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Understanding the Role of User Needs and Perceptions Related to Sub-Seasonal and Seasonal Forecasts on Farmers' Decisions in Kenya: A Systematic Review

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One major challenge facing farmers and other end users of weather and climate information (WCI) in Kenya is the linkage between their perceptions, needs, and engagements with producers of the information. This is highlighted by increased interest in understanding the constraints on appropriate use of weather information by farmers in decision-making. The choice between sub-seasonal and seasonal forecasts can enable better decisions by farmers if the forecast information is reliable and integrated through a coproduction process. This study analyzes user needs and perceptions of crop farmers, pastoralists, and agro-pastoralists in relation to sub-seasonal and seasonal forecasts for five counties in Kenya. A total of 258 peer-reviewed articles and gray literature were systematically analyzed using Search, Appraisal, Synthesis and Analysis (SALSA) to understand how the needs and perceptions of users of WCI shaped access and use in decision-making. The study also evaluated factors influencing use and uptake of sub-seasonal and seasonal forecasts as well as the barriers to use. Results show that farmers' perceptions shaped the choice of WCI that is used and also highlight how sub-seasonal and seasonal forecasts were used for diverse applications. Gender, availability of resources, access, and mode of communication were key factors influencing the use of seasonal forecasts. For example, access to seasonal forecasts of farmers in drier counties enabled them to manage floods and reduce risk. One lesson learned was that farmers combined WCI with other coping practices such as agronomic practices and water efficiency management. Despite a number of challenges by forecast users such as insufficient resources and lack of access to information, there is potential to improve forecasts according to user needs through a coproduction process. This study recommends stakeholder engagements with producers in the development and evaluation of forecast products and communication pathways to improve uptake and use of forecasts in decision-making.

Keywords: user needs, perceptions, sub-seasonal forecast, seasonal forecast, indigenous knowledge, farmer, co-production

INTRODUCTION

Kenya, like many other Sub-Saharan African countries, is highly vulnerable to extreme weather and climate risks associated with poor infrastructure and low adaptive capacity. Climate change impacts will alter agricultural production and increase pressure on communities' livelihoods (Brown and Hansen, 2008; Kipkogei et al., 2017). For example, droughts and floods are more frequent in Kenya and the region in the last decade (Bunyasi, 2012; Huho and Kosonei, 2013; Mugalavai and Kipkorir, 2013; Yvonne et al., 2016).

In efforts to address these problems, several studies highlight that weather and climate information (WCI) can play a significant role in minimizing the negative impacts of climate disasters (Carr et al., 2016; Ketiem et al., 2017). The use of this information can translate to social and economic opportunities when favorable weather and climate conditions occur (Coe and Stern, 2011; Mugi-Ngenga et al., 2016; Apgar et al., 2017; Ketiem et al., 2017; Ozor and Nyambane, 2018). Nonetheless, climate information services (CIS) in sub-Saharan Africa are already being developed, although with relatively little focus on end users and their specific needs (Carr et al., 2016). At the moment, increasing attention is shifting to engagements between users and producers of WCI, which is believed to promote user-centered climate services (Rarieya and Fortun, 2010). It is postulated that by identifying user needs and perceptions, producers of WCI can integrate farmers and other stakeholders in the formulation, production, and dissemination of WCI. It is within this context that we review user needs and perceptions in relation to sub-seasonal and seasonal forecasts for decision-making in Kenya.

To build this, global trends in understanding user needs and perceptions related to sub-seasonal and seasonal forecasts in agriculture and related sectors are first highlighted. Several examples on this area can be cited from the United States (Brewer et al., 2020), Europe (Soares et al., 2018; Damm et al., 2019; Kusunose et al., 2019), China (Golding et al., 2017), Sub-Saharan Africa (Jones et al., 2015; Singh et al., 2018; Nkiaka et al., 2019), and Australia among other regions (Tarhule and Lamb, 2003; Mase and Prokopy, 2014; Nalau et al., 2017; Williamson et al., 2017). Brewer et al. (2020) and Williamson et al. (2017) opine that users' perceptions are important as a guide to science, research, innovation, and capacity and have the capabilities of developing high-quality weather products that lead to improved services, access, and stewardship. Further, users' perceptions enable the identification of constraints to the use of weather information across diverse user attributes such as gender and socioeconomic status where, for instance, women are ignored from most farm decisions (Carr et al., 2016; Snorek et al., 2018). Several studies also show that knowledge on users' perceptions makes it easier to know the drivers and barriers to adoption and uptake of WCI such as limited resources and uncertainty of climate forecasts (Sitas et al., 2014; Damm et al., 2019; Nkiaka et al., 2019). Yet, Carr et al. (2020) and Stewart-Ibarra et al. (2019) show that users' perceptions are important in linking user needs and activities to climate services and promoting practices and concept of coproduction of climate services, which bring together users and producers of WCI. In contrast to the latter, Coe and Stern (2011) indicate that the perceptions of farmers in sub-Saharan Africa tend to overemphasize extreme weather impacts rather than opportunities that come when better weather conditions occur. Despite these, knowledge of users' needs and perceptions does not always lead to uptake and use of WCI where other constraints exist (Rasmussen et al., 2017). It is therefore useful to examine how users' perceptions on WCI can influence decision-making in agriculture and other farm-related activities. Notwithstanding the benefits of WCI, uptake and use of WCI require sustained interaction between the producers and users of WCI, which can bridge the gap between them (Guido et al., 2016; Jones et al., 2017; Haavisto et al., 2020).

Due to frequent threats posed by extreme weather, WCI is becoming necessary for early warning decision-making by users in minimizing agriculture-related climate impacts (Tall et al., 2018). This is one of the key reasons why meteorological forecasters regularly produce and provide a lot of information to users in the agriculture and other climate-sensitive sectors. This process of production and provision of climate information to users is also referred to as climate services (CSs) and comprise institutional arrangements, contextualizing of information, communication, stakeholder's engagements, capacity building, and research (Kwena, 2015; Pathak and Lúcio, 2018; Carr et al., 2020). The Global Framework for Climate Services (GFCS) by the World Meteorological Organization shows that CSs are meant to improve users' capabilities to adapt to the impacts of climate change (Vaughan and Dessai, 2014).

Where CSs and WCI are not utilized by users (Flagg and Kirchhoff, 2018; Singh et al., 2018), it might be due to the limited attention these pay to users' needs and requirements (Skelton et al., 2019; Manon et al., 2020), institutional barriers (Dilling and Lemos, 2011; Biesbroek et al., 2018), low forecast accuracy (Buizer et al., 2005; Morss et al., 2008), difficult terminology and clarity (Briley et al., 2015), and other producer-driven constraints (Feldman and Ingram, 2009). Producers of WCI presuppose that meteorological forecasters can develop products and services without involving the users or their needs and perceptions but anticipate that users will find the information usable and useful (Cash et al., 2006). While providing WCI that is tailored to the users' needs and demands may address some of the challenges highlighted, the user-driven process can be successful and translate to usability of the information if institutional support, dissemination, and communication strategy are put in place (Rasmussen et al., 2017; VanderMolen et al., 2020). According to Wilkinson et al. (2015), a useful forecast is one which satisfies a user's need in regard to accuracy, timeliness, space, and time resolution and other user-sensitive attributes. If this is achieved, increased uptake and use of WCI can be realized across sectoral needs. However, this will only be possible if we shift CSs from being producer-oriented to user-focused through the process of coproduction of WCI, which brings the user onboard through a multidisciplinary and participatory process (Dilling and Lemos, 2011; Lemos et al., 2012; Tall et al., 2012; Bremer et al., 2019). This concept of coproduction between producers and users of WCI is believed to have led to increased usability and dissemination of forecasts (Roncoli et al., 2011; Meadow et al., 2015), development of forecast products that are tailored to user's needs (Cash et al., 2006; Howarth and Morse-Jones, 2019), and increased efficiency, trust, and capacity for using the information to make decisions (Lemos and Morehouse, 2005; Buizer et al., 2016). In this regard, coproduction through use of participatory workshops infuses a better understanding of WCI and trust among farmers and other stakeholders in the uptake and use of WCI (Tall et al., 2012). Another issue that can be strengthened through the engagement process between users and producers of WCI is paying attention to the changes in forecast uncertainty at nowcasting to seasonal timescales. These changes influence user's decisions such as planting time and other agricultural practices as well as how the information is communicated.

This study recognizes the attention that development partners are giving to the challenges of climate change in developing and least developing countries (Sovacool et al., 2017; Teklu, 2018). One of the focus areas is the strengthening of capacity for WCI and the pathways to provide solutions to vulnerable communities. This can be achieved through climate data analysis and inclusion of user needs and demands within the climate services through code signing and co-development of products and services that address communities' socioeconomic concerns. The support for climate services can provide an opportunity to include users' needs, perspectives, and contributions of producers of WCI. The gains from the efforts by development partners are highlighted by several studies on WCI in Kenya and in Sub-Saharan Africa, which show that working with farmers and other stakeholders has improved the farmers' capacity and enabled better understanding and identification of users' needs and demands, enhancement of dissemination and use of WCI in decision–making, and also improved access to analyzed data for use in the management of climate risks in agriculture and related activities (Coe and Stern, 2011; USAID, 2013; Aura et al., 2015).

Specifically, this paper establishes user needs and perceptions of crop farmers, pastoralists, and agro-pastoralists (collectively "farmers") with respect to sub-seasonal and seasonal forecasts in five Kenyan counties. The specific objectives are to: (1) identify WCI needs of farmers in the five counties in Kenya; (2) establish the main drivers influencing the uptake, use, and adoption of sub-seasonal and seasonal forecasts by farmers in the target counties; (3) determine the barriers that hinder the uptake, use, and adoption of sub-seasonal and seasonal forecasts by users in the target counties; and (4) analyze how users' perceptions on sub-seasonal and seasonal forecasts influence farm decisions in the study counties.

METHODOLOGY

Literature review was chosen as the ideal research approach to address the objectives of this study, which seek to get a better understanding of the existing information and research gaps on users' needs and perceptions related to seasonal and sub-seasonal forecasts in the study counties. It was deemed suitable, since it is a key component of research and allows a rigorous scrutiny process and comprehensive analysis of diverse and previous research work and theories by different authors collectively covering a longer period of time rather than a single exploratory study over a short period of time and using participatory rural appraisals and surveys in the study areas (Benzies et al., 2006; Ridley, 2012; Rahman et al., 2020). In addition, literature review in this study is used to provide a basis for a follow-up exploratory survey that was conducted later in four of the five study counties and to place the findings within the context of existing literature. In other words, the analysis of the survey data will be useful in validating the literature review findings from this study.

Specifically, our study adopts a systematic review approach that allows existing knowledge and case studies to be synthesized under common themes from previous research and for obtaining most and the best evidence for many review decisions (Booth et al., 2016). In contrast to traditional narrative reviews, this approach seeks to minimize bias and enhance transparency and has been preferred by several scientists to obtain and compare evidence from research studies (e.g., Nkiaka et al., 2019; Carr et al., 2020). The review approach is different from other reviews, since it is based on specific research questions. Other literature review approaches differ by the extent to which they are systematic and are also based on broad research questions and qualitative analysis rather than comparison of evidence between studies (Booth et al., 2016). The review targeted English-language peer-reviewed and non-peer-reviewed literature published between 1985 and 2020. We largely examined research studies in this period in order to have a better background on farmers' needs and perceptions related to sub-seasonal and seasonal forecasts in decision-making. The inclusion and exclusion criteria of research articles are described in **Table 1**. The process involved selection of research articles that addressed one or more of the following:

- Timescale of the forecast
- The type of climate information and combination provided (short- or long-term forecast, agronomic information, water conservation measures, market information)
- The needs and perceptions of farmers related to WCI
- Methods of communicating weather and climate forecast
- Information related to the use of indigenous forecast (IF) by farmers
- Barriers that impede the use of WCI in agriculture
- Factors that influence the uptake, use, and adoption of WCI by farmers
- Farmers' perception of forecasts being provided and how this can influence decision-making.

We used the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) as the reporting guidelines for database searches, number of articles/abstract screening, and the texts retrieved (Liberati et al., 2009; Moher et al., 2015; **Figure 1**).

To ensure the review captured all relevant publications that address the scope of the study, we carried out preliminary scoping of literature to identify appropriate search terms. Additionally, we used our research scope to formulate four research questions and the research limits to determine and identify the review method. Scoping enables decision-making on the type of topics to be selected or excluded from the review. Several keywords were then captured consisting of "need," "perception," "use," "user,"

TABLE 1 | Inclusion and exclusion criteria.

Criteria	Inclusion	Exclusion
Research article type	– Peer-reviewed research articles – Gray literature (unpublished academic research, government reports, project reports)	– Conference proceedings, book series and chapters, book, conference series
Language	– English articles	– Non-English articles
Year of publication	– From 1998 to June 2020	– Before 1998
Citation Indexes	– H-Index among others (Google Scholar)	– Non-science citations
Countries and sub-national	– Kenya and study counties, few regional and global articles (for example, studies' references)	– Other countries (excluding example studies used for background and references)

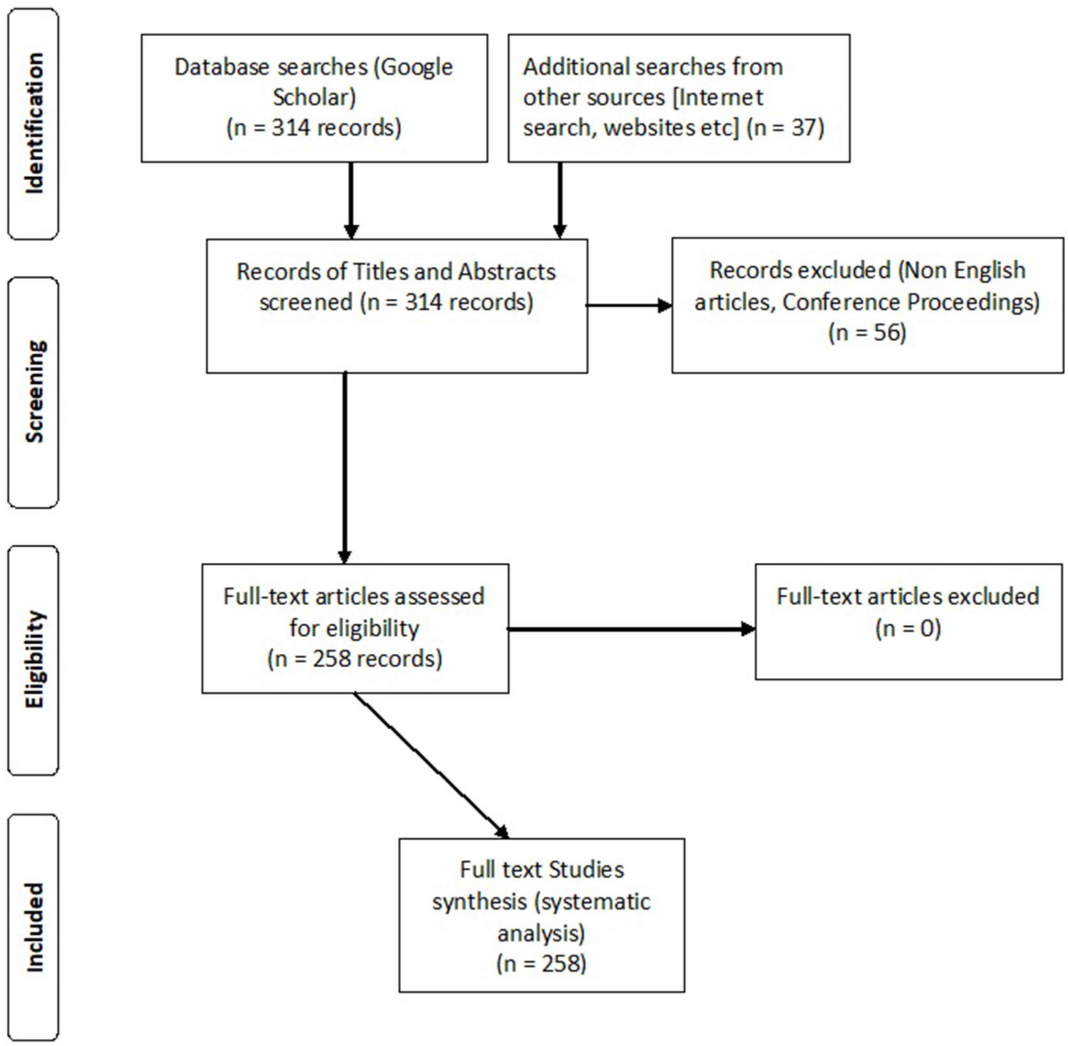

FIGURE 1 | Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram.

"forecast," "information," "demand," "weather information," "climate," "product," "access," "dissemination," "communication," "barrier," and "meteorological." These keywords and terms generally relate with or appear in the title of the study and also highlight aspects of the research questions and study objectives. For example, in the study by Kadi et al. (2011), "The State of Climate Information Services for Agriculture and Food Security in East African Countries," most of the keywords appear several times, e.g., Need, 86 times; Use, 248 times; user, 86 times; demand, 25 times; forecast, 121 times; information, 311 times; weather information, 8 times; climate, 505 times; product, 231 times; disseminate, 23 times; communication, 22 times; barriers, 14; and meteorological, 120 times. It is worth noting users' perception with regard to aspects or attributes of WCI (sub-seasonal and seasonal forecasts) that link with specific keywords. Subsequently, the keywords were useful in determining if the selected publication highlighted issues related to the study and whether they should be included or excluded in the review. We used the following search terms/strings based on the specific county name and, in some cases, country name and used Google Scholar as the main database to retrieve information. For gray literature, other databases including government websites and research/academic institutions' knowledge management systems were used in the search, which also utilized the search terms identified. The search terms included the following:

- User needs and perceptions of weather and climate information in Kenya
- Climate information services in Kenya
- Coproduction of weather and climate information
- Climate change impacts and mitigation on agriculture in Kenya
- Use of seasonal and sub-seasonal forecast by farmers and pastoralists in Kenya
- Use of IF in agriculture/pastoralism
- Farmers' perception of weather information and climate services.

The literature search strategy and selection criteria enabled a total of 314 publications to be retrieved from Google Scholar. A detailed examination of the article title and abstract led to the elimination of 56 articles, while 258 articles (both reviewed and non-peer-reviewed) were included in the systematic review.

Considering the four objectives of the study on user needs and perceptions related to sub-seasonal and seasonal forecasts, we formulated four research questions, as indicated below. The research questions were as follows:

1. What is the specific weather and climate information needs of farmers in the study counties?
2. Which are the key factors that promote the uptake, use, and adoption of weather and climate information by users in the study counties?
3. What are the barriers to the uptake, use, and adoption of weather and climate information by farmers in the study counties in Kenya?
4. How do farmers' perceptions on weather and climate information influence farm decisions in the study counties?

To answer the four research questions, our study used the Search, Appraisal, Synthesis and Analysis (SALSA) approach, which is described and used in the subsequent section.

This paper is composed of the following sections. Section [Study area description and systematic review process] describes the study area and data collection and review methods used in the study. Section [Results] gives the results of the study and is divided into four parts in line with the research questions. Firstly, reviews on user needs on WCI are discussed. Secondly, factors that influence the uptake, use, and adoption of sub-seasonal and seasonal forecasts are identified and examined. Thirdly, barriers to the uptake, use, and adoption of sub-seasonal and seasonal forecasts are established. The last part examines how user perceptions on WCI influence farm decisions in the study counties. A discussion of the review findings follows, and finally the review paper provides the conclusion with significance of the findings.

Study Area Description and Systematic Review Process

To carry out the systematic review, we separately targeted each of the five study counties in Kenya. The analysis focused on three counties characterized by arid to semiarid agro-climates (Machakos, Isiolo, and Laikipia) and two counties with semi-humid to humid agro-climates (Trans Nzoia and Meru), which were selected because they represent typical different climatic regimes in the country in the context of food and agriculture production potential so as to capture a diverse understanding of the user needs and perceptions in relation to sub-seasonal and seasonal forecasts. Agriculture in Kenya is largely rain-fed, and the types of production, rainfall patterns, and needs for WCI vary between the arid/drier and the humid counties. The arid counties also provide ideal case studies representing populations with lesser resources and low adaptive capacity to climate change compared with the humid areas. Adaptive capacity with regard to communities and climate change impacts refers to the ability of individuals (or institutions and systems) to adjust to potential risks, take advantage of opportunities, and be able to cope with the consequences.

The systematic review and analysis of the selected publications follow the approach by Mengist et al. (2020). The approach utilizes the elements of the SALSA framework (Booth et al., 2016). The SALSA is a methodology that helps to decide the search protocols that a systematic review should follow and ensures comprehensiveness, systematic analysis, accuracy, and replication among other benefits. This method involves four steps: The search that defines the search keywords or terms and the types of search databases, the appraisal that describes the criteria used for inclusion and exclusion of literature articles and their assessment, the synthesis that defines the way the required information was extracted and classified/categorized, and the analysis that involves the narration of the findings and conclusions. In addition to SALSA, this study also linked the search protocol and reporting of the results in the review process (Mengist et al., 2020).

Using this approach, the study scope as applied in the systematic review was defined using the Population, Intervention, Comparison, Outcome, and Context (PICOC) framework (Booth et al., 2016). Within this context, the Population is captured as user needs and perceptions related to sub-seasonal and seasonal forecasts in Kenya and is applied in the systematic review to answer research questions dealing with needs and perceptions of farmers in the study counties. Intervention is used to address the problem identified (questions) on sub-seasonal and seasonal forecasts and applied to review barriers and to use of weather information and how these can be addressed. Comparison is used for determining techniques for testing different interventions in the use of WCI and perceptions of farmers on sub-seasonal and seasonal forecasts and how these vary between counties or farmers. According to Booth et al. (2016), outcome relates to the measure used to evaluate the existing knowledge and limitations in the selected publications. In this case, the systematic review may look for existing categories of forecasts being used by farmers, the purpose and decisions made through forecast use, and barriers related to use, access, and other factors in line with the research questions. Generally, barriers to use of WCI might be linked to a number of attributes such as usability, availability, credibility, responsiveness, and others (Dilling and Lemos, 2011). The context specifies areas of the population and application of the systematic review to examine the trends of research on user needs and perceptions on sub-seasonal and seasonal forecasts and categories of counties. Within the context of the scope of the study, the steps of the SALSA framework are described later.

To use systematic review within the scope of the study, we defined the concept of perception from Michaels (2000) who views perception as the various ways in which people are aware of or receive information from their environment through experiences from the past to help control their actions. In this study, perceptions about sub-seasonal and seasonal forecasts refer to farmers' behavior, attitude, motivations, judgments, and choices with respect to the use of sub-seasonal and seasonal forecasts in decision-making. We used WCI as the collective term(s) that describes all types of forecasts (and products) spanning from time frames of hours to seasons. Within our study context, we defined sub-seasonal and seasonal forecasts as forecasts of timescales of 2–6 weeks and 3–6 months, respectively (Jie et al., 2017; Schepen et al., 2018; Vitart and Robertson, 2018). This definition varies slightly with others like Jones et al. (2015) where short-term climate information is associated with 3 months' timescale and Wilkinson et al. (2015) who generalize climate information as forecasts of different timescales ranging from few days to several months. The concept of sub-seasonal to seasonal forecasts is a new and growing area in forecasting aimed to narrow the gap between weather and seasonal climate predictions. This is due to the fact that most management decisions in agriculture and climate disaster sectors are taken within this window (Robertson et al., 2019).

To review perceptions of farmers, we considered socioeconomic attributes such as gender and income that influence the uptake, use, and adoption of WCI (Kitinya et al., 2012), phenomena or events they observe, and the information they access among other factors that motivate uptake of forecasts and use of other technologies (Parita et al., 2012). To improve the understanding of the context of users' perceptions on sub-seasonal and seasonal forecasts, our review has also mentioned other interventions by farmers such as indigenous knowledge (IK) and other technologies due to their use by farmers in decision-making alongside sub-seasonal and seasonal forecasts.

Overall, 258 articles were obtained out of which 26.4% (68 articles) highlighted mostly the use of WCI by farmers; 20.9% (54 articles) indicated perceptions of farmers on the use of WCI and climate change; 29.8% (77 articles) related to adaptation to impacts of weather and climate change in agriculture; 12% (31 articles) on application of seasonal and climate forecasts in agriculture; 60.2% (153 articles) on mixed topics such as the use of IK forecasts, weather and climate forecasts, and other innovations by farmers, use of climate smart agriculture, and regional and global articles highlighting the use of sub-seasonal and seasonal/WCI in agriculture and water sectors. Themes on barriers and farmers' perceptions influencing farmer decisions are found across several of the articles. Using similar search terms, the final documents consisted of gray literature such as reports from national government ministries and agencies, counties, non-governmental organizations (NGOs), and unpublished Ph.D. and master's theses. A total of 56 articles were obtained/searched: 66.1% (37 thesis articles related to climate change preparedness including the use of climate information), 19.6% (11 governments reports) of diverse topics from mainstreaming of climate information in policy decisions, and 14.3% (eight other/project reports) articles related to agriculture adaptation to climate change, resilience, and livelihoods.

Under appraisal, we considered articles between the years 1985 and 2020 and in advanced article search for keywords: e.g., "need," "perception," "use," "user," "forecast," "information," "demand," "weather information," "climate," "product," "access," "dissemination," "communication," "barrier," and "meteorological." Under our systematic review, we considered reports and documents available up to 2020. Search for the keywords also highlighted the earlier ones and other additions such as "adaptation," "agriculture," and "farmers."

For the synthesis, we conducted qualitative content analysis. The information from the publications was organized in a tabular form with four categories of headings: title of article, thematic part, aspects analyzed per unit, context/link to research questions, and impact. Similarly, these were organized in a tabular/matrix form with four categories of headings: title of article, thematic/meaningful unit, issue analyzed unit, context/link to research questions, and impact.

The number of articles reviewed varied between 11.9% (Meru) and 26.4% (Isiolo) of the total number of publications reviewed. As can be seen in **Figure 2**, there were more research articles reviewed for arid and semiarid counties compared to the humid counties. The highest numbers of articles (40) were published in 2015, and only one article each was published in 2000, 2003, 2004, and 2011 consecutively.

From the methods presented, the results of this study are structured as follows. First, the results regarding the needs for WCI by farmers in the study counties are discussed. The factors that influence the uptake and adoption of WCI in the study counties are then reviewed. This is followed by presentation of the barriers and challenges that farmers face in the uptake, use, and adoption of WCI. Finally, the results concerning how farmers' perceptions on WCI influence their farm decisions are presented.

RESULTS

Weather and Climate Information Needs of Farmers

It is important to acknowledge that different farmers and users of sub-seasonal and seasonal forecast exist, with each having

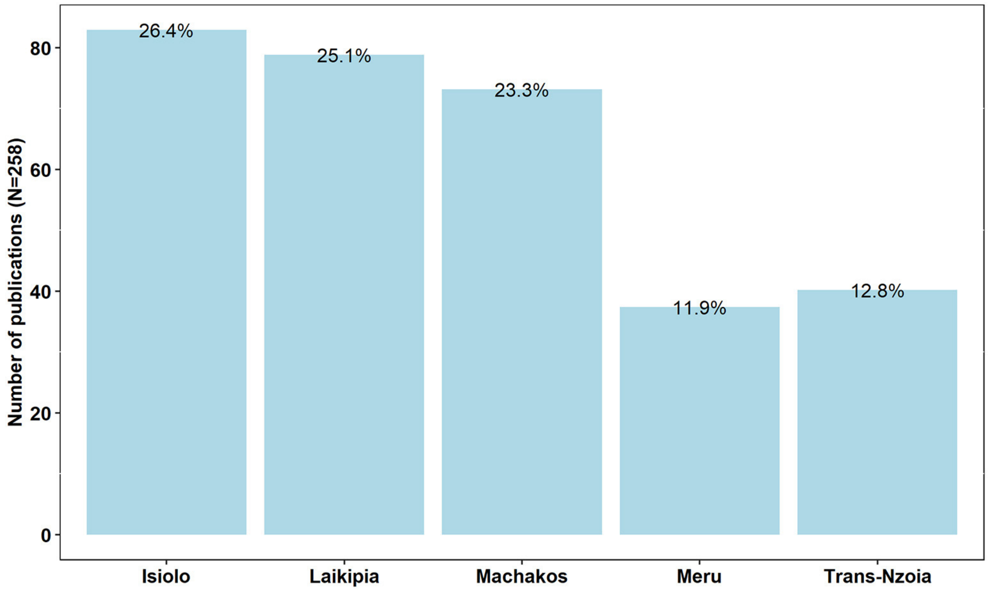

FIGURE 2 | Number of publications per county and depicted as a percentage of the total number of articles searched.

their own needs. Information on needs of farmers in Kenya can be obtained from perceptions related to climate information, which have extensively been studied (Ogalleh et al., 2012; Few et al., 2015; INTASAVE Africa, 2018; Mareverwa, 2018). Mogaka et al. (2005) noted that seasonal forecasts by the Kenya Meteorological Department (KMD) and Intergovernmental Authority on Development (IGAD) Climate Prediction and Application Centre provided in advance could solve the perennial water needs of farmers in Laikipia. The need for information on rainfall patterns by farmers in Laikipia is highlighted by Karanja et al. (2017) who studied drought patterns during rainy seasons in Laikipia and realized that the area experienced more than eight droughts between 1984 and 2010. Future rainfall projections in Laikipia further indicate declining rainfall in the short rains [October–November–December (OND)] season (Ogega, 2018).

According to the International Development Research Centre (INTASAVE Africa, 2018), farmers in arid areas like Laikipia require better communication channels, since the provision and dissemination of WCI to the farmers through combined communication such as community radio and TV have been shown to improve their ability to cope with climate disasters and also promote good agricultural adaptation practices such as planting of drought-tolerant crops.

While, Mwangi (2013) found that farmers accessed and used WCI in Laikipia, Parita et al. (2012) indicated that they specifically needed seasonal forecasts for decision-making than sub-seasonal forecasts. This suggests that farmers did not expect to cope with short-term or sudden weather extremes (e.g., storms) requiring sub-seasonal forecasts or advisories. Regardless, the 2019/2020 Laikipia County Development Plans seem to support dissemination of monthly weather bulletins to farmers and other users in order to deal with weather risks (County Government of Laikipia, 2018). One household baseline study in Laikipia revealed that farmers' needs for agriculture and climate information are relevant if disaggregated by gender and vulnerability (MoALF, 2014). In other words, for sub-seasonal or seasonal forecasts to be used, they should be tailored according to gender and level and degree of vulnerability to climate impacts. This can be compared with findings from other studies conducted in Machakos, Makueni, and Western Kenya Counties, where the roles and perceptions of male and female farmers differed with regard to uptake and use of WCI in managing climate impacts due to factors related to access to farm inputs and markets (Ifejika, 2006; Kalungu et al., 2013; Kristjanson et al., 2015; Mwangi et al., 2015; Mungai et al., 2017).

Similar to Laikipia, crop farmers and agro-pastoralists in Machakos often need seasonal forecasts compared to other forecasts (Ngugi et al., 2011; Kalungu et al., 2013; Mortimore, 2013; Mwalusepo et al., 2015). In contrast, however, Momo et al. (2013) found that 97% of the farmers in Machakos used sub-seasonal forecasts including daily forecasts and advisories. This two contrasting scenarios suggest that farmers in this region may have specific farm decisions that require both sub-seasonal and seasonal forecasts for their farm decisions. This is attested by the fact that the farmers in Machakos found the forecasts useful in addressing their needs to select the right type of crops and seeds and other farm inputs (Agesa et al., 2019). This contrasts with the perceptions of a majority of farmers and pastoralists surveyed in the neighboring counties of Makueni and Kajiado who said that while they needed and used seasonal forecasts that they deemed accurate, they were less useful for their farming decisions such as guiding grazing patterns and other decisions (Amwata, 2013). This shows that while the farmers need accurate information, it should also be usable and relevant to their farm decision-making.

Similar to many other semiarid areas in Kenya and the region, Bosire et al. (2019) indicates that increased temperature trends and declining rainfall found in Machakos are factors that trigger shorter growing seasons and need farmers to adopt to shorter duration maturing crops relative to long maturing crops. This is the situation reported by Kalungu et al. (2013) and Baaru and Gachene (2016) who found that farmers in Machakos cited declining crop production due to increased droughts, floods, and temperatures prompting them to adopt appropriate coping measures such as short maturing crops. In this regard, farmers and producers can work together to enable them to shift from seasonal forecasts to sub-seasonal forecasts in response to constraints posed by changes in the weather patterns. According to the farmers, they needed to know when the rains will start in order to decide what farm practices to follow in order to trigger early planting and new tillage methods. These were considered good coping mechanisms to respond to erratic weather patterns (Yvonne et al., 2016). To satisfy these needs, Recha et al. (2013) found that the farmers visited the local meteorological station in Machakos to obtain agro-meteorological information and agricultural advisories from meteorologists. Interestingly, the farmers preferred specific information such as rainfall amounts, distribution, and rainfall onset dates. These also included market and traders' information comprising the suppliers of inputs such as seed varieties and fertilizers that the meteorological office could not provide. Nonetheless, farmers can get the WCI integrated through agricultural advisories from agriculture extension services. According to Bourne et al. (2015) and Leal Filho et al. (2017), for agricultural advisories to be usable and relevant to farmers, they must be disseminated in a timely manner and through appropriate channels such as bulletins, radio, and TV. This suggests the need to promote a close relationship between users, WCI, and producers of weather information and agriculture-related actors to enable effective communication and use of the information. The importance of communication in helping farmers access climate and agricultural information is critical for management of climate risks (Casmir et al., 2012). In West Africa, such linkages between communications, needs of users, uptake and use of WCI, and dissemination processes are largely not documented (Ouedraogo et al., 2018). Nonetheless, Jones et al. (2015) have reviewed some cases where communication has enabled the access and use of forecasts in sub-Saharan Africa. According to Jones et al. (2015), communication of WCI can benefit from multi-stakeholder involvement at varied levels such as scientific communities, government, and the end user communities.

Pastoralists need IFs that have a seasonal timescale and are location-specific, use environmental indicators, and are the mostly used strategy to manage climate risks in Isiolo (Aklilu and Wekesa, 2002; Habane, 2010; Kagunyu et al., 2016; Okitoi et al., 2016; Gumo, 2017). Interestingly, pastoralists in Isiolo utilize IFs in probabilistic terms, although its usefulness has gradually weakened with increased frequency and severity of drought in recent years (Rao et al., 2019). Due to the latter reason, pastoralists in the area need and have been using seasonal forecasts. In this case, pastoralists need the forecasted rain amounts but also if they will guarantee sufficient pasture and water for their livestock (de Jode, 2015). Curry (2001) had earlier assessed climate information needs for institutions offering climate services in Isiolo and other areas in northern Kenya and the greater horn of Africa region and found that farmers needed the capacity to help them use and make decisions using the forecasts and strengthening of engagements with the producers of the forecasts. On the other end, it appears that pastoralists need information on droughts and other climate disasters in order to improve their resilience to climate shocks (Karani and Kariuki, 2017). This suggests that pastoralists need sub-seasonal and seasonal forecasts to enhance their resilience and productivity (Jillo and Koske, 2014; Kuria et al., 2016). In the meantime, the pastoralists have tended to diversify to subsistence farming. Further, Quandt and Kimathi (2016) found that farmers in Isiolo County needed information on how to adapt to climate change impacts. It has been shown that climate change impacts are closely linked to loss of pastoralist livelihoods (livestock) that require suitable strategies to deal with risks of floods and droughts through the use of weather advisories and seasonal forecasts (King-Okumu et al., 2016). Ofoegbu et al. (2018) suggests that early warning and response advisory services in Kenya can benefit from weather and climate forecasts tailored to the diverse needs of the pastoral communities. Effective early warning needs to be supported with other livelihood interventions (Leeuw et al., 2011; Maina, 2012).

In Meru, erratic rainfall patterns have been noted as a major problem to farmers' ability to adjust their agricultural practices and therefore raise the need for the development of specific forecasts for each season targeting farmers in the area (Ogalleh et al., 2012). Ogalleh et al. (2012) says that rains had been more predictable in the earlier years but now and in recent years have become erratic and a barrier to farmers due to climate change. Since significant advances have been made in improving seasonal forecasts in Kenya and the sub-Saharan (Tadesse et al., 2008), sub-seasonal and seasonal forecasts that are of broader resolution may need to be downscaled to provide finer information for easier use by end users in Meru and other regions (Shiferaw et al., 2014). In addition, farmers in Meru need capacity building considering that none of the farmers accessed WCI despite their knowing that they exist (Karani and Wanjohi, 2017). Nonetheless, farmers' needs in Meru are aligned to gender of the household, access to weather information such as onset and rainfall distribution, and type of farming activity among other factors (Karienye et al., 2019). According to Percy (2013), farmers in Meru prefer sub-seasonal and seasonal forecasts alongside other information such as farm inputs and market through extension services in order to make informed decisions.

In Trans Nzoia, one study indicated that more than 60% of the farmers need seasonal forecasts, and in particular, they needed early warning information on floods and droughts that they deemed useful (Chepkemoi, 2014). Few other farmers want reliable forecasts that can address their needs for climate information. Similar to Trans Nzoia, farmers in neighboring Bungoma County needed and used IF together with seasonal forecasts in their farm decisions (Barasa et al., 2017). In addition and in line with the other study counties, farmers in Trans Nzoia require information on when to plant their maize crops. Since most of the farmers prefer dry planting their crops before the start of the March–May seasonal rains and October–December rainy seasons, they need timely forecast at few weeks' lead time (Hassan and Ransom, 1998). Whereas farmers in this county need information and education on soil fertility improvement technologies, this was found to be strongly related to access of information on markets, WCI (Kanyenji et al., 2020). There is yet the need by farmers in Trans Nzoia to integrate IF with seasonal forecasts among local communities in order to benefit from both (Guthiga and Newsham, 2011). A similar study in Malawi found that there was a higher agreement between the need for IF and WCI, although end users were reluctant to use WCI (Kalanda-Joshua et al., 2011). While the push to integrate IF with WCI is gaining momentum, the skill of IF is yet to be tested empirically Ifejika et al., 2008).

In general, the review of farmers' perceptions on WCI needs shows that farmers in all the five counties in Kenya mentioned that they needed sub-seasonal and seasonal forecasts largely due to the frequency of climate risks such as erratic rainfall and droughts. Farmers required specific information such as rainfall amounts, distribution, and rainfall onset dates. However, demand for seasonal forecasts was higher in drier counties than in the humid counties. Farmers from each of the counties also had specific information preferences for communication channels, although radio was the most common mode for dissemination of WCI. Other needs from the farmers included need for accessible, timely, and usable WCI together with agricultural advisories.

The review on WCI needs reflects other findings from East Africa, West Africa, and Asia (Förch et al., 2011; Kadi et al., 2011; Lebel, 2013; Shackleton et al., 2015), which indicate that users' perceptions can enable the identification of users' needs for climate and agriculture information and help in managing climate risks. A comprehensive review of users' perceptions and needs related with WCI in semiarid areas over East Africa can be found in Few et al. (2015).

Key Factors That Influence the Uptake, Use, and Adoption of Weather and Climate Information

To review the factors that influence the uptake, use, and adoption of sub-seasonal and seasonal forecasts, we must envision both scientific and the concept of IK where applicable considering that IK is part of the tools used to manage climate risk by a number of communities in Kenya. IK is used to develop IFs that have attributes highlighting culture, social, and economic and environmental aspects in a given community (Leclerc et al., 2013).

Different ways of communication and dissemination of sub-seasonal and seasonal forecasts influence the uptake, use, and adoption by farmers in Laikipia. For example, use of short messages through mobiles phones, provision of information through officers from the agriculture office and the KMD has improved the making of appropriate decisions on farming methods and production (Parita et al., 2012; The Ministry of Agriculture, Livestock and Fisheries, 2017). In Laikipia, Information Communication Technology has proven useful in bringing together different stakeholders including the KMD, county government, and NGOs to engage farmers through promotion of agriculture practices and climate information (Cox and Sseguya, 2015). Other incentives to the uptake, use, and adoption of WCI include frequent engagements and interactions by KMD that has encouraged users to continuously use sub-seasonal forecasts that include 5-day, weekly, and monthly forecasts and severe weather advisories (Parita et al., 2012; Shilenje and Ogwang, 2015). Even with the engagements between users, their needs, and improved use of WCI, it is argued that the efforts need to be supported by forecast-based financing mechanisms that can guarantee social security of users through an action-based anticipatory process (Eriksen et al., 2017). Another factor that affects the uptake, use, and adoption of forecasts is the shift of farmers from pastoral to smallholder agricultural systems due to erratic rainfall patterns and resultant impacts on livestock production (Huho et al., 2012). This highlights the need to use seasonal forecasts to manage changing and unpredictable rainfall patterns (Ulrich et al., 2012; Muthama et al., 2013). Potentially, weather-based crop insurance as a factor can draw value from seasonal forecasts to reduce climate risks, but low uptake by farmers in Laikipia suggests that improved provision and use of WCI and training may improve their coping capacity on climate risks (Wairimu et al., 2016; Njue et al., 2018). On the other hand, downscaling of sub-seasonal and seasonal forecasts at the local level is a key consideration by farmers to use the information, since it enhances forecast skill and relevance and usability by smallholder farmers and pastoralists in Laikipia and other arid areas (Parita et al., 2012).

Furthermore, in Laikipia, factors of human capital such as education and literacy level, social capital such age, gender, and types and quality of farm and food production, as well as financial capital such as size of livestock ownership and access to financial credit influenced the pastoralists' access, use, and uptake of WCI in Laikipia (Nganga and Coulibaly, 2017). For example, having a higher formal education and literacy levels enabled individuals to obtain employment and income that supported livelihoods and adaptation to climate risks through the use of WCI and other interventions. More financial capital such as larger livestock herd or savings resulted in better decision-making such as stocking of fodder during drought periods, timely livestock migratory schedules, and destocking. However, livestock ownership for most pastoralists was limited to smaller herds due to recurrent and endemic drought that suppressed pasture and water availability, leading to livestock deaths, which somewhat may have necessitated demand and use of WCI.

A highly variable rainfall pattern and resultant impacts are some of the main factors influencing the use of seasonal forecasts in Machakos (Ouma, 2015). It is for these reasons that many farmers have been using WCI in Machakos since rainfall patterns have changed in the last several years following occurrences of frequent droughts, pests, and diseases (Recha et al., 2016; Yvonne et al., 2016; Gichangi and Gatheru, 2018). In recent years, direct engagements with weather forecasters by farmers in Machakos have been important in motivating them to use forecasts in their decision-making. Another factor that is closely linked with the use of weather forecasts is the ease to integrate the information with other farm-based interventions (Recha et al., 2013). This encourages farmers to make informed decisions based on the forecasts provided. Forums such as Participatory Scenario Planning between farmers and other stakeholders motivate and generate better understanding, uptake, use, and adoption of WCI, since farmers' opinions are taken into account (INTASAVE Africa, 2018).

IFs are perceived to be reliable and useful in the management of climate risks in Machakos and neighboring Makueni counties (Gichangi et al., 2015). However, availability and use of sub-seasonal and seasonal forecasts to farmers from the two counties have encouraged the successful combined use with IF and resulted in increased farmers' ability to manage changes in weather patterns (Speranza et al., 2010).

The overarching factor driving the uptake and use of WCI in Machakos is over reliance on rain-fed agriculture. Another important factor influencing the uptake by farmers and pastoralists is their knowledge on technology and use of WCI in agricultural adaptation to climate risks (Kalungu and Leal Filho, 2018). It was found that those from more drier and warmer areas had better knowledge than those from semi-humid and cooler areas. This seemed to link well with a higher number of farmers from the warmer and semiarid areas using WCI compared to those in the latter areas. The motivation to use sub-seasonal or seasonal forecasts to manage climate impacts in Machakos and other semiarid areas may also be justified from declining maize and other crop yields relative to decreasing rainfall amounts and rising temperatures in the region (Nyandiko et al., 2014; Kiprotich et al., 2015; Gichangi and Gatheru, 2018). Other determinants of the uptake and use of WCI in the region included access of WCI, age of the household head, farm size, gender and size of the household (Muema et al., 2018), and declines in historical rainfall amounts (Okumu, 2013).

Mode of dissemination through radio is a key factor through which farmers receive weather information in Machakos (Vervoort et al., 2016; Apgar et al., 2017; Ndavula and Lungahi, 2018), while local meetings also influence farmers' need for WCI (Kitinya et al., 2012). The radio is an important factor for adoption of WCI, since it is an effective communication tool for influencing the use of WCI and triggering action among smallholder farmers in Kenya (Mwaniki et al., 2017). The findings in Machakos corroborate those from the East African region, which show the importance of using appropriate communication modes for WCI by vulnerable communities to manage climate risks (Kadi et al., 2011). Aura et al. (2015) indicate that workshops and farm visits from forecasters were key factors that improved the ability of the farmers to understand and use weather information on their farms in Machakos. These suggest that farmers in the region made better and informed decisions on their farms to manage climate disasters and opportunities. Coe and Stern (2011) recognize the need to assess the value of WCI to understand whether end users' needs are addressed adequately. Kristjanson et al. (2015) showed that socioeconomic factors related to gender also influence decisions on the use of forecasts and other inputs in Machakos. It was noted that women in Machakos make decisions on sale of crops, but men decided how the returns would be used. Like in other developing countries, men have a higher chance to access resources, skills, and climate information than women (Goh, 2012).

One of the drivers of the uptake, use, and adoption of sub-seasonal and seasonal forecasts in Isiolo by pastoralists is the belief that the use of IF integrated with WCI and other strategies was the most ideal means to manage drought patterns (Aklilu and Wekesa, 2002). Increased droughts often lead to water scarcity and conflicts between herders (Rao et al., 2019). Closely influencing the need and use of seasonal forecasts is the prevalence in livestock diseases in Isiolo (Kuria et al., 2016), where some pastoralists had previously resisted using weather forecasts to manage climate change risks due to cultural beliefs (Mosberg et al., 2017). Due to climate change threats, pastoralists and farmers in the county are also being motivated by combining both agriculture and business to improve their resilience and livelihoods against floods and droughts and hence the desire to use WCI in decision-making (Quandt and Kimathi, 2016; Quandt et al., 2017). Some pastoralists have slowly been replacing cattle production to rearing camels due to declining rainfall patterns (Kagunyu and Wanjohi, 2014). Financial support is also supposed to influence decisions on uptake and adoption of forecasts in any region. For example, the Climate Adaptation Fund initiated in Isiolo on climate resilience among pastoralists targeted direct financial support relative to enhancing early warning and actions (Greene, 2015) where management of drought expenditure between 2010 and 2014 was estimated at Ksh 400 million (Barrett, 2014).

Similar to Machakos and Laikipia, Kagunyu (2014) found that more than 70% of farmers sampled in Isiolo use WCI because of easier access through radio, and in recent years, WCI has been delivered in Isiolo and few other counties in Kenya through participatory scenario planning forums (Karani et al., 2015; Carabine et al., 2016; Karani and Kariuki, 2017). Despite these drivers, a number of pastoralists and agro-pastoralists have been reluctant to fully uptake WCI possibly due to their sedentary lifestyle (The Ministry of Agriculture, Livestock and Fisheries, 2017).

Another study conducted by Apgar et al. (2017) in Isiolo and Kitui counties showed that poor farmers in the area can be influenced to adopt WCI through using equity to improve their ability to make decisions in agriculture-related activities. While this was an issue that had been overlooked in the past, there have been some efforts to improve communication of WCI to the communities in the area through the establishment of RANET community radio stations in Isiolo and several other counties. These radio stations broadcast WCI through translation to local languages, which in turn encourage both the poor and others to uptake and use forecasts in decision-making (Ageyo and Muchunku, 2020). Gender desegregation is an important factor in Isiolo and the neighboring regions where women play a central role in identifying environmental indicators for forecasting local weather conditions (e.g., emergence of rare insects, change of color of leaves, etc.) and in carrying out other social responsibilities (Luseno et al., 2003).

The ability to sow early in March–May rainfall season may have influenced farmers in Meru to utilize forecasts. According to Ogutu et al. (2018), there is potential skill for seasonal forecasts over Laikipia and Meru for farmers sowing in the March–May long rainy seasons, a fact confirmed from onset dates from the historical data (Huho, 2011). This also reflects (Hansen et al., 2009) who show that forecasts can be used in making decisions on planting and fertilizer application. According to Ndambiri et al. (2013), adoption of climate information and other technologies by farmers in Meru and other eastern parts of Kenya is influenced by access of the information and extension services. Farmers receive information of agricultural inputs, practices, and climate information, which enable them to make timely and effective decisions. The KMD has been one of the key sources of localized weather information for crop farmers and pastoralists in Meru County (Percy, 2013). However, IK is also a key factor that plays a key role in weather forecasting and other decisions among this community (Kamwaria et al., 2015). Seasonal forecasts tested in the region suggest that forecast skill for dry conditions is higher in the semiarid areas of Meru compared to the wetter areas that indicate higher skill for wet conditions (Recha et al., 2012). This can create more interest for special and area-specific WCI for farmers in the region. This may be achieved through engagements with farmers and other stakeholders (e.g., through coproduction process) in order to understand and design the specific demand-driven WCI. Just like in all other study areas, frequent, and extreme weather conditions are major drivers of the uptake, use, and adoption of sub-seasonal and seasonal forecasts (Ngetich et al., 2014). In Meru, extreme weather is manifested in failed rains and other erratic weather patterns that trigger the need for WCI where it leads to crop failures and water scarcity. To influence the need and uptake of WCI in Meru and other regions, Amissah-Arthur et al. (2002) insist that the information must be useful, usable, and relevant as well as accurate both in time and space and aligned to users' adaptation measures.

Access to information and advisories is a major factor driving application of forecasts by farmers in Trans Nzoia considering that they can enhance the ability to improve their adaptive capacity to impacts of climate change (Thorlakson and Neufeldt, 2012). High levels of awareness, income, and education have enabled farmers in the Trans Nzoia County to adopt and uptake technology services to improve their resilience against climate risks and impacts (Olila and Pambo, 2014).

Like in the previous other study areas, uptake of technology and particularly mobile apps have influenced some farmers in the region to access farming information through sending a short message (Baumüller, 2016). Mobile phones can be extended to provide and disseminate WCI. This can improve access and timeliness of the information for decision-making. Closely linked to this is the influence of engagements between users, forecasters, and other stakeholders through a participatory process that brings together different actors including KMD, water, agriculture, Kenya Red Cross Society, and others in identifying how developed forecasts can be aligned and tailored according to user needs (Karani and Kariuki, 2017; KMD, 2018). This enables farmers and other users to understand how to design and apply the forecast information in their decision processes. Yet gender had influence on the level of vulnerability to climate risks, and hence, women who were perceived to be highly vulnerable to climate impacts on agriculture use WCI for preparedness and response to impacts. Cumiskey (2016) and Muhua and Waweru (2017) highlight the role of the media as a key factor and player in influencing end users to uptake and use WCI in Kenya. Most users end up accessing the information alongside listening to other news. In Kenya and across the region, there exists a multisectoral interaction between users, WCI producers, and indigenous forecasters and other actors such as agricultural advisers and NGOs (Waweru et al., 2013; Karani et al., 2015; Leal Filho et al., 2017; Ameso et al., 2018).

Whereas, various factors influence the uptake, use, and adoption of WCI, Flagg and Kirchhoff (2018) indicate that the relationship between users and forecasters does not always lead to uptake and use of forecasts and neither does usable WCI end up being used. In such situations, they observed that to increase the use and uptake of WCI, there was a need to align the needs of the user (farmer) in context of all other activities at the farm and other levels. This is not unusual, since forecast information is seldom used to trigger financing early actions or crop insurance unless integrated with other additional farm-related information (Nobre et al., 2019).

From the reviewed work above, various factors that influence the uptake, use, and adoption of WCI across all the study counties were reviewed. Changing rainfall patterns and extreme weather were key factors due to the impact they have on farmers' activities and decisions. Technology including the use and adoption of mobile phones plays a key role in enabling access and use of the information. Yet, the use of IF combined with WCI was found mostly in the drier counties to be important factors influencing uptake, whereas engagements between forecaster, users, and other stakeholders also seemed to strongly influence adoption of forecasts in farm management decisions.

Barriers to the Use, Uptake, and Adoption of Weather and Climate Information by Farmers

Although farmers in Laikipia experience declining rainfall patterns, high temperatures, and deforestation that limit their adaptive capacity to climate risks (Speranza, 2013; Maoncha et al., 2016), one of the key barriers to addressing these problems is the lack of access to early warning information such as seasonal forecasts (Ojwang et al., 2010; MoALF, 2014). Similarly, the sedentary lifestyle of the pastoralists and agro-pastoralists in Laikipia is also a constraint to the provision of WCI in a timely manner (e.g., because pastoralists migrate from one place to another in search of pasture and water; Njoki et al., 2015).

Luseno et al. (2003) and Ryan (2005) showed that late access to forecasts in Laikipia and other northern regions makes them not useful in farm decisions. There is similarly a link between the later to limited access to information where, for instance, farmers have a slow tendency to uptake technologies such as mobile phones that play a crucial role in dissemination of WCI using the Short Messaging Service or through WhatsApp messages (Parita et al., 2012). Several studies on farmers in Laikipia suggest that having informal education reduced the uptake of WCI compared to having formal education (Waweru et al., 2013; Karanja, 2018). Similar findings have been reported showing low adoption of climate information and other disaster strategies related to high illiteracy levels among most pastoralists in Laikipia (Syomiti et al., 2015). This corroborates findings of a study in Bangladesh, which found that educated and medium- to large-scale farmers had higher adoption of agricultural and climate information and other practices compared to smallholder farmers due to disparity in levels of education (Baumüller, 2016).

Lack of financial support to farmers in Laikipia and Meru limited their ability to enhance their livestock production and adoption of technology, e.g., not able to buy equipment and inability to access WCI (Schäfer et al., 2008). Further, Krell et al. (2020) found that while use of smartphones by women was a key barrier to communication and dissemination of climate information, it is the high cost of ownership and use that made it difficult to use in Laikipia and Meru Counties. Whereas Laikipia and other semiarid areas have challenges in access of WCI, uncertainty in various types of climate information is also a major problem and only few farmers in Kenya and the region pay attention to uncertainty in their decision-making, opting to ignore (Luseno et al., 2003; Silvestri et al., 2012; Apgar et al., 2017). However, end users are also advised that when forecasts seem to report higher skill, there is a need to be careful before using them and that they should not assume lower uncertainty (McSweeney et al., 2010).

Lack of access and inadequate information were identified by several farmers in Machakos as some of the greatest barriers to adoption of WCI and hence the need for action on climate risks (Mabon, 2020). Yet in several other studies, most farmers in Machakos cited limited access to farm inputs or insufficient resources, new agricultural technologies and information and extension services as critical barriers to managing climate disasters (Momo et al., 2013). Similar findings have been reported in Embu County—a humid region where farmers identify access to farm inputs and extension services as a hindrance to adaptation to climate change (Oscar Kisaka et al., 2015). Lack of financial resources, farm inputs, and other enablers has also been identified in African agricultural systems as a key constraint to coping with climate change impacts (Bryan et al., 2013; Leal Filho et al., 2017). Whereas language barrier is a key constraint to the use of WCI in Machakos and other areas, the use of vernacular radio stations in the local language has increasingly made it easier for farmers to understand, uptake, and use WCI and agricultural advisories in their farm decisions (Mwalusepo et al., 2015; Mwangangi, 2015; Gichangi and Gatheru, 2018). Other barriers to the use of WCI include lack of trust and relevance of the WCI to farmers (Dilling and Lemos, 2011) and low adoption of technology, e.g., mobile phones (Aker, 2011; Tall et al., 2018). Further, sparse weather observational network is an overarching barrier to improvement of accuracy of information and if addressed can immensely improve weather and climate forecasting in Machakos and the country as a whole (Karuma et al., 2016).

In Isiolo County, Luseno et al. (2003) recognize the limited attention given to user needs for WCI among pastoralists in northern Kenya as one of the problems. This is closely related to lack of access and information as well as limited access to extension services and WCI, which are key barriers poorer pastoralists face in the region (Kuria et al., 2016; Apgar et al., 2017). This is evidenced by Kagunyu et al. (2016) and Okitoi et al. (2016) who show that most pastoralists in Isiolo have been using IFs when scientific forecasts are not available. But use of IF cannot predict climate change in this region, and this poses a challenge to addressing farmers concerns, and hence uptake of sub-seasonal and seasonal forecasts can help farmers and agro-pastoralists in this region to improve their resilience to impacts of floods, droughts, and high temperature (Quandt and Kimathi, 2016). Actually, Habane (2010) and Ontiri and Robinson (2015) confirm that drought and water scarcity are major issues affecting pastoralists in semiarid lands in Kenya, which strengthens the previous suggestion that such risks can be addressed using WCI. For example, reports of increasing droughts, floods, and temperatures in Isiolo are consistent with historical climate data (Ouma, 2015; Ouma et al., 2018; Recha, 2018). Lack of credit is a hindrance to adoption and use of WCI and ability to buy inputs in Isiolo and other semiarid areas as well as cultural and religious beliefs and poverty, which increases vulnerability (Luseno et al., 2003; Mosberg et al., 2017) and migration patterns of pastoralists (Syomiti et al., 2015; Zwaluw, 2015). Recha et al. (2013) report that credit advanced to farmers can enable them to acquire inputs and better deal with erratic weather conditions. In the Isiolo County, the government and other actors support farmers and pastoralists with farm inputs including storage facilities, WCI, and other information (Rao et al., 2019). Many studies suggest that barriers to uptake and use of WCI in Kenya are necessary to help address and strengthen gaps in climate services (Orindi et al., 2007). Other barriers to the use of WCI in Isiolo include social differences and status between wealthier households who have connections to providers, Internet, and radio or TV to access seasonal and monthly forecasts compared to poorer households owing to their low adaptive capacity (Apgar et al., 2017; The Ministry of Agriculture, Livestock and Fisheries, 2017). Overall, Carabine et al. (2016) argue that the difference between what end users need and what producers of WCI provide can determine how constraints to access and use of WCI can be addressed.

Percy (2013) identifies low adaptive capacity and inability to adopt new farming methods to address impacts of erratic weather patterns as other issues affecting farmers in Meru County, although they have better knowledge of accessing inputs and doing business. Ironically, Krell et al. (2020) found that access to WCI is shown to be a main barrier to adaptation to climate risks in Meru, although the cost of usage of technologies such as mobile phones poses a constraint to usage due to lack of credit to access seasonal and sub-seasonal forecasts. Similarly, the use of mobile agriculture/livestock services was seen as a key barrier to use of WCI by women than men. Factors limiting the use of mobile phone services (m-services) in Meru are lack of awareness, lack of availability, and lack of understanding about how m-services work. Ameru et al. (2018) show that challenge to access of weather and agricultural market information could be associated with poor technological infrastructure and lack of capacity by farmers.

In Trans Nzoia County, myriad constraints to the use of WCI exist. While access to and timeliness of forecasts have been cited as some of the barriers to efficient use and adoption to weather information, the most critical issue affecting farmers here is low soil fertility reported in the area (Hassan and Ransom, 1998). Similar to other regions in sub-Saharan Africa, Tittonell et al. (2005) and Sileshi et al. (2010) found that soil fertility in the area varied with farm size, farm type, and level of income, suggesting that for WCI uptake and use, these are potential factors that could hinder success and should be taken into consideration. One study across eight agro-climatic zones and particularly maize-producing county like Trans Nzoia found several constraints related to climate information such as poor access to agriculture and climate information and low adoption of technology, e.g., mobile phones, and concluded that there was a need to relate these to agro-climatic and soil characteristics for better management of climate risks (Tittonell et al., 2005; Bozzola et al., 2018). According to Lemos et al. (2012) addressing the barriers to use of climate information is strongly related to the difference between the scale and nature of the communities and their information needs and the producers of WCI.

Whereas farmers and other end users of WCI in Trans nzoia were constrained by lack of access and delayed weather information (Onywere et al., 2007), severe floods (Odira et al., 2010), and declining rainfall amounts in Trans Nzoia and shift in rainfall onset dates (Mugalavai and Kipkorir, 2013) may continue to create challenges to address the need for WCI in the area. While there has been contradicting results on increasing rainfall trends indicated in the same region, there is a need to provide user-specific weather information to address climate risks (Ouma, 2017; Mumo et al., 2018). This might be the reason why farmers in Trans Nzoia indicated that they found WCI to be insufficient in addressing their needs and required to be improved in order to address climate disasters and enhance their preparedness in a specific area (Onyango et al., 2014). Broadly speaking, one of the major challenges the KMD faces in the provision of WCI is the inability to provide site-specific weather information due to its sparse weather observation network (Guthiga and Newsham, 2011). This is also highlighted as one of the significant challenges in the use of WCI in the sub-Saharan Africa region, which mainly requires means and ways for addressing gaps in WCI to meet the needs of end users, including paying attention to timeliness, relevance, and sustainability for specific locations (Cooper et al., 2008; Caine et al., 2015).

Generally, a review on barriers and constraints to the use of WCI by Coelho and Costa (2010) showed that one of the key challenges to the use of seasonal forecasts by farmers and other users was the lack of integration in their applications and decision process in an objective manner. The World Meteorological Organization reiterates that it is crucial to examine barriers to WCI use in order to determine the usefulness of WCI (World Meteorological Organization, 2011).

In summary, for review on the barriers to the uptake, use, and adoption to forecasts, it appears that varied constraints are reported across the five study counties. The most common barrier is the changing weather patterns that constrain both farmers' resources and capability to cope with climate risks. Other barriers and challenges facing farmers include lack of access, insufficient resources and agricultural inputs, language barrier, timeliness, and spatial aspects in the provision of WCI and weak engagements between users and forecasters. Evident also is the challenge in the adoption of technologies such as mobile phones and the costs related to receiving WCI.

Influence of Farmers' Perceptions of Weather and Climate Information on Farm Decision-Making

Meijer et al. (2015) indicate that perceptions of farmers about any given technology or innovation are closely dependent on the knowledge or view they have on the innovation. In agro-pastoral areas of Kenya, user needs and perceptions can inform how weather and climate services may be designed to suit and meet farmers' needs and how decisions can be made (Gichangi et al., 2015). Momo et al. (2013) and Zwaluw (2015) show that perceptions and knowledge of farmers can inform policy, provide a broader view of the communities system and thinking (Juana et al., 2013; Mortimore, 2013), and inspire the adoption of technology and adaptation to climate change (Muita et al., 2016).

In Laikipia, perceptions on the access to weather information (e.g., knowing the rainfall patterns expected), increased agricultural information, access to agricultural extension services, credit availability, and higher levels of education enabled farmers to increase the use of hybrid seeds and enhance productivity (Atsiaya et al., 2019). Farmers' expectations of upcoming seasonal weather are important measures of farm decision-making in Laikipia County where Rembold et al. (2014) analyzed the impacts of food security and found that KMD forecasts, European Centre for Medium-Range Weather Forecasts (ECMWF) seasonal forecast, and Global Forecasting System can predict varied food situations in the country. The perception of drier conditions informed farmers' decisions on measures that needed to be taken to address the problem in Laikipia County (Karanja et al., 2017). For example, farmers with larger farms opted not to cultivate maize crop when drought conditions were predicted to avoid crop failure and losses. While farmers' perceptions are important determinants of how climate forecasts can be used in decision-making, some regional studies over arid areas such as Laikipia that recognize strategies used to cope with climate shocks pay less attention to the role that climate forecasts can play in decision-making (Few et al., 2015; Ameso et al., 2018).

Gumo (2017) studied IF among several farming communities from Machakos, Kitui, Meru, and Kakamega Counties and indicated that IF integrated with WCI can result in improved decisions on planting and choice of agricultural practices. Similar context is mentioned by Flagg and Kirchhoff (2018) who suggest that decision-making through the use of WCI can be enhanced if knowledge from social groups (community) and organizations as well as interactions between users and producers of WCI is taken into account to address changes in the weather patterns. According to Ngugi et al. (2011), collective efforts between farmers and forecasters can lead to better decision-making to address diverse constraints in the use of WCI in Machakos. This will lead to improved resilience to climate-related impacts and other benefits. Further, Yvonne et al. (2016) indicate that weather information has been useful in planning early planting of crops and new tillage methods, which have helped farmers in the county to cope with weather impacts. It has also been acknowledged that farmer perceptions and knowledge on technology and use of weather and agricultural information have enabled better adaptation to climate risks in Machakos (Kalungu and Leal Filho, 2018). For example, farmers and pastoralists from more drier and warmer areas gained better knowledge on managing climate risks compared to those in wetter areas in the county. Farmers' knowledge on technology in Machakos also led to high levels of awareness especially in households led by male than female and resulted in increased adoption and use of WCI and better decisions on climate-related risks.

Similar to Laikipia and elsewhere, seasonal and sub-seasonal forecasts enabled farmers in Machakos select the right type of seeds, crops, and other inputs (Amwata, 2013). The use of sub-seasonal and seasonal forecasts by farmers in Machakos was influenced more by negative impacts of climate variations on farm yields (e.g., declining rainfall patterns and droughts led to reduced maize and other crop yields; Nyandiko et al., 2014; Kiprotich et al., 2015). Progress has also been achieved by farmers in Machakos in using information on the start and end of rainy seasons to guide their farm activities such as early planting and application of fertilizers (Omoyo et al., 2015). Farmers' perceptions were closely similar to the latter situation where decisions made in response to declining rains and hence shorter growing seasons forced farmers to revert to fast-maturing crops (Bosire et al., 2019). Kalungu et al. (2013) and Baaru and Gachene (2016) show that farmers in Machakos adopted suitable coping measures to manage declining crop production, which was resulting from increased frequencies of droughts and floods in the area.

In Isiolo, the use of IF, which is a key strategy to manage extreme climate risks (Habane, 2010; Kagunyu et al., 2016; Gumo, 2017), also motivated recognition and need for sub-seasonal and seasonal forecasts, leading to beneficial adaptation actions by pastoralists (Apgar et al., 2018). This follows the realization that IF fails to adequately address climate change due to increased frequencies and severity of dry conditions (Rao et al., 2019). It is for this reason that pastoralists in Isiolo have been diversifying to subsistence farming and business with expectation to enhance their resilience and productivity (Jillo and Koske, 2014; Kuria et al., 2016). Other perceptions related to WCI and influencing decision-making in Isiolo regard the impacts of livestock diseases and cultural beliefs constraining uptake and adoption of seasonal forecast (Kuria et al., 2016; Mosberg et al., 2017). Pastoralists and farmers in Isiolo have combined agriculture and other investments to strengthen their resilience and livelihoods against extreme climate disasters (Quandt and Kimathi, 2016). For example, in an effort to manage drought, pastoralists in Isiolo were destocking their livestock and replacing cattle production with camel farming (Kagunyu and Wanjohi, 2014). Subsequently, perceptions of pastoralists on their needs to cope with weather vagaries have led to the use of advisories and seasonal forecasts to manage floods and other climatic risks (King-Okumu et al., 2016). Interestingly, women who spend more of their time working on the farm compared to men have led to women taking the lead in identifying environmental indicators for forecasting of local weather conditions, which enables the community to be better prepared against weather extremes (Luseno et al., 2003).

Based on the previous assertion, in Isiolo, more women than men used better agricultural practices such as water conservation, minimum tillage, mixed cropping, and mulching to manage their farms' productions against climate-related risks and losses as well as practicing early planting, weeding, and sale of crops in order to guarantee food security and other family needs (Muthee et al., 2016). Ngetich et al. (2014) indicate that due to perceptions of failed rains by farmers in the county, they have improved their farming practices to enable them to cope with crop failures. According to Ameru et al. (2018), farmers have embraced weather forecasts and sought extension services in order to boost their adaptive capacity in their farm activities. This has also included the use of IK to strengthen weather forecasting and other on-farm decisions (Kamwaria et al., 2015; Gumo, 2017). It is interesting that seasonal forecasts have been found to show skill and usefulness in Meru (Recha et al., 2012). Similar to Laikipia and Machakos, farmers' perceptions have led to utilization of onset dates in planning planting times and choices of seeds to plant by farmers in Meru County (Philippon et al., 2016). Another perception influencing decisions in Meru regards farmers' combining forecasts and other agricultural and market information in managing climate risks (Percy, 2013).

Due to dependence on rain-fed agriculture and maize production, farmers in Trans Nzoia County have developed various strategies to manage extreme weather occurrences (Dixit et al., 2011). Farmers' perceptions about combination of IF and seasonal forecast have enabled farmers in the county to make better informed decisions against weather risks including changes in choice of seeds and planting times and other agricultural practices (Guthiga and Newsham, 2011; Kipkorir et al., 2011; Barasa et al., 2017). Mubangizi et al. (2018) show that shorter seasons due to declining rainfall patterns have also made farmers in Trans Nzoia to prefer the use of seasonal forecasts than other innovations. This can be corroborated from Bernier et al. (2015) who indicated that availability of weather forecasts did not make farmers adopt them in conservation agriculture but their decision to use seasonal forecasts was driven by extreme or severe weather patterns and occurrences. Farmers in Trans Nzoia have also reverted to dry planting of their crops early in the season in order to increase their chance for higher yields (Hassan and Ransom, 1998). In general, farmers in Trans Nzoia perceive that access to early warning information and advisories improved their adaptive capacity to impacts of extreme climate including managing floods and droughts (Thorlakson and Neufeldt, 2012; Chepkemoi, 2014).

In summary, perceptions related to WCI were found to influence decision-making across all the study counties. Declining trends in rainfall and other climate extremes led farmers to develop better coping mechanisms including the use of either seasonal or sub-seasonal forecasts or IFs. Pastoralists in arid counties reverted to reducing the number of livestock to avoid losing them to drought conditions. Farmers also tended

TABLE 2 | Summary of findings of the review on perceptions and needs related to weather and climate information (WCI) in five counties in Kenya.

Research question	Findings per county				
	Laikipia	**Machakos**	**Isiolo**	**Meru**	**Trans Nzoia**
1) What is the specific weather and climate information needs of farmers in the study counties?	– Seasonal than sub-seasonal forecasts – Tailored WCI products – Accessible and timely WCI – Better communication channels	– Seasonal forecasts – Onset dates and amounts – Agricultural and market information – Better communication channels	– Indigenous and seasonal forecasts – Rain amounts and droughts – Capacity to use WCI – Integrate WCI with other interventions	– Sub-seasonal forecasts – Capacity to use WCI – WCI access – Onset dates and rainfall distribution – WCI integrated with market and agriculture information	– Seasonal forecast–indigenous forecasts – Information on drought and floods – Timely forecasts – Integrate WCI with IF
2) Which are the key factors that influence the uptake, use, and adoption of weather and climate information by users in the study counties?	– Changing rainfall patterns – Type of communication modes – Access to technology – Downscaled forecasts – Training	– Changing rainfall patterns – Engagement with forecasters – Combined use of IF and WCI – Use of technology – Declining yields – Type of communication modes	– Increased droughts – Combined use of IF and WCI–Combining agriculture and business – Availability of accessible communication modes and WCI – Translation of WCI local language – Gender desegregation	– Changing rainfall patterns – Timely and ability to sow early – Adoption of technology – Ability to obtain other agriculture information – Accurate forecasts for drier areas	– Accessibility to forecasts – Higher levels of awareness – Levels of income and education – Adoption of technology – Engagement with forecasters – Availability of accessible communication channels
3) What are the barriers to the uptake, use, and adoption of weather and climate information by farmers in the study counties in Kenya?	– Poor access – Sedentary lifestyle – Slow adoption of technology – Having informal education – Lack of inputs –Limited resources – High cost of mobile phones	– Poor access – Lack of access to inputs –Limited financial resources – Lack of access and high cost of technology – Uncertainty in forecasts – Language barrier – Sparse observational network	– Limited attention to forecasts – Use of IF – Lack of credit – Limited financial resources – Limited access to inputs – Cultural and religious beliefs – Sedentary lifestyle – Social status	– Poor access – Lack of access to inputs –Limited financial resources – Lack of access and high cost of technology/mobile phones – Uncertainty in forecasts – Uncertainty in weather patterns – Low adaptive capacity – Lack of awareness	– Poor access and timeliness – – Low soil fertility levels – Weak engagements with forecasters – Poor access to other inputs – Low adoption of technology
4) How do farmers' perceptions on weather and climate information influence farm decisions in the study counties?	– Perceptions help the farmers to improve their knowledge on how to better suit WCI and other interventions into effective farm decisions, e.g., when to plant – They inform farmers ability to choose between interventions, e.g., use of hybrid seeds instead of other seeds as informed by WCI and agriculture information – They help farmers to select which components to use in WCI, e.g., rainfall probabilities or amounts to deal with drier/drought conditions – Perceptions enhance farmers' ability to use their education and literacy levels in making effective decisions from WCI – Farmers' perceptions also inform how financial resources can be used to access WCI and other inputs for better farm decisions – Farmers' perceptions enable them to notice accuracy in WCI and make appropriate decisions	– Perceptions of reduced reliability of IF to tackle climate risks force farmers to integrate WCI in decision-making – Perceptions of past experiences, e.g., failed rains informed farmers to make better decisions using WCI, e.g., early planting – Perceptions of farmers on the value of WCI increase engagements with forecasters – Perceptions (e.g., experience and knowledge of technology) enable collective efforts between farmers and forecasters leading to increased use of WCI – Perceptions on the usefulness of agricultural information interfaced with WCI enable better adaptation to climate risks – Farmers' perceptions on changing weather patterns lead to increased levels of awareness and WCI use – Perceptions on WCI enable farmers to notice accuracy in WCI and make appropriate decisions	– Pastoralists' perceptions on limitations of IF necessitated farmers to use seasonal forecasts in decision-making on suitable interventions – Perception that WCI was useful promoted farming diversification – Perceptions of WCI accuracy encourage combination of agriculture and other interventions – Farmers' perceptions of changing weather patterns encouraged the use of advisories (WCI) to manage climate risks and chose appropriate actions, e.g., avoiding flood risks – Pastoralists' perceptions on benefits of using WCI enhance participation of women in weather observations, since they spend more time in the farm than men – The perceptions of increased reliability of WCI influenced use in decisions such as destocking and stocking of fodder	– The perception of reliability of WCI in farm decisions encouraged the use of extension services that help in choice of appropriate seeds and other farm inputs – Farmers' perceptions of changing weather patterns have necessitated the use of WCI to enhance their adaptive capacity on climate risks – The perception of reduced reliability of IF has made farmers integrate seasonal forecasts in decision-making – Perceptions and recognition of skillful forecasts have led to increased use of WCI in informing when to plant and to buy seeds and other inputs – Perceptions of farmers combining forecast information and agricultural and market information have led to improved adaptive capacity toward climate risks	– Farmers' perception of changing rain patterns influenced the uptake of seasonal forecast and decisions on selection of appropriate maize seeds and planting times suited to their rain-fed agriculture systems – The perception that combining of WCI and other information, e.g., agricultural and market information, has enabled farmers to choose the right coping strategies that minimize loss to crop failure and heavy rainfall – The perception of reducing rainfall patterns and shorter growing seasons has led to the use of seasonal forecasts that enabled the use of proper agricultural practices such as what crop varieties to plant, early, and dry planting to reduce failure – Perception of increased floods and droughts has necessitated increased use of WCI in developing coping actions, e.g., terraces

to adopt and plant early-maturing crops among other measures against extremes.

The summary of findings from this study is presented in **Table 2**.

DISCUSSION

Farmers' needs in the study counties comprise the choice for forecasts, where seasonal forecasts were more needed and preferred compared to sub-seasonal forecasts, need for IFs and combination with seasonal forecasts and particularly information on when the rains start and end, and other specific information such as rainfall amounts, types of crops and seeds to plant, and when to plant. In this regard, seasonal forecasts were more preferred in the drier counties such as Laikipia and Machakos compared to humid counties such as Meru and Trans Nzoia. This reflects a study by Ingram et al. (2002) who found out that the use and preference for forecasts for farmers in West Africa varied across different climatic zones. The need for reliable communication channels revealed that radio was the most preferred mode of dissemination and communication of WCI in the study counties. Yet, farmers felt that WCI can be more valuable if it was accompanied by agriculture advisories and other innovations as these would enhance their ability to manage climate risks through better decision-making.

Factors that influence the uptake, use, and adoption of WCI across all the study counties suggest that rainfall patterns and extreme weather events formed the most disastrous threats to farmers for the negative impact they posed on their lives and activities. Other factors that influence uptake and use of WCI include technology use in accessing and using climate information. Use of IF and combination with WCI in the drier counties influenced how sub-seasonal and seasonal forecasts are adopted. Ziervogel and Opere (2010) show that combining IF and WCI could solve the challenges of climate change experienced by farmers and other users of WCI.

Further, the review revealed several barriers to the uptake, use, and adoption of forecasts, including climate extremes and changing weather patterns, lack of access, insufficient resources and agricultural inputs, language barrier, and other constraints. These findings on barriers to the use of WCI in Kenya corroborate findings of others in Europe (Soares and Dessai, 2016), the US (Bolson et al., 2013), and South Africa (Wilk et al., 2017) where farmers and other users of WCI identify barriers that constrained them from making better decisions using WCI. Briley et al. (2015) discuss some ways of overcoming the barriers in the coproduction of forecasts between users and producers in Africa. They identify three main barriers, namely, different and difficult terminologies between forecasters and users of WCI, unrealistic demands and expectations from users on the availability and dissemination of relevant WCI to solve climate risks, and inadequate capacity or knowledge on how users and stakeholders should integrate or translate WCI into decision-making. Subsequently, the review highlights that these barriers can be overcome through myriad ways. Generally, most of the barriers can be overcome through identification of the most important needs demanded by users and developing tailored and context-appropriate products and services. Difficult terminologies and mismatched expectations can be overcome by translating climate information to locally relevant, simple, and understandable narratives, e.g., using local languages and images, downscaling WCI to the types of information stakeholders find usable, and packaging the information in accessible formats. The review revealed that users preferred information summaries and other simpler ways of displaying forecasts and required data, e.g., spatial detail. Integration and fitting of WCI in the stakeholders' decision-making process require direct interactions and engagements with forecasters. This helps to reduce vulnerability and uncertainties in the climate information that could lead to losses and other impacts due to wrong or weak decisions.

Subsequently, perceptions related to WCI and influencing decision-making across all the study counties included declining trends in rainfall, adjustment in farm management practices such as change of crop, or choice of seasonal or sub-seasonal forecasts and IFs. Availability of farm inputs and access to resources and technology were some of the factors that influence users' perceptions and enhance the uptake, use, and adoption of WCI and improve decision-making on climate risks and impacts. These findings support others that show that adoption of WCI by farmers depends on social capital, resources, and awareness as opposed to the knowledge of forecasts by users (e.g., Marshall et al., 2011).

CONCLUSION

This study addressed four objectives that sought to identify and analyze WCI needs of farmers, key factors influencing the uptake, use, and adoption of sub-seasonal and seasonal forecasts, barriers that hindered the uptake, use, and adoption, and how farmers' perceptions on WCI influenced farm decisions in five counties in Kenya. All the objectives were addressed through a systematic literature review of research articles published between 1985 and 2020.

The review revealed that farmers needed both seasonal and sub-seasonal forecasts, specific communication channels for dissemination and access of WCI among other needs. This finding is important in providing users' specific WCI that is suitable for decision-making on climate-related impacts and agricultural productivity. Income, education, and other human capital resources among other factors influenced the uptake, use, and adoption of sub-seasonal and seasonal forecasts in the study counties. Nonetheless, numerous barriers such as lack of access, lack of resources, e.g., farm inputs, and lack of access to technology (e.g., mobile phones) constrained the use of WCI. Farmers' perceptions on WCI were found to influence farm decisions in myriad ways where for example access to agricultural extension services and credit availability enabled farmers to increase the use of better farm inputs and practices to improve productivity, depressed seasonal rainfall leading to shortening of the growing seasons made farmers to plant fast-maturing crops, and the integration of IF with WCI enabled improved decision-making against climate risks such as shifting of planting times and dry planting. Yet farmers' ability to access loans or resources, income, and having education enabled them to make access and use technology and apply WCI in decisions that minimize climate-related risks and losses.

The findings from this study stemmed from a number of questions relating to user needs and perceptions on WCI. These questions were in the context of the literature reviews from several studies and pertaining to constraints existing in the uptake, use, and adoption of WCI by farmers, how climate services can adjust from being producer-centered to being user-focused, the importance and role of coproduction in understanding users' needs and perceptions, interactions between users and forecasters, and the overarching aspect of dealing with changes in weather patterns and forecast uncertainty at sub-seasonal and seasonal timescales among others. The review findings showed that there is tremendous evidence that numerous barriers to the use of WCI exist and limit the use of WCI in the study regions, which necessitates the development of suitable climate services that can address and limit impacts of the changes in weather and climate. Numerous users' needs for either or both sub-seasonal and seasonal forecasts as well as IFs add to the knowledge that farmers in Kenya still demand that these be accurate, reliable, and appropriate for decision-making in addressing the myriad climate-related risks. To enable these, there is a need to strengthen institutional capacity, access, dissemination, and capacity of users to utilize WCI in decision-making.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

AUTHOR CONTRIBUTIONS

RM, AD, JM, and RG developed and rationalized the concept idea and methodology. SA, DA, and EN shaped and edited the review of literature. LH and FO conducted the analysis of literature on meteorological aspects of the study. JM and AD secured funding for the work. LH edited the final manuscript. All authors contributed to the article and approved the submitted version.

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