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TOPICAL REVIEW

Identifying user needs for weather and climate services to enhance resilience to climate shocks in sub-Saharan Africa

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Abstract

The vulnerability of social-ecological systems in sub-Saharan Africa (SSA) to climate variability and change means that there is an urgent need to better integrate weather and climate information into societal decision-making processes. Long-term climate adaptation in these regions has received increasing attention, with recent initiatives aiming to increase resilience to climate change at timescales of years to decades. Less focus has been given to weather and short-term climate information. However, users are principally interested in shorter timescales (hours to seasons) where actions can immediately reduce the impacts of severe weather events. Focusing on the priority sectors of agriculture and food security, water and disaster management, this paper uses a systematic literature review approach to analyse 61 empirical case studies drawn from academic literature and projects across SSA. We identify the main users of climate services and outline current practices and reported benefits. Barriers that impede the delivery and uptake of climate services are identified and potential strategies for overcoming them outlined based on the reporting of successful practices. Our findings show that greater capacity building of personnel working for National Meteorological and Hydrological Services and Agricultural Extension staff and reinforcing and sustaining collaboration between different stakeholders (climate scientists, hydrologists, extension workers, farmers and other user groups), are essential factors for improving the uptake and utility of weather and climate services to enhance resilience to climate shocks in SSA.

1. Introduction

Sub-Saharan Africa (SSA) faces increasing risks from climate variability and change. These risks include water stress, coastal inundation, changes in river hydrology and extreme weather events (Niang *et al* 2014). It is therefore essential to better integrate weather and climate science into societal-decision-making processes to support climate adaptation and build resilience to climate shocks (Jones *et al* 2016). Of particular importance is weather and short-term climate information at timescales of hours, days, weeks, months and seasons, which are particularly critical for decision-making in disaster management, agriculture and food security, energy and water resources management (Tall *et al* 2012, Boyd *et al* 2013, Roudier *et al* 2014).

Weather and climate services (WCS) involve the timely production, translation, and delivery of useful weather and short-term climate information, which is fit-for-purpose and produced in formats that can be integrated into societal decision-processes (Vaughan *et al* 2016). Considerations critical to the delivery of

WCS include the nature of the risks being managed, region, sector, governance structure and context specific (Adger *et al* 2009, Goddard *et al* 2010). The development of WCS has been facilitated by technological development for observing, mapping, modelling, predicting atmospheric events and telecommunication (Deconinck *et al* 2017). This rapid advancement in technology creates new possibilities to integrate WCS into short-term decision-making (Boyd *et al* 2013). However, the use of climate information and knowledge is still limited and the most vulnerable in society are not benefitting from the recent scientific and technological advancements in WCS (Allis *et al* 2019).

To meet the demand for improved climate services, the World Meteorological Organisation (WMO) launched the Global Framework for Climate Services (GFCS) in 2012. The GFCS has a mandate to provide and facilitate access to WCS to users with different requirements through observations and monitoring; research, modelling, and prediction; capacity building; and the creation of user interface platforms (Hewitt *et al* 2012). Despite these efforts, users of WCS often raise concerns that forecasts are difficult to understand because of inconsistent use of terminology by different WCS providers (Brasseur and Gallardo 2016, Vaughan *et al* 2018). In this paper, climate service users are defined as policymakers, managers, engineers, researchers, students, farmers and the general public that use weather and short-term climate information and knowledge to inform decision making. Climate service providers are the public or private institutions that supply weather and short-term climate information and knowledge.

The need for reliable, timely WCS to enhance resilience to climate shock in SSA has been highlighted previously (e.g. Boyd *et al* 2013, Jubach and Tokar 2016). However, the WCS landscape in SSA remains poorly understood partly due to the lack of systematic assessments of users' needs for WCS especially forecast timescales and lead times. There are also very few evaluations of how the provision of WCS has benefitted end users in SSA.

To address these research gaps, this paper addresses the following research questions using a systematic literature review of existing evidence: (i) What are the forecast timescales that are most relevant to users of WCS in SSA? (ii) To what extent do users of WCS in SSA derive benefits from using WCS products? and (iii) What are the barriers impeding the successful delivery and uptake of WCS in SSA.

We aim to provide evidence to enhance the delivery of WCS and to facilitate the development of products that better address the users' needs. Considering that WCS have potential applications in many sectors; we limit our scope to three climate sensitive sectors; agriculture and food security, disaster management, and water resources management and hydropower. These sectors have been identified as key for WCS development due to their climate sensitivity (Vaughan and Dessai 2014, Vaughan *et al* 2016) and are priority areas within the GFCS.

The target regions for this review are East and West Africa. These regions were selected as being representative of the different agro-ecological zones found across in SSA (Seo 2014). Moreover, they exhibit dynamic climates controlled by deep mesoscale convective systems and other complex atmospheric processes which makes it challenging to provide accurate forecasts (Cornforth 2012). The current generation of forecast models such as UK Met Office operational seasonal forecasting system (GloSea5), Meteo-France seasonal forecasting system 5 and the European Centre for Medium-Range Weather Forecasts (ECMWF) seasonal forecasts System 4 are all reported to show very good representation of weather and short-term climate forecasts over these regions (Vellinga *et al* 2013, Batté *et al* 2018, Tucker *et al* 2018, Gbangou *et al* 2019). The availability of these forecasting models offer new opportunities to enhance the delivery of WCS in these regions.

2. Methodology

This paper adopts a systematic literature review approach. This review approach is used here because it allows existing knowledge and evidence from individual case studies to be summarised under common themes (Ford and Pearce 2010, Ford *et al* 2010). Through this method, it is possible to identify gaps and provide recommendations for new research directions and best practice based on evidence from across a range of case studies (Portia Adade *et al* 2018). The systematic literature review adopted here follows the approach proposed by Butler *et al* (2016) that seeks to minimise bias and enhance transparency. A similar approach has been used in other climate services reviews by Vaughan and Dessai (2014). The review targeted English language peer-reviewed and non-peer review (grey) literature published from January 2010 to June 2019 (to correspond with the launch of GFCS). Moreover we targeted only empirical case studies highlighting how users of WCS used forecasts for weather and short-term climate information to make short-term decisions. To maximise the number of relevant articles/reports captured, two academic databases were searched: Web of Science and Google Scholar.

We used the search terms shown in table 1 and searches based on the specific country names and regions; Kenya, Ghana, Nigeria, Senegal, East Africa, West Africa. Papers were included in the study if they included evidence addressing one of the following:

(1) The forecast timescales solicited by users

(2) The nature of WCS provided to users

Table 1. Search terms and number of papers reviewed.

	Total number of papers/reports			
	Web of science		Google scholar	
Search terms	Retrieved	Included	Inspected	Included
Weather/climate information services for agriculture/food security Africa	95	14	150	13
Weather/climate information services for water resources/hydropower management Africa	12	7	150	2
Weather/climate information services for disaster risk management/reduction Africa	15	10	150	9
Barriers delivery, uptake and use of weather and short-term climate information Africa	19	2	150	4

For Google Scholar, only the top 150 papers were reviewed for each search.

(3) The kind of decisions made by users and benefits derived

(4) Barriers to the uptake and adoption of WCS in SSA

The number of articles/reports reviewed and included in the systematic literature review are shown in table 1. In total 61 articles/reports were included in the review of which 8 were non-peer reviewed or grey literature. Some studies covered more than one sector and also highlighted some barriers to the uptake and adoption of WCS in SSA. Few examples from neighbouring countries were included to highlight the benefits of using specific WCS products.

As with any systematic literature review ours has its limits. While our focus on the key areas of agriculture and food security, disaster management and water resources is justified by their climate sensitivity (Vaughan and Dessai 2014, Vaughan *et al* 2016) and their status as priority areas within the GFCS, we acknowledge that these are not the only sectors of critical importance for WCS development in Africa. The health sector, for instance, represents an important potential user of WCS at weather and short-term climate timescales, in terms of both direct impacts (e.g. heatwave hazards) and predicting potential disease outbreaks at seasonal to sub-seasonal timescales. Nonetheless, this focussed approach allows us to identify key uses of WCS and barriers to their uptake across a representative range of climate zones in SSA.

3. Results

Studies from Kenya and Senegal accounted for over 50% of those reviewed, while fewer than 2% were from Nigeria despite the country's size and population. In West Africa, more than 75% of studies were from Senegal (figure 1(a)). One possible reason why Senegal has been the focus of more studies relates to the international attention and media coverage elicited by historic climate and weather related disasters in the Sahel region, including droughts in the 1970s and 1980s and flooding in the 2000s (Tschakert *et al* 2010, Engel *et al* 2017). Our literature search also showed that studies of users' needs for climate services are more numerous for the agriculture and food security sector than the other focal sectors, with more than 50% of studies satisfying the inclusion criteria for this review focusing on agriculture or food security (figure 1(b)). This can be attributed to the importance that donors and funding organisations attach to agriculture and food security in SSA. In East Africa, the majority of the studies relevant to disaster management focused on Lake Victoria due to the high number of weather related deaths on the lake.

Appendix provides a comprehensive overview of empirical studies included in the review.

3.1. Agriculture and food security

Across the studies we reviewed, arable farmers identified a range of forecast information and timescales relevant to their farming activities. A summary of climate services and benefits identified in the agriculture and food security sector is shown in Table 2. These include; daily weather forecasts, daily forecasts on extreme rainfall events, false rainfall alerts, rainfall breaks, 10 d forecasts for rainfall; droughts; and soil moisture content, seasonal forecasts for rainfall and droughts, rainfall onset for expected sowing dates, rainfall cessation dates, monsoon onset dates, forecasts on temperature, and the spatial distribution of daily and 10 d forecasts for rainfall (Onyango *et al* 2014, Roudier *et al* 2014, 2016, Amegnaglo *et al* 2017, Tarchiani *et al* 2017, Ouedraogo *et al* 2018, Gbangou *et al* 2019, Nyadzi *et al* 2019). Policy makers were more interested in WCS that used a combination of seasonal forecasts and crop models to predict crop yield at regional scale using impact based models (Wetterhall *et al* 2015).

For pastoralists, key forecast information and timescales included; seasonal forecasts on the availability of pasture, seasonal forecasts for water resources availability, forecast for the onset date of rains, daily forecast for extreme rainfall events, and spatial distribution of rainfall during the rainy season, dry spells, the end date of the rainy season, daily potential lightning zones during the rainy season which pastoralists highlighted as the principal cause of animal loss, 10 d rainfall forecast (Rasmussen *et al* 2014, Ouedraogo *et al* 2018).

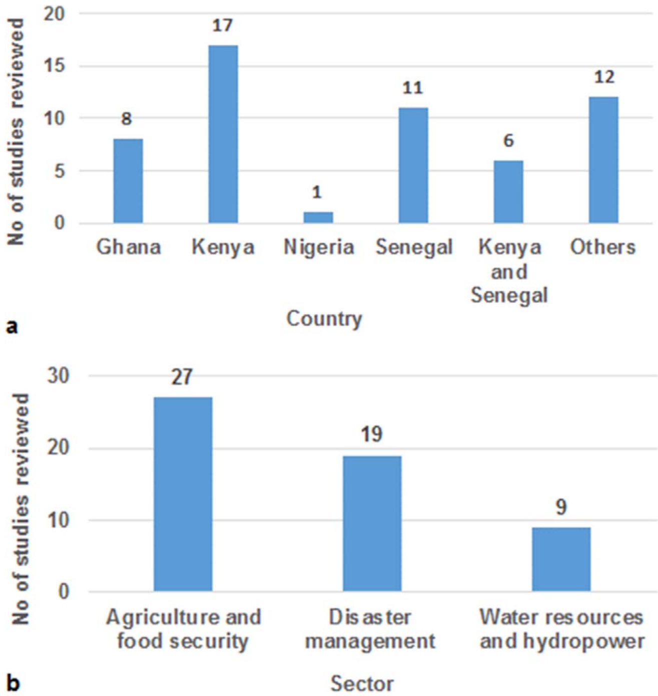

Figure 1. Number of studies reviewed by (a) Country and (b) sector.

Table 2. Summary of climate services and benefits in the agriculture sector.

WCS identified	Benefits
Seasonal forecast	Famers strategic decisions on crop selection and seed variety, geographic distribution of plots, used with process based crop simulation models to predict seasonal crop yields
Expected sowing dates, decadal forecast (10 d), the false alerts (when detected)	Farmers choose the most appropriate sowing dates, selecting favourable periods for different farming operations such as land preparation, weeding dates and application of fertiliser
Forecasting monsoon onset dates	Help farmers improve their decision-making about the selection of crop types and varieties and can also reduce the risks and costs related to the re-sowing or re-planting process
Forecasts on temporal distribution of rainfall	Farmers plan for the purchase of pesticides and fungicides for pest and disease control and application of fertiliser
Daily weather forecast and forecast on extreme events	Farmers and herders avoid flood prone areas
Forecasts on cessation dates	Plan and take decisions on post-harvest operations to prevent crops from germinating in the soil
	Prevent damage from pests and diseases that thrive under humid conditions
Provision of training and rain gauges to communities	The availability of community managed weather station raised the farmers' consciousness on climate change, encourage strategies to support NMS so that farmers/pastoralist can gather climate data from the local level and give a sense of ownership
Forecasts on fodder and water resource availability throughout the year, forecasts on the availability of grazing resources in different areas, the onset date of rains	Herders plan for the purchase of supplementary fodder, make choices on transhumance destinations, prevent farmer—pastoralist conflicts
Forecast on daily potential lightning zones during the rainy season	Herders avoid lightening zones thereby reducing risk hazards caused by lightning on cattle
Potential diseases occurrence zones (decadal forecasts), transhumance corridors (decadal forecasts)	Herders make choices on transhumance destinations, make changes in herd composition
Information on crop varieties, information on crop and livestock management, information on input availability and market price, access to market information, pest outbreak warnings	Help the farmers to cope with climate variability and change

The decisions made by arable farmers varied depending on the time-scale of the forecasts. They used seasonal forecasts to make strategic decisions on seed variety, geographic distribution of plots, land management techniques, management of pest and disease outbreak through the timely purchase of pesticides and fungicides; daily to 10 d forecasts were used to adjust sowing dates, and plan for cropping operations such as land preparation, application of fertiliser, weeding, plan early harvest and post-harvest operations, (Onyango *et al* 2014, Roudier *et al* 2014, Kniveton *et al* 2015, Tarchiani *et al* 2017, Mckune *et al* 2018). The availability of community-managed rain gauges also enhanced farmers' decisions as it helped them to determine if the rainfall threshold was exceeded so as to adjust cropping operations (Kniveton *et al* 2015, Tarchiani *et al* 2017).

The benefits derived by farmers after using climate services for their farming decisions were similar in the studied regions. Results from a study across four West African countries including Ghana indicated that the use of WCS by farmers helped to increase maize yields by an average of 44% (Tarchiani *et al* 2017). A separate study in Burkina Faso reported that the use of forecasts by farmers induced changes in farming practices among 75% of the target farmers; leading to a 30% increase in grain production and substantially reduced post-harvest losses (Roudier *et al* 2014). Results from the same study also indicated that 10 d forecasts were more useful to farmers than seasonal forecasts. These results were supported by a similar study in Niger (Roudier *et al* 2016). A survey of 289 farmers in Senegal found that: 78% used WCS to guide their farming decisions at the onset of the rainy season, 96% expressed satisfaction with the farming decisions taken after receiving WCS and 78% reported of a substantial increase in crop yield (Ouedraogo *et al* 2018). In Benin, 95% of 354 maize farmers involved in an assessment of the economic benefits of WCS, indicated that they changed their farming decisions after receiving WCS. Results from a study covering both Senegal and Kenya showed that more than two-third of the farmers who participated in the study attributed the increase in crop yield to their ability to change farming decisions based on the accessibility to and use of WCS (Kniveton *et al* 2015). Likewise, in Ghana, Kenya and Senegal farmers reported a substantial increase in crop yield after using climate services (Onyango *et al* 2014, Anuga and Gordon 2016, Mckune *et al* 2018).

The benefits of forecasts for pastoralists were also widely varied. In Burkina Faso, the 10 d forecast is particularly useful for making decisions on which transhumance corridors to use, purchase of supplementary fodder and to identify potential diseases occurrence zones (Rasmussen *et al* 2014, Ouedraogo *et al* 2018). A separate study in the West African Sahel, indicated that access to weather and short-term climate information contributed substantially in preventing farmer—pastoralist conflicts by guiding the mobility of pastoralists (Mertz *et al* 2016).

The channels through which WCS are received have been found to be broadly consistent across different farmer groups. Separate studies focusing on different farming communities indicate that the following have a positive impact on farming decisions: translation of WCS into local languages; transmission of forecast information through mobile phones; increasing the frequency of sharing forecast information; broadcasting of forecasts through local radio stations; and scheduling of special broadcast times for farmers (Onyango *et al* 2014, Anuga and Gordon 2016, Jost *et al* 2016, Amegnaglo *et al* 2017, Tarchiani *et al* 2017, Mckune *et al* 2018, Ouedraogo *et al* 2018). Where literacy is limited but mobile phones are accessible, voice messages in local languages are also be valuable, as indicated by the work with pastoralist communities in Burkina Faso (Rasmussen *et al* 2015). At community level, informal networks such as farmers groups, local village elders and agricultural extension workers can also play an important role in disseminating forecast information (Amegnaglo *et al* 2017). Where forecasts are not regularly disseminated through easily accessible channels, farmers may rely solely on traditional forecast methods, as evidenced by findings from Ghana (Jost *et al* 2016).

With respect to stated preferences for receiving forecasts, results from multiple studies suggest that a large proportion of farmers strongly favour radio broadcasts (Onyango *et al* 2014, Mckune *et al* 2018). Some have also expressed a preference for forecasts to be accompanied by agricultural information about new seed varieties, new farming practices and advise on livestock management (Mckune *et al* 2018).

Taken together, our findings suggest that the use of WCS in the agriculture sector is gaining momentum in the target regions with direct evidence of benefits being realised in terms of increased yields. However, they also highlight the critical importance of forecast information being provided in a way that is accessible to farming communities, with key requirements being the availability in local languages, the provision of verbal communications for those who cannot read, and ensuring that forecasts are disseminated to communities in a consistent and timely manner linked to specific actions and agricultural extension advice.

3.2. Disaster management

To adequately manage an increasing number of climate related disasters, save lives and manage resources more efficiently, there is an increasing push for disaster management authorities to shift from focusing primarily on crisis response, to making use of early warning systems to prepare for high impact events (Braman *et al* 2013, Tall *et al* 2013, Wilkinson *et al* 2018). In climate sensitive regions such as SSA, the potential use of early warning information to directly

Table 3. Summary of climate services and benefits in the disaster management sector.

WCS identified	Benefits
Seasonal forecast, monthly, 7 d forecasts, use seasonal rainfall forecast to drive the Global Flood Awareness, combine crop models and seasonal forecast to predict crop yield at regional scale, and identifying the drivers of seasonal flooding	Implement an early warning and early action strategy for enhanced flood preparedness and response, issue county-level monthly drought warning bulletins, put in place strategies to reduce the response to get to the victims of disasters, launch an early appeal for food aid or relief from the international community
combination of reanalysis precipitation forecast with standardized precipitation index	Provide information on the spatial extent and intensity of a drought event
Development of Lake Victoria Intense storm Early Warning System (VIEW)	To complement support ongoing efforts from the Numerical Weather Prediction (NWP) community in the region to forecast hazardous thunderstorms over Lake Victoria

aid vulnerable communities in better coping with climate hazards, saving lives and preserving livelihoods has been widely acknowledged (e.g. Tall *et al* 2012). A summary of climate services and benefits in the disaster management sector is shown in Table 3.

At seasonal timescales, recent advances mean that scientific capacity to predict potential severe events is improving. In a study covering the whole SSA, ECMWF seasonal rainfall forecasts were used to drive the Global Flood Awareness System with results indicating that ECMWF seasonal forecasts are reliable for identifying the drivers of seasonal flooding and could be used for flood preparedness in the semi-arid regions of Africa (De Perez *et al* 2017). In a separate study in West Africa, it was demonstrated that ECMWF seasonal to sub-seasonal forecasts (ECMWF-S2S) were skillful in predicting rainfall anomalies in the semi-arid Sahel and are useful for monitoring droughts (Olaniyan *et al* 2018). A similar study in East Africa showed that forecasts from ECMWF analysed using Standardized Precipitation Index (SPI) could be used to predict the spatial extent and intensity of droughts (Mwangi *et al* 2014).

Within the disaster management sector, there is increasing evidence of the uptake of seasonal forecast information for disaster planning and preparedness. In West Africa, the International Federation for Red Cross and Red Crescent (IFRC) have used seasonal forecasts to implement an early warning and early action strategy to enhance flood preparedness and response (Braman *et al* 2013). In Niger, seasonal forecasts obtained from tropical applications of meteorology using satellite (TAMSAT) have been combined with Rainwatch (http://walker.ac.uk/rw/) real time monitoring (Maidment *et al* 2017) to monitor monsoon rainfall in Niger. Rainwatch places a current Sahel monsoon in the context of other seasons and outputs information of the monsoon evolution in comparison with key historical information (Boyd *et al* 2013). In East Africa, humanitarian agencies also combined seasonal forecasts with analogue data from past El Niño events to develop contingency plans to implement response activities for emergency relief operations (De La Poterie *et al* 2018). In Senegal disaster management teams use forecasts to make strategic decisions such as pre-positioning flood relief items, training local personnel to improve disaster response time, developing flood contingency plans, and launching pre-emergency funding requests from the international community (Hamer *et al* 2017). Notably, a national flood management committee has been established and with forecasts becoming more impact-based, different flood preparation and response strategies can be triggered by members of this committee (Hamer *et al* 2017).

At shorter (0–6 h) timescales, timely and actionable forecasts are also critical to limiting the harm caused by severe weather events. This need is illustrated by a recent study investigating the use of WCS to enhance navigation safety in Lake Victoria, which shows that storms, strong winds and strong waves were responsible for 13%–29% of annual reported accidents on the Lake (Kiwanuka-Tondo *et al* 2019). To reduce the number of casualties from weather related events, the Lake Victoria Intense storm Early Warning System (VIEWS) has been developed to forecast hazardous thunderstorms over the lake at night (Thiery *et al* 2017). For the information emerging from these systems to be successfully used at community level, it is critical to ensure that they meet the needs of the users. Gender should be taken into account when considering the accessibility and dissemination of forecast information. In Ghana, for instance, it has been recommended that women should be given greater involvement in disaster management operations at local level, due to their leading role in organisational networks, which can facilitate both the dissemination of information and subsequent response (Caruson *et al* 2014).

The evidence reviewed here evidences both growing scientific capacity to forecast severe events in SSA at weather to short-term climate timescales, and growing uptake by disaster management organisations. For the potential benefits of WCS for disaster management in SSA to be fully realised, further work is essential to ensure that early warning systems developed to support community resilience are tailored to meet the needs of the diverse range of potential users.

Table 4. Summary of climate services and benefits in the water management sector.

WCS identified	Benefits
Seasonal forecasts with lead times of one season or more	Use in guiding the storage and release decision for hydro-power dams
Monthly, 7 d forecasts	Use for managing reservoirs for hydropower, urban water supply and irrigation water management by looking for alternatives in case of failure
Development of an open source software water observation and information system (WOIS) for Africa	Open source software facilitate the management of water resources at basin level, water quality monitoring.
Development of open source software platform, combining rainfall-runoff model(s) and seasonal forecast to predict regional water yield	Hydrological modelling and flood forecasting using remote sensing, predict water level, timing of the flood peaks and the maximum flood extent
Famine Early Warning Systems Network (FEWS NET) Land Data Assimilation System (FLDAS)	Used for characterising water resources availability and as a tool for humanitarian decision support
Water and food security	Sub-Saharan Africa drought monitoring and seasonal forecasting system

In summary, the main WCS identified in the disaster management sector include: seasonal, monthly, 7 d, 5 d and 0–6 h forecasts and combining forecasts with other tools to gain relevant information on the precursors of a disaster, its extent and intensity.

3.3. Water resources management and hydropower

Within the water resources management and hydropower sector WCS are used to make both tactical decisions at seasonal timescale (3–9 months) and operational decisions at short-term (daily, weekly to monthly forecast). These uses may include operating rules for system control schemes, dam releases to meet downstream users' needs, and environmental requirements (Ziervogel *et al* 2010). A summary of climate services and benefits identified in the water resources sector is shown in Table 4.

In East Africa, seasonal forecasts with lead times of one season have been useful in guiding the storage and release decision for hydropower dams; thereby increasing energy output, reducing energy losses and improving reliability (Dinku *et al* 2014). There is a vital need to incorporate forecasts information into a rainfall-runoff model to produce streamflow forecasts coupled with a hydropower management model to assess whether forecasts add value. Using the same approach, seasonal forecasts can also be used to manage reservoirs for urban water supply and irrigation water management (e.g. Stewart 2011).

In Kenya, the Turkuna County Water Resources Management Authority and National Drought Management Authority (NDMA) use forecasts from Kenya Meteorological Department (KMD) to run operational models which enable them to make strategic water management decisions (Haines *et al* 2017). The different water resource management authorities have indicated their trust in the forecasts provided by the KMD because of its base as a government institution which they felt cannot provide unverified forecasts to other government institutions (Haines *et al* 2017).

Tailored platforms have been identified as a means to integrate forecasts into water resource decision-making in West Africa also. The open-source 'water observation and information system' (WOIS) was developed under the Tiger-Net project for trans-basin management of water resources, hydrological modelling and flood forecasting using remote sensing data in Africa (Guzinski *et al* 2014). In Niger, the open-source 'Outil de Prédiction des Inondations dans le Delta Intérieur du Niger' (OPIDIN) platform was developed to predict water levels, the timing of flood peaks, and maximal flood extent for the Inner Niger Delta (Cools *et al* 2016). The potential for such platforms is highlighted by Wetterhall *et al* (2015), who found that one-month forecasts from a global climate model used to predict end-of-season maize yield and accumulated streamflow showed high potential for a commodity-orientated forecast system for application in assessing agricultural impacts and actions.

Although the water resources and hydropower sector are less well represented amongst the papers identified in this review, the available evidence does suggest high potential for further integration of WCS with hydrological models.

The key WCS identified in the water management sector include: seasonal forecasts with lead times of one season, monthly, 7 and 5 d forecasts which are used to run operational models, development of open source software to enhance water management at basin scale, combining rainfall-runoff model(s) and seasonal forecast to predict regional water yield.

3.4. Barriers to the delivery and uptake of WCS

The production and delivery of WCS does not guarantee that the information will be used or is even useful for decision-making. In the studies reviewed, common barriers to the uptake and use of WCS in SSA have been identified.

3.4.1. Awareness, understanding and accessibility

The comparatively low uptake of WCS in SSA has been attributed to many factors including; awareness of WCS, accessibility of WCS, poor communication of forecasts, inappropriate use of language, illiteracy and culture (Ochieng *et al* 2017). Firstly, users must be aware that relevant WCS exist in order to utilise them. Potential users cannot realise benefits from services that they are unware of. For example results from a study investigating climate risk communication for navigation safety in the Lake Victoria reported that more than 70% of the stakeholders interviewed (fishermen, fish traders, fish transporters, boat owners/commercial ship operators) were not aware that weather information was available for navigation safety (Kiwanuka-Tondo *et al* 2019).

Where potential users are aware of the existence of WCS, poor understanding of forecasts because the content and format are too technical and not clearly explained can lead to low uptake (Ochieng *et al* 2017). A lack of access to communication devices such as radios, televisions and mobile telephones used in transmitting forecast can limit who is able to use this information (Ochieng *et al* 2017). Challenges in accessing forecast information may be compounded by gender, with female farmers having lower access to WCS than their male counterparts (Oyekale 2015, Carr *et al* 2016).

3.4.2. Relevance and capacity to act

Ensuring that information is accessible and understandable is not sufficient to guarantee uptake. Where forecast information is not provided at the right time for decision making, or is provided at an inappropriate spatial scale, it may lack relevance for users. Even when forecasts contain decision relevant information, and are received and understood by their intended audience, there may be barriers to the utilisation of this information in decision making. For instance, farmers may have limited capacity to act on forecast information due to lack of access to improved seed varieties, inadequate information about performance of improved varieties, and high seed price (Fisher *et al* 2015). Similarly, poverty and competing demand for other livelihood challenges, along with lack of access to farm inputs, land, equipment, and credit can mean that they are unable to take adaptive actions in response to WCS information (Tall *et al* 2014). At a national and institutional level, lack of long-term historical climate information, insufficient technological, infrastructural and human resources, low level of economic development and poor institutional capacity are also highlighted as barriers to the uptake of WCS in SSA (e.g. Dinku *et al* 2014).

3.4.3. Trust

Lack of trust in forecasts or forecast providers represents a key barrier to forecast uptake. In SSA this may be particularly pronounced due to risk involve in taking decisions based on forecasts with no social protection mechanisms to safeguard users when forecasts fail (Tall *et al* 2014). Amongst agrarian communities in SSA indigenous forecasting methods which have been relied on to enhance resilience to the vagaries of weather over centuries, may be highly trusted. Where corresponding trust in state provided information is low, it may be difficult to combine the information from two sources for the benefits of the WCS users (Jiri *et al* 2016).

3.4.4. Institutional barriers

At an institutional level, key barriers to the use of forecasts for early warning action in Africa has been attributed to inaccessibility of WCS, low level of relevance of warnings to humanitarian response teams, and lack of communication between the forecast providers and the humanitarian response team (Baudoin and Wolde-Georgis 2015). In Senegal, the poor management of disasters using early warning system is attributed to many factors including the political and personal appropriation of disaster management-related processes, the dichotomy between central government and municipalities, and fragmented institutional framework with overlapping roles (Schaer and Hanonou 2017). Results from multiple projects in Kenya indicated that even when WCS pilot projects demonstrate the potential to provide high benefits for target sectors, these may ultimately fail to scale-up to operational services, as clear financial models for sustainability are often not mainstreamed at the project design state (Singh *et al* 2016). In East Africa, the humanitarian response teams complained that they do not have sufficient information about vulnerable communities due to the absence of risk maps (Baudoin *et al* 2016, Lumbroso *et al* 2016).

3.4.5. Addressing barriers

Our review shows that belonging to a social group such as a farmer-based organisation, having access to loans and owning a mobile phone were important factors that influenced the uptake of WCS in West and East Africa (Amegnaglo *et al* 2017, Tarchiani *et al* 2017, Oladele *et al* 2018). Given the role of farmer based organisations in influencing the uptake of WCS by local communities, providers of WCS should work in partnership with other institutions which have already established such groups and use them as entry points to disseminate WCS. Given the high penetration rate of mobile communication in SSA, WCS providers could create partnerships with such companies to facilitate the dissemination of WCS information to end users.

3.5. Impact of capacity building and co-production of knowledge in the uptake of WCS

Professional development of personnel working at NMHSs is a critical factor in the provision and delivery of WCS in SSA (Lamb *et al* 2011, WMO 2013, De La Poterie *et al* 2018, Hansen *et al* (2019)). This review shows that capacity building courses provided to personnel through different projects should include: engagement in the conceptualisation of WCS to facilitate the development of forecasting products that maximise societal value; guidance on how to download outputs from global forecasting systems and cascade them to their country level, the interpretation and verification of forecasts at different timescales, training on the use of new forecast products and software, computer coding and the use of high performance computers.

Through the Enhancing National Climate Services (ENACTS) initiative, personnel at NMHSs in Senegal and Kenya have been trained on how to develop high-resolution, spatially and temporally complete gridded historical meteorological datasets and disseminate them through web-based platforms. This initiative is helping the NMHSs in these countries to provide enhanced WCS by overcoming the challenges of data quality, availability and access (Dinku *et al* 2018).

In Ghana and Kenya, the Participatory Scenario Planning (PSP) approach was amended to train farmers on how to interpret forecasts uncertainties (Ambani and Percy 2011). Using this approach, local community users of WCS (representing different farming groups) and climate scientists from NMHSs came together before the onset of the rainy season to use local and scientific knowledge to contextualise forecasts and create appropriate suite of possible adaptation measures for the farmers (Ambani and Percy 2011). Owing to its success, the approach was adopted in other projects in the region (e.g. Ambani and Fiona 2014). Moreover, it has been mainstreamed as government policy in Kenya to facilitate bottom-up community-led disaster risk management and food security coordination (Nurye 2016).

Our review also shows that access to extension services and proximity of NMHSs to farmers can facilitate the adoption and trust in WCS through enhanced collaboration between the NMHSs personnel, agriculture extension officers and famers (Stigter *et al* 2013).

In Senegal, the NMS has put in place a system to train, disseminate and share forecasts to users of WCS through different projects in the country. A mechanism to disseminate forecast through Short Message Service (SMS) and community radios has also been put in place. Through these initiatives, more than 3 million users of WCS mostly farmers and fishermen receive forecast on a regular basis.

Impact based forecasting represents another potential means to improve the delivery and uptake of WCS in SSA. This approach, which is endorsed by the WMO (WMO 2015), goes beyond providing forecasts about meteorological conditions alone, linking forecast information to users relevant impacts of users. This review has highlighted the importance of impact-based forecasts through the coupling of forecast to impact models such as a crop model, rainfall-runoff model and flood inundation model to assess decision-relevant impact thresholds.

4. Discussion and conclusions

This paper has used a systematic literature review approach to identify the forecast timescales that are most relevant to the users of WCS, highlight the benefits that users of WCS derive from using these products and identify the barriers to the delivery and uptake of WCS across SSA.

Our review shows that the forecast timescales demanded by users of WCS, forecast lead times and methods of communicating the forecasts remain sector specific. In contrast to the agriculture and food security sector where communication mediums are important for user uptake of WCS, this is less important for disaster management and water sectors. Experts in these sectors are better equipped to deal with scientific information about forecast uncertainty. However, unlike the agricultural sector where farmers can take immediate forecast-based decisions, these sectors require that forecasts be processed using other tools to define decision-relevant impact thresholds such as the threshold discharge in a river that is needed to trigger a hydrological drought or flooding warning.

In the agriculture and food security sector, the provision of timely and well-tailored WCS enabled different user groups within the sector to make important livelihood decisions that enhanced their resilience to climate shocks and delivered multiple benefits. These included: increased crop yields and timely purchase of fungicides and pesticides for farmers, prevention of farmer–pastoralist conflicts in the Sahel, purchase of new livestock breeds, making life saving decisions e.g. avoiding lightning and flooding zones for pastoralists and their animals, and the prevention and efficient management of humanitarian disasters.

For small-holder farmers and pastoralists, needs go beyond the provision of timely weather and short-term climate information and should be accompanied by advisory information to help them to make informed decisions about their farming and pastoral activities. For policy makers using seasonal forecasts to run agriculture impact models to predict regional crop yield is critical for making decisions on food security. It also help them to determine if crop failure is an emergency situation that needs external support and therefore make timely contacts with donor agencies to avert food insecurity. To promote the use of WCS in SSA, there is need to set-up new farmer-based organisations or use existing ones as entry points to facilitate the delivery of WCS. This review demonstrates that WCS are useful for enhancing resilience to weather and climate shocks in the agriculture and food security sector in SSA. However, for its potential benefits to be realised, it is critical to both address challenges in accessibility and to tailor provision to the decisions that are undertaken by different user groups.

For disaster management sector, our findings also show that substantial benefits have been obtained in the use of WCS especially in West Africa. Many studies highlight the benefits of WCS in forecasting droughts and floods especially for making strategic decisions such as the pre-positioning of disaster relief materials, training of local personnel, developing flood contingency plans, and making requests for pre-emergency funding. The need to incorporate women in disaster management operation was also highlighted. The benefits of WCS were also very substantial in the water management sector including, reservoir management, predicting water levels in a river, timing of the flood peaks and determining maximum flood extent.

In the Lake Victoria basin specifically, it was observed that lack of information about the availability of WCS by most actors involved in fishing and navigation was a key barrier to its used. Hence, there is need for regional governments to put in place better communication strategies aimed at raising awareness about the value of WCS among the different actors who use the lake to carryout different economic activities. This has the potential to reduce the number of weather related accidents and deaths as the skill of numerical weather prediction models to capture storms, strong winds and strong waves in the lake keeps improving.

Lack of information on vulnerable communities was also identified as a key barrier impeding the use of forecast for early action in disaster management. This indicates that apart from improving forecast skills and enhancing forecast communication techniques, attention also has to focus on identifying the most vulnerable communities/people to different types of weather events. Risk maps showing areas that are prone to particular weather triggered events should be developed to guide humanitarian response teams during disaster preparation. Meanwhile substantial work is still needed for WCS to be fully integrated in the water management sector in SSA.

To increase the uptake and use of WCS it is critical to reinforce and sustain collaboration between different stakeholders (climate scientists, hydrologists, extension workers, farmers and other user groups). The advancement of WCS relies on multiple factors including; (i) providing forecasts with appropriate spatial extent; (ii) decentralised NMHSs by taking services closer to the users of WCS; (iii) training a greater number of NMHSs staff and extension workers on relevant techniques to take this role; (iv) establishing more social protection mechanisms that users can rely on when the forecast fails; and (v) facilitate access to loans for the timely purchase of farm inputs, equipment for land preparation, and the purchase of fodder for pastoralists. The implementation of these developmental activities have the potential to enable users of WCS to continue to realise substantial benefits from using weather and short-term climate information.

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Data availability statement

Any data that support the findings of this study are included within the article.

Appendix

Summary of empirical studies reviewed by sector

Sector	References
Agriculture and Food security	Sultan *et al* (2010), Kadi *et al* (2011), Jost (2013), Onyango *et al* (2014), Rasmussen *et al* (2014), Roudier *et al* (2014), Tall *et al* (2014), Fisher *et al* (2015), Kniveton *et al* (2015), Oyekale (2015), Rasmussen *et al* (2015), Anuga and Gordon (2016), Carr *et al* (2016), Jost *et al* (2016), Mertz *et al* (2016), Roudier *et al* (2016), Amegnaglo *et al* (2017), Nyasimi *et al* (2017), Ochieng *et al* (2017), Tarchiani *et al* (2017), Mckune *et al* (2018), Ogutu *et al* (2018), Oladele *et al* (2018), Ouedraogo *et al* (2018), Gbangou *et al* (2019), Hansen *et al* (2019), Nyadzi *et al* (2019)
Disaster management	Tall *et al* (2013), Tall *et al* (2012), Boyd *et al* (2013), Braman *et al* (2013), Baudoin and Wolde-Georgis (2015), Baudoin *et al* (2016), Mwangi *et al* (2014), Cools *et al* (2016), Nurye (2016), De Perez *et al* (2017), Haines *et al* (2017), Thiery *et al* (2017), De La Poterie *et al* (2018), Olaniyan *et al* (2018), Kiwanuka-Tondo *et al* (2019), Batté *et al* (2018), WMO (2013), Caruson *et al* (2014), Hamer *et al* (2017)
Water resources management and hydropower	Ziervogel *et al* (2010), Lamb *et al* (2011), Dinku *et al* (2014), Guzinski *et al* (2014), Sheffield *et al* (2014), Wetterhall *et al* (2015), Cools *et al* (2016), Haines *et al* (2017), Mcnally *et al* (2017)
Barriers	Carr *et al* (2016), Jiri *et al* (2016), Lumbroso *et al* (2016), Singh *et al* (2016), Schaer and Hanonou (2017), Tall *et al* (2014)

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