifying indigenous knowledge bio-indicators within their environment (Muita et al., 2021). The different household roles and cropping strategies of man and women also determine the type of information both genders require (Carr and Owusu-Daaku, 2016). In a study by Ngigi and Muange, 2022, due to gender preferences, men required information on rainfall patterns and women required information on local specific forecasts for their decision making.

Improving equity of CIS by providing channels of information that are readily accessible to both genders can improve the uptake of information (Gumucio et al., 2018; Tall et al., 2014a). Considering gender roles, cultural structures and education levels within a community can aid the CIS providers in designing the best dissemination channels which are context specific.

Household size

Household size translates to the readily available family labour within smallholder farming systems (Rapsomanikis, 2015).The household size proved to influence access of CIS information. The bigger the household size, the greater the likelihood of accessing CIS (Muema et al., 2018). Smaller families have a low chance of accessing CIS. Ndamani and Watanabe (2016) outlines that larger households are more likely to employ adaptation strategies to climate change due to the presence of unpaid family labour. A large household presents a greater opportunity to access and share CIS, however there are also increased chances of misinformation (from non-official sources) resulting in failure to use the CIS (Ngigi and Muange, 2022).

Natural capital

The natural capital focused on the agroecological zone, nature of crop and livestock grown on the farm, and farm size. The agroecological zone of the farmer shapes how they perceive and use CIS (Carr and Owusu-Daaku, 2016).The farm size is generally linked to land access. Smallholder farmers are affected by unsecure land rights and own smaller land sizes. This has a negative effect on the use and uptake of CIS (Ofori-Kyereh et al., 2023; Partey et al., 2020).

Agro-ecological zone

The agro-ecological zone plays a role in influencing the farmers' use and uptake of CIS. Farmers in rainfed arid and semi-arid regions are more aware, use and value CIS more than farmers in humid regions due to increased risk of crop failure (Carr and Owusu-Daaku, 2016; Muita et al., 2021; Ouedraogo et al., 2022). Farmers perceptions to CIS are based upon previous experiences of climate extremes and their local conditions (Guido et al., 2020), hence the need to improve the temporal (onset and cessation of rain season) and spatial resolution of forecasts on a field scale (Chisadza et al., 2020).

Farming systems and animal and crop species

The specific nature of cropping and livestock systems tightly linked to the agroecological zone was found to influence awareness, access and use of CIS. Vegetables farmers (short cycle crops) were 16 times more likely to be aware and access CIS from the radio and television compared to long term crops (avocado, coconut, bananas, yams) (Buckland and Campbell, 2021). Increased potential use of CIS was also recorded on vegetable, fruit producers and row crop farmers (Templeton et al., 2018). Root crop farmers had the lowest CIS uptake. Austen et al. (2002) also noted differences in use of CIS by farmers in the three different locations in South-east Australia depending on their product line. Introduction of new or a change in crop varieties and crop species planted by farmers may also prompted the use of CIS (Crane et al., 2010). Farmers' decision making is also usually linked to specific growth stages of a particular crop (Nyadzi et al., 2019). Livestock farmers preferred a combination of indigenous forecasts and scientific forecasts compared to crop farmers (Nkuba et al., 2020). Particularly the livestock farmers use the information to select adaption strategies such as destocking in the event of climate extremes. Crop farmers with crops such as cereals which are sensitive to water stress are less tolerant to inaccurate forecasts. This causes low uptake in the event that the forecasts received by farmers has a low level of accuracy (Nkuba et al., 2020).

Ouedraogo et al. (2022) suggested that CIS providers provide crop specific and livestock advisory services that target agroclimatic regions and specific crops grown in the communities to enhance the uptake of CIS. Farmers can benefit more from forecasts which assists them to make decisions on their specific farming enterprise. Livestock or crop specific information reduces the probability of losses and increases reliability of the information.

Farm size

Farm size tends to have a positive influence on access to CIS, larger farms had increased access to CIS (Muema et al., 2018; Oyekale, 2015) due to the magnitude of loses (Onyeneke et al., 2023). Furthermore, larger farms have an increased capacity to adjust farm activities according to the climate information. Bigger farms are more likely to adopt climate change mitigation practices while maintaining their profitability (Ogisi and Begho, 2023). However, Amegnaglo et al. (2017) observed a negative relationship between farm size and uptake of CIS on the farm which he attributed to increased diversification on bigger farm which acts as a buffer to climate variability. Coffee farmers with bigger farm size placed more value on CIS as compared to those with smaller sizes (Lechthaler and Vinogradova, 2017). This emphasizes the importance of the farm size and enterprise on the use of CIS.

Social capital

The social capital resources which in this case consisted of group affiliations and access to agriculture extension officers play an important role in the adoption of sustainable farming practices which in this case is the CIS. They facilitate the adoption of CIS and enable sharing of the other four capital resources (Dapilah et al., 2019; Jacobs et al., 2016). The social capital is key in how the smallholder farmers perceive, access and use the CIS through interactions with other farmers, trainings and contact with agriculture extension.

Group affiliation

Affiliation to a group increased the likelihood of accessing and uptake of CIS because social groups promote networking hence access to information is enhanced (Chiputwa et al., 2020; Kumar et al., 2020; Muema et al., 2018; Ruzol et al., 2020). Buckland and Campbell (2021) noted that farmers who are members to a group had a likelihood of 15 times more to access CIS than nonmembers through online bulletins. Extension workers often engage with farmer groups providing CIS, promoting its use and uptake (Buckland and Campbell, 2021). Uptake of information is also influenced by the availability of resources to action on the CIS which are made accessible through farmer groups and institutions that pull resources together or have access to external support and funding.

Extension services

Availability of extension services to farmers greatly influences awareness, access, use and uptake of CIS (Satishkumar et al., 2013). Extension officers advise farmers on the available sources of information and also assist in interpreting the information to farmers (Amegnaglo et al., 2017; Buckland and Campbell, 2021; Muita et al., 2021). Access to extension services also increases the willingness to pay in contingent valuation of CIS implying increased value. On the contrary distrust in extension services and communication will result in low uptake and use of CIS (Guido et al., 2020; Ncoyini et al., 2022). Face to face sources are preferred in some communities because they give assurance of the credibility of the information to farmers (Kumar et al., 2020).

In a study conducted on extension services in Africa, Antwi-Agyei and Stringer, (2021) showed that agriculture extension officers were often hindered from serving the whole community due to the large number of farmers they have to assist. This results in the extension officers concentrating on well-resourced farms. The agricultural extensionists also require training to improve their capacity to assist farmers to access and use CIS in their communities as they influence the farmers adoption of CIS (Etwire et al., 2017). Engaging farmers in local farmer groups and farmer field schools where they receive information and discuss how climate change impacted their productivity, was found to favor farmers' adoption of CIS (Paparrizos et al., 2021b; Rhiney and Tomlinson, 2017).

Financial/economic capital and physical capital

The financial and physical capital were combined to include access to capital, credit, subsidies, hired labour, off farm activities and communication gadgets. The synthesis revealed that these resources mainly hinder the access to CIS as some farmers have no access to communication gadgets or technologies (Muema et al., 2018; Muita et al., 2021; Ngigi and Muange, 2022). Furthermore, after access the use and uptake of CIS is mainly anchored on these resources (Warner et al., 2022). The farmer requires credit, labour and the desired farm inputs to act on the information (Gitonga et al., 2020; Ngigi and Muange, 2022). Farm size denotes the farmers' financial capital, a bigger land size allows the farmer to produce more for profit and also diversify the farming enterprises. Hence affect the use of CIS. Some of the smallholder farmers in Africa are affected by unsecure land rights and own smaller land sizes (Muita et al., 2021). This has a negative effect on the use and uptake of CIS (Ofori-Kyereh et al., 2023; Partey et al., 2020).

Access to capital, credit, subsidies, hired labour, off farm activities, ownership of communication gadgets

Radio, television, mobile phone ownership and in some cases access to a community radio station also increase the likelihood of a farmer to access and be aware of CIS (Amegnaglo et al., 2017; Muema et al., 2018; Muita et al., 2021; Oyekale, 2015). The presence of an external off-farm source of income increased the probability to access CIS by 7 percent in the study done by Muema et al. (2018). Less resourced smallholder farmers that use most of their time looking for food are less likely to access CIS (Antwi-Agyei et al., 2021a). The same results were also recorded by Buckland and Campbell (2021) showing increased access to online platforms by farmers with an alternative source of income and farmers with larger land sizes. Total dependency on farming as a source of livelihood also had the same effect, as farmers seek to maximize their gains. Access to improved seed, subsidized farm inputs, credit, hire labour, land ownership increases access, utilization and value of CIS (Amegnaglo et al., 2017; Moeletsi et al., 2013; Ncoyini et al., 2022; Nkuba et al., 2020; Vogel, 2000).

Accessing CIS in most communities require resources such as televisions, radio and mobile phones. However, despite the improved levels of acceptance of the mobile phones, access to CIS via mobile phones in Africa is still limited. A survey by GSMA (2020) showed that smart phone adoption was 45 % in Africa as of year 2019. Furthermore, the distribution of the smartphones among the urban and rural populations is not balanced making it a less reliable channel to access CIS by farmers (Simelton and McCampbell, 2021). This emphasizes the point of raising awareness of new technologies including the mobile phones and to develop user friendly interfaces in local languages to engage farmers in all regions. Simultaneously, information disseminated through the traditional media (radio and television) should be more location specific, accurate and easier to understand as they are the most preferred channels of access by most farmers in Africa (Oyekale, 2015; Satishkumar et al., 2013; Vogel, 2000). Establishment of community radios in farming communities across Africa may enhance the use and uptake of CIS as an easily accessible channel (Al-hassan et al., 2011; Khan et al., 2017).

Practical implications for smallholder farmers

There is no single best way that perfectly suits all the users but climate service providers benefit from having the knowledge of the various users and conscientiously design targeted CIS. The five capital resources outlined the key idealistic resources that when present, a farmer is better positioned to adopt CIS. However, a large number of smallholder farmers in Africa may not have all the capital resources at their disposal. There are some underserved groups who are in the need of the CIS and may be excluded from accessing the information such as women, illiterate, families more vulnerable to climate extremes in arid agroclimatic zones, the elderly and poorly resourced farmers (Archer, 2003; Carr and Owusu-Daaku, 2016). Land is generally the most limiting resource of smallholder farmers, farmers with smaller farming land area and have non-farm-based income have less access to CIS increasing their risk to climate variability, yet there are less likely access CIS. Based on the sustainable livelihoods approach, CIS design should consider these underserved groups when selecting dissemination channels and packaging the information to be accessible to all users. Successful CIS is directed at specific users to cater for specific vulnerabilities.

Provision of CIS on its own is not enough for smallholder farmers in Africa to put the information to practical use. Efforts to strengthen the social capital and human capital resources of smallholder farmers for CIS can be made through the use of participatory methods such as Participatory Integrated Climate Services for Agriculture (PICSA) (Clarkson et al., 2019; Dayamba et al., 2018). This allows smallholder farmers to meet and be trained on the use and interpretation of climate and weather forecasts in groups hence social networks are formed (Antwi-Agyei et al., 2021a). The social networks also favor sharing and regularizing the indigenous knowledge and climate and weather information (Kreft et al., 2023; Sprout, 2022). In turn, this bridge the education gap, resulting in an increase in the adaptive capacity of the farmers to CIS. Taking advantage of the vast experience farmers may have on the indigenous forecasts, providing concurrent indigenous forecasts with scientific forecasts can cater for the short falls of both types of forecast (Roncoli et al., 2001) Partnerships with gender sensitive local organizations can assist in the design of CIS which suits the local context of women.

On improving the physical capital resources of the farmer, National Frameworks for Climate Services (NFCS) must ensure the development of decentralized weather stations to cater for more accurate and point specific information. There is need to improve communication infrastructure since the radio and telecommunication platforms have become the major dissemination channels for CIS.

National policies that allow farmers to have access to input subsidies, insurance services and credit improve the smallholder farmers financial resources, leading to adoption of climate change adaptation strategies

(Abid et al., 2017; Ruben et al., 2019). Agricultural inputs suppliers should be actively involved in raising awareness and distribution of CIS. CIS can be bundled with other services and the supply of well labelled products such as seed that assists farmers in decision making with regards to climate information. Smallholder farmers in remote areas also benefit from instore advice from agro-dealers.

Conclusion

The review outlined 18 attributes of the farm and the farmer that determine awareness, access, use and uptake of CIS, classified under the different capital resources namely natural, financial, physical, human and social. The farm and farmer attributes that were assigned to the five capital resources are not limited only to the 18 discussed in this paper.

The adoption of climate information services as an adaptation strategy to climate variability by smallholder farmers in Africa is key in ensuring sustainable farming systems. The five capital resources provide a frame of the key idealistic attributes that a smallholder farmer should possess to increase their chance of adopting CIS for decision making in their farming system. The sustainable livelihoods approach brought to attention that CIS are mostly fused to farmers having better resources such as access to education, ownership of information communication and technology devices, access to off farm income and credit, members of groups and have access to agricultural extension officers. This result questions the adequacy of the current CIS to smallholder famers particularly in Africa.

Finally, participatory approaches could contribute significantly to the social and human capital resources by closing the education gap through farmer trainings and group affiliations. Policies to support farmers to adapt to climate change can be made by governments that allow smallholder farmers to have access to credit and input subsidies improving the financial capital resource.

CRediT authorship contribution statement

Rejoice S. Nyoni: Conceptualization, Methodology, Data analysis, Writing – original draft, Writing – review & editing. **Guillaume Bruelle:** Conceptualization, Methodology, Data analysis, Supervision. **Regis Chikowo:** Writing – original draft, Validation. **Nadine Andrieu:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Rejoice Nyoni reports financial support was provided by RAIZ project.

Data availability

No data was used for the research described in the article.

Acknowledgement

Funding: This work was supported by the Resilience Building through Agroecological Intensification in Zimbabwe (RAIZ) project, EU funding.

Appendix 1. Summary of the attributes of the classified under the five capital resources and their influence on adoption of CIS

Attributes of the five capital resources	Awareness	Access	Use	value	uptake
Age	The age group 30–39 yr has the relative highest awareness and 20–29 yr age group has relatively high awareness of online CIS (Buckland and Campbell, 2021)	Farmers above age 50 were less likely to use multiple CIS Age of HH head is correlated with reduced likelihood of access to CIS (Muema et al., 2018; Oyakale, 2015)	Negatively and inversely proportional to ICT proficiency (Alant and Bakare, 2021)	Age was negatively correlated to WTP, but participatory training can offset the age effect (Paparrizos et al., 2021)	Uptake is relative to other variables. Intergenerational gaps in ICT literacy plays a role in uptake (Buckland and Campbell, 2021)
Education	Increase in education level is likely to result in a farmer being more aware of scientific weather knowledge (Kalawole et al., 2014)	Probability of accessing forecasts increased with attainment of education (Oyakale, 2015)	Those who used CIS through modern media had a secondary-level education (Buckland and Campbell, 2021). Higher education levels increased use of CIS (Muita et al., 2021)	Education positively influences willingness to pay (Paparrizos et al., 2021)	Having informal education/ illiteracy reduced uptake (Muita et al., 2021)
Gender	Some studies show no significant differences in awareness to CIS by gender. Buckland and Campbell (2021), however shows that it depends on the social structures in a community.	Men had more access to weather forecasts than women (Oyakale, 2015). There are differences in how man (newspaper, SMS, WhatsApp or internet) and woman (community leaders, SMS, the out-grower management and extensionists) prefer to access information (Henriksson et al.,2021)	In general females had a greater tendency to use multiple sources than males (Buckland and Campbell, 2021)Females had low use of CIS (Buckland and Campbell, 2021; Henriksson et al.,2021) Female HH had a higher likelihood of utilizing CIS (Muema et al., 2018)Man and woman differed in use of CIS. (Muita et al., 2021)	There is no significant difference in value of CIS between gender (Paparrizos et al., 2021)	Man and woman differed in uptake of CIS (based on literacy levels and access). (Muita et al., 2021)
Household Size	Increase in household size increases awareness of CIS (Muema et al., 2018)	Increase in household size increased likelihood to access CIS (Muema et al., 2018) and the opposite was observed in East Africa (Oyakale, 2015)	Bigger households are likely to adopt CIS due to presence of labour (Muema et al., 2018)		Bigger households are likely to adopt CIS due to presence of labour (Muema et al., 2018)

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Attributes of the five capital resources	Awareness	Access	Use	value	uptake
Community/ Institution Membership/ NGOs	Increased awareness (Roncoli et al., 2009)	Improves access to online sources (Buckland and Campbell, 2021), increased access (Muema et al., 2018; Access to multiple sources of information e.g early warnings (Ruzol et al., 2020). Social networks are important in accessing IK (Kolawole et al., 2014)	Membership to an institution influences use of CIS. (Chiputwa et al., 2020)	Membership to a group or institution increases the value of CIS to a farmer (Chiputwa et al., 2022: Paparrizos et al., 2021)	Membership to an institution influences uptake of CIS positively (Roncoli et al., 2009: Muema et al., 2018; Chiputwa et al., 2020)
Farming experience	It is positively correlated to increased awareness of local knowledge (Kolawole et al., 2014)	Negatively and inversely proportional to ICT proficiency (Alant and Bakare, 2021)	The use of CIS may decrease with more farming experience (Oyekale, 2015: Muema et al., 2018)		The probability of CIS uptake reduces with more farming experience (Muema et al., 2018)
Farm Size	Larger farm sizes had greater likelihood of being aware (Buckland and Campbell, 2021)	Farmers with larger farm sizes had greater likelihood of having access A unit increase in farm size increased the likelihood of accessing climate information services by 2.3 % (Muema et al., 2018)	Increase in size decreases likelihood of adoption (Amegnaglo et al., 2017	Positive influence on Willingness to Pay (Amegnaglo et al.,2017	Uptake of CIS is greater in smaller farms to buffer climate variability (Amegnaglo et al., 2017)
Crop	Vegetable farmers are more likely to be aware of CIS (Buckland and Campbell, 2021)	Vegetable farmers are more likely to access CIS (Buckland and Campbell, 2021)	Crop variety determines use of specific information and timing (Nyadzi et al., 2018; Nkuba et al., 2020)	Farmers producing crops of higher value tend to value CIS more.	If scientific forecasts are not accurate farmers resort to IF for their crop management (Nkuba et al.,2020)
Access to financial capital, and land ownership	Increase probability of awareness of CIS (Oyakale, 2015)	Access to capital improved use of CIS (Muita et al., 2021; Oyakale, 2015)	Increase the use of CIS when available (Muema et al.,2018), constraint to use when unavailable (Vogel, 2000)	Access to credit increases the WTP amount significantly (Amegnaglo et al.,2017	Sharecropping may decrease uptake of CIS (Vogel, 2000), land ownership enhances uptake of CIS (Nkuba et al., 2020)
Extension services	Extension services improves awareness of CIS (Buckland and Campbell, 2021)	Increases access (Amegnaglo et al., 2017: Buckland and Campbell, 2021; Satishkumar et al., 2013; Ncoyini et al., 2022)	Increases Use (Amegnaglo et al., 2017: Buckland and Campbell, 2021; Satishkumar et al., 2013)	Increases Willingness to Pay (Amegnaglo et al., 2017)	Increase uptake (Chiputwa et al., 2020)

Appendix 2. Summary of papers included in the literature review

Author(s)	Publication Year	Location	Region	Type of Study	Specific area of study	Type of CIS	Farming systems employed, Livestock/ crops
Alant, B.P. and Bakare, O.O.	2021	South Africa	Africa	Case study on smallholder farmer's ICT literacy levels	Access		subsistence crop farming, irrigation cooperatives
Amegnaglo, C.J. et al.,	2017	Benin	Africa	Economic evaluation of Climate services. WTP (willingness to pay)	Value	SCF	Cereals, tubers, pulses, vegetables and livestock
Chiputwa et al.,	2022	Senegal	Africa	Impact studies assessment (ex-post) CIS mediated by a multidisciplinary working group MWG – Target group -smallholder farmers	Impact	SCF, WF, Agricultural advisory information	rainfed rural areas
Chiputwa et al.,	2020	Senegal	Africa	Assessment of co-production in the uptake and use of different weather and climate	Uptake, Use	SCF, WF, Agricultural advisory information	rainfed rural areas
Gbangou et al.,	2020	Ghana	Africa	Evaluation of co-production, usability, usefulness	Coproduction, Use	Daily weather forecast	conventional (peri urban area)
Guido et al.,	2020	Kenya	Africa	Impacts of seasonal rainfall expectations on decision making	Use	WF, monthly rainfall forecast	Maize
Henriksson et al.,	2021	Malawi	Africa	Assessment on availability, accessibility and use of CI (based on gender)	Access, Use	Short term SCF	Sugarcane (irrigated fields)
Kolawole et al.,	2014	Botswana	Africa	Use of ethno-meteorology and scientific weather forecasting	Uptake, Access, Use	WF, local indigenous forecast	75 % rainfed farming, 25 % flood plains
Moeletsi et al.,	2013	South Africa	Africa	Use of rainfall forecasts	Use	SCF, short term WF	rain fed – maize intercrop with pulses
Muema et al.,	2018	Kenya	Africa	Access and utilization of climate information by smallholder farmers in Kenya	Access, Use	SCF	crops (cereals and pulses fruit trees, livestock rearing.

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Author(s)	Publication Year	Location	Region	Type of Study	Specific area of study	Type of CIS	Farming systems employed, Livestock/ crops
Muita et al.,	2021	Kenya	Africa	User needs and perceptions of crop farmers, pastoralists, agro-pastoralists in relation to seasonal and sub-seasonal forecasts.	Uptake, Use	SCF, short term WF	rainfed, crop farmers, pastoralists, agro-pastoralists
Ncoyini et al.,	2022	South Africa	Africa	Assessment of access and use and impact of CI	Impact, Access, Use	SCF, daily WF, early warning	conventional-rain fed (sugarcane farmers)
Nkuba et al.,	2020	Uganda	Africa	Influence of Indigenous Knowledge and Scientific Climate Forecasts on climate adaptation methods	IKS	SCF, short term WF	Arable farming, livestock rearing
Nyadzi et al.,	2019	Ghana	Africa	Matching information needs and forecast performance	Use	SCF	Rice farmers-under irrigation and rainfed
Ofoegbu, C. and New, M.	2021	Namibia	Africa	collaboration relations in climate information productions	Co-production	SCF, WF, intradecadal and decadal forecasts	Crops grown are grains (maize, millet, sorghum), vegetables and livestock rearing
Oladele et al.,	2019	Kenya and Ethiopia	Africa	Adoption studies / use (smallholder farmers)	Use	SCF, WF, agro-advice	Climate smart agriculture
Oyekale, A.S.	2015	East and West Africa	Africa	Assessment of factors influencing access (baseline survey)	Access	SCF, pests forecast, agro-advice	not specified
Sutanto et al.,	2022	Ghana	Africa	Role of soil moisture content in developing Climate services	Access, Use,	WF, agro-advice	Cereals, pulses, vegetables, pepper, and livestock rearing
Tall et al.,	2018	Africa	Africa	Review of evaluation methodologies and practices	Impact		NA (focuses on farmers as the end users of CS)
Vogel, C.	2000	South Africa	Africa	Assessment of long-term seasonal forecasts	Use, Value	SCF	maize, sunflower, beans
Ziervogel et al.,	2005	Lesotho	Africa	Impact of Seasonal climate forecast application among smallholder farmers	Impact	SCF	maize and sorghum
Cinco et al.,	2020	Philippine	Asia	An assessment on the Usefulness of the CI	Awareness, Access, Use	SCF, short term WF, early warning	Rice, urban gardening, organic fertilizer production and farm mechanization
Diona et al.,	2020	Philippine	Asia	Economic value of Weather forecasts	Value	Short term weather forecast	Not specified. Crops of interest in the study are cereals corn and rice
Kumar et al.,	2020	Bangladesh	Asia	Role of information in farmers' response to weather	Access and use	SCF, WF, agro advice	Cropping systems – paddy, jute sesame and vegetables
Kumar et al.,	2021	India	Asia	Impact assessment of weather based agro-advisory services	Impact	SCF, WF, agro-advice	Traditional subsistence agriculture, vegetable farming 23 types
Paparrizos et al.,	2021	Bangladesh	Asia	Assessment of value of Climate Information Services (WTP)- ex-post	Value	Short term WF, agro advice	Peri urban agriculture
Ruzol et al.,	2020	Philippine	Asia	Mapping access and use of weather information	Access, Use	SCF, WF, early warning	
Satishkumar et al.,	2013	India	Asia	Comparison of utilization patterns of various channels of weather information	Access	SCF, WF	Rainfed smallholder farms
Simelton, E. and McCampbell, M.	2021	Southeast Asia	Asia	Digital Climate services (literature review)	Access, Use	WF, agro-advice	NA
Buckland, S. and Campbell, D.	2021	Jamaica	North America	Assessment of factors influencing awareness, access, use	Awareness, Access, Use	SCF, short term WF, early warning	not specified
Fay Buckland, S. and Campbell, D.	2021	Jamaica	North America	Agroclimatic services and drought risk management	Awareness, Access, Use, Uptake	SCF, short term WF, early warning	yellow yams
Guido et al.,	2018	Jamaica	North America	Role of Climate Services	Access, Use	SCF, short term WF	small scale coffee growers, most participants farmed plots less than 5 acres
Lechthaler, F. and Vinogradova,	2017	Peru	South America	Value of climate services in coffee farming	Value	WF, early warning	coffee and maize

Appendix 3. Summary of papers included in the literature review using the snowball method

Author	Publication year	Location	Region	Type of Study
Anang et al.,	2020	Ghana	Africa	Adoption and income effects of agricultural extension
Antwi-Agyei et al.,	2021b	Ghana	Africa	Use of climate information
Jiri et al.,	2016	Southern Africa	Africa	Seasonal climate prediction and adaptation
Partey et al.,	2020	Ghana	Africa	Climate information use, gender and climate risk management
Djido et al.,	2021	Ghana	Africa	Adoption of climate-smart agriculture through climate information services
Warner et al.,	2022	Not specific	Not specific	Use of climate information
Ngigi, M.W. and Muange, E.N.	2022	Kenya	Africa	Access to climate information
Onyeneke et al.,	2023	Nigeria	Africa	Impact of climate information services
Gitonga et al	2020	Namibia	Africa	Access, use and impact of climate information services
Carr, E.R. and Owusu-Daaku, K.N.	2016	Mali	Africa	Climate services development
Ofori-Kyereh et al.,	2023	Ghana	Africa	Adaptive capacity to climate variability and change
Ogisi, O.D. and Begho, T.	2023	Sub-Saharan Africa	Africa	Adoption of climate smart agriculture

References

Abid, M., Ngaruiya, G., Scheffran, J., Zulfiqar, F., 2017. The role of social networks in agricultural adaptation to climate change: implications for sustainable agriculture in Pakistan. Climate 5, 85. https://doi.org/10.3390/cli5040085.

Abrams, L., 2018. Unlocking the Potential of Enhanced Rainfed Agriculture. Stockholm International Water Institute, Stockholm.

Adato, M., Meinzen-Dick, R.S. (Eds.), 2002. Assessing the impact of agricultural research on poverty using the sustainable livelihoods framework, EPTD Discussion Paper 89. 10.22004/ag.econ.16074.

Alant, B.P., Bakare, O.O., 2021. A case study of the relationship between smallholder farmers' ICT literacy levels and demographic data w.r.t. their use and adoption of ICT for weather forecasting. Heliyon 7. https://doi.org/10.1016/j.heliyon.2021.e06403.

Al-hassan, S., Andani, A., Abdul-Malik, A., 2011. The role of community radio in livelihood improvement: the case of simli radio. Field actions science reports. J. Field Actions.

Alidu, A.-F., Man, N., Ramli, N.N., Mohd Haris, N.B., Alhassan, A., 2022. Smallholder farmers access to climate information and climate smart adaptation practices in the northern region of Ghana. Heliyon 8, e09513.

Amegnaglo, C.J., Anaman, K.A., Mensah-Bonsu, A., Onumah, E.E., Amoussouga Gero, F., 2017. Contingent valuation study of the benefits of seasonal climate forecasts for maize farmers in the Republic of Benin, West Africa. Clim. Serv. 6, 1–11. https://doi.org/10.1016/j.cliser.2017.06.007.

Amenyah, I.D., Puplampu, K.P., 2013. Women in agriculture: an assessment of the current state of affairs in Africa.

Anang, B.T., Bäckman, S., Sipiläinen, T., 2020. Adoption and income effects of agricultural extension in northern Ghana. Scientific Afr. 7, e00219.

Antwi-Agyei, P., Amanor, K., Hogarh, J.N., Dougill, A.J., 2021a. Predictors of access to and willingness to pay for climate information services in north-eastern Ghana: a gendered perspective. Environ. Develop. 37, 100580 https://doi.org/10.1016/j.envdev.2020.100580.

Antwi-Agyei, P., Dougill, A.J., Abaidoo, R.C., 2021b. Opportunities and barriers for using climate information for building resilient agricultural systems in Sudan savannah agro-ecological zone of north-eastern Ghana. Clim. Serv. 22, 100226 https://doi.org/10.1016/j.cliser.2021.100226.

Antwi-Agyei, P., Stringer, L.C., 2021. Improving the effectiveness of agricultural extension services in supporting farmers to adapt to climate change: Insights from northeastern Ghana. Clim. Risk Manag. 32, 100304 https://doi.org/10.1016/j.crm.2021.100304.

Archer, E., 2003. Identifying underserved end-user groups in the provision of climate information. Bull. Am. Meteorol. Soc. 84, 1525–1532. https://doi.org/10.1175/BAMS-84-11-1525.

Austen, E.A., Sale, P.W.G., Clark, S.G., Graetz, B., 2002. A survey of farmers' attitudes, management strategies and use of weather and seasonal climate forecasts for coping with climate variability in the perennial pasture zone of south-east Australia. Aust. J. Exp. Agric. 42, 173–183. https://doi.org/10.1071/EA01030.

Birachi, E.A., Hansen, J., Radeny, M.A.O., Mutua, M.M., Mbugua, M.W., Munyangeri, Y., Rose, A., Chiputwa, B., Solomon, D., Zebiak, S.E., Kagabo, D.M., Nsengiyumva, G., 2020. Rwanda Climate Services for Agriculture: Evaluation of farmers' awareness, use and impacts (Working Paper). CGIAR Research Program on Climate Change, Agriculture and Food Security.

Biteye, M., 2016. 70% of Africans make a living through agriculture, and technology could transform their world [WWW Document]. World Economic Forum. URL https://www.weforum.org/agenda/2016/05/70-of-africans-make-a-living-through-agriculture-and-technology-could-transform-their-world/ (accessed 4.27.23).

Buckland, S., Campbell, D., 2022. Agro-climate services and drought risk management in Jamaica: a case study of farming communities in Clarendon Parish. Singap. J. Trop. Geogr. 43, 43–61. https://doi.org/10.1111/sjtg.12414.

Bullock, R.M., Katothya, G., 2022. Understanding Gendered Access and Uptake of Climate Services to Develop Socially Inclusive Programming in Kenya (Working Paper). International Livestock Research Institute.

Carr, E.R., Goble, R., Rosko, H.M., Vaughan, C., Hansen, J., 2020. Identifying climate information services users and their needs in Sub-Saharan Africa: a review and learning agenda. Clim. Dev. 12, 23–41. https://doi.org/10.1080/17565529.2019.1596061.

Carr, E.R., Owusu-Daaku, K.N., 2016. The shifting epistemologies of vulnerability in climate services for development: the case of Mali's agrometeorological advisory programme. Area 48, 7–17. https://doi.org/10.1111/area.12179.

Chiputwa, B., Wainaina, P., Nakelse, T., Makui, P., Zougmoré, R.B., Ndiaye, O., Minang, P.A., 2020. Transforming climate science into usable services: the effectiveness of co-production in promoting uptake of climate information by smallholder farmers in Senegal. Clim. Serv. 20 https://doi.org/10.1016/j.cliser.2020.100203.

Chiputwa, B., Blundo-Canto, G., Steward, P., Andrieu, N., Ndiaye, O., 2022. Co-production, uptake of weather and climate services, and welfare impacts on farmers in Senegal: a panel data approach. Agric. Syst. 195 https://doi.org/10.1016/j.agsy.2021.103309.

Chisadza, B., Mushunje, A., Nhundu, K., Phiri, E.E., 2020. Opportunities and challenges for seasonal climate forecasts to more effectively assist smallholder farming decisions. S. Afr. J. Sci. 116 https://doi.org/10.17159/sajs.2020/4649.

Cinco, T., Agustin, W., Cooper, B., Declaro, A., de Guzman, R., Juanillo, E., Marasigan, R., Solis, A., Hayman, P., 2020. From climate data to actionable climate knowledge: Dost-pagasa experience providing climate services to smallholder farmers in calapan, oriental mindoro. Philipp. Agric. Sci. 103, 11–24.

Clarkson, G., Dorward, P., Osbahr, H., Torgbor, F., Kankam-Boadu, I., 2019. An investigation of the effects of PICSA on smallholder farmers' decision-making and livelihoods when implemented at large scale – The case of Northern Ghana. Clim. Serv. 14, 1–14. https://doi.org/10.1016/j.cliser.2019.02.002.

Conde, C., et al., 2006. Climate change and climate variability impacts on rainfed agricultural activities and possible adaptation measures. A Mexican case study. Atmósfera 19.

Crane, T.A., Roncoli, C., Paz, J., Breuer, N., Broad, K., Ingram, K.T., Hoogenboom, G., 2010. Forecast skill and farmers' skills: Seasonal climate forecasts and agricultural risk management in the southeastern United States. Weather Clim. Soc. 2, 44–59. https://doi.org/10.1175/2009WCAS1006.1.

Dapilah, F., Nielsen, J., Friis, C., 2019. The role of social networks in building adaptive capacity and resilience to climate change: a case study from northern Ghana. Clim. Dev. 12 https://doi.org/10.1080/17565529.2019.1596063.

Dayamba, D.S., Ky-Dembele, C., Bayala, J., Dorward, P., Clarkson, G., Sanogo, D., Diop Mamadou, L., Traoré, I., Diakité, A., Nenkam, A., Binam, J.N., Ouedraogo, M., Zougmore, R., 2018. Assessment of the use of Participatory Integrated Climate Services for Agriculture (PICSA) approach by farmers to manage climate risk in Mali and Senegal. Clim. Serv. 12, 27–35. https://doi.org/10.1016/j.cliser.2018.07.003.

Directorate-General for Research and Innovation (European Commission), Jacob, D., Runge, T., Street, R., Parry, M., Scott, J., 2015. A European Research and Innovation Roadmap for Climate Services. Publications Office of the European Union, LU.

Djido, A., Zougmoré, R.B., Houessionon, P., Ouédraogo, M., Ouédraogo, I., Seynabou Diouf, N., 2021. To what extent do weather and climate information services drive the adoption of climate-smart agriculture practices in Ghana? Clim. Risk Manag. 32, 100309 https://doi.org/10.1016/j.crm.2021.100309.

Etwire, P.M., Buah, S., Ouédraogo, M., Zougmoré, R., Partey, S.T., Martey, E., Dayamba, S.D., Bayala, J., 2017. An assessment of mobile phone-based dissemination of weather and market information in the Upper West Region of Ghana. Agric. Food Secur. 6, 8. https://doi.org/10.1186/s40066-016-0088-y.

Fay Buckland, S., Campbell, D., 2021. An assessment of factors influencing awareness, access and use of agro-climate services among farmers in Clarendon, Jamaica. Geoforum 126, 171–191. https://doi.org/10.1016/j.geoforum.2021.07.032.

Fellmann, T., 2012. The assessment of climate change-related vulnerability in the agricultural sector: reviewing conceptual frameworks. pp. 37–61. 10.13140/2.1.4314.8809.

Gbangou, T., Sarku, R., Van Slobbe, E., Ludwig, F., Kranjac-Berisavljevic, G., Paparrizos, S., 2020. Coproducing weather forecast information with and for smallholder farmers in Ghana: evaluation and design principles. Atmos. 11.

Gitonga, Z.M., Visser, M., Mulwa, C., 2020. Can climate information salvage livelihoods in arid and semiarid lands? An evaluation of access, use and impact in Namibia. World Develop. Perspect. 20, 100239 https://doi.org/10.1016/j.wdp.2020.100239.

GSMA, 2020. The State of Mobile Internet Connectivity Report 2020 – Mobile for Development. Mobile for Development. URL https://www.gsma.com/r/somic-2020/ (accessed 8.16.22).
Guido, Z., Zimmer, A., Lopus, S., Hannah, C., Gower, D., Waldman, K., Krell, N., Sheffield, J., Caylor, K., Evans, T., 2020. Farmer forecasts: Impacts of seasonal rainfall expectations on agricultural decision-making in Sub-Saharan Africa. Clim. Risk Manage. 30 https://doi.org/10.1016/j.crm.2020.100247.
Henriksson, R., Vincent, K., Archer, E., Jewitt, G., 2021. Understanding gender differences in availability, accessibility and use of climate information among smallholder farmers in Malawi. Clim. Dev. 13, 503–514. https://doi.org/10.1080/17565529.2020.1806777.
Hordofa, L., Yazew, T., 2023. Evaluating impacts of climate variability on smallholder livelihoods and adaptation practices in the western Shewa Zone, Oromia, Ethiopia. Front. Clim. 5.
Jacobs, B., Nelson, R., Kuruppu, N., Leith, P., 2016. An Adaptive Capacity Guide Book: assessing, building and evaluating the capacity of communities to adapt in a changing climate.
Jaramillo, S., Graterol, E., Pulver, E., 2020. Sustainable transformation of rainfed to irrigated agriculture through water harvesting and smart crop management practices. Front. Sustain. Food Syst. 4.
Jiri, O., Mafongoya, P., Mubaya, C.P., Owen, M., 2016. Seasonal climate prediction and adaptation using indigenous knowledge systems in agriculture systems in southern Africa: a review. J. Agric. Sci. 8, 156. https://doi.org/10.5539/jas.v8n5p156.
Kabobah, L., Nukpezah, D., Ntiamoa-Baidu, Y., 2018. Adaptive capacity of farmers to climate change in the Kassena Nankana Municipality of Ghana: implications for climate adaptation strategies. West Afr. J. Appl. Ecol. 26, 14–26.
Khan, M.A.A., Khan, M.M.R., Hassan, M., Ahmed, F., Haque, S.M.R., 2017. Role of community radio for community development in Bangladesh. Int. Technol. Manage. Rev. 6, 94–102. https://doi.org/10.2991/itmr.2017.6.3.3.
Kolawole, O.D., Wolski, P., Ngwenya, B., Mmopelwa, G., 2014. Ethno-meteorology and scientific weather forecasting: Small farmers and scientists' perspectives on climate variability in the Okavango Delta. Botswana. Clim. Risk Manage. 4, 43–58. https://doi.org/10.1016/j.crm.2014.08.002.
Kreft, C., Angst, M., Huber, R., Finger, R., 2023. Farmers' social networks and regional spillover effects in agricultural climate change mitigation. Clim. Change 176, 8. https://doi.org/10.1007/s10584-023-03484-6.
Kumar, U., Werners, S., Roy, S., Ashraf, S., Hoang, L., Datta, D., Ludwig, F., 2020. Role of information in farmers' response to weather and water related stresses in the lower Bengal Delta, Bangladesh. Sustainability 12. https://doi.org/10.3390/su12166598.
Lechthaler, F., Vinogradova, A., 2017. The climate challenge for agriculture and the value of climate services: application to coffee-farming in Peru. Eur. Econ. Rev. 99, 5–30. https://doi.org/10.1016/j.euroecorev.2017.06.006.
Lemi, T., Hailu, F., 2019. Effects of Climate Change Variability on Agricultural Productivity. IJESNR 17, 1–7. doi:10.19080/IJESNR.2019.17.555953.
Lowder, S.K., Sánchez, M.V., Bertini, R., 2021. Which farms feed the world and has farmland become more concentrated? World Dev. 142, 105455 https://doi.org/10.1016/j.worlddev.2021.105455.
Masson-Delmotte, V., Zhai, P., Pirani, A., Connors, S.L., Pean, C., Berger, S., Caud, N., Chen, Y., Goldfarb, L., Gomis, M.I., Huang, M., Leitzell, K., Lonnoy, E., Matthews, J.B.R., Maycock, T.K., Waterfield, T., Yelekci, O., Yu, R., Zhou, B., 2021. IPCC, 2021: climate change 2021: the physical science basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (report). Cambridge University Press, Cambridge, UK.
Moeletsi, M.E., Mellaart, E.A.R., Mpandeli, N.S., Hamandawana, H., 2013. The use of rainfall forecasts as a decision guide for small-scale farming in Limpopo Province, South Africa. J. Agric. Educ. Ext. 19, 133–145. https://doi.org/10.1080/1389224X.2012.734253.
Muema, E., Mburu, J., Coulibaly, J., Mutune, J., 2018. Determinants of access and utilisation of seasonal climate information services among smallholder farmers in Makueni County, Kenya. Heliyon 4. https://doi.org/10.1016/j.heliyon.2018.e00889.
Muita, R., Dougill, A., Mutemi, J., Aura, S., Graham, R., Awolala, D., Nkiaka, E., Hirons, L., Opijah, F., 2021. Understanding the role of user needs and perceptions related to sub-seasonal and seasonal forecasts on farmers' decisions in Kenya: a systematic review. Front. Clim. 3 https://doi.org/10.3389/fclim.2021.580556.
Ncoyini, Z., Savage, M.J., Strydom, S., 2022. Limited access and use of climate information by small-scale sugarcane farmers in South Africa: a case study. Clim. Serv. 26 https://doi.org/10.1016/j.cliser.2022.100285.
Ndamani, F., Watanabe, T., 2016. Determinants of farmers' adaptation to climate change: a micro level analysis in Ghana. Sci. Agric. (Piracicaba, Braz.) 73, 201–208. https://doi.org/10.1590/0103-9016-2015-0163.
Ngigi, M.W., Muange, E.N., 2022. Access to climate information services and climate-smart agriculture in Kenya: a gender-based analysis. Clim. Change 174, 21. https://doi.org/10.1007/s10584-022-03445-5.
Nkiaka, E., Taylor, A., Dougill, A.J., Antwi-Agyei, P., Fournier, N., Bosire, E.N., Konte, O., Lawal, K.A., Mutai, B., Mwangi, E., Ticehurst, H., Toure, A., Warnaars, T., 2019. Identifying user needs for weather and climate services to enhance resilience to climate shocks in sub-Saharan Africa. Environ. Res. Lett. 14, 123003 https://doi.org/10.1088/1748-9326/ab4dfe.
Nkuba, M.R., Chanda, R., Mmopelwa, G., Kato, E., Mangheni, M.N., Lesolle, D., 2020. Influence of indigenous knowledge and scientific climate forecasts on arable farmers' climate adaptation methods in the Rwenzori region, Western Uganda. Environ. Manage. 65, 500–516. https://doi.org/10.1007/s00267-020-01264-x.
Nyadzi, E., Saskia Werners, E., Biesbroek, R., Long, P.H., Franssen, W., Ludwig, F., 2019. Verification of seasonal climate forecast toward hydroclimatic information needs of rice farmers in northern Ghana. Weather Clim. Soc. 11, 127–142. https://doi.org/10.1175/WCAS-D-17-0137.1.
Ofori-Kyereh, B.E., Morton, J.F., Chancellor, T.C.B., 2023. Constraints on farmers' adaptive capacity to climate variability and change. Clim. Dev. 15, 312–324. https://doi.org/10.1080/17565529.2022.2083546.
Ogisi, O.D., Begho, T., 2023. Adoption of climate-smart agricultural practices in sub-Saharan Africa: a review of the progress, barriers, gender differences and recommendations. Farming Syst. 1, 100019 https://doi.org/10.1016/j.farsys.2023.100019.
Onyeneke, C.J., Umeh, G.N., Onyeneke, R.U., 2023. Impact of climate information services on crop yield in Ebonyi State, Nigeria. Climate 11, 7. https://doi.org/10.3390/cli11010007.
Ouedraogo, A., Egyir, I.S., Ouedraogo, M., Jatoe, J.B.D., 2022. Farmers' demand for climate information services: a systematic review. Sustainability 14, 9025. https://doi.org/10.3390/su14159025.
Oyekale, A.S., 2015. Access to risk mitigating weather forecasts and changes in farming operations in east and west Africa: evidence from a baseline survey. Sustainability 7, 14599–14617. https://doi.org/10.3390/su71114599.
Page, M.J., McKenzie, J.E., Bossuyt, P.M., Boutron, I., Hoffmann, T.C., Mulrow, C.D., Shamseer, L., Tetzlaff, J.M., Akl, E.A., Brennan, S.E., Chou, R., Glanville, J., Grimshaw, J.M., Hróbjartsson, A., Lalu, M.M., Li, T., Loder, E.W., Mayo-Wilson, E., McDonald, S., McGuinness, L.A., Stewart, L.A., Thomas, J., Tricco, A.C., Welch, V.A., Whiting, P., Moher, D., 2021. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 372, n71. https://doi.org/10.1136/bmj.n71.
Paparrizos, S., Kumar, U., Amjath-Babu, T.S., Ludwig, F., 2021a. Are farmers willing to pay for participatory climate information services? Insights from a case study in peri-urban Khulna, Bangladesh. Clim. Serv. 23 https://doi.org/10.1016/j.cliser.2021.100241.
Paparrizos, S., Kumar, U., Amjath-Babu, T.S., Ludwig, F., 2021b. Are farmers willing to pay for participatory climate information services? Insights from a case study in peri-urban Khulna, Bangladesh. Clim. Services 23.
Partey, S.T., Dakorah, A.D., Zougmoré, R.B., Ouédraogo, M., Nyasimi, M., Nikoi, G.K., Huyer, S., 2020. Gender and climate risk management: evidence of climate information use in Ghana. Clim. Change 158, 61–75. https://doi.org/10.1007/s10584-018-2239-6.
Quandt, A., 2018. Measuring livelihood resilience: the household livelihood resilience approach (HLRA). World Dev. 107, 253–263. https://doi.org/10.1016/j.worlddev.2018.02.024.
Rapsomanikis, G., 2015. The economic lives of smallholder farmers.
Ray, D.K., Gerber, J.S., MacDonald, G.K., West, P.C., 2015. Climate variation explains a third of global crop yield variability. Nat. Commun. 6, 5989. https://doi.org/10.1038/ncomms6989.
Rhiney, K., Tomlinson, J., 2017. Assessing the role of farmer field schools in promoting pro-adaptive behaviour towards climate change among Jamaican farmers. J. Environ. Stud. Sci. 8 https://doi.org/10.1007/s13412-017-0461-6.
Roncoli, C., Ingram, K., Kirshen, P., 2002. Reading the rains: local knowledge and rainfall forecasting in Burkina Faso. Soc. Nat. Resour. 15, 409–427. https://doi.org/10.1080/08941920252866774.
Ruben, R., Wattel, C., van Asseldonk, M., 2019. Rural finance to support climate change adaptation: experiences, lessons and policy perspectives. In: Rosenstock, T.S., Nowak, A., Girvetz, E. (Eds.), The Climate-Smart Agriculture Papers: Investigating the Business of a Productive, Resilient and Low Emission Future. Springer International Publishing, Cham. pp. 301–313. Doi:10.1007/978-3-319-92798-5_26.
Ruzol, C., Lomente, L.L., Pulhin, J., 2020. Mapping access and use of weather and climate information to aid farm decisions in the philippines. Philipp. Agric. Sci. 103, 25–39.
Satishkumar, N., Tevari, P., Singh, A., 2013. Utilization pattern of different sources and channels of weather information by the rainfed farmers. Indian J. Agric. Res. 47, 248–252.
Sayers, A., 2007. Tips and tricks in performing a systematic review. Br. J. Gen. Pract. 57, 759.
Scoones, I., 1998. Sustainable Rural Livelihoods: A Framework for Analysis.
Serrat, O., 2017. The sustainable livelihoods approach. In: Serrat, O. (Ed.), Knowledge Solutions: Tools, Methods, and Approaches to Drive Organizational Performance. Springer, Singapore. pp. 21–26. Doi:10.1007/978-981-10-0983-9_5.
Simelton, E., McCampbell, M., 2021. Do digital climate services for farmers encourage resilient farming practices? Pinpointing gaps through the responsible research and innovation framework. Agriculture 11. https://doi.org/10.3390/agriculture11100953.
Sprout, E., 2022. Assessing the role of social networks in women's access and use of climate services in Sub-Saharan Africa: evidence from literature. Curr. Opin. Environ. Sustain. 59, 101232 https://doi.org/10.1016/j.cosust.2022.101232.
Tall, A., Kristjanson, P.M., Chaudhury, M., McKune, S., Zougmoré, R.B., 2014. Who gets the information? Gender, power and equity considerations in the design of climate services for farmers (Working Paper).
Tarchiani, V., Coulibaly, H., Baki, G., Sia, C., Burrone, S., Nikiema, P.M., Migraine, J.-B., Camacho, J., 2021. Access, uptake, use and impacts of agrometeorological services in Sahelian rural areas: the case of Burkina Faso. Agronomy 11, 2431. https://doi.org/10.3390/agronomy11122431.
Templeton, S.R., Hooper, A.A., Aldridge, H.D., Breuer, N., 2018. Farmer interest in and uses of climate forecasts for Florida and the carolinas: Conditional perspectives of extension personnel. Weather Clim. Soc. 10, 103–120. https://doi.org/10.1175/WCAS-D-16-0057.1.
Thomas, V., Lopez, R., 2015. Global increase in climate-related disasters. SSRN J. https://doi.org/10.2139/ssrn.2709331.
Ulukan, D., Bergkvist, G., Lana, M., Fasse, A., Mager, G., Öborn, I., Chopin, P., 2022. Combining sustainable livelihood and farm sustainability approaches to identify

relevant intensification options: implications for households with crop-based and gathering-based livelihoods in Tanzania. Ecol. Indic. 144, 109518 https://doi.org/10.1016/j.ecolind.2022.109518.
Vogel, C., 2000. Usable science: An assessment of long-term seasonal forecasts amongst farmers in rural areas of sourth africa. S. Afr. Geogr. J. 82, 107–116. https://doi.org/10.1080/03736245.2000.9713700.
Wani, S.P., Rockström, J., Oweis, T.Y., 2009. Rainfed Agriculture: Unlocking the Potential, Comprehensive Assessment of Water Management in Agriculture Series. CABI, Wallingford.
Warner, D., Moonsammy, S., Joseph, J., 2022. Factors that influence the use of climate information services for agriculture: a systematic review. Clim. Serv. 28, 100336 https://doi.org/10.1016/j.cliser.2022.100336.
WMO, 2022. State of the Global Climate 2021 (WMO-No. 1290). WMO, Geneva.
WMO, (World Meteorological Organisation), 2020. 2020 State of Climate Services: Risk Information and Early Warning Systems, WMO. WMO, Geneva.
WMO, W.M., 2011. Climate Knowledge for Action: A Global Framework for Climate Services – Empowering the Most Vulnerable – Summary Report, WMO. WMO, Geneva.
WMO, 2021. Weather-related disasters increase over past 50 years, causing more damage but fewer deaths [WWW Document]. URL https://public.wmo.int/en/media/press-release/weather-related-disasters-increase-over-past-50-years-causing-more-damage-fewer (accessed 8.8.22).
Ziervogel, G., Bithell, M., Washington, R., Downing, T., 2005. Agent-based social simulation: a method for assessing the impact of seasonal climate forecast applications among smallholder farmers. Agric. Syst. 83, 1–26. https://doi.org/10.1016/j.agsy.2004.02.009.