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Opportunities and barriers for using climate information for building resilient agricultural systems in Sudan savannah agro-ecological zone of north-eastern Ghana

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ABSTRACT

Empirical evidence on the opportunities and barriers to the uptake of climate services by smallholder farmers for resilient agricultural systems in sub-Saharan Africa is limited. This paper addresses this important gap by evaluating the opportunities and barriers to the uptake of climate information (from short-term weather forecasts, through seasonal forecasts to longer-term climate change information on decadal timescales) by smallholder farmers in the Sudan savannah agro-ecological zone of Ghana. The paper answers the following research questions: i) what kinds of weather and climate information are available and accessible to smallholder farmers for agricultural management decision-making? ii) what opportunities exist for using climate information in agricultural systems in the Sudan savannah agro-ecological zone? iii) what are the key barriers to the uptake of climate information by smallholder farmers in the Sudan savannah agro-ecological zones of Ghana? The study used participatory approaches including household surveys with 555 farmers, 3 stakeholder workshops, 15 key informant interviews and 12 focus group discussions across 6 communities in the Sudan savannah agro-ecological zone. Findings show that more than a third of the study respondents (40%; n = 555) were not receiving climate information. Out of the 60% receiving climate information, the majority (91%; n = 335) indicated receiving information on rainfall with fewer respondents 21% and 26% receiving information on temperature and windstorms, respectively. Radio was the key medium for receiving weather and climate information. Both female and male smallholder farmers were using climate information to make critical farming decisions including time of land preparations (79%), crop variety selection (50%), changing cropping patterns (36%), planting time adjustments (31%), harvesting time (21%) and disease/pest management (10%). Increasing uptake of weather and climate information is confronted with multiple barriers including inadequate information on seasonal forecast for long-term planning, low accessibility of climate information, high levels of illiteracy, difficulties in understanding technical language used in communicating climate information and misalignment between the climate information provided and what smallholder farmers need. Climate information should be linked directly to agricultural impacts and management decision-making to ensure it is both available to, and usable by smallholder farmers.

Practical implications

- Addressing the climate change effects on food production in dryland farming systems is important to avoid food insecurity in vulnerable households. This can be achieved through the implementation of appropriate adaptation interventions including changes in crop management and water conservation practices as well as timely access to, and use of, accurate climate information by smallholder farmers to build resilience in agricultural systems. We assessed the opportunities and barriers to the uptake of climate information by smallholder farmers to help with the building of more resilient agricultural systems, using northeast Ghana as a case study.

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- Our findings demonstrate that over one-third of the smallholder farmers interviewed did not have access to climate information. Amongst those that were receiving some kinds of climate information, the majority were solely receiving weather forecast information relating to rainfall with fewer respondents receiving information on temperature and windstorms. The main channels of communicating weather and climate information to farmers included the use of radios, mobile text messages, and workshops. Others included the use of extension agents, community groups and social media. We highlight that smallholder farmers in Ghana's dryland farming systems are using climate information in making critical farm decisions in relation to land preparations, crop variety selection, changing cropping patterns, planning planting time and managing crop risks.
- We found that the successful uptake of climate information by smallholders is affected by multiple socioeconomic and cultural barriers. These barriers included inadequate information on seasonal forecast for long-term planning, low accessibility of climate information, high levels of illiteracy, misalignment between the information provided and what is needed by smallholder farmers and timeliness of weather forecast/climate information.
- It is important to support smallholder farmers to overcome these challenges to facilitate the implementation of adaptation interventions in climate change vulnerability hotspots such as northeast Ghana. We propose that there should be closer collaboration between National Meteorological Services and Ministries and Agencies responsible for food production and environmental management to address the barriers hampering the successful uptake of climate information by smallholder farmers to build capacity to manage climate risks. Climate information should be communicated in languages understood by local farmers and linked directly to agricultural management decision-making to ensure it is both timely and usable by smallholder farmers.
- The study proposes the following recommendations: (i) forecast information should be communicated in local language so that it is easily understood and appreciated by agricultural extension workers and smallholder farmers; (ii) climate information should be linked to agricultural practices for smallholder farmers to appreciate the usefulness of such information; (iii) climate information should be co-produced with farmers and where possible, integrated with the local indigenous knowledge. Communication of climate information should also be directly linked to agronomic advice to make such information usable by smallholder farmers.

1. Introduction

Scientific evidence suggests that the climate is changing at a faster rate than anticipated, with serious repercussions for socio-economic development in developing countries (Intergovernmental Panel on Climate Change (IPCC), 2018). Climate sensitive sectors such as agriculture and forestry will be disproportionately affected by changing rainfall patterns and increasing temperature (Dube et al., 2016). Africa is particularly vulnerable to the threats posed by climate change due to socio-economic and political problems, low adaptive capacity and multiple stressors across different scales and sectors (Niang et al., 2014).

Previous studies (including Connolly-Boutin and Smit, 2016; Antwi-Agyei et al., 2017; Reid and Vogel, 2006) suggest that West Africa is confronted with multiple biophysical, political and socioeconomic stressors that interact to exacerbate the exposure and sensitivity of livelihood systems to climate extremes including increased temperature and erratic rainfall. Climate change is the leading stressor that is manifesting itself in changes in frequency and severity of extreme weather events including droughts, floods and windstorms, with severe implications for food security in West Africa (Sylla et al., 2018; Sultan and Gaetani, 2016).

Ghana is one country that is most vulnerable to the adverse effects of climate change (Asante and Amuakwa-Mensah, 2015) due to over-dependence on rain-fed agricultural systems and natural resource based livelihoods. Research suggests it will experience higher temperatures, suffer more intense droughts and variable rainfall patterns (Christensen et al., 2007) and make agricultural production less resilient. This threatens the attainment of the Sustainable Development Goals particularly those relating to food security (goal 2) and poverty eradication (goal 1) and perpetuates existing poverty and climate vulnerability of millions of households (Antwi-Agyei et al., 2012). However, a growing body of literature suggests that improved access to timely climate information services offers prospects for dryland smallholder farmers to maintain productivity and build resilient agricultural systems in the face of changing rainfall patterns (e.g. Jones et al., 2015; Hansen et al., 2019; Singh et al., 2018). Climate services involve "the generation, provision, and contextualization of information and knowledge derived from climate research for decision making at all levels of society" (Vaughan and Dessai, 2014, p.1). Climate information refers to both short-term weather forecasts, through seasonal forecasts to longer-term climate change information on decadal timescales (Nkiaka et al., 2019; Singh et al., 2018).

To be useful to smallholder farmers, the provision of climate information or forecasts need to be accompanied by agronomic advice meaningful for farm management decision-making to offset climate risks (Nkiaka et al., 2019; Dilling and Lemos, 2011). Climate information is only useful in addressing the threats posed by climate change, when they can be accessed in a form easily understood by smallholder farmers (Muema et al., 2018). However, the provision of climate information is usually confronted with a host of technical and socioeconomic barriers, limiting the uptake and utilisation of climate information for effective decision-making. Therefore, it is important to evaluate the key factors that limit the uptake of climate information for effective adaptation by smallholder farmers.

Several authors (including Antwi-Agyei et al., 2020; Vincent et al., 2017; Nkiaka et al., 2019; Singh et al., 2018) have highlighted the need for timely climate information for effective decision making to address climate shocks in sub-Saharan Africa. Empirical evidence on the opportunities associated with climate information and the barriers to greater uptake of climate information services by smallholder farmers is still largely lacking in sub-Saharan Africa and this hampers the adaptive capacity of smallholder farmers to address climate risks. The aim of the paper is to unravel the opportunities and barriers to the uptake of climate information by smallholder farmers for resilient agricultural systems. The paper answers the following research questions: i) what kinds of climate information are available and accessible to smallholder farmers for agricultural management decision-making? ii) what opportunities exist for using climate information in agricultural systems in the Sudan savannah agro-ecological zone of Ghana, iii) what are the key barriers to the uptake of climate information by smallholder farmers in the Sudan savannah agro-ecological zones of Ghana?

2. Study design and methods

2.1. Study area

Three local assemblies – Kassena-Nankana Municipal (urban area), Talensi (rural area), and Bawku West (semi-urban) in the Upper East region were selected (Fig. 1 and Table 1), based on their levels of climate vulnerability and advice from agricultural development officers. Within each local assembly, two communities were selected based on information obtained through interviews with local extension officers and agricultural development officers – Vunania and Saboro (from Kassena-Nankana Municipal), Telli and Yarigu (from Bawku West district), and Tindongo and Yameriga (from the Talensi district). The Upper East region is bordered by Burkina Faso to the north and Togo to the east. The

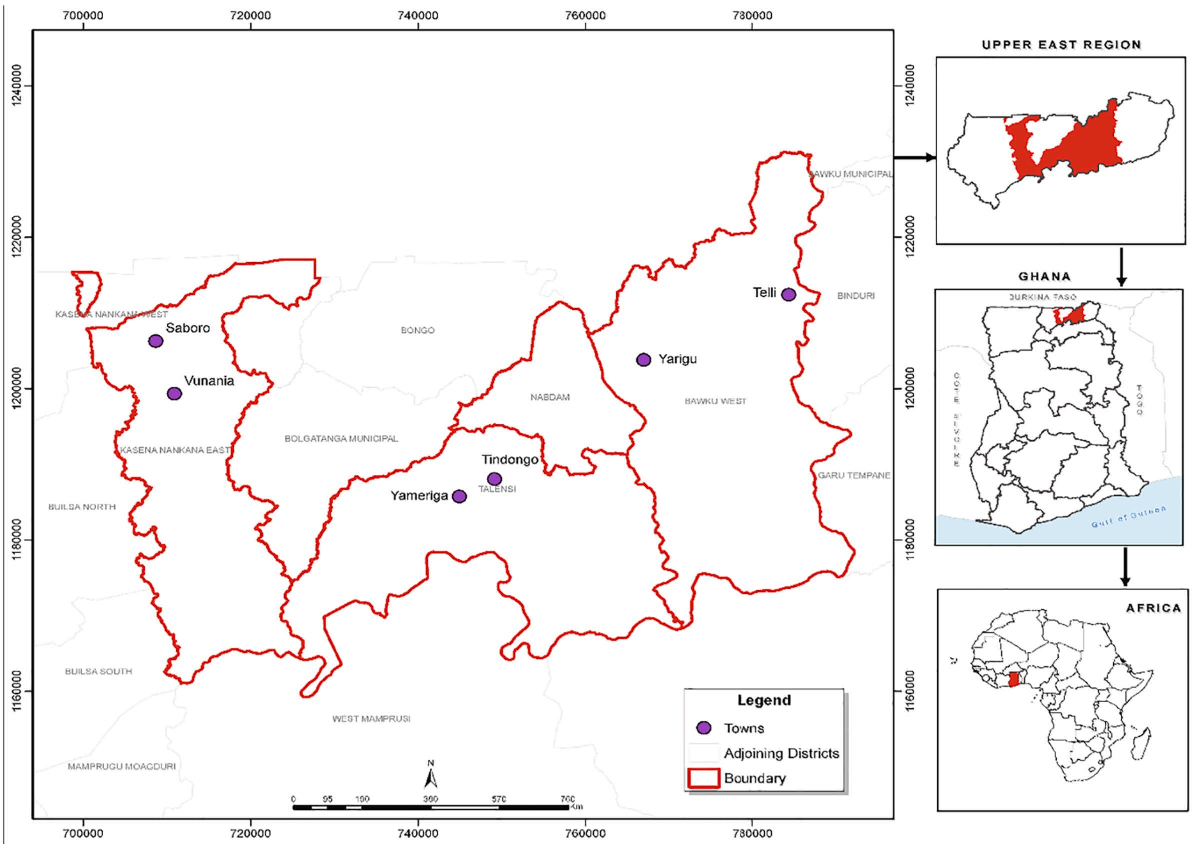

Fig. 1. Study districts with communities.

Table 1
Background characteristics of study communities.

	Kassena-Nankana Municipality		Bawku West District		Talensi District	
Study community	Vunania	Saboro	Yarigu	Telli	Tindongo	Yameriga
GPS coordinates	N10°51′ W001°04′	N10°54′ W001°05′	N10°52′ W000°33′	N10°57′ W000°23′	N10°48′ W000°48′	N10°44′ W000°43′
Total households (2017)	535	1,585	230	247	600	488
Number of study households	94	94	86	99	87	95
Major crops grown	Maize, sorghum, groundnut, rice, bambara beans, millet	Maize, sorghum, groundnut, rice, bambara beans, millet	Maize, millet, sorghum, rice	Maize, millet, sorghum	Groundnuts, millet, rice, maize	Groundnuts, millet, rice, maize, sorghum
Economic trees	Shea nut, dawadawa	Shea nut, baobab, cashew	Dawadawa, shea nut, baobab	Dawadawa, shea nut, kapok	Shea nut, acacia, dawadawa	Dawadawa, shea nuts, baobab
Ethnicity	Kasena	Kasena	Kusasi	Kusasi	Talensi	Talensi
Key livelihood activities	Farming	Farming	Farming	Farming	Farming	Farming
Focus group discussion (males)	$N = 9$	$N = 8$	$N = 10$	$N = 8$	$N = 13$	$N = 11$
Focus group discussion (females)	$N = 10$	$N = 14$	$N = 12$	$N = 15$	$N = 16$	$N = 14$

region falls within the Sudan savannah agro-ecological zone of Ghana, which is characterised by a unimodal rainfall pattern with an average annual rainfall of 750 to 1050 mm between May and October; followed by a long dry season from November to April. The peculiar geographical and socio-economic stressors including a lack of infrastructural development, high poverty rates and low literacy rates (GSS, 2013) put smallholder farmers in this region at more risk of severely suffering from the adverse impacts of climate change events (Antwi-Agyei et al., 2012). The majority of the people are mixed crop-livestock farmers who are dependent on rainfall for their livelihoods. The major crops produced include sorghum, millet and groundnuts.

3. Research methods

The study employed ethnographic fieldwork that allowed the lived experiences of smallholder farmers in climate vulnerability hotspots to be examined. Ethnographic fieldwork has been employed in related research (e.g. Antwi-Agyei et al., 2020; Aniah et al., 2019; Nyantakyi-Frimpong, 2019) and this study explored the utility of using this approach to understand how smallholder farmers access climate information and the barriers constraining farmers' uptake of this climate information as provided by the Ghana Meteorological Agency (GMet). The study used participatory approaches given low levels of literacy in the study area (GSS, 2013). The fieldwork was conducted from September to October 2019 in three phases, with findings from one phase feeding into the succeeding phase. Phase one involved 2 regional stakeholder workshops held in Bolgatanga and Navrongo to understand the broader issues involved in climate information services delivery in the Upper East region. Outcomes of the workshops informed the design of the data survey instruments to better reflect the prevailing conditions in the study area. Thus, phase one provided opportunity to fine-tune the questionnaire and removed inappropriate questions from the final survey instrument.

Phase two involved local community engagements held in all the 6 study communities where the objectives of the study were introduced to community members. Between September and October 2019, 555 household surveys were administered in the 6 communities with the help of CSPro software. Households were randomly selected in each community and the head of the household was interviewed, or his representative in the absence of the head. Questionnaires were administered in the local dialect with the assistance of local interpreters. Survey questionnaires probed the kinds of climate information accessible to smallholder farmers, the use of climate information and the key barriers relating to the uptake of such information.

During the household surveys, participants that demonstrated appreciable agro-ecological and environmental knowledge were selected for focus group discussions. In all, 12 focus group discussions (2 in each community) were held in the 6 study communities with participants ranging from 8 to 16. Separate male and female focus groups were held because of sociocultural differences that prevented women from freely expressing their views on issues in the presence of their male counterparts. Focus groups provided useful insights based on lived experiences from participants.

In phase three, 15 key informant interviews were held, which provided in-depth information on opportunities and barriers relating to the uptake of climate information in the study communities (Creswell, 2014). Key informants were selected based on the comprehensive understanding of local environmental change and agricultural systems within the six communities. The findings from the household surveys were presented to Agricultural Extension Officers and Agents in a multi-stakeholder workshop held in Bolgatanga in February 2020.

Qualitative data obtained from key informants and focus group discussions were coded and indexed and analysed using intensive content analysis that allowed the major responses that emerged to be identified (Krippendorff, 2004). Descriptive analysis using frequencies and percentages were performed on quantitative data. The study used the independent sample *t*-test technique to measure the difference between means of the two groups (male farmers and female farmers). The formula for calculating the t-values of differences is given below:

$t = \frac{\overline{X}_1 - \overline{X}_2}{\sqrt{\frac{SE_1+SE_2}{N_1+N_2}}}$; d.f. $= N_1 + N_2$where; SE_1 = Standard error calculated for each variable for female farmers, SE_2 = Standard error calculated for each variable for male farmers, N_1 = Sample size for female farmers, N_2 = Sample size for male farmers, $\overline{X}_1$ = mean obtained for variable among female farmers, $\overline{X}_1$ = mean estimated for variable among male farmers.

4. Results and discussion

4.1. Key climate variables received by smallholder farmers in the study area

Results show that only 60% of the study respondents received climate information in the 6 study communities (Table 2). Out of the respondents receiving climate information, the majority (91%; n = 335) indicated receiving information on rainfall with fewer respondents

Table 2
Receipt of climate information reported by smallholder farmers (%).

	All Sample (N = 555)	Females (N = 222)	Males (N = 333)
Yes	60.4 (335)	59.5 (132)	61.0 (203)
No	39.6 (220)	40.5 (90)	39.0 (130)

Numbers in parenthesis indicate counts of households.

(21%, n = 335) receiving information on temperature (Table 3). Information on windstorm was also cited by 26% of the respondents (Table 3). These results suggest that, slightly more than a third (40%) of all study respondents in this vulnerable region were not receiving any kind of climate information. This is worrying given that these smallholder farmers rely predominantly on rain-fed agricultural systems to support themselves and households. The lack of access to climate services reduces their ability to manage climate risks because information about future climate variability is required to inform decision-making on farm management practices. Coupled with high poverty rates, increasing fluctuations in rainfall patterns over the years have increased the vulnerability of communities in this region to climatic change effects.

In the past, smallholder farmers have often depended on their agro-ecological knowledge to determine the pattern of rainfall, using various indicators of the weather. Smallholder farmers have developed complex mental models of the climate including the flowering of Baobab tree (*Adansonia digitata*) and appearance of certain birds to inform adaptation practices. Such agro-ecological knowledge helps in making important climate change adaptation decisions including when to plant or harvest. However, with climate change projected to increase in the future with uncertainties of extreme climate events, the reliance on local traditional knowledge by smallholder farmers has been brought under scrutiny (Roncoli et al., 2008). The traditional indicators are either becoming less reliable or disappearing all together because of climate change effects (Basdew et al., 2017). The ability of the smallholder famers to withstand climate change is therefore contingent on the availability and timely access to evidence-based climate information including temperature and rainfall.

These results advance those provided by previous studies including Diouf et al. (2019), Oyekale (2015) and Zongo et al. (2016) suggesting that smallholder farmers in many countries across West Africa are not receiving climate information needed to make important decisions. For instance, in Burkina Faso, only 22% of sampled farmers (*n* = 629) had access to climate information (Zongo et al. 2016). Access to reliable climate information is critical to effective adaptation by farmers, yet, most smallholder farmers in Ghana are confronted with challenges in accessing accurate climate information (Antwi-Agyei et al., 2020; Hirons et al., 2018), increasing the vulnerability of farmers to the adverse impacts of climate change.

Table 4 shows the main channels for receiving climate information in the study communities. Radio (75%; n = 335) was the key medium for receiving climate information, followed by mobile text message (36%; n = 335) and workshops (28%; n = 335). This confirms previous studies by Diouf et al. (2019) in Senegal, Muema et al. (2018) in Kenya and

Table 3
Climate variables received by smallholder farmers (%).

Climate variables	All Sample (N = 335)	Female (N = 132)	Male (N = 203)
Rainfall (onset, distribution, amount, and cessation of the rains)	91.0	88.6	92.6
Temperature (expected average temperatures)	21.2	16.7	24.1
Windstorms (intensity of the storms)	25.7	33.3	26.9
Others (including relative humidity, incidences of floods etc.)	0.6	0.8	0.5

Table 4
Medium for receiving climate information.

Channel for receiving information	All Sample (N = 335)	Female (N = 132)	Male (N = 203)
Radio	74.6	68.9	78.3
Mobile Text Message	36.4	48.5	28.6
Phone Voice Message	1.5	0.0	2.5
Newspaper	4.5	3.0	5.4
Workshops	28.1	33.3	24.6
Television	2.4	0.8	3.4
Extension Officers	8.7	7.6	9.4
Community Groups	5.7	6.1	5.4
Social Media	2.1	2.3	3.0

Amegnaglo et al. (2017) in Benin, suggesting that radio is the key medium for communicating climate information. Although many more people are having mobile phones, national climate forecast are disseminated through radios and televisions. At the local and regional levels, climate information is also disseminated via radios and not mobile phones. Dissemination of climate information via mobile phone is a new practice being experimented by NGOs such as ESOKO and FARMERLINE within the study area. The other receptors including extension officers and agents, televisions, and social media were reported by fewer respondents.

Access to capital assets including radios and mobile phones have been considered as key in reaching out to smallholder farmers in vulnerable regions. Diaz (2016) demonstrated the importance of people's access and control over productive and economic assets and resources in building adaptive capacity. Cherotich et al. (2012) in reporting on the channels through which women and the elderly (vulnerable people) accessed climate information in a semi-arid area of Kenya mentioned that, majority of the women preferred radio while the elderly preferred indigenous knowledge to accessing climate information. Nyantakyi-Frimpong (2019) reported similar results suggesting radio was the main channels through which farmers received climate information in the Upper West region of Ghana.

Although radio was the most preferred communication channels, Nyantakyi-Frimpong (2019) has raised concerns related to radios including the lack of opportunities to clarify contentious issues compared to face-to-face delivery options such as workshops. Time constraints due to household labour commitments and chores on the part of women sometimes preclude them from listening to radio for climate information. Extension agents as channels of disseminating climate information was reported by fewer respondents (about 9%; n = 335) due to the inability of extension agents to deliver such information in a timely manner.

4.2. Opportunities for the use of climate information by smallholder farmers

Table 5 shows how smallholder farmers are using climate information to make several critical farming and cropping choices decisions. About 79% of the respondents who were receiving climate information indicated that they used such information to make decisions on land preparations. The study communities are characterised by unimodal rainfall patterns with rainfall starting from May/June to September/October (GSS, 2013). Ecologically and economically, northern Ghana is less endowed compared to its southern counterpart. It is deprived in terms of infrastructural development and is characterised by high poverty levels and low literacy rates (GSS, 2013). Currently, smallholder farmers usually prepare their lands in anticipation of the rains and sometimes have to wait for several weeks after land preparation to witness the onset of the rains for planting. This puts extra stress on household food security and perpetuates existing poverty and climate change vulnerability amongst farming households. Therefore, it is crucially important for these farmers to get information on when the rains will start to inform when land preparation should commence.

Results further showed that, both male and female farmers reported using climate information for equally important decisions including crop variety selection (50%), changing cropping patterns (36%), and harvesting time decisions (21%) (Table 5). Smallholder farmers require different types of climate information at different periods during the farming season. Receiving climate information makes it easier for farmers to make decisions on crop varieties to grow (Amegnaglo et al., 2017). Selecting the appropriate varieties of crops is crucial in the face of changing rainfall patterns and increasing temperatures. Consequently, farmers are now employing more drought tolerant and early maturing varieties of crops to manage climate risks (Aniah et al., 2019). Smallholder farmers need information on the expected amount and distribution of rainfall as well as the length of the growing season provided through sub-seasonal and seasonal forecasts to make critical decisions on the type of crops to plant for the season. The number of rainy days and dry spells are also crucial in making decisions on when to plant, disease management and harvesting times (Coulibaly et al., 2015). For crop disease management, wind direction, wind speed, average temperatures, dry spell, as well as relative humidity are quite important for smallholder farmers in dryland farming systems. Adjusting the timing of planting has become one of the important adaptation measures for dryland farming systems and about 32% of the study respondents reported that they used climate information to make decisions on when to plant their crops. A farmer reported: *"we need information on when the rains will start to enable us make important decision regarding when to plant our crops and which kinds of crops may be suitable for the season in the light of the climate information provided"* (Farmer, Focus Group Discussion, Telli, October 2019).

Farmers vary their planting time in order to avoid drought that could be devastating for crops and food security for vulnerable smallholder farmers in the study communities. With temperatures projected to increase and rainfall becoming more variable across all agro-ecological zones of Ghana (Asante and Amuakwa-Mensah, 2015), the ability of smallholder farmers to make informed farming and cropping choices is critical for building resilience to climate change.

Similar studies elsewhere have established that climate information is critical in building the adaptive capacity of farmers to address climate risks. In Burkina Faso, Lugen et al. (2018) reported that, farmers adjusted their planting times to fit the rains. Similar studies conducted in northern Ghana (Nyadzi et al., 2018) also reiterated that farmers'

Table 5
Use of climate information by study respondents receiving climate information (%).

Farm operations	Examples of climate information required by smallholder farmers	All sample (n = 335)		Females (n = 132)		Males (n = 203)	
		N	%	N	%	N	%
Land preparations	Onset and cessation dates, amount and distribution of rainfall, length of season.	265	79.1	108	81.8	157	77.3
Crop variety selection	Amount and distribution of rainfall, average temperature, relative humidity.	168	50.1	71	53.8	97	47.8
Changing cropping patterns	Average temperature, length of the growing season, number of rainy days.	121	36.1	43	32.6	78	38.4
Harvesting time decisions	Cessation of the rains, number of rainy days, and number of dry spells.	70	20.9	32	24.2	38	18.7
Crop risk management	Relative humidity, wind speed and direction, soil moisture content, etc.	34	10.1	10	7.6	24	11.8
Planting time adjustments	Onset of the rains, average temperature, length of the growing season, etc.	107	31.9	37	28.0	70	34.5
Diseases & pests management	Average temperature, relative humidity, number of rainy days, etc.	9	2.7	2	1.5	7	3.4

knowledge on climate information and services are critical to guide their decision of planting times. Most smallholder farmers received climate information that informed their decision on land allocation and preparation at the beginning of the growing season in Kenya (Josephert et al., 2019) and Burkina Faso (Lugen et al., 2018). Hansen et al. (2019) argued that climate services can be used to support the adaptation needs of African farmers.

4.3. Barriers to the uptake of climate information by smallholder farmers

The successful uptake of climate information is often confronted with multiple socioeconomic and cultural barriers. Results from the household surveys and focus group discussions revealed a number of key barriers militating against the successful uptake of climate information for building the adaptive capacity of smallholder farmers in the study communities (Table 6). Key amongst the barriers were inadequate information on seasonal forecast for long-term planning, low accessibility of climate information, high levels of illiteracy, misalignment between the climate information provided and what is needed by smallholder farmers and timeliness of climate forecast/information. Other barriers reported included the lack of awareness on climate change, technical language used in communicating climate information and mistrust in climate information by smallholder farmers.

About 81% of the study respondents reported that inadequate information on seasonal forecast for long-term planning was a key barrier constraining smallholder farmers' ability to utilise climate information (Table 6). A smallholder farmer stated: "*it is difficult to plan long-term farming practices and take farm management decisions based on daily forecasts. We need information on duration of the rainfall and dry spells during the season. This will help us to plan our farming activities*" (Farmer, Focus Group Discussion, Yameriga, October 2019). Climate information is produced by GMet and shared through various means to different end-users. However, most often, the climate information is delivered through daily forecasts and may not be useful for long-term farm management decision making by smallholder farmers. The misalignment between the climate information provided and the needs of smallholder farmers was reported by about 55% of study respondents. A key informant remarked: "*most often, there is a misalignment between climate information provided by national meteorological agencies and the needs of the end users. We usually need information on the onset of the rains as well as dry and wet spells during the farming seasons. However, these kinds of information are not provided to farmers and this is worrying*" (Key Informant Interview, Tindongo, October 2019). It was reported during focus group discussions that farmers need information on the onset of the rains as well as the cessation of the rains in order to plan planting and harvesting activities. Farmers also need monthly and seasonal climate outlook that can help them to make informed decisions on the projected rainfall and temperature patterns during the farming season.

Farmers are unable to use climate information because scientists sometimes, presume that the users of climate information think just like them and construct their "idealized users" (Bruine de Bruin and Bostrom, 2013). Scientists end up misunderstanding the needs of end-users of climate information (Porter and Dessai, 2017). An extension officer stated: "*we are interested in the distribution of the rains in the course of the season and this information is usually not provided to smallholder farmers. This makes it difficult to make important farm decisions*" (Agricultural Extension Officer, Key Informant Interview, Bolgatanga, 2019). Such findings are in consonance with other studies suggesting widespread gaps between the climate informational needs of farmers vis-à-vis the information services that are routinely provided to farmers (Hansen et al. 2011, Lemos et al., 2012).

These findings resonate with studies in other parts of Africa, suggesting that the disconnection between producers and users of climate information is a constraining factor for the uptake of climate information (Sultan et al., 2020; Lemos et al., 2012; Ouedraogo et al., 2018). To overcome challenges related to misalignment, climate information should be co-produced with the end-users. This will ensure the appreciation and ownership of such information and enhance the propensity for farmers to utilize such information for critical farm management decisions. Co-produced climate information ensures an inclusive, collaborative and flexible process (Vincent et al., 2018). When farmers are sidelined in the production of climate information, their concerns and needs are not fully taken into consideration, making the uptake of such information less attractive to, and useable by farmers.

High illiteracy levels is also a key factor constraining farmer's uptake of climate information in the study communities and this was reported by 77% of the study respondents (Table 6). A stakeholder stated: "*high level of illiteracy amongst farmers in this region is alarming. Many of our people do not have formal education and this makes it difficult for them to sometimes appreciate and understand climate information* (Agricultural Development Officer, Navrongo, September 2019). The study communities are characterised by high levels of illiteracy, with majority of farmers having no formal education (GSS, 2013). High levels of illiteracy is prevalent in the study communities with Kassena-Nankana Municipal, Talensi and Bawku West districts having 44%, 58% and 36% illiteracy rates, respectively (GSS, 2013). The uptake of information is often related to the level of education with those with good education better appreciating the use of climate information in making farm management decisions.

Our results also show that farmers have less trust in weather and

Table 6
Barriers constraining the uptake of using climate information.

Reported barriers	All (Male and Female)		Female		Male		Difference		
	%	SE	%	SE	%	SE	%	SE	T-value
Not sure how to get this climate information	55.0	0.248	54.5	0.249	55.3	0.248	−0.8	0.0432	−0.560
Not clear how this information can be used to help with farming	49.9	0.251	47.7	0.251	51.2	0.251	−3.5	0.0560	−0.625
Don't trust weather forecasts/information	42.7	0.245	40.2	0.242	44.3	0.248	−4.1	0.0553	−0.755
The information is difficult to understand (technical language)	54.0	0.249	47.0	0.251	58.6	0.244	−11.6**	0.0557	−2.098
Misalignment between the climate information provided and what is needed by farmers	54.6	0.249	47.0	0.251	59.6	0.242	−12.6**	0.0556	−2.281
Sociocultural norms related to the use of climate information	33.1	0.222	25.0	0.189	38.4	0.238	−13.4***	0.0523	−2.568
Lack of reliability of climate forecast/information	63.0	0.234	50.0	0.252	71.4	0.205	−21.4***	0.0529	−4.054
Timeliness of climate forecast/information	64.8	0.229	59.1	0.244	68.5	0.217	−9.4*	0.0533	−1.760
Vagueness of climate information	52.8	0.250	44.7	0.249	58.1	0.245	−13.4**	0.0555	−2.420
High illiteracy levels amongst smallholder farmers	76.8	0.179	77.9	0.173	76.0	0.183	1.9	0.0364	0.562
Lack of awareness of climate information	74.6	0.190	73.4	0.196	75.4	0.186	−2.0	0.0380	−0.865
Low accessibility of climate information (lack of TV, radios etc.)	78.2	0.171	77.0	0.178	79.0	0.167	−2.0	0.0361	−0.583
Inadequate information on seasonal forecast for long-term planning	80.9	0.155	77.5	0.175	83.2	0.140	−5.7	0.0348	−1.484

Note ***, **, and * respectively, denote significant levels of 1%, 5%, and 10%.

climate information (Table 6). A farmer provided a characteristic remark: "*most farmers do not trust weather information because some information conflict with that disseminated by agents. Most farmers do not have any trust in the climate information provided on radios and television because of previous experiences*" (Farmer, Focus Group Discussion, Vunania, September 2019). Lack of trust in climate information can be attributed to past experiences of smallholder farmers relating to inaccurate predictions by the national meteorological agency. In Ghana, Kabobah et al. (2018) stated that farmers received early-warning weather information but its utilization was minimal due to mistrust, as previous information had been inaccurate and had led to over- and under- cultivation of crops. Forecast information are usually given for large regions of the country and if such forecasts are not realised by particular areas, farmers become sceptical about subsequent forecasts. Therefore, there is the need to change the way national meteorological services produce and present seasonal forecasts regionally and nationally (Hansen et al. 2019).

About 54% of the study respondents also reported that forecast information are mostly communicated in technical terms not easily understood by smallholder farmers (Table 6). Participants at focus group discussions and key informants bemoaned the technical language used in communicating climate information. A focus group participant indicated: "*the information provided to farmers on radio and television is difficult to understand. The use of jargons, terminologies and foreign languages instead of the local ones result in misunderstanding of weather information by farmers. Most radio programs are conducted in the English language and most of our farmers do not understand the English language*" (A Farmer, Focus Group Discussion, Telli, October 2019). An extension agent remarked: "*it is difficult to decode the language used in forecasting climate information. We sometimes, struggle to find appropriate local language to translate technical jargons into local languages for easier comprehension by the smallholder farmers. This limits the usability of such climate forecast*" (Extension Agent, Key Informant Interview, Bolgatanga, October 2019). Illiterately levels are very high in these communities and this calls for innovative and easy to follow approaches of communicating climate information to smallholder farmers who badly need such information. Climate information becomes more accessible and usable when such information is delivered in the language easily understood by the end-users (Dilling and Lemos, 2011). It is therefore more useful when information is delivered in the local dialect for easy comprehension by farmers. Nyantakyi-Frimpong (2019) examined climate information service delivery and knowledge flows among smallholder farmers in northern Ghana by employing a participatory diagramming approach. He identified several structural barriers to acquiring climate information services including technicalities associated with climate forecasts presented to farmers with no formal education.

Results from the t-test showed a statistically significant difference between the barriers to the uptake of climate information reported by male and female farmers (Table 6). For instance, male smallholder farmers are likely to experience difficulties relating to technical language of climate information (Difference = -0.116, SE = 0.0557, $p < 0.05$), misalignment between the climate information provided and what farmers need for farming (Difference = -0.126, SE = 0.0556, $p < 0.05$) and vagueness of climate information (Difference = -0.134, SE = 0.0555, $p < 0.05$). Other perceived barriers that demonstrated significant difference between male and female farmers included a lack of reliability of climate forecast/information (Difference = -0.214, SE = 0.0529, $p < 0.10$) and sociocultural norms related to the use of climate information (Difference = -0.134, SE = 0.0523, $p < 0.001$). These results corroborate the findings of Antwi-Agyei et al. (2014) who observed that sociocultural norms serve as barriers to adaptation to the threats posed by climate change.

Our results showed that, men generally have a strong perception of barriers to climate change information access relative to the women. In a patriarchal society where women work more than men; but have less control and access to capital assets including climate information receptors, male farmers are more likely to access climate information. Intuitively, male farmers are more likely to become aware of perceived barriers and challenges to access and use of climate information than their female counterparts. Thus, gender norms and expectations as well as patriarchal values can be implicated and largely blamed for a lack of access to and uptake of climate information services.

5. Conclusions

This study sought to evaluate the opportunities and barriers to the increased uptake of climate information by smallholder farmers in the Sudan savannah agro-ecological region in northern Ghana. The results indicated that more than a third of study respondents (40%; n = 555) in this vulnerability hotspot were not receiving any kind of climate information. This has serious repercussions for food security of smallholder farmers whose livelihoods are dependent on rain-fed agricultural systems. Findings suggested that the majority of those receiving climate information were receiving information on rainfall (91%; n = 335) with fewer indicating that they received information on temperature (21%) and windstorms (26%). Radio was reported as the key medium for receiving climate information, followed by mobile text messages and workshops. Results further indicated that both male and female farmers reported using climate information for important decisions including land preparations (79%), crop variety selection (50%), changing cropping patterns (36%), and harvesting time decisions (21%). Others also employed climate information for planning planting time (32%) and managing crop risks (10%).

Despite the utility of climate information to direct and guide adaptation practices towards climate change and national development, findings show that the successful uptake of climate information remains confronted with multiple socioeconomic and cultural barriers in West Africa. Key barriers militating against the successful uptake of climate information for building the adaptive capacity of smallholder farmers include inadequate information on seasonal forecast for long-term planning, low accessibility of climate information, high levels of illiteracy in the study communities, lack of awareness on climate change, timeliness of climate forecast/information, mistrust in climate information by smallholder farmers, and misalignment between the climate information provided and what is needed by farmers.

Appropriate training programmes need to be implemented by environmental and agricultural planning bodies to reduce barriers, which limit the diffusion of climate services as practical tools for supporting decision-making processes. Training initiatives, managed by the Ghana Meteorological Agency and international organizations including the World Meteorological Organization Training Centres should be targeted in building the capacities of agricultural extension workers for more effective and tailored communication of climate information to different user groups. This will provide a possible strategy to overcome the barriers to the adoption of climate services, and facilitate the delivery of new information tools and deeper awareness on climate change.

The study proposes the following recommendations: (i) forecast information should be communicated in local language so that it is easily understood and appreciated by smallholder farmers; (ii) climate information should be linked to agricultural practices for smallholder farmers to appreciate the usefulness of such information; (iii) climate information should be co-produced with farmers and where possible, integrated with the local indigenous knowledge. Communication of climate information should also be directly linked to agronomic advice to make such information usable by smallholder farmers.

Findings from this study provide important insights for policy makers and agricultural planning officers and institutions such as the Ministry of Food and Agriculture, the Ghana Meteorological Agency as well as the Environmental Protection Agency to address the barriers militating against the successful uptake of climate information to build the adaptive capacity of farmers in Ghana. There is the need to provide improved communication infrastructure as part of the National Framework for Climate Services. Training should be provided for staff of

Ghana Metrological Agency and extension officers of the Ministry of Food and Agriculture for more effective and tailored communication of climate information to different user groups.

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CRediT authorship contribution statement

Philip Antwi-Agyei: Conceptualization, Funding acquisition, Methodology, Writing - original draft, Writing - review & editing. **Andrew J. Dougill:** Conceptualization, Writing - original draft, Writing - review & editing. **Robert C. Abaidoo:** Conceptualization, Writing - original draft, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

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.

Aniah, P., Kaunza-Nu-Dem, M.K., Ayembilla, J.A., 2019. Smallholder farmers' livelihood adaptation to climate variability and ecological changes in the savannah agro ecological zone of Ghana. Heliyon. 5, e01492 https://doi.org/10.1016/j.heliyon.2019.e01492.

Antwi-Agyei, P., Amanor, K., Hogarh, J.N., Dougill, A.J., 2020. Predictors of access to and willingness to pay for climate information services in north-eastern Ghana: a gendered perspective. Environmental Development. 100580 https://doi.org/10.1016/j.envdev.2020.100580.

Antwi-Agyei, P., Fraser, E.D.G., Dougill, A.J., Stringer, L.C., Simelton, E., 2012. Mapping the vulnerability of crop production to drought in Ghana using rainfall, yield and socioeconomic data. Appl. Geogr. 32 (2), 324–334. https://doi.org/10.1016/j.apgeog.2011.06.010.

Antwi-Agyei, P., Quinn, C.H., Adiku, S.G.K., Codjoe, S.N.A., Dougill, A.J., Lamboll, R., Dovie, D.B.K., 2017. Perceived stressors of climate vulnerability across scales in the Savannah zone of Ghana: A participatory approach. Reg. Environ. Change 17, 213–227. https://doi.org/10.1007/s10113-016-0993-4.

Antwi-Agyei, P., Stringer, L.C., Dougill, A.J., 2014. Livelihood adaptations to climate variability: insights from farming households in Ghana. Reg. Environ. Change 14 (4), 1615–1626. https://doi.org/10.1007/s10113-014-0597-9.

Asante, F.A., Amuakwa-Mensah, F., 2015. Climate Change and Variability in Ghana: Stocktaking. Climate 3 (1), 78–99. https://doi.org/10.3390/cli3010078.

Basdew, M., Jiri, O., Mafongoya, P.L., 2017. Integration of indigenous and scientific knowledge in climate adaptation in KwaZulu-Natal, South Africa. Change and Adaptation in Socio-Ecological Systems 3 (1), 56–67. https://doi.org/10.1515/cass-2017-0006.

Bruine de Bruin, W., Bostrom, A., 2013. Assessing what to address in science communication. Proc. Natl. Acad. Sci. 110 (3), 14062–14068. https://doi.org/10.1073/pnas.1212729110.

Cherotich, V.K., Saidu, O., Bebe, B.O., 2012. Access to Climate Change Information and Support Services by the vulnerable groups in semi-arid Kenya for adaptive capacity development. Afr. Crop Sci. J. 20 (2), 169–180.

Christensen, J.H., Hewitson, B., Busuioc, A., Chen, A., Gao, X., Held, R., Jones, R., Kolli, R.K., Kwon, W., Laprise, R., 2007. Regional climate projections: climate change: the physical science basis. Contribution of working group I to the IPCC fourth assessment report. Cambridge University Press, Cambridge 7.

Connolly-Boutin, L., Smit, B., 2016. Climate change, food security, and livelihoods in sub-Saharan Africa. Reg. Environ. Change 16 (2), 385–399. https://doi.org/10.1007/s10113-015-0761-x.

Coulibaly, J.Y., Mango, J., Swamila, M., Tall, A., Kaur, H., Hansen, J., 2015. What climate services do farmers and pastoralists need in Tanzania? Baseline study for the GFCS Adaptation Program in Africa. CCAFS, Copenhagen, Denmark.

Creswell, J.W., 2014. Research Design. Qualitative, Quantitative and Mixed Methods Approaches. Sage Publications Inc., Thousand Oaks, California.

Diaz, H.P., 2016. A conceptual framework for understanding vulnerabilities to extreme climate events. In: Leal Filho, W., Musa, H., Cavan, G., O'Hare, P., Seixas, J. (Eds.), Climate Change Adaptation, Resilience and Hazards. Climate Change Management, Springer, Cham, pp. 143–156.

Dilling, L., Lemos, M.C., 2011. Creating usable science: opportunities and constraints for climate knowledge use and their implications for science policy. Global Environ. Change 21 (2), 680–689. https://doi.org/10.1016/j.gloenvcha.2010.11.006.

Diouf, N.S., Ouedraogo, I., Zougmoré, R.B., Ouedraogo, M., Partey, S.T., Gumucio, T., 2019. Factors influencing gendered access to climate information services for farming in Senegal. Gender, Technology and Development 23 (2), 93–110. https://doi.org/10.1080/09718524.2019.1649790.

Dube, T., Moyo, P., Ncube, M., Nyathi, D., 2016. The impact of climate change on agro-ecological based livelihoods in Africa: A review (January 29, 2016). Dube, T., Moyo, P., Mpofu, M., Nyathi, D. (2016). The impact of climate change on agro-ecological based livelihoods in Africa: A review. Journal of Sustainable Development 9 (1), 256-267. 10.5539/jsd.v9n1p256.

GSS, 2013. 2010. Population and Housing Census. National Analytical report, Ghana Statistical Service, Accra, Ghana.

Hansen, J.W., Vaughan, C., Kagabo, D., Dinku, T., Carr, E.R., Körner, J., Zougmoré, R.B., 2019. Climate services can support African Farmers' context-specific adaptation needs at scale. Frontiers in Sustainable Food Systems 3, 1–16. https://doi.org/10.3389/fsufs.2019.00021.

Hansen, J.W., Mason, S.J., Sun, L., Tall, A., 2011. Review of seasonal climate forecasting for agriculture in sub-Saharan Africa. Exp. Agric. 47 (2), 205–240. https://doi.org/10.1017/s0014479710000876.

Hirons, M., Boyd, E., McDermott, C., Asare, R., Morel, A., Mason, J., Malhi, Y., Norris, K., 2018. Understanding climate resilience in Ghanaian cocoa communities–advancing a biocultural perspective. Journal of Rural Studies 63, 120–129. https://doi.org/10.1016/j.jrurstud.2018.08.010.

Intergovernmental Panel on Climate Change (IPCC), 2018. Global warming of 1.5°C: Summary for policymakers. Geneva, Switzerland: World Meteorological Organization.

Jones, L., Dougill, A., Jones, R.G., Steynor, A., Watkiss, P., Kane, C., Vincent, K., 2015. Ensuring climate information guides long-term development. Nat. Clim. Change 5 (9), 812–814. https://doi.org/10.1038/nclimate2701.

Josephert, A.A., Wilberforce, C., Caroline, M., Ong'anyi, P.O., 2019. Access and Use of Seasonal Climate Forecasts Information on Maize Crop Production in Vihiga County, Kenya. International Journal of Research and Innovation in Social Science 3 (3), 328–338.

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 African Journal of Applied Ecology 26, 14–26.

Krippendorff, K., 2004. Content analysis: an introduction to its methodology. Sage Publications Inc., Thousand Oaks, California.

Lemos, M.C., Kirchhoff, C.J., Ramprasad, V., 2012. Narrowing the climate information usability gap. Nat. Clim. Change 2 (11), 789–794. https://doi.org/10.1038/nclimate1614.

Lugen, M., Diaz J., Sanfo, S. ,Salack, S., 2018. Using climate information and services to strengthen resilience in agriculture: the APTE-21 project in Burkina Faso, KLIMOS Working Paper n°15, KLIMOS-ACROPOLIS, Brussels, Belgium.

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 (11), e00889 https://doi.org/10.1016/j.heliyon.2018.e00889.

Niang, I., Ruppel, O., Abdrabo, M., Essel, A., Lennard, C., Padgham, J., Urquhart, P., 2014. Africa, climate change: impacts, adaptation and vulnerability – Contributions of the Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. 1199–1265. Cambridge: Cambridge University Press.

Nkiaka, E., Taylor, A., Dougill, A.J., Antwi-Agyei, P., Fournier, N., 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 (12), 123003 https://doi.org/10.1088/1748-9326/ab4dfe.

Nyadzi, E., Nyamekye, A.B., Werners, S.E., Biesbroek, R.G., Dewulf, A., Slobbe, E.V., Ludwig, F., 2018. Diagnosing the potential of hydro-climatic information services to support rice farming in northern Ghana. NJAS - Wageningen Journal of Life Sciences 86–87, 51–63. https://doi.org/10.1016/j.njas.2018.07.002.

Nyantakyi-Frimpong, H., 2019. Combining feminist political ecology and participatory diagramming to study climate information service delivery and knowledge flows among smallholder farmers in northern Ghana. Appl. Geogr. 112, 102079 https://doi.org/10.1016/j.apgeog.2019.102079.

Ouedraogo, I., Diouf, N.S., Ouedraogo, M., Ndiaye, O., Zougmore, R., 2018. Closing the gap between climate information producers and users: Assessment of needs and uptake in Senegal. Climate 6 (1), 13. https://doi.org/10.3390/cli6010013.

Oyekale, A., 2015. Access to risk mitigating weather forecasts and changes in farming operations in East and West Africa: Evidence from a baseline survey. Sustainability 7 (11), 14599–14617. https://doi.org/10.3390/su71114599.

Porter, J.J., Dessai, S., 2017. Mini-me: Why do climate scientists' misunderstand users and their needs? Environ. Sci. Policy 77, 9–14. https://doi.org/10.1016/j.envsci.2017.07.004.

Reid, P., Vogel, C., 2006. Living and responding to multiple stressors in South Africa-glimpses from Kwazulu-Natal. Global Environmental Change 16 (2), 195–206. https://doi.org/10.1016/j.gloenvcha.2006.01.003.

Roncoli, C., Jost, C., Kirshen, P., Sanon, M., Ingram, K.T., Woodin, M., Hoogenboom, G., 2008. From accessing to assessing forecasts: An end to end study of participatory climate forecast dissemination in Burkina Faso (West Africa). Clim. Change 92, 433–460. https://doi.org/10.1007/s10584-008-9445-6.

Singh, C., Daron, J., Bazaz, A., Ziervogel, G., Spear, D., Krishnaswamy, J., Zaroug, M., Kituyi, E., 2018. The utility of weather and climate information for adaptation decision-making: current uses and future prospects in Africa and India. Climate and Development 10 (5), 389–405. https://doi.org/10.1080/17565529.2017.1318744.

Sultan, B., Lejeune, Q., Menke, I., Maskell, G., Lee, K., Noblet, M., Sy, I., Roudier, P., 2020. Current needs for climate services in West Africa: Results from two stakeholder surveys. Climate Service 18, 100166. https://doi.org/10.1016/j.cliser.2020.100166.

Sultan, B., Gaetani, M., 2016. Agriculture in West Africa in the twenty-first century: Climate change and impacts scenarios, and potential for adaptation. Front. Plant Sci. 7, 1–20. https://doi.org/10.3389/fpls.2016.01262.

Sylla, M.B., Pal, J.S., Faye, A., Dimobe, K., Kunstmann, H., 2018. Climate Change to Severely Impact West African Basin Scale Irrigation in 2°C and 1.5°C Global Warming Scenarios. Sci. Rep. 8 (1), 14395. https://doi.org/10.1038/s41598-018-32736-0.

Vaughan, C., Dessai, S., 2014. Climate services for society: Origins, institutional arrangements, and design elements for an evaluation framework. Wiley Interdiscip. Rev. Clim. Change 5 (5), 587–603. https://doi.org/10.1002/wcc.290.

Vincent, K., Dougill, A.J., Dixon, J.L., Stringer, L.C., Cull, T., 2017. Identifying climate services needs for national planning: insights from Malawi. Climate Policy 17 (2), 189–202. https://doi.org/10.1080/14693062.2015.1075374.

Vincent, K., Daly, M., Scannell, C., Leathes, B., 2018. What can climate services learn from theory and practice of co-production? Climate Service 12, 48–58. https://doi.org/10.1016/j.cliser.2018.11.001.

Zongo, B., Diarra, A., Barbier, B., Zorom, M., Yacouba, H., Dogot, T., 2016. Farmers' perception and willingness to pay for climate information in Burkina Faso. Journal of Agricultural Science 8 (1), 175–187. https://doi.org/10.5539/jas.v8n1p175.