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The contribution of weather forecast information to agriculture, water, and energy sectors in East and West Africa: A systematic review

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The provision of timely and precise weather information could reduce the vulnerability of people to climate change risks. In this study, we conduct a systematic review to synthesize the existing evidence on weather information services for the agriculture, water, and energy sectors of East and West Africa and identify priorities for future research. This systematic review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) statement checklist. The review identified relevant peer-reviewed publications using ScienceDirect and Scopus databases for original research articles published in English from 2000 to 2022. After applying the eligibility criteria, 25 articles were included in the final review. The themes emerging from the articles were extracted, and a summary was provided to illustrate each theme. The review revealed that weather information studies focus more on the agriculture sector than energy production and water resource management. Users of weather information mainly accessed information related to rainfall and temperature, and the information was accessed mainly through radio, mobile phones, and television. Most of the information provided focused on generic meteorological forecasts instead of tailored impact-based forecasts. Only very few users can access, or benefit from the information produced due to poor communication and technical understanding of weather information. In addition, a lack of downscaled information, logistics, and trust hinders the uptake and use of climate information. Consequently, mainstreaming capacity-building of key stakeholders is required to promote effective adoption and strengthening of climate information services across East and West Africa.

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KEYWORDS

climate change, decision-making, climate change adaptation, extreme events, food security, climate vulnerability

Introduction

There has been a surge in climate change-induced extreme weather events such as floods, droughts, and storms in the past decade (2010—2020), particularly in tropical regions such as sub-Saharan Africa (Codjoe and Atiglo, 2020; Dube et al., 2021). The effects of such extreme events are more profound in Africa due to limited capacity to manage risks, weaker revenue capability, and lower institutional ability to upgrade infrastructure (Kayaga et al., 2013; Horne et al., 2018). Extreme events can result in the loss of human lives and livelihoods, decreased crop productivity, destruction of electricity distribution infrastructure, and interruption to water supplies (Connolly-Boutin and Smit, 2016; Curtis et al., 2017; Ife-Adediran and Aboyewa, 2020; Intergovernmental Panel on Climate Change, 2021).

One way to minimize the impact of extreme weather is by improving weather forecasting and better communication of weather warnings. The ability to provide timely and precise weather forecasts offers the potential to reduce the vulnerability of people to the impacts of extreme weather (Singh et al., 2018; Alley et al., 2019; Nost, 2019; Antwi-Agyei et al., 2021a). However, accurate forecasting of weather variables remains a major challenge for the scientific community (Mani and Mukherjee, 2016), especially in tropical regions. The need to safeguard lives and livelihoods from extreme weather events has made the provision of timely weather forecasts an essential adaptation initiative (Oyekale, 2015). Improving the weather forecast's accuracy is crucial for people's safety and protecting key economic sectors, including agriculture, aviation, water, energy, and emergency response (Parker et al., 2021). In addition, availability, accessibility, and usability of accurate weather information are key for climate-informed decision-making (Dinku et al., 2014; Mabe et al., 2014; Nkiaka et al., 2019). As weather forecasts become progressively more accurate and timelier, their use can inform climate change risk mitigation strategies. However, the benefits linked to these improvements will only be appreciated if the forecasts are used directly in management decisions (Blum and Miller, 2019).

There is an urgent need to assess the forecasting of high-impact weather in sub-Saharan Africa to minimize the devastating effects of extreme events on the economy and livelihoods (Woodhams et al., 2018; Carter et al., 2019). With improved warning systems, it is possible to reduce the extent of damage by improving the resilience of at-risk populations and reinforcing the preparedness of the population to cope with extreme events (Anaman et al., 2017). The production and use of improved weather information to deliver early warnings and adequately manage these extreme events are essential in societal preparedness against extreme weather events (Anaman et al., 2017).

Studies have highlighted the importance of weather and climate services in mitigating risks such as drought, flooding, and loss of lives and livelihoods (Mabe et al., 2014; Sena et al., 2014; Oyekale, 2015; Mittal, 2016; Guido et al., 2021; Kayaga et al., 2021). These studies have considered the effects of extreme weather events on agriculture, health, water, and energy sectors in South America, Asia, and Africa. Despite the plethora of information on climate services, the effect of observations of climate change on using weather forecasts has not been investigated in depth in East and West Africa regions (Seo, 2014; Nkiaka et al., 2019). Studies have not synthesized all of the evidence on the contribution of weather and climate information in Africa into a single study to enhance decision-making. The choice of East and West Africa was influenced by the geographic and socioeconomic characteristics, which make these regions most vulnerable to climate change. In addition, gaps remain between the production of climate services, its use in decision-making, and the societal benefits derived from climate services (Webber, 2019; Harvey et al., 2021).

This review focused on the agricultural, energy, and water resource sectors. These sectors are critically important as they contribute significantly to the gross domestic product (GDP) of the East and West Africa regions (Coers and Sanders, 2013; Food and Agriculture Organisation and African Development Bank, 2015; Nhemachena et al., 2018; Gashu et al., 2019) and are highly prone to climate variability and change (Cervigni et al., 2015; Butterfield et al., 2017).

With respect to water resources, many African countries encounter numerous difficulties in the acquisition of sustainable and sufficient quality water to meet the needs of a rapidly increasing population and socioeconomic development without compromising on safeguarding the essential ecosystems that water resources depend on (Global Water Partnership, 2015). Water scarcity in these two regions has risen due to climate change and other factors, with negative consequences projected at the river basin level (Yomo et al., 2019). It is predicted that water security will be significantly affected due to urbanization and rapid population growth in various continents (United Nations, 2019), as more water is required for domestic water supply, agriculture, and business. General Circulation Models (GCMs) in East Africa predict a 10–20% surge in rainfall and a shift in rainfall distribution. For example, in Uganda, the impact of climate change on seasonal rainfall is projected to be more significant compared to variations in annual rainfall (Kisakye and Van der Bruggen, 2018). In addition, rapid population growth, usage of agrochemicals, industrialization, urbanization, soil steepness, and land-use and cover changes threaten water quality (Mukanyandwi et al., 2018). Similarly, West Africa is dependent on rain-fed agriculture and already prone to extreme weather events such as floods and droughts. The region is projected to face a declining crop yield by 2050 if the large-scale water cycle changes already observed deteriorate (International Water Management Institute, 2022). An assessment of available water resources in Burkina Faso indicates that the country is heading toward water scarcity with ever-increasing demands for water. This situation could affect key sectors that are important for socioeconomic development, such as agriculture, and endanger the well-being of more than 340 million people in the region (WaterAid, 2021). However, water resource management and development have primarily paid less attention to the interdependence of the various uses of water—for agriculture, domestic, and industrial use and for maintaining the ecosystems and hydrological services. Inadequate data and information on the state of renewable water resources further worsen water planning and governance (Global Water Partnership, 2015).

The agriculture sector is the backbone of many African countries' economies. The sector employs about 65–70% of the labor force, supports 90% of household livelihoods, and is responsible for about one-fourth of the continent's gross domestic product (OECD/FAO, 2016; World Bank, 2016). The growth in the agriculture sector is more effective in easing poverty than growth in non-agricultural sectors (Mukasa et al., 2017). The agriculture sector is by nature subtle to climate conditions and is also prone to the impacts of climate change (Parker et al., 2019). In most African countries, agriculture is largely small scale and rain-fed, thus making it vulnerable to climate variability and change (Ochieng et al., 2016; Hlophe-Ginindza and Mpandeli, 2021). The economy and the livelihoods of many households in East and West Africa have become vulnerable to climate change owing to heavy dependence on rain-fed agriculture and natural resources (Ochieng et al., 2016; Sultan and Gaetani, 2016; Kalai et al., 2017). Due to climate change, observed and projected disruptions in precipitation patterns are likely to reduce growing seasons and negatively affect crop yield (Guido et al., 2020). The agriculture sector is predominated by smallholder farmers with limited access to the resources and technology needed to cope with the impacts of extreme events (Abdul-Razak and Kruse, 2017). To cope with the devastating effects of climate change on food production, farmers have been adopting new farming technologies and practices. These practices include improved management systems such as introducing microcatchments, crop cover, crop rotations, ridges, planting trees, improved pastures, and innovative technologies such as shorter cycle varieties, improved seeds, and drought-tolerant varieties (Kristjanson et al., 2012; Anuga and Gordon, 2016). East and West Africa are key producers of the African continent's food; therefore, strengthening the resilience of the agricultural system to climate change is crucial to reducing poverty (SDG1) and averting hunger (SDG 2) (FAO, 2015).

The review also focused on the energy sector of East and West Africa. The economy and energy systems of East Africa are extremely reliant on natural resources and thus very prone to current and projected effects of climate change (Ddamulira, 2016). The region's present energy state is marked by a high reliance on biofuels in rural areas. While biofuels are renewable clean energy options, their use remains traditional, with major environmental and health consequences (Waindi and Khalid, 2011). Heavy system losses also harm the electricity sector in East Africa. This is owing to a high reliance on hydropower for electricity generation. However, the climate in the region has an impact on this reliance since the occurrence of severe drought results in significant losses in electricity output (Waindi and Khalid, 2011). This results in widespread power rationing which has negative impacts on the socioeconomic livelihoods of the people across space and time. The West African region is similarly faced with the realities of energy vulnerability, system unreliability, and fuel price volatility. Energy poverty (lack of access to modern energy services) and its effects on local economies and social development are projected to remain the predominant challenge through 2030 (Merem et al., 2017). The potential impacts of climate change on the energy sector could include substantial stress on the production, distribution, and utilization of energy. This may lead to increased use of fossil fuels or reinforced infrastructure, and increasing greenhouse gas (GHG) emissions, for instance, reduced efficiency of power stations, reduction in renewable energy resources, or increased risks of storm damage to coastal infrastructure (Cronin et al., 2018). These would undermine all of the achievements made in the energy sector.

These sectors (water resources, agriculture, and energy) are inextricably connected because the usage in one sector influences the availability and usage in the other sectors (Mpandeli et al., 2018). It is crucial to assess the influence of weather information on how users can use the information to make important decisions. In this study, weather information users are defined as managers, policymakers, engineers, students, researchers, farmers, and the general public that use weather information and knowledge to inform decision-making (Nkiaka et al., 2019). As yet, there is no comprehensive review of studies evaluating the effects of weather forecasts on these key economic sectors in Africa. Specifically, this review sought to

- identify the type of weather and climate information being accessed by water, agriculture, and energy users across East and West Africa;
- assess the influence of weather and climate information on users' ability to make important decisions with respect to water, agriculture, and energy sectors; and
- identify key barriers to the uptake of weather information in the energy, water, and agriculture sectors in East and West Africa.

Methods

The systematic review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Liberati et al., 2009).

Eligibility criteria

We focused on studies that considered the contribution of weather forecast information to agriculture, water, and energy sectors in East and West Africa. Studies were included for this review if they met all of the underlisted criteria:

1) conducted in either East or West Africa;
2) focused on either agriculture, energy, or water resource sectors;
3) assessed whether weather forecast information helped users to make informed decisions;
4) assessed the barriers to the uptake of weather information;
5) assessed the synergies and trade-offs between the water–energy–food nexus; and
6) original peer-reviewed publications.

We excluded studies that were conducted in other regions, focused on sectors other than those of interest, and considered outcomes not relevant to this study. In addition, papers were excluded if they were not published in English or published before 2000. Reviews, book sections, opinions, letters to the editor, and papers reporting only mathematical models were excluded from this review.

Information sources and search strategy

The review targeted peer-reviewed articles published in English from January 2000 to January 2022. The year 2000 marked a surge of pilot-scale studies with African farmers ensuing the much-publicized 1997/1998 El Nino (Hansen et al., 2011). Articles were searched from two major databases, ScienceDirect and Scopus, due to their broad coverage and quality of content. The search terms included search strings such as ("weather forecast" OR "weather information" OR "weather service") AND ("Agriculture" OR "water resource" OR "energy") AND ("Africa"). Furthermore, we manually searched the reference list of selected articles for articles pertinent to the study but were not captured during The electronic search. Supplementary Table S1 shows the search strategy and results of the various databases.

Study selection

Articles obtained using the search terms were exported into the EndNote reference manager (version X20), and duplicates were removed. Two reviewers (TPA and PA-A) independently screened titles and abstracts of the articles retrieved from the electronic databases and hand searches. Articles that failed to meet the inclusion criteria were excluded. We then downloaded the full-text articles and reviewed them for inclusion. At this stage, studies were excluded for reasons (Supplementary Table S2). Any disagreements in the screening and selection of articles were resolved by dialogue and involvement of a third reviewer.

Data extraction and analysis

A data-extraction form was designed and piloted to gather information according to the focus of the study. The form captured information on the author's name and year of publication, the title of the article, country and region, sector, weather information accessed, whether the information helped make decisions, and key barriers to the uptake of climate information. Regarding data analysis, descriptive statistics were used to present information on study countries and the medium of receiving weather and climate information. Included studies were analyzed using thematic analysis. The themes emerging from the articles were extracted, and a summary was provided to illustrate each theme. These themes include information accessed, user decision-making, and key barriers. Quality assessment of the included papers was not done due to the heterogeneity of the papers.

Results

Search results

Using the search terms, 38,636 and 348 articles were retrieved from ScienceDirect and Scopus databases, respectively. Fourteen (14) additional papers were obtained through random Google search and manual screening of the reference lists of included studies. After removing duplicates, 35,349 records were retained. The titles and abstracts were then screened to obtain 52 records to be included for full-text assessment. Twenty-seven (27) articles were excluded for reasons (Supplementary Table S2), while 25 articles fully met the inclusion criteria (Figure 1).

Study setting

Of the 25 included studies, 20 reported findings from only West Africa, four from East Africa, and one article reported findings from East and West Africa. These studies were conducted in 11 countries across East and West Africa, with the majority of the studies reporting findings from Ghana ($n = 9$), followed by Burkina Faso and Senegal ($n = 5$), Kenya and Tanzania ($n = 3$), Benin, Ethiopia, Niger and Uganda ($n = 2$), and Mali and Nigeria ($n = 1$) (Figure 2). All of the 25 studies focused on the agriculture sector (Table 1).

Information accessed

Twenty-one studies reported on different types of weather information accessed by users. Most of the weather and climate information provided focused on generic meteorological forecasts instead of a tailored impact-based forecast. Though all of the included studies focused on agriculture, the information

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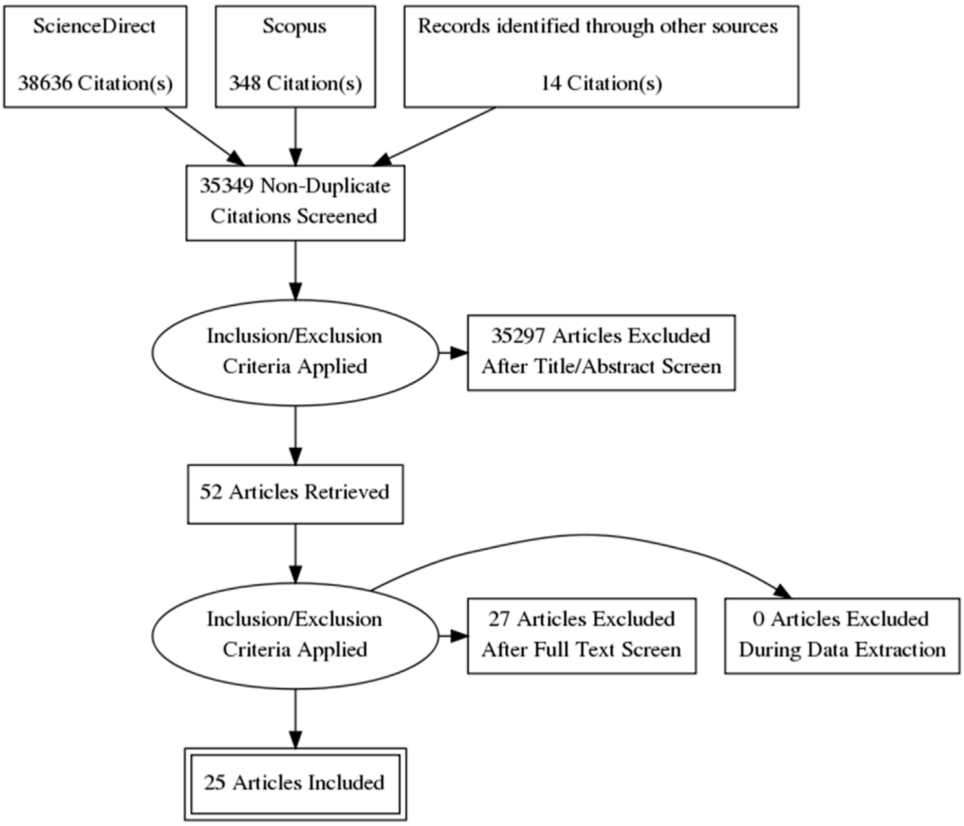

FIGURE 1
Flow diagram of included and excluded studies in the review.

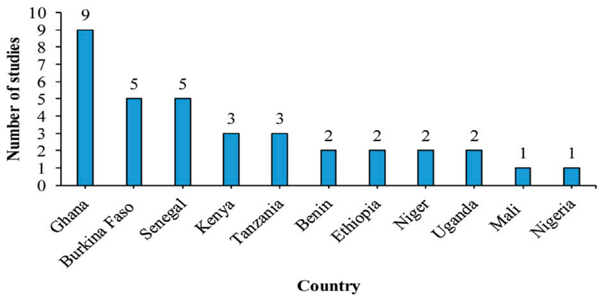

FIGURE 2
Breakdown of the included studies by country.

accessed by users differed based on whether they were into animal husbandry or crop farming. The majority of the studies reported that for users in crop farming, the climate information needed or accessed was related to rainfall and temperature, such as the onset of rains, rainfall distribution and amount, end of rains, the intensity of the dry season, dry spells, and the speed of winds during the rainy season (Rasmussen et al., 2015; Amegnaglo et al., 2017; Diouf et al., 2019; Radeny et al., 2019; Bacci et al., 2020; Partey et al., 2020; Antwi-Agyei et al., 2021c). Some studies reported that pastoralists needed or accessed extra information such as the outbreak of livestock and crop pests/diseases (Oyekale, 2015) and the availability of grazing resources (Rasmussen et al., 2015). However, four studies did not mention the specific type of weather information needed by users. For example, Chiputwa et al. (2022) reported that users needed or accessed information on daily forecasts, early warning system (EWS), and seasonal forecasts, while Wamalwa et al. (2016) reported that users had access to agro-weather and climate information. In addition, disaster forecasts such as flooding, wind and windstorms, dry/wet spells, and drought were reported by eight studies (Rasmussen et al., 2015; Amegnaglo et al., 2017; Ouedraogo et al., 2018; Diouf et al., 2019; Radeny et al., 2019; Bacci et al., 2020; Antwi-Agyei et al., 2021c; Ouedraogo et al., 2021) (Table 2).

The medium through which weather and climate information was received was also assessed. The most common means of accessing climate information included radio, mobile phone (text messages and voice calls), television, and extension officers (Figure 3).

TABLE 1 Characteristics of included studies.

Sn	Author, year	Title	Country	Sector
1	Amegnaglo et al. (2017)	Contingent valuation study of the benefits of seasonal climate forecasts for maize farmers in the Republic of Benin, West Africa	Benin[a]	Agriculture
2	Antwi-Agyei et al. (2021b)	Predictors of access to and willingness to pay for climate information services in north-eastern Ghana: A gendered perspective	Ghana[a]	Agriculture
3	Antwi-Agyei et al. (2021c)	Opportunities and barriers for using climate information for building resilient agricultural systems in Sudan savannah agro-ecological zone of north-eastern Ghana	Ghana[a]	Agriculture
4	Bacci et al. (2020)	Agrometeorological forecast for smallholder farmers: A powerful tool for weather-informed crops management in the Sahel	Niger[a]	Agriculture
5	Chiputwa et al. (2022)	Co-production, uptake of weather and climate services, and welfare impacts on farmers in Senegal: A panel data approach	Senegal[a]	Agriculture
6	Diouf et al. (2019)	Factors influencing gendered access to climate information services for farming in Senegal	Senegal[a]	Agriculture
7	Ebhuoma and Simatele (2019)	"We know our Terrain": indigenous knowledge preferred to scientific systems of weather forecasting in the Delta State of Nigeria	Nigeria[a]	Agriculture
8	Naab et al. (2019)	The role of climate services in agricultural productivity in Ghana: The perspectives of farmers and institutions	Ghana[a]	Agriculture
9	Nyadzi et al. (2018)	Diagnosing the potential of hydro-climatic information services to support rice farming in northern Ghana	Ghana[a]	Agriculture
10	Nyambo and Chengula (2017)	Dissemination of agricultural weather forecasts under weather and climate variability: a case of the smallholder farmers in Moshi rural district, Tanzania	Tanzania[b]	Agriculture
11	Nyang'au et al. (2021)	Smallholder farmers' perception of climate change and adoption of climate smart agriculture practices in Masaba South subcounty, Kisii, Kenya	Kenya[b]	Agriculture
12	Ouedraogo et al. (2021)	Utility and triggers in uptake of agricultural weather and climate information services in Senegal, West Africa	Senegal[a]	Agriculture
13	Ouedraogo et al. (2018)	Closing the gap between climate information producers and users: Assessment of needs and uptake in Senegal	Senegal[a]	Agriculture
14	Oyekale (2015)	Access to risk mitigating weather forecasts and changes in farming operations in east and west Africa: Evidence from a baseline survey	Ethiopia[b], Kenya[b], Tanzania[b], Uganda[b]	Agriculture
			Burkina Faso[a], Ghana[a], Mali[a], Niger[a], Senegal[a]	
15	Partey et al. (2020)	Gender and climate risk management: evidence of climate information use in Ghana	Ghana[a]	Agriculture
16	Radeny et al. (2019)	Indigenous knowledge for seasonal weather and climate forecasting across East Africa	Ethiopia[b], Tanzania[b,] and Uganda[b]	Agriculture
17	Rasmussen et al. (2015)	Improving how meteorological information is used by pastoralists through adequate communication tools	Burkina Faso[a]	Agriculture
18	Sanfo et al. (2022)	Effects of customised climate services on land and labour productivity in Burkina Faso and Ghana	Burkina Faso[a], Ghana[a]	Agriculture
19	Sarku et al. (2021)	Tracing hybridity in the provision of ICT-enabled agricultural weather information services in Ghana	Ghana[a]	Agriculture
20	Sarku et al. (2022)	Usability of weather information services for decision-making in farming: Evidence from the Ada East District, Ghana	Ghana[a]	Agriculture
21	Tall (2010)	Climate Forecasting to Serve Communities in West Africa	-	Agriculture
22	Tarchiani et al. (2021)	Access, uptake, use and impacts of agrometeorological services in Sahelian rural areas: The case of Burkina Faso	Burkina Faso[a]	Agriculture
23	Wamalwa et al. (2016)	Agro weather and climate information dissemination and its influence on adoption of climate smart practices among small scale farmers of Kisii country, Kenya	Kenya[b]	Agriculture
24	Yegbemey et al. (2021)	The Impact of Short Message Services (SMS) Weather Forecasts on Cost, Yield and Income in Maize Production	Benin[a]	Agriculture
25	Zongo et al. (2016)	Farmers' perception and willingness to pay for climate information in Burkina Faso	Burkina Faso[a]	Agriculture

NB.
[a]West Africa.
[b]East Africa.

TABLE 2 Summary of the type of weather information accessed by users.

Author, year	Weather information accessed
Amegnaglo et al. (2017)	Onset of rains, rainfall distribution and amount, end of rains, the intensity of the dry season, and the speed of winds during the rainy season
Antwi-Agyei et al. (2021b)	Information on rainfall and temperature
Antwi-Agyei et al. (2021c)	Information on rainfall (onset, distribution, amount, and cessation of the rains), temperature (expected average temperatures), and windstorm (intensity of the storms)
Bacci et al. (2020)	Information on rainfall and temperature
Chiputwa et al. (2022)	Information on the daily forecast, early warning system (EWS), and seasonal forecast
Diouf et al. (2019)	Onset date of rains, cessation date, daily rain forecast, and dry spells
Naab et al. (2019)	General daily, monthly, and seasonal rainfall and temperature forecast
Nyadzi et al. (2018)	Information on rainfall and temperature
Nyambo and Chengula (2017)	Information on rainfall and temperature
Nyang'au et al. (2021)	Information on rainfall and temperature
Ouedraogo et al. (2021)	Information on rainfall, wind, flood, and dry spell
Ouedraogo et al. (2018)	Seasonal forecast, the onset and cessation dates, the optimal sowing dates, daily rainfall forecasts, the false starts, the cumulative rainfall, and the dry and wet spells
Oyekale (2015)	Information on the outbreak of livestock and crop pests/diseases and the start of the rainfall
Partey et al. (2020)	Information on rainfall and temperature
Radeny et al. (2019)	Amount of rainfall, the onset of rainfall, rainfall distribution, cessation of rainfall, duration of cropping/rainy season, drought occurrence, the severity of weather events
Rasmussen et al. (2015)	Onset date of the rains, flooding events, availability of grazing resources in various areas, and fine-scale information on rainfall amount during the first weeks of the rainy season
Sanfo et al. (2022)	Information on rainfall and temperature
Sarku et al. (2021)	General forecast, farming-specific forecasts, and temporal forecasts
Wamalwa et al. (2016)	Farmers had access to agro-weather and climate information
Yegbemey et al. (2021)	Farmers received weather-related information
Zongo et al. (2016)	Farmers had access to official seasonal forecasts prior to the agricultural campaign

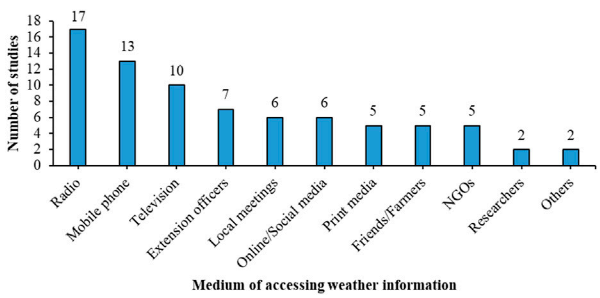

FIGURE 3
Medium of accessing weather information.

User's decision-making

Decisions made due to the access to weather and climate information ranged from land preparation to harvesting time. One study reported that most of the respondents who received the information used it to make decisions such as preparing farmlands, selecting crop varieties, varying cropping patterns, and harvesting time (Antwi-Agyei et al., 2021c). Furthermore, farmers who received seasonal, daily, and early warning systems (EWS) made significantly more farm management decisions and had a higher yield of crops than non-users of weather and climate information services (Chiputwa et al., 2022) (Table 3). In the fisheries sector, climate information helped fishers postpone their activities on the sea or go to sea while using their life jacket (Ouedraogo et al., 2018). However, the proportion of fishers who used weather information in decision-making was low. Of those who had access to weather and climate information, only a few utilized the information to decide on various activities (Oyekale, 2015; Nyang'au et al., 2021). In some instances, users combined indigenous and scientific forecasts. Though they acknowledge the limitations in using indigenous forecasts, they considered it better for decision-making than the scientific forecast provided by the state agency responsible for the forecast (Nyadzi et al., 2018) (Table 3).

Key barriers to the uptake of weather information

The production and delivery of weather information is not an assurance that the information will automatically inform

TABLE 3 Summary of decisions made by users after accessing weather information.

Author, year	Decision made
Amegnaglo et al. (2017)	Farmers believed that access to climate information can inform their farming decisions. The vast majority of farmers (95%) will respond to the introduction of seasonal climate forecasts by adopting at least one strategy (either intensified or nonintensified).
Antwi-Agyei et al. (2021c)	1) About 79% of the respondents receiving climate information indicated that they used such information to make decisions on land preparations.
	2) Female farmers reported using climate information for equally important decisions, including crop variety selection (50%), changing cropping patterns (36%), and harvesting-time decisions (21%).
Bacci et al. (2020)	1) Forecasts could correctly predict the weather for the next decade with a percentage of 87.5. This information is crucial for farmers because they can plan their agricultural activities or take measures against dry spells in the coming decade (delay of sowing, use of fertilizers, etc.).
	2) Users perceived the agrometeorological 10-day forecasts as important for their decision-making processes, even if they were not quantitatively accurate.
Chiputwa et al. (2022)	1) Households in locations with a multidisciplinary working group (MWG) used significantly more combinations of different types of seasonal and daily forecasts to inform farming decisions than households in locations with no MWG.
	2) Farmers with access to a MWG made significantly more farm management decisions after receiving seasonal, daily, and early warning systems (EWSs) than farmers without access to an MWG.
	3) Farmers who used weather and climate information services (WCIS) had a significantly higher yield of crops than nonusers of WCI.
Diouf et al. (2019)	The climate information service was useful for farmers in determining sowing periods.
Nyadzi et al. (2018)	The survey revealed that adaptive farm decisions of farmers are generally based on information generated from indigenous and scientific forecasts. While farmers were quick to acknowledge the limitations in their personal forecast, they considered it better for decision-making than the scientific forecast provided by Ghana Meteorological Agency as this was perceived to be generic and not locally specific to their community and needs.
Nyang'au et al. (2021)	Seventy-four percent of the total sampled households had access to weather and climate information from multiple sources. Of those who gained access, only 34.2% of them utilized the information in deciding on various farming activities.
Ouedraogo et al. (2021)	Farmers use weather and climate information services (WCIS) to make decisions on crop choice and sowing dates during the offset of the growing season. These WCIS also guide the farmers to identify crop varieties that are suitable for the length and quality of the season. The type of croplands (topography and soil type), as well as the cropland size, are decided based on the WCIS disseminated during the period.
Ouedraogo et al. (2018)	1) Majority of farmers who received climate information services (CIS) took decisions related to the choice of croplands, crop varieties, sowing, plowing, and fertilizer-spreading dates.
	2) At the end of the rainy season, the evaluation revealed that 95.7% of the respondent farmers were very satisfied with the decision that they had taken following the reception of the CIS and 78.4% certified that their crop yield had been substantially improved.
	3) In the fisheries sector, the evaluation showed that about 45% of the respondents decided to postpone their activities on the sea after they received the warning; 15% decided to go to sea while using their life jackets.
Oyekale (2015)	1) 33.2 and 44.2% of the farmers from East Africa were able to take some specific farm decisions based on pieces of advice received on the outbreak of pests/diseases and the start of rainfall, respectively.
	2) Among West African farmers, 13.3 and 34.0% of the farmers were able to use weather forecasts received on the outbreak of pests/diseases and the start of rainfall, respectively.
Partey et al. (2020)	Increased rainfall variability and increased drought frequency in the study area significantly influenced farmers' use of climate information services (CIS).
Sanfo et al. (2022)	The customized climate service (CCS) positively impacted corn, cowpea, and sorghum productivity. Farmers who received CCS recorded higher yields than those who did not.
Tarchiani et al. (2021)	Most farmers with access to the information used seasonal forecast (SF) to choose crop varieties and toposequences to exploit and prepare the land, choose the seeding time, and other cropping practices.
Yegbemey et al. (2021)	Providing smallholders with weather-related information through mobile phone SMS can help them reduce labor costs and positively affect yield and farm income.
Zongo et al. (2016)	Farmers believed that weather information could help them make informed decisions as most (93%) farmers want to integrate climate information in their decision process for agricultural production.

decision-making because barriers can hinder the use of information. In the studies reviewed, 18 studies reported barriers to the uptake and use of weather information in East and West Africa. The four key barriers reported include; poor communication and understanding of weather information (n = 12), lack of downscaled information (n = 8), lack of logistics (n = 5) and lack of trust (n = 4). Other barriers include meteorological information not tailored to meet the information needs of vulnerable group decision-makers at the sub-national level

TABLE 4 Summary of key barriers to the uptake of weather or climate information.

Key barrier	Details	References
Poor communication and understanding of weather information (*n* = 12)	1) Uncertainty of obtaining information on time, continuously, and of difficulties in understanding the information 2) 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, and the technical language used in communicating climate information 3) The inability to comprehend how anthropogenic activities contribute to climate change have also been identified as a key factor that impedes the uptake of seasonal climate forecast 4) Available information is not communicated to the understanding of all, and there is a lack of collaboration between local institutions in the production and dissemination of climate service 5) Challenges in information access and interpretation are faced by illiterate farmers who cannot read a text, and even literate farmers lack the necessary skills to understand technical information because of the format they are presented 6) Missing climate information service (CIS) and the untimely delivery of CIS. 7) The paucity of communication channels between national-level producers of climate knowledge and community-level users 8) Farmers' inability to understand the necessity of climate information to make their decisions in terms of agricultural production	(Tall, 2010; Oyekale, 2015; Zongo et al., 2016; Amegnaglo et al., 2017; Nyadzi et al., 2018; Ouedraogo et al., 2018; Ebhuoma and Simatele, 2019; Naab et al., 2019; Antwi-Agyei et al., 2021c; Ouedraogo et al., 2021; Tarchiani et al., 2021; Sarku et al., 2022)
Lack of downscaled information (*n* = 8)	1) Lack of downscaled information (farmers emphasized that they would like to get downscaled information to allow them to take site-specific decisions) 2) Seasonal climate forecasts are not usually tailored to meet end-user needs 3) Not reliable and area-specific and difficult to interpret by ordinary people 4) Seasonal weather forecasts are often not downscaled and are provided for wide areas and generalized	(Rasmussen et al., 2015; Nyambo and Chengula, 2017; Ouedraogo et al., 2018; Diouf et al., 2019; Ebhuoma and Simatele, 2019; Radeny et al., 2019; Ouedraogo et al., 2021; Sarku et al., 2022)
Lack of logistics (*n* = 5)	1) Unavailability of dissemination technology and technical expertise 2) Lack of permanent funding sources and relevant training on the ground 3) Inadequate access as a result of limitations in transmission equipment 4) Lack of training on interpretation of the information and limited participatory sharing and interpretation of weather and climate forecasts	(Oyekale, 2015; Wamalwa et al., 2016; Ouedraogo et al., 2018; Bacci et al., 2020; Partey et al., 2020)
Lack of trust (*n* = 4)	1) The lack of management options and trust in the information source 2) Loss of confidence due to previous imprecise forecast that affected farmer productivity 3) Lack of trust in the 'unknown voices that communicated the information' hindered the willingness to rely on weather/climate information 4) The origin of the information is a factor that affected usable WIS, as farmers preferred to know the source of information and how it is produced	(Rasmussen et al., 2015; Amegnaglo et al., 2017; Ebhuoma and Simatele, 2019; Sarku et al., 2022)
Others (*n* = 5)	1) Agrometeorological services are given less priority from the Ghana Meteorological Agency (GMA) compared to other services such as aviation and military 2) Lack of interest in the information and inadequate and inconvenient time slot allocated for seasonal climate forecasts (SCFs) broadcasting in relation to farm activity schedules of the rural people 3) The belief in indigenous knowledge 4) Meteorological information is in most cases not tailored to meet the information needs of vulnerable group decision-makers at the subnational level 5) The low information uptake was also attributed to delay in forecasts, development of advisories, and subsequent dissemination of advisories	(Tall, 2010; Wamalwa et al., 2016; Nyambo and Chengula, 2017; Naab et al., 2019; Ouedraogo et al., 2021)

NB: n means the number of studies.

and the belief in indigenous knowledge (Table 4). One study reported that the inability to comprehend how anthropogenic activities contribute to climate change impeded the uptake of seasonal climate forecasts (Ebhuoma and Simatele, 2019). Regarding logistics and training, the inability to interpret climate information and convert it into actions affected the user's ability to use the information in decision-making (Partey et al., 2020).

Discussion

This study reviewed and assessed literature for evidence on the uptake, use and adoption of weather and climate information in the Agriculture, Water and Energy sectors in East and West Africa. The review revealed many research gaps and highlighted significant findings for policy-making.

Our review showed that studies on weather information services had focused predominantly on West Africa than East Africa. The dominance of studies in West Africa, especially Ghana, could be attributed to the region's vulnerability to climate risks (Karambiri et al., 2011; Sultan and Gaetani, 2016; Akinsanola and Zhou, 2019). Most of the studies were conducted in rural communities without focusing on users in urban communities. Future studies are needed to identify the weather and climate information needs of urban users (especially farmers) and evaluate the influence of the information on users' ability to make informed decisions. Further studies are also needed to identify the type of weather and climate information needed by users in sectors such as fisheries, energy, and water resources.

Regarding the type of weather information accessed by users, our results revealed that the information accessed differs even within a specific sector. Most farmers were more interested in accessing rainfall (such as the likely amount and distribution of rainfall) and temperature (such as the intensity of the dry season) forecasts. The findings are consistent with other results from South Africa, Europe, and Asia (Lebel, 2013; Mudombi and Nhamo, 2014; Shackleton et al., 2015), highlighting rainfall and temperature information as crucial information needed by users to manage climate risks. Many households in East and West Africa regions rely on agro-based livelihoods that are extremely vulnerable to the adverse impacts of climate change. Forecast on rainfall and temperature helps farmers to plan what to plant and when to do it. In addition, it helps them put measures in place to reduce the devastating impacts of extreme events on their livelihoods. However, most of the information received by users was a daily forecast instead of a seasonal forecast. This is in agreement with the findings of Baffour-Ata et al. (2022) who observed that few farmers received seasonal forecasts. They attributed this to the possibility of farmers encountering a digital divide (i.e., a gap between demographics and regions with access to modern information and communications technology and those that do not or have restricted access) in the access to seasonal forecasts. It is also important to stress the space–time relevance of seasonal forecasts to the needs of decision-makers. This has often been attributed to the greater uncertainty and probabilistic information associated with seasonal forecasts provided by national meteorological agencies (see Antwi-Agyei et al., 2021c). There is a need to build the capacity of meteorological agencies in the provision of accurate seasonal forecasts to aid decision-making. The availability of seasonal forecasts could provide advanced early warning of rainfall variability and help users plan ahead of time (Young et al., 2020).

The review further showed that few studies reported on impact-based forecasts such as drought, windstorms, and floods. Impact-based forecasts bridge the gap between forecasts and possible impacts of impending hazards [World Meteorological Organisation (WMO), 2015]. The provision of an impact-based forecast helps farmers to act before disasters in order to minimize the effects of weather and climate hazards on their livelihoods. The medium of communicating weather and climate information is important as it ensures users access the required information to make the right decisions. Our review revealed that the key media for communicating weather and climate information included radio, mobile phones, and television. Findings are consistent with other studies (Ajani, 2014; Coulier et al., 2018; Sikhondze, 2020; Henriksson et al., 2021), reporting radio as the most preferred medium of receiving weather and climate information. However, in rural areas that do not have electricity, farmers have to purchase batteries to enable them to operate their radios, and this places an extra financial burden on them. This could discourage farmers from using radios, thus denying them access to weather and climate information. Therefore, policymakers should prioritize extending electricity to rural farming communities or providing them with alternative effective means of accessing weather and climate information.

The significance of weather and climate information depends on mainly the ability to produce information that is usable and delivered in ways that can be incorporated into decision-making processes (Singh et al., 2018). The review showed that users who had access to weather and climate information used it to make several decisions related to land preparation, crop variety selection, varying cropping patterns, and harvesting time. Farmers also made key farm management decisions such as the application of fertilizers and pesticides, irrigation, and drying of crops based on weather and seasonal forecasts (Antwi-Agyei et al., 2021c). The decisions often lead to a significant increase in crop yields and farmer income and welfare. However, the review also highlights that few users utilized the information accessed. One fundamental gap identified is that most of the included studies did not have a comparison group (who did not use weather and climate information) in their analysis, making it difficult to assess the impact of using the information in decision-making.

The production and delivery of weather and climate service do not necessarily warrant that the information will be used or is even helpful for decision-making (Nkiaka et al., 2019). Our review revealed several challenges confronting the uptake, use, and adoption of weather and climate information. Key among them include poor communication and understanding of weather and climate information, lack of downscaled information, and lack of logistics. These findings support the findings of other studies in Europe, North America, and South Africa (Bolson et al., 2013; Bruno Soares and Dessai, 2016; Singh et al., 2018), where farmers and other users of weather and climate information identified barriers that prevented them from making better decisions using weather and climate information. Other studies have documented similar challenges affecting the use of climate and weather information for the implementation of climate-smart agricultural practices in Ghana (Antwi-Agyei et al., 2022). These barriers, if not addressed, could erode the efforts made in the provision of weather and climate information to aid farmers in planning their farming activities and also build their resilience to climate change. The review noted that there is a need to integrate scientific and indigenous knowledge to ensure locally appropriate framing of communications and use of weather and climate information services. Studies on cost–benefit analysis of the reliance on indigenous knowledge and scientific weather and climate information are needed. Further studies are required to explore the effectiveness of integrating indigenous knowledge of climate information into scientific weather and climate information to increase the uptake, use, and adoption of weather and climate information.

The use of weather and climate information in the agriculture sector could present some synergies and trade-offs in other sectors such as the energy and water resource sectors. For instance, cultivating plants that require low water will reduce water withdrawal for irrigation. In addition, the use of solar-powered pumps, promotion of microirrigation, and other forms of farming, such as hydroponics, would address the trade-offs associated with increasing food production (Mpandeli et al., 2018). Weather and climate information services can play a substantial role in guiding nexus-related decision-making (Conway et al., 2015). Unfortunately, studies on weather and climate information have not explored the synergies and trade-offs between the water–energy–food (WEF) nexus. Implementing measures that enhance the synergies and reduce the trade-offs between the WEF nexus is crucial in attenuating the devastating impacts of climate change on livelihoods (Mpandeli et al., 2018).

Conclusion and policy implications

This review reveals that studies on weather and climate information have to date focused more on West Africa than East African countries. The uptake, use, and adoption of climate information helped users to take key decisions to reduce the impact of extreme weather events. However, few studies reported on the impact-based forecast, and few users could access or benefit from the information produced due to poor communication and understanding of weather and climate information, lack of downscaled information, lack of logistics and trust, etc. These challenges, if not addressed, may regress the achievements made in the provision of weather and climate information. Therefore, sustainable efforts should be made to address these challenges through practical training and capacity building of end-users. This will facilitate the creation of awareness and understanding of climate information to help mitigate the impacts of stern climate events on livelihoods.

There is a need for weather and climate information that is easily accessible, understandable, and tailored to meet the needs of users. Weather and climate information delivery should be a key factor in policy discussions at all levels to improve climate risk management. Investors and governments could also increase their revenue base by expanding and diversifying technology in the delivery of impact-based forecasts specific to key sectors of the economy. Future studies are required to evaluate the production of the impact-based forecast, its performance, uncertainties, and how it translates into farmers' decision-making.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material, and further inquiries can be directed to the corresponding author.

Author contributions

TA conceived the study design and drafted the manuscript. PA-A and AD participated in the study design, critically revised important intellectual content, and acquired the funding for this study. All authors have read and agreed to the published version of the manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fenvs.2022.935696/full#supplementary-material

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